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Sustainable Real Estate

Management, Assessment and Innovations

Edited by

Pierfrancesco De Paola, Francesco Tajani and Marco Locurcio

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Sustainable Real Estate: Management, Assessment and Innovations

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Editorial

Sustainable Real Estate: Management, Assessment and Innovations

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1. Introduction

Production and consumption activities have determined a weakness of the sustainable real estate economy. The main problems are the subordination of public decision-making, which is subjected to pressure from big companies, inefficient appraisal procedures, excessive use of financial leverage in investment projects, the atypical nature of markets, income positions in urban transformations and the financialization of real estate markets with widespread negative effects.

A delicate role in these complex problems is assigned to real estate appraisal activities, called to formulate value judgments on real estate goods and investment projects, the prices of which are often formed in atypical real estate markets, giving ever greater importance to sustainable development and transformation issues.

This Special Issue is dedicated, but not only limited, to developing and disseminating knowledge and innovations related to most recent real estate evaluation methodologies applied in the fields of architecture and civil, building, environmental and territorial engineering.

A total of 24 papers were submitted. Following a rigorous procedure of peer review, only 12 papers were accepted and published. The different countries of the Authors' affiliation (Korea, Lithuania, Italy, UK, Finland, Poland and so on) have given the Special Issue a strongly international character.

Considering all 24 papers submitted, 19 different countries of the Authors' affiliation can be found (Figure 1). This number drops to 15 if only the published papers are contemplated (Figure 2).

In compliance with the objectives of this Special Issue, the published papers can be grouped into three main themes, reflecting the major lines of research within the real estate sector: (i) sustainable real estate (five papers), (ii) econometric models (five papers) and (iii) multi-criteria decision analysis (two papers).

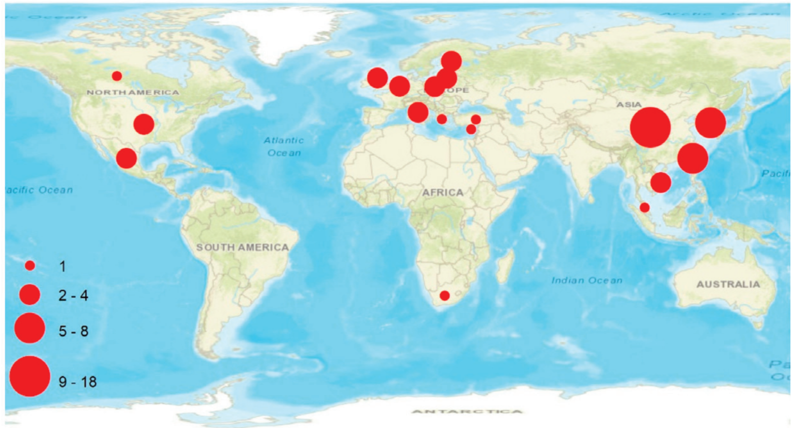

Figure 1. Number of Authors for countries affiliation (papers submitted).

Figure 2. Number of Authors for countries affiliation (papers published).

2. Sustainable Real Estate

The theme of sustainability in real estate is central to this Special Issue, and it is declined in its environmental, social and economic components.

In "*Pricing ESG Equity Ratings and Underlying Data in Listed Real Estate Securities*" Dirk Brounen, Gianluca Marcato and Hans Op 't Veld [1] examine and discuss the application of transparent environmental, social and governance (ESG) ratings and their interaction with public real estate performance across European markets. The Authors, starting from the European Public Real Estate Association's (EPRA) Sustainability Best Practices Recommendations (sBPR) database for the listed European real estate market, construct two ESG measures that analyze the ESG completeness and performance. Through a statistical analysis on a sample of 64 European listed real estate firms, the Authors outline that since both ESG measures covary across firms, then firms that score highly on ESG completeness also tend to score higher than average on ESG performance.

In "*The Unequal Impact of Natural Landscape Views on Housing Prices: Applying Visual Perception Model and Quantile Regression to Apartments in Seoul*", Hyejin Lee, Byoungkil Lee and Sangkyeong Lee [2] analyze the impact of natural landscape views on housing prices for apartments in Seoul. Through a visual perception GIS-based model, the Authors describe the natural landscape views of Seoul and the corresponding impact on housing prices. The implementation of a quantile regression (that takes into account housing factors as the net surface, the floor level, the location, etc.) highlights that natural landscape views have positive impacts on housing prices, in particular for higher-priced apartments.

The paper by Eerika Janhunen, Niina Leskinen and Seppo Junnila entitled "*The Economic Viability of a Progressive Smart Building System with Power Storage*" [3] sets out to understand the cash flows and economic viability of a real-life smart system investment in a building. The "case building" is a European shopping center located in southern Finland involved in a smart energy investment (PV system, battery storage, active LEDs, EV charging, advanced demand management) equal to six million Euro in 2018. On February 2020, after the first full operational year of the smart energy system, the Authors have carried out a survey of six representatives of the case building's owner (three real estate managers, the business the development director and the CEO) in order to determine the smart readiness indicator (SRI), and are able to evaluate a building's potential to optimize the overall energy consumption. The case building's final score is 92% of the maximum on the SRI rating scale, which indicates that the building is indeed exceptionally smart in terms of its technological implementations. Furthermore, the performance indicators (IRR, ROI, NPV, payback period) show that the investment is also financially convenient.

The paper by Youngme Seo entitled "*Varying Effects of Urban Tree Canopies on Residential Property Values across Neighborhoods, social and economic benefits*" [4] utilizes spatial models to empirically evaluate the impact of Urban Tree Canopy (UTC) on residential property values in the housing market. The Author elaborates a dataset that includes 24,203 single-family residential sales from 2007 to 2015 in the city of Des Moines (Iowa). The dataset involves structural factors, such as the size of the living area, the size of land, bedrooms, bathrooms, construction year, condition of the structure, and presence and type of garage. Through a GIS-based model and buffering techniques the main "amenities" (accessibility and view) and "disamenities" (noise and traffic) are mapped. The application of Multi-Level Mixed (MLM) models points out that UTC determines a positive effect on housing prices, especially on those ones characterized by large sizes and located in more stately neighborhoods. In fact, trees and green surfaces are relevant not only for mitigating the environmental problems in the urban areas and reducing energy use, but they "shield" residential areas from the noise pollution generated by car traffic.

In "*Do Women Affect the Final Decision on the Housing Market? A Case Study*", Sabina Zróbek, Elzbieta Zysk, Mirosław Bełej and Natalija Lepkova [5] show the results of their research on the effect of customer gender on tenure choice (ownership or tenancy) in the housing market. The survey is conducted among residents of two cities—Olsztyn (Poland) and Vilnius (Lithuania). Through almost 200 questionnaires submitted from October to December 2019 to a specialized online platform, it has been possible to detect that women generally have greater decision-making autonomy in residential issues than men, with Lithuanian women doing this much more often than Polish women. Although the number of respondents' answers is not very large, the results may also contribute to more sustainable development of enterprises in the housing construction sector.

3. Econometric Models

Due to the dissemination of databases that combine real estate and socio-economic information, econometric models are widely used for forecasting issues in complex contexts where real estate takes on a central role.

In "*The Impact of Uncertainty on State-Level Housing Markets of the United States: The Role of Social Cohesion*" Linyan Dai and Xin Sheng [6] study the impact of uncertainty on housing markets across the 50 states of the USA, plus the District of Columbia, using the local projection method for panel data. The application of a series of indexes (index values of the Freddie Mac House Price Indexes, adjusted Consumer Price Index, State Social Capital Index, Macro and Financial Uncertainty Indexes), constructed at a monthly frequency and ranging from December 1999 to December 2019, highlights that macroeconomic and financial uncertainties reduce real housing returns, with the strongest effect originated from the macro-economic uncertainty over the long term.

The paper by Yener Coskun, Christos Bouras, Rangan Gupta and Mark E. Wohar entitled "*Multi-Horizon Financial and Housing Wealth Effects across the U.S. States*" [7] uses an expanded dataset (period 1975–2012) with regional data to investigate the link between wealth and consumption in the USA. The goal is to better understand the wealth effect-induced household consumption behaviors in the USA and the role of housing and financial wealth effects. Through the multi-horizon test the Authors outline that generally in the USA housing (financial) wealth growth causes consumption growth.

In "*Retirement Age and Housing Consumption: The Case of South Korea*" Chunil Kim, Hyobi Choi and Yeol Choi [8] investigate the impact of the timing of retirement on housing consumption. The Authors observe that in the "aged societies" there are many people who do not save enough money in preparation for retirement, and they are thus not likely to have the essential financial resources required to maintain their standard of living in retirement. In these cases, for which the house is often the largest asset owned by most households, Housing Downsizing is a possible strategy that ensures a good standard of living of the owners. Thanks to a dataset containing socio-demographic and financial information for households of all generations, through a statistical treatment, the Authors analyze the demand for housing by comprehensively considering the simultaneous linkage of housing tenure choice and housing consumption using.

The paper by Kuo-Cheng Hsu entitled "*House Prices in the Peripheries of Mass Rapid Transit Stations Using the Contingent Valuation Method*" [9] aims to examine the residential market of the areas where the mass rapid transit (MRT) stations in the Taipei metropolitan area in Taiwan are located. To assess the prices that people are willing to pay for houses in the peripheries of MRT stations, the Author has submitted a willingness-to-pay questionnaire and has analyzed the outputs using the contingent valuation method. Furthermore, a Tobit regression model points out that, regardless of the typology of transit stations (elevated or underground stations), the current market house prices are higher than the price levels the respondents were willing to pay.

The paper by Marco Locurcio, Pierluigi Morano, Francesco Tajani and Felicia Di Liddo entitled "*An Innovative GIS-Based Territorial Information Tool for the Evaluation of Corporate Properties: An Application to the Italian Context*" [10] proposes an Automated Valuation Model for the corporate market segment, in order to support the investors', the credit institutions' and the public entities' decision processes. The application of the model to the corporate real estate segment market of the cities of Rome and Milan (Italy) outlines the potentialities of this approach in property big data management. The elaboration of input and output data in the GIS environment allows the development of an intuitive platform for the immediate representation of the results and their easy interpretation, even to non-expert users.

4. Multi-Criteria Decision Analysis (MCDA)

MCDAs remain particularly useful tools in uncertain decision-making contexts in which different stakeholders intervene, often with conflicting objectives, and the decision-maker is called to choose through a shared platform.

The paper by Eglė Klumbytė, Raimondas Bliūdžius, Milena Medineckienė and Paris A. Fokaides entitled "*An MCDM Model for Sustainable Decision-Making in Municipal Residential Buildings Facilities Management*" [11] presents a multi-criteria decision-making (MCDM) model for the sustainable decision-making, tailored to municipal residential buildings facilities management. The delivered model is applied to 20 municipal social housing buildings of Kaunas city, located in Lithuania, to identify the worst-case real estate, for which strategic decisions have to be made. The proposed model starts from 109 requirements of three groups for social housing buildings: through expert assessment methods, the Authors reduce the requirements to 30 (10 normative, 10 municipal and 10 resident requirements). The main outcomes of the model concern recommendations for the management, use and disposal of municipal buildings, in compliance with the principles of public law, rationality, management efficiency and economic benefits.

In "*An Integrated Methodological Analysis for the Highest Best Use of Big Data-Based Real Estate Development*", Jaehwan Kim, Ducksu Seo and You Seok Chung [12] investigate the integration of methods for real estate development planning and feasibility studies in the changing business environments of emerging big data. Through the support of a valuer of the Korea Land and Housing Corporation, the study used big data to distinguish those factors preferred by business entities planning to implement high-rise building mixed-use development projects, and by consumers who look at such projects, to determine evaluation items. The effects of high-rise mixed-use building development projects are analyzed through four categories (economy and industry, society and culture, technology and environment, reputation) divided into 13 evaluation fields and 39 evaluation factors. The fuzzy inference is used to measure the influence factors of each category and the Analytic Hierarchy Process (AHP) technique is implemented to set priorities based on the factors in each hierarchy. The methodological approach uses different techniques (AHP and fuzzy logic) combined with big data for the definition of the highest and best use of high-rise mixed-use buildings.

5. Concluding Remarks

The sector of construction and real estate in general has taken on a central role with regard to the theme of environmental sustainability, declined from different points of view, such as the need to limit land consumption through incentive mechanisms [13,14], the green enhancement of existing buildings [15–17] and/or parts of cities to be redeveloped [18]. Over the years, environmental sustainability has evolved to include social, financial and economic aspects [19–21]. Additionally, thanks to the spread of the 17 Sustainable Development Goals promoted by the United Nations Department of Economic and Social Affairs, the concept of sustainability has been expanding in recent years to environmental, social and governance (ESG) investments. ESG investments are key in the European Green Deal [22] and are constantly growing in the portfolio of investors around the world [23–25].

This Special Issue takes into account the several lines of current research developed in the field of "sustainable real estate". The 12 papers selected and published investigate different aspects (social, environmental, economic, etc.) of sustainability and the central role of real estate sector in achieving these objectives. Many papers, written by scholars and academics of prestigious universities and international research institutes, converge on the same topics, highlighting the interest and topicality of the proposed research issues and the relevance of real estate sector in achieving the objectives of sustainability.

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Article

The Impact of Uncertainty on State-Level Housing Markets of the United States: The Role of Social Cohesion

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Abstract: While considering the role of social cohesion, we analyse the impact of uncertainty on housing markets across the 50 states of the United States, plus the District of Columbia, using the local projection method for panel data. We find that both short-term and long-term measurements of macroeconomic and financial uncertainties reduce real housing returns, with the strongest effect originated from the macro-economic uncertainty over the long term. Moreover, the degree of social cohesion does not change the nature of the impact of uncertainty on real housing returns dramatically, but the size of the negative effects is relatively large for states with low social cohesion.

Keywords: social cohesion; uncertainty; U.S. housing markets; local projection method; impulse response functions

JEL Classification: C23; R31; P25

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1. Introduction

In recent years, there has been growing research interest in the linkage between uncertainty and economic activity, following an influential paper of Reference [1]. The important role of uncertainty in the economy has gained increasing attention from researchers and policymakers. In general, this strand of literature focuses on the macro-economic impacts of uncertainty and finds that uncertainty plays an important role in driving macro-economic fluctuations at the country-level (See Reference [2] for a review of the relevant literature). Existing literature overwhelmingly reports a negative influence of uncertainty on macro-economic variables, such as output growth, interest rates, inflation, employment, and stock returns [3–7]. Moreover, realising that big heterogeneities are existing among different regions of a large economy, e.g., across the states in the United States (U.S.), recent studies [8,9] have also highlighted the negative effect of uncertainty on macroeconomic variables at the regional level.

In a related stream of literature, there has also been a surge of interest in studying the relationship between uncertainty and housing market returns, especially in the wake of the 2007 subprime mortgage crisis in the U.S. housing market, and the subsequent 2008–2009 Global Financial Crisis (GFC), in which a meltdown in the U.S. housing market acts as a catalyst for an economic and financial crisis that spreads globally [10–16]. It is noteworthy that existing studies mainly examine the link of uncertainty and housing markets at the aggregate country level and mostly use a news-based measure of uncertainty, such as the economic policy uncertainty (EPU) index of Reference [17].

Given uncertainty is a latent variable, it requires an appropriate measurement of uncertainty to study the effect of uncertainty. Besides various news-based measures of uncertainty (see References [17,18]) that are constructed based on the search results in newspapers for keywords related to uncertainty, another stream of literature has employed the econometric approach to measure uncertainty (see Reference [19]). This approach computes uncertainty based on estimation from the structural vector autoregression models

(SVAR) and overcomes the shortfalls of the news-based measures, which typically have a high bar for news coverage. The news-based measures may not be able to fully capture uncertainty when news editors fail/neglect to cover the relevant uncertainty events [20]. In contrast, the uncertainty measures of Reference [19] provide estimates of macroeconomic and financial uncertainties as average time-varying variances in the unpredictable components of the real and financial variables including 134 macroeconomic time series and 148 measures of monthly financial indicators. This uncertainty measure provides a comprehensive portion of macroeconomic and financial uncertainties, which includes a rich information set.

Against this background, we aim to build on the existing research by examining the impact of uncertainty on U.S. housing markets at the state level and using the uncertainty measures of References [19,21]. Moreover, we consider the interaction between economic and social factors by studying the informational role of social cohesion in each state with the impact of uncertainty on U.S. housing markets. Social cohesion is the concept that has been used by policymakers since the 1990s in the developed economies and is often referred to as the "glue" to keep the societies together [22–24]. Up to now, there is no consensus on the formal definition of social cohesion in the academic literature. The theoretical discussions about the concept of social cohesion in an economic domain have attracted great attention from academic researchers and policymakers following an influential paper by Reference [25] (See Reference [24] for a review of relevant literature). Social cohesion is considered to be a key factor to promote people's well-being, a condition for social and political stability, a justification for government spending on social policies, and a source of the sustainable development of economic growth. Social cohesion can keep members of a social system together (e.g., the family or the neighbourhood or the society) [26]. If a society is less cohesive, it may display social inequality, social disorder and conflict, disparate moral values and less social interaction, and can negatively impact the economy of society [27]. Acket, S [28] also reports empirical evidence for strong and statistically significant correlations between social cohesion and macro-economic variables across 39 European countries.

From a socio-economic point of view, Reference [29] suggests that individual societies differ in their social cohesions, and more cohesive societies can benefit from a higher cooperation between economic agents, which is an advantage for the society and impacts its economic outcome. It is notable that, in theory, a society with high social cohesion is characterised by great social and political stability based on improved well-being, shared moral values, and high cooperation of its members instead of inequality, disorder, and conflict. Cohesive societies that are socially and politically stable can focus on the development of the business and economy in times of great uncertainty, which mitigates the impact of uncertainty on macroeconomic variables, including the housing market returns. Since individual U.S. states can be different in terms of their social cohesion, we analyse the heterogeneous impacts of the uncertainty on state-level real housing returns by estimating the impulse response functions (IRFs) using the local projection method for panel data and by making the IRFs contingent on the status of social cohesion in each state. We examine both linear and nonlinear impulse responses of real housing returns to uncertainty by using the local projection method of Reference [30]. The panel data-based local projection method allows for consideration of the heterogeneity and cross-sectional dependence among individual U.S. states and, thus, assists in deducing correct statistical inferences. Following the work of Reference [31], we use a switching variable to distinguish the social cohesion of U.S. states into high-regimes and low-regimes.

The objectives of this paper are two-fold. First, we investigate the impulse responses of U.S. real housing market returns to uncertainty using the local projection method for panel data across all 50 states, plus the District of Columbia, over a monthly period from December 1999to December 2019 Second, we also examine if the impact of uncertainty on state-level housing markets of the U.S. is contingent on the status of social cohesion in each state. To the best of our knowledge, this is the first paper in the literature to study the effects of macro-economic and financial uncertainties on U.S. housing markets using a large panel dataset at the state level while considering the role of social cohesion in each state.

The remainder of the paper is organised as follows. Section 2 describes the data and methodology. Section 3 discusses the empirical results, and Section 4 concludes the paper.

2. Data and Methodology

2.1. Data

In terms of housing markets data, we employ the seasonally adjusted nominal housing price data for the 50 states of the U.S., plus Washington, D.C., derived from the monthly index values of the Freddie Mac House Price Indexes (The data are accessible from http://www.freddiemac.com/research/indices/house-price-index.page, accessed on 27 January 2021). The indexes are calculated based on a database of loans purchased by Freddie Mac/Fannie Mae and provide a measure for U.S. housing prices at the state level. The nominal price data are then deflated using the seasonally adjusted Consumer Price Index (CPI) downloadable from the Federal Reserve Bank of St. Louis database (The data can be found from https://fred.stlouisfed.org, accessed on 27 January 2021). To work with the stationarity data, we take the first log-difference of the data to obtain real housing returns. We use the State Social Capital Index derived from the U.S. Congress Social Capital Project as a measurement of social cohesion in each state (In an economic context, Reference [32] defines social cohesion as the depreciated stock of past social capital investment. Social capital is conceptually and closely related to social cohesion and can be used as a measurement of social cohesion [4]. See Reference [33] for the detailed theoretical discussions about the concepts of social cohesion and capital. (The data are available from https://www.jec.senate.gov/public/index.cfm/republicans/2018/4/the-geography-of-social-capital-in-america, accessed on 27 January 2021). To measure broader macro-economic and financial uncertainties in the U.S., we employ the Macro and Financial Uncertainty Indexes following the methodology described by References [19,21] using 134 macroeconomic time series and 148 measures of monthly financial indicators, respectively (The data are downloadable from www.sydneyludvigson.com/data-and-appendixes, accessed on 27 January 2021). The uncertainty data are computed based on the h-step-ahead forecasts from a vector autoregression (VAR) system at the 1-month and 12-month ahead forecast horizons so that uncertainty in the short-term and long-term can be both captured. We also use several macro-economic fundamental variables at the U.S. country level, including interest rates, industrial production growth rates, and inflation rates to control for the influence of macroeconomic fundamentals in affecting real housing returns across U.S. states (The data are available from https://fred.stlouisfed.org, accessed on 27 January 2021). Our panel dataset is constructed at a monthly frequency and ranged from December 1999 to December 2019 over a sample period of 20 years. We describe the variables used in this study in Table 1.

Table 1. Descriptions of variables.

Name of Variable	Description	Unit of Measure	Source
$R_{i,t}$	The real housing returns of U.S. states calculated by taking the first log difference of monthly index values of the Freddie Mac House Price Indexes, deflated by using the seasonally adjusted Consumer Price Index (CPI).	In percentage	www.freddiemac.com/research/indices/house-price-index.page (accessed on 27 January 2021)
MU_t	Uncertainty for the broader macroeconomy in the U.S.	In percentage	www.sydneyludvigson.com/data-and-appendixes (accessed on 27 January 2021)
FU_t	Uncertainty for the financial sector in the U.S.	In percentage	www.sydneyludvigson.com/data-and-appendixes (accessed on 27 January 2021)
$X_{i,t}$	A vector of control variables for macro-economic fundamentals in the U.S., including interest rates, industrial production growth rates, and inflation rates.	In percentage	https://fred.stlouisfed.org (accessed on 27 January 2021)

2.2. Methodology

The linear model for computing impulse response functions (IRFs) following the Local Projection (LP) method of Reference [21] can be specified as follows:

$$R_{i,t+s} = \alpha_{i,s} + \beta_s U_t + \epsilon_{i,t+s}, \quad \text{for } s = 0, 1, 2, \ldots H \tag{1}$$

where $R_{i,t}$ is the real housing returns of state i at time t, s is the length of forecast horizons up to the maximum forecast horizon H (The maximum length of forecast horizons is set to 12 months in this research, corresponding to a one-year forecast horizon), $\alpha_{i,s}$ captures the fixed effect, and β_s measures the responses of housing returns at time $t + s$ to the uncertainty measure (denoted by U_t) at time t. The LP IRFs are computed as a series of β_s, which are calculated separately at each horizon (s) (Let us consider an univariate process for generating the IRF of R_t to a unit increase in the shock U_t. At the time of the shock, $E[R_t] = R + U_t$, where R is the mean average. For the sake of simplicity, assuming two lags are selected, the IRF function in the next period is then calculated by regressing $R_t = \alpha + \beta_1 R_{t-1} + \beta_2 R_{t-2} + U_t$. The IRF estimate for the period after the shock is: $E[R_{t+1}] = \alpha + \beta_1(\overline{R} + \overline{U}) + \beta_2 \overline{R}$, and the confidence intervals are obtained using the standard errors of the regression coefficients. $E[R_{t+2}]$ is formed using a separate ordinary least squares (OLS) regression in each subsequent period. See Reference [21] for more detailed discussions about the local projection method).

We also test if the impacts of uncertainty on real housing returns are contingent on the status of social cohesion in each state. Equation (1) can be respecified into a regime-dependent model in which IRFs are depending on the social cohesion profile of each state [31]. A switching variable that distinguishes states with high social cohesion from those with low social cohesion can be incorporated into a nonlinear model defined as follows:

$$R_{i,t+s} = (1 - D)\left[\alpha_{i,s}^{high} + \beta_s^{high} U_t\right] + D\left[\alpha_{i,s}^{low} + \beta_s^{low} U_t\right] + \epsilon_{i,t+s}, \quad \text{for } s = 0, 1, 2, \ldots H \tag{2}$$

where D is a switching variable that takes a value of 1 if state i has low social cohesion, and 0 otherwise. Superscripts *high* and *low* denote high-social and low-social cohesion states, respectively (The states with high social cohesion in our dataset are based on the state social capital index derived from U.S. Congress Social Capital Project 2018. There are 22 states include Alaska, Colorado, Connecticut, Idaho, Indiana, Kansas, Maine, Massachusetts, Minnesota, Montana, Nebraska, New Hampshire, North Dakota, Oregon, Rhode Island, South Dakota, Utah, Vermont, Virginia, Washington, Wisconsin, and Wyoming. Understandably, the remaining 28 states, plus the District of Columbia, are characterized as states with low social cohesion). The model distinguishes the responses of real housing returns to uncertainty in high social cohesion states from low social cohesion states.

To test the robustness of our results, we also consider several control variables that can affect housing returns at the U.S. country level. The model specified in Equation (2) can be extended as follows.

$$R_{i,t+s} = (1 - D)\left[\alpha_{i,s}^{high} + \beta_s^{high} U_t\right] + D\left[\alpha_{i,s}^{low} + \beta_s^{low} U_t\right] + X_t \gamma_s + \epsilon_{i,t+s}, \quad \text{for } s = 0, 1, 2, \ldots H \tag{3}$$

where $X_{i,t} = [X_{1,t}, X_{2,t}, X_{3,t}]'$ is a vector of control variables for the U.S. macro-economic fundamentals. $X_{1,t}$, $X_{2,t}$, and $X_{3,t}$ represent the U.S. interest rates, industrial production growth rates, and inflation rates, respectively.

3. Empirical Results

Figure 1 shows the impact of macro-economic and financial uncertainties at the 1-month and 12-month ahead forecast horizons (i.e., short-term and long-term uncertainties) on the state-level real returns in the U.S. housing markets. The figure indicates the linear impulse response functions calculated by the local projection method to a 1-unit increase of the uncertainty on the future path of real housing returns for 1-month to 12-month-ahead, along with the 95% confidence bands.

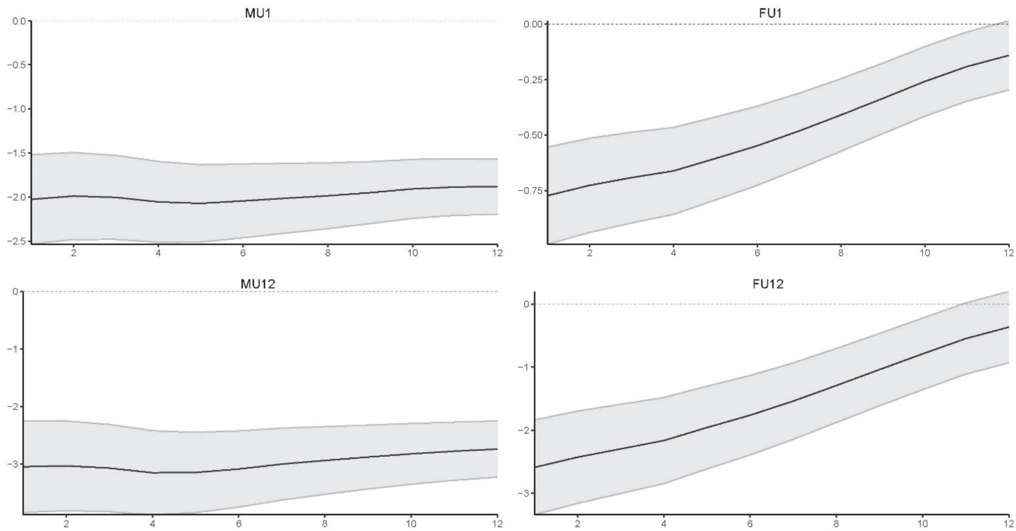

Figure 1. Responses of state-level real housing returns to macroeconomic uncertainty (MU) and financial uncertainty (FU).

The figures display the impulse responses of state-level real returns in the U.S. housing markets to a 1 unit increase in various measures of uncertainty. The shaded areas are the 95% confidence intervals. MU1 and MU12 represent macro-economic uncertainty at the 1-month and 12-month ahead forecast horizons (i.e., short-term and long-term macroeconomic uncertainties). FU1 and FU12 represent financial uncertainty at the 1-month and 12-month ahead forecast horizons (i.e., short-term and long-term financial uncertainties).

The first pattern that we can observe is that both types of uncertainties have a statistically significant and negative impact on real housing returns over the 12-month horizon, but macro-economic uncertainty exerts a relatively bigger influence comparing to their financial uncertainty counterparts. Moreover, we find that long-term uncertainties have a larger negative impact in size on housing returns than short-term uncertainties for both macro-economic and financial uncertainties with the strongest negative effect originating from the macro-economic uncertainty in the long term. The negative impact of uncertainty on housing returns can be explained by the decrease of demand in housing markets associated with low economic activity and high macro-economic and financial uncertainties. Our results are in line with country evidence in the literature about the negative linkage between uncertainty and housing market returns [11,15].

In Figure 2, we re-analyse the effect of uncertainty with a non-linear impulse response functions contingent on the social cohesion of individual U.S. states, derived based on the nonlinear version of the model described in Equation (2). We find that responses of real housing returns in U.S. states with both high-social and low-social cohesion are very similar to those derived from the linear model, as shown in Figure 1. The degree of social cohesion does not change the nature of the impact of uncertainty on real housing returns dramatically.

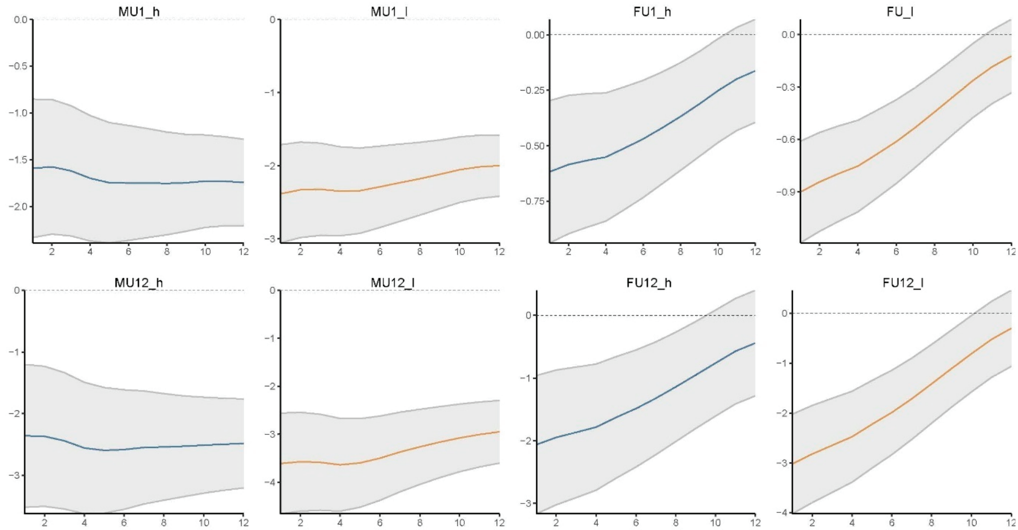

Figure 2. Responses of state-level real housing returns to macroeconomic uncertainty (MU) and financial uncertainty (FU) contingent on high (h) and low (l) social cohesion. **Note:** See Notes to Figure 1. _h and _l denote U.S. states with high and low social cohesion, respectively.

More importantly, we find that the impact of uncertainty on real housing returns is state-contingent on the social cohesion of individual U.S. states. Our results show that an increase in uncertainty tends to reduce real housing returns in a bigger magnitude in low-social cohesion states than high-social cohesion states. The relatively large negative influence of uncertainty on the real housing returns of the low-social cohesion states is in line with a socioeconomic intuition. In states with high social cohesion, the society tends to be more inclusive, people are more likely to have a high level of trust and engage with strong local community life, and the level of violent crimes tends to be lower. These social factors could contribute to mitigating the negative effects of uncertainty on housing markets.

In Figure 3, we find that housing return responses to uncertainty are robust to the influence of U.S. economic fundamentals in both high-social and low-social cohesion states. The patterns of IRFs are qualitatively the same as the ones reported in Figure 2. In comparison with Figure 2, the impulse responses presented in Figure 3 show that the negative effects of macro-economic and financial uncertainties on housing market returns have slightly increased in size for both high-social and low-social cohesion states when U.S. interest rates, industrial production growth rates, and inflation rates have been included in our model specified in Equation (3) as control variables.

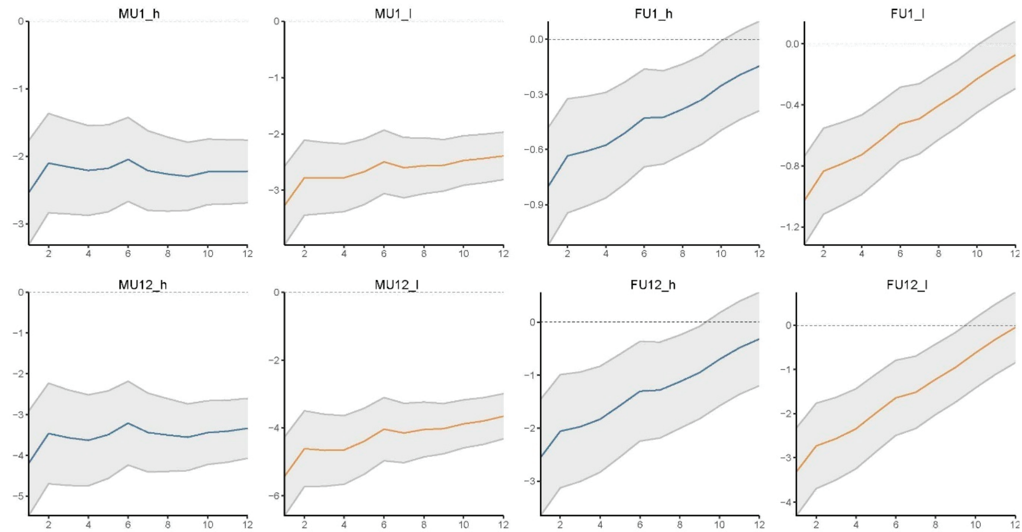

Figure 3. Responses of state-level real housing returns to macroeconomic uncertainty (MU) and financial uncertainty (FU) contingent on high (h) and low (l) social cohesion with control variables. **Note:** See notes to Figure 2.

4. Conclusions

This study investigates the impact of uncertainty on U.S. housing markets across all 50 states, plus the District of Columbia (Washington, D.C., USA) while considering the role of social cohesion in each state. The study contributes to the literature by examining both linear and nonlinear impulse responses of state-level housing returns to shot-term and long-term measurements of economic and financial uncertainties using the local projection method in a large panel dataset at the monthly frequency. We consider the heterogeneity of social cohesion in individual U.S. states and test if the responses of housing returns to uncertainty are regime-dependent on the status of social cohesion in each U.S. state. We find that both short-term and long-term measurements of macroeconomic and financial uncertainties reduce real housing returns, and the strongest impact originates from the macro-economic uncertainty over the long term. More importantly, we find that the effect of uncertainty on the housing markets is state-contingent on the social cohesion of individual U.S. states. Our results show that an increase in uncertainty tends to reduce real housing returns in a larger magnitude in low-social cohesion states than high-social cohesion states. Our study provides empirical evidence that social cohesion plays an important role in affecting the impact of uncertainty on real returns in the U.S. housing markets. The study highlights the important role of social cohesion with the impact of uncertainty on U.S. housing markets. Our results have great policy implications. It is important to policymakers to take into consideration the interplay between social and economic indicators when designing policies for the sustainable development of the real estate market, especially in times of great uncertainty. For future research, it would be useful to extend our analysis to an out-of-sample forecasting exercise. Moreover, our analysis can be extended to more countries, contingent on the limitation of data availability for uncertainty and social cohesion measurements at the regional level for other economies.

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sustainability

Article

An MCDM Model for Sustainable Decision-Making in Municipal Residential Buildings Facilities Management

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Abstract: Measuring and monitoring sustainability plays an essential role in impact assessment of global changes and development. Multi-criteria decision-making (MCDM) represents a reliable and adequate technique for assessing sustainability, especially in the field of municipal buildings management, where numerous parameters and criteria are involved. This study presents an MCDM model for the sustainable decision-making, tailored to municipal residential buildings facilities management. The main outcome of this research concerned normalized and weighted decision-making matrixes, based on the complex proportion assessment (COPRAS) and weighted aggregated sum product assessment (WASPAS) methods, applied for ranking investment alternatives related to the management of the buildings. The delivered model was applied to 20 municipal buildings of Kaunas city municipality, located in Lithuania, which an EU member state employing practices and regulations in accordance with the EU acquis, as well as a former Soviet Republic. The proposed model aspires to enhance sustainability practices in the management of municipal buildings and to demonstrate a solid tool that will allow informed decision-making in the building management sector.

Keywords: sustainable decision-making; sustainable social housing management; multi-criteria decision-making (MCDM); AHP; WASPAS; COPRAS

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1. Introduction

The United Nations stated that by 2050, 68% of the earth's population is projected to be urban, which is about 14% more than in 2018 [1]. In order to adopt the 2030 Agenda for Sustainable Growth, including attempts to forge a new urban development system, it is important to consider the key developments in urbanization that are likely to unfold over the coming years [2]. According to Eurostat data in 2018, 26.1% of final energy consumption belongs to households [3], being 0.5% more than in 2015 [4]. To meet the increasing housing needs, societies should proactively account for future demands. Municipalities are anticipated to have a significant role under this context, mainly due to the fact that they manage social housing, which currently consists of the main affordable housing for thousands of families around Europe and worldwide.

Advanced practices in construction management and engineering involve complex methods and applications, which deliver an increased amount of data, resulting in the need for developing tools and methodologies for data management [5,6]. The use of data, new information, and communication technologies has led to sustainable developments related to established sustainable development goals (SDGs), including SDG 7 (Affordable and clean energy), SDG 11 (Sustainable Cities and Communities), SDG13 (Climate action), and others [2,7,8].

Sustainable construction sets the boundaries of morality, ethics, and performance in the architectural and construction sectors. It creates the necessary conditions for cost-effective processes that reduce negative environmental impacts and save energy as well as natural resources.

In order to promote sustainable construction management practices, one should employ advanced methodologies, including digitalization and enhanced decision-making techniques, such as multi-criteria decision-making. Digitization drives the changes in the Industrial 4.0 revolution in the construction sector. With the help of digitization, new business models are anticipated to be created, focusing on the integration of equipment, the IT systems, and people. [9]. Sustainable decision-making [2,7,8,10–12] stands for decision-making that contributes to the transition to sustainable society [7]. The significance of reducing resources consumption in building sector has been underlined in the recent past in numerous studies [13–16].

Multi-criteria decision-making (MCDM) application in the sustainability field has been constantly growing by presenting the potential of applying MCDM methods for sustainable decision-making in civil engineering, construction building technology, public environmental occupational health, social issues, and multidisciplinary engineering. In order to justify the backgrounds of this study and to emphasize its novelty, we conducted an analysis of scientific articles. The Clarivate Analytics (Web of Science) database was employed, aiming to elucidate the prevalence of the application of MCDM methods in construction-related scientific publications. Studies employing MCDM methods were identified and articles related to measuring, monitoring, and applying MCDM in the sustainability field were identified (Figure 1).

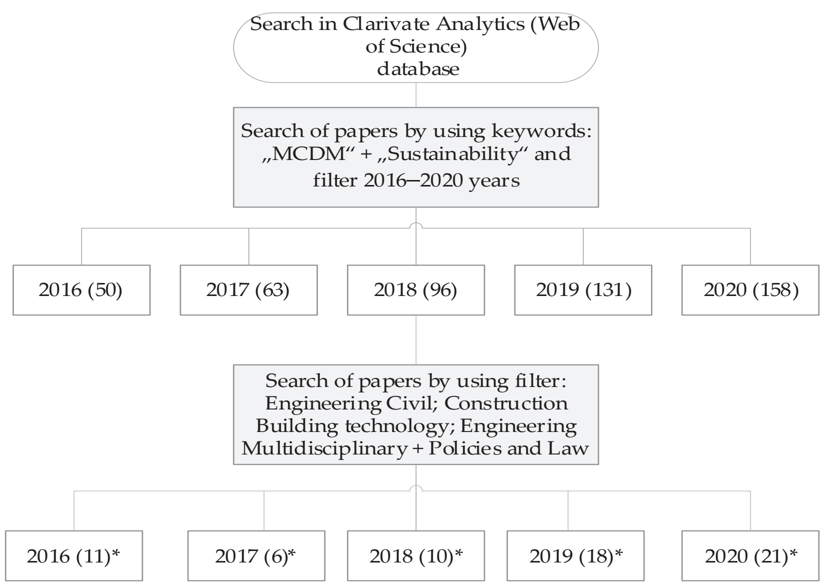

Figure 1. The search procedure and preliminary results. Note: * the number contained in brackets indicates the number of articles in the sustainability topic.

The number of studies using the keywords "MCDM" and "Sustainability" that were filtered for the years 2016–2020 is shown in Figure 1.

The literature overview reveals that although MCDM is trending in buildings sustainability management, and analysis of specific types of buildings, providing further insights in building management practices, are still to be conducted. The significance of municipal building management has been justified in the recent past in numerous studies [13,16,17]

The main research goal of this study was to develop and to introduce a comprehensive MCDM model for the sustainability assessment of municipal buildings. The proposed model is based on the generation of a priority que of facilities compliance regulations, delivering recommendations on the management of social housing, and meeting the minimum established criteria on the basis of the economic ratio calculations. The proposed model can also be used for the optimization of government and municipal facilities management, incorporating the concept of social sustainability into the technical assessment and management of buildings. The level of detail of the information demonstrated in this study allows for the development of the backend and frontend of an appropriate application, enabling the replication and establishment of the proposed model. The MCDM model demonstrated in this study considers related SDGs to the building sector, resulting in decision-making tailored to the needs of informed resources consumption, and is in line with the requirements of the EU policy on research efficient Europe. It is also a consumer-centric model that satisfies building users comfort needs in more efficient buildings, leading to social sustainability. The research purpose was to present a new perspective of sustainability through sustainable decision-making methods and to present residential buildings facilities management model for municipalities [17,18] that are based on MCDM techniques by using complex proportion assessment (COPRAS) [19] and weighted aggregated sum product assessment (WASPAS) [20,21] methods.

2. Research Methodology for the Evaluation and Sustainable Decision-Making in Municipal Residential Buildings Facilities Management

2.1. Application Levels of the Municipal Social Housing Evaluation Model

The municipal social housing assessment method developed by the authors includes the required elements for a comprehensive decision-making scheme. In particular, the scheme is based on a system of normative documents, the requirements for municipal social housing, as well as the compliance of social housing residents' needs for their housing and environment with the established requirements. The methodology also includes a ranking procedure according to the requirements described, presented in Figure 2.

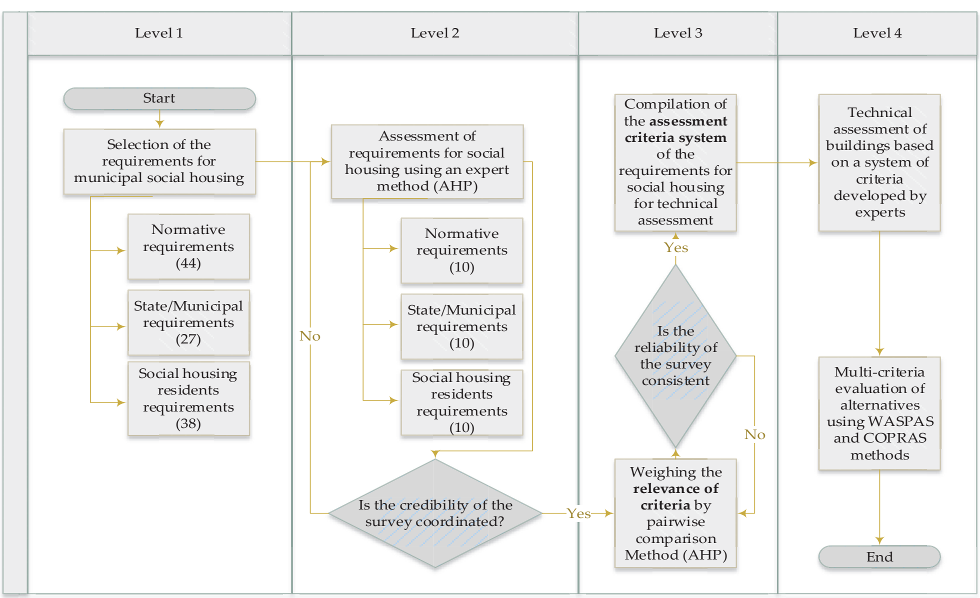

Figure 2. Application levels of the municipal social housing evaluation model (developed by the authors).

The proposed model consists of the following key levels:

The first level is the development of a system of requirements for municipal buildings by normative documents, functions assigned to municipalities, and other needs of building residents assigned to buildings. One hundred and nine requirements were selected in the analysis of normative documents, municipal requirements, and the needs of the residents of social housing. A survey of 63 residents of social housing was conducted, with the aim to identify the requirements of social housing tenants.

The second level is the optimization of the requirements system by selecting the most important requirements with the use of an expert method.

The work aimed to reduce the number of requirements for social housing buildings and to select the 109 most important from each group of requirements, according to which the municipal buildings would be assessed. The priorities of the requirements according to the normative documents, municipal requirements for the social housing, and residents of premises requirements were determined by the expert method. A group of 43 national level experts was set up for this purpose. It consisted of certified construction engineers, maintenance managers, and researchers. The experts analyzed the compliance of the buildings with the submitted requirements and presented their assessments on a 10-point scale, where 1 was the highest rank, and 10 was the least significant criterion.

A selection of the 10 requirements for each group with the lowest sum of evaluation scores is presented in Table 1. From here on, x_{n1}, x_{m1}, and x_{r1} mark criteria (n—the criteria of the requirements applicable by regulations, m—the criteria of requirements applicable by municipalities, r—the criteria of resident's requirements applicable to social housing). The selected sets of requirements were named as criteria for assessing the condition of buildings. The reliability of the survey was checked, and the calculations revealed that the survey was reliable; thus, its results could be used for further calculations.

Table 1. Ratings of the requirements for residential buildings.

Rank	Normative Requirements Applicable to Social Housing		Municipal Requirements Applicable to Social Housing		Social Housing Resident's Requirements Applicable to Social Housing	
1	x_{n1}	Compliance with specific social housing requirements	x_{m1}	Good technical condition of the asset	x_{r1}	Safety
2	x_{n3}	Safety of heating installations	x_{m2}	Low heating costs	x_{r4}	Infrastructure
3	x_{n8}	Requirements for sustainable buildings	x_{m9}	The premises are without difficulties to dispose of and manage them	x_{r2}	Comfort
4	x_{n2}	Energy needs for heating	x_{m5}	Energy performance class of buildings	x_{r3}	Neighbors
5	x_{n4}	Building type	x_{m4}	The price of 1 m^2 of usable floor area	x_{r9}	Utilities
6	x_{n9}	Natural sunlight requirements	x_{m3}	Apartment with amenities	x_{r5}	Car parking
7	x_{n7}	Power and low power supply systems	x_{m8}	Social housing is suitable for families with young children	x_{r8}	The main characteristics of the rooms
8	x_{n5}	Social housing's heating and air conditioning system	x_{m7}	Social housing is adapted for people with disabilities	x_{r6}	Environment
9	x_{n6}	Water supply system	x_{m6}	Access to the building by car	x_{r7}	Entrance
10	x_{m10}	Number of places for parking	x_{m10}	Car parking	x_{r10}	Environmental pollution in the area

The third step in optimizing the system of building criteria is to determine the significance of the criteria for municipal residential buildings—q_{ij}. At this stage, a group of 34 experts completed a paired comparison (AHP, analytic hierarchy process) questionnaire to determine the significance of the criteria using the AHP method [22]. The method is convenient to use as the criteria can be compared in pairs [22–25].

Only duly completed questionnaires were evaluated (11, 13, and 10). Initially, the ranking of criteria was performed according to the obtained data (Appendix A, Tables A1–A3). The averages of the significance of the criteria obtained by experts were calculated, the compatibility of the survey was checked, and a system of evaluation criteria for municipal social housing buildings was created. The consistency index (S) of all three expert groups was sufficient, with a significance level of 0.01 [26–29]. The last step was to calculate the significance values of the criteria, which were calculated according to the methodology described below:

- The pairwise comparison of the criteria, x_i and x_j is denoted by x_{ij}, where i, j = 1,..., n. x_{ij} is the ratio of ranks of criteria i and j, which were presented by the expert. The criteria were compared in pairs and their numerical priority values were determined. The results of the pairwise comparison table are written in matrix P [17]:

$$P = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} \tag{1}$$

The pairwise comparison matrix is inverse, symmetric, i.e.,

$$x_{ij} = \frac{1}{x_{ji}}, \ (i, j = 1, 2, \ldots, n),$$

- Each element of column P of the matrix is divided by the sum of the elements of that column:

$$b_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \ (i, j = 1, 2, \ldots, n) \tag{2}$$

This gives a new matrix B:

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \tag{3}$$

- The arithmetic mean of the elements of rows B of the matrix and gives the significance values of the respective criteria according to the matrix of the pairwise comparison of one expert:

$$q_j = \frac{1}{n} \sum_{j=1}^{n} b_{ij}, \ (i, j = 1, 2, \ldots, n), \tag{4}$$

The significance of the criteria (Appendix A, Tables A4–A6) obtained according to Equations (1)–(4) can be used in further calculations if the compatibility of the pairwise comparison matrix P is sufficient, i.e., the elements of the matrix P satisfy the condition of transitivity:

$$(A \ \phi \ B) \wedge (B \ \phi \ C) \Rightarrow (A \ \phi \ C), \tag{5}$$

where A, B, and C are elements of the same set.

The research results allowed the team to identify 30 criteria that make up the municipal social housing building assessment system, which is used in the next stages to perform a technical assessment of buildings. It is important to note that municipal buildings can be assessed according to each group of criteria separately. Thus, the analysis would be more detailed or all together. In our case, the buildings were assessed by covering the whole system of criteria, each of them setting the significance level 1/3. The developed model is easily applied to any buildings, and municipal social housing was chosen because Lithuania faces the most problems in managing this real estate.

Last step—technical assessment and rating of buildings in accordance with the criteria system presented in paragraphs below.

2.2. Technical Assessment of the Facilities Following the System of Facilities Assessment Criteria

After assessing the significance of the criteria, we performed a technical assessment of social housing. Its stages (Figure 3) are described in this section.

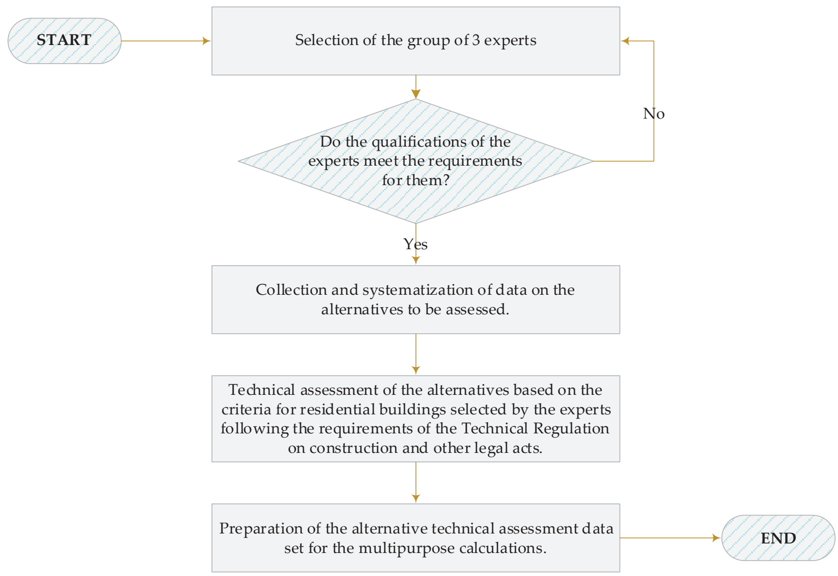

Figure 3. The process of technical assessment of social housing (developed by the authors).

In the first stage, a group of experts consisting of at least three certified building experts, maintenance managers, or engineers with at least 10 years' experience in construction were selected. These experts undertook an independent assessment of the designated buildings according to social housing requirements chosen by experts by the Technical Regulation on Construction [30] and other normative acts, using the experience and the necessary standard testing methods.

The second step was to collect and systematize data on the alternatives under assessment.

The third stage was the technical assessment of alternatives according to the criteria of the requirements for municipal social housing selected by the expert group.

The fourth stage was the preparation of alternative technical assessment data for multi-criteria calculations.

2.3. Methodology for Multi-Criteria Decision-Making Methods, Case Study, and Results

This case study was calculated according to the two most successfully applied multi-criteria decision-making (MCDM) methods: weighted aggregated sum product assessment (WASPAS) [21,22] and complex proportion assessment (COPRAS) [20]. The fact that the selected MCDM methods are appropriate and successfully used for this type of case study is proven by a series of research [17,31,32]. The AHP method was selected for weighting criteria for COPRAS method, which also includes an additive version of AHP and is actively being used for this type of case study's calculations. The WASPAS method basically combines additive and multiplicative versions of AHP. Many case studies, which were calculated by the authors, were related with the main direction towards sustainable goals.

Normalized values $\overline{x}_{ij}$ of the j criterion for i alternative with COPRAS method are calculated on the basis of Equation (6). Regarding the direction of optimization of the line of particular criteria, we chose the following normalization formulas: if criteria are minimizing, thus normalization for WASPAS method is carried out with Equation (7); if criteria are maximizing—Equation (8). For the WASPAS method, normalized and weighted values are calculated separately for the summarizing of determination and separately for the multiplication section, and are implemented with the help of Equations (9) and (10), respectively.

$$\overline{x}_{ij} = \frac{x_{ij} \cdot q_j}{\sum_{i=1}^{m} x_{ij}}, \text{where } i = \overline{1,m};\ j = \overline{1,n}. \tag{6}$$

From here on, x_{ij} is the value of j criterion for i alternative; m is the number of alternatives, n is the number of criteria; q is the weight of a criterion.

$$x_{ij} = \frac{\underset{i}{opt}\, x_{ij}}{x_{ij}}, \text{ where } i = \overline{1,m};\ j = \overline{1,n}., \tag{7}$$

If optimal value is minimizing

$$x_{ij} = \frac{x_{ij}}{\underset{i}{opt}\, x_{ij}}, \text{ where } i = \overline{1,m};\ j = \overline{1,n}, \tag{8}$$

If optimal value is maximizing [33].

$$\overline{x}_{ij,sum} = \overline{x}_{ij} q_j, \text{ where } i = \overline{1,m};\ j = \overline{1,n}. \tag{9}$$

$$\overline{x}_{ij,mult} = \overline{x}_{ij}^{\,q_j}, \text{where } i = \overline{1,m};\ j = \overline{1,n}. \tag{10}$$

Final determination is carried out by applying the following formulas: Equation (11) for COPRAS method, and Equation (12) for WASPAS method.

$$Q_i = S_{+j} + \frac{S_{-min} \cdot \sum_{i=1}^{m} S_{-j}}{S_{-j} \cdot \sum_{i=1}^{m} \frac{S_{-min}}{S_{-j}}}, \tag{11}$$

where $i = \overline{1,m};\ j = \overline{1,n}$

S_{+j}—the sum of maximizing values from j row's alternative.

S_{-j}—the sum of minimizing values from j row's alternative.

S_{-min}—minimum value from the whole determined S_{-j} column, where $i = \overline{1,m}$; $j = \overline{1,n}$ [32]

$$WPS_i = 0.5 \sum_{j=1}^{n} \overline{x}_{ij} + 0.5 \prod_{j=1}^{n} \overline{x}_{ij}, \text{ where } i = \overline{1,m};\ j = \overline{1,n}, \tag{12}$$

3. Modelling the Sustainable Decision-Making Process: The Case of Lithuanian Municipal Buildings

In order to evaluate the proposed method, we applied the municipal social housing evaluation model for the case of Lithuanian municipal buildings. The developed method is based on a system of requirements for municipal social housing buildings, as well as on the determination of their compliance with the declared needs. The scheme delivers a ranking according to the methodology of technical assessment of buildings.

With the collapse of the Soviet Union in 1990, Lithuania regained its independence, and the Lithuanian state and municipalities took over a large part of the real estate. However, 30 years after the restoration of independence, the 2020 audit of state real estate management [34] revealed real estate management problems—no institution has a summary of real estate and how much it is transferred to municipalities. In many cases, municipalities do not possess sufficient information concerning their building properties. One-third of the municipalities managing the state do not have accurate information about the state real estate managed by the right of trust [34]. According to 2020 data concerning Lithuanian building stock, housing stock in 2019 increased by 10.4 thousand (0.7%) compared to 2018, and amounted to 1.5 million dwellings [34]. The useful floor area of dwellings in Lithuania was 102.4 million m^2 and increased by 1 million m^2 (1%) over the year. Private ownership accounted for 98.6% of the housing stock, with the remainder owned by the state and municipalities. The useful floor area of the housing stock was 62.1 million m^2 in urban areas and 40.3 million m^2 in rural areas (Table 2).

Table 2. Housing stock at the end of 2019, in thousands of square meters of usable area [34].

	Housing Stock	Of Which by Forms of Ownership				The Average Useful Floor Area per Capita Was
		Private	%	State and Municipal Property	%	
Total	102,430.8	100,964.1	98.6	1466.7	1.4	36.7
Urban areas	62,154.2	61,110.9	98.3	1043.3	1.7	33
Rural areas	40,276.6	39,853.2	98.9	423.4	1.1	44.1

At the end of 2019, there were 531 dwellings per 1000 inhabitants in Lithuania (as of 31 December 2018—527 dwellings). The average useful floor area per capita was 36.7 m^2. Of these, in urban areas—33 m^2, in rural areas—44.1 m^2. The average size of private housing (Table 3) was 69.5 m^2, of which 63.3 m^2 was in the city and 81.7 m^2 in the countryside. State and municipal dwellings were smaller. The average size of one dwelling was 49.1 m^2, in urban areas—45.5 m^2, and in rural areas—60.9 m^2.

Table 3. Number of dwellings at the end of 2019, in thousands [34].

	Number of Dwellings, Total	Average Useful Floor Space of Dwellings, m^2
Urban areas	988.3	62.9
Rural areas	494.7	81.4
Private property	1453.1	69.5
Urban areas	965.4	63.3
Rural areas	487.7	81.7
State and municipal property	29.9	49.1
Urban areas	22.9	45.5
Rural areas	7	60.9
Total	1483.0	69.1

During the technical assessment process, 20 social housing buildings of Kaunas City Municipality were randomly selected. This number was chosen according to the smallest municipality in Lithuania, which has the same number of social housing buildings as in our case. This choice confirms that the model works with a minimum number of buildings.

Information on buildings, energy consumption, air condition in the district, and other necessary data was also collected by official registers, JSC "Kauno energija", Environmental Protection Agency, Information Technology and Communications Department, and independent real estate appraisers. A group of three experts appointed by the municipality assessed the condition of the municipality's social housing by filling in questionnaires according to the provided criteria.

A common system of assessment criteria must be used for the technical assessment of buildings at least every 5 years. Because the evaluation criteria have different measurement dimensions, we chose multi-criteria evaluation methods for the calculations. The investigated MCDM case study was defined with the use of 20 different alternatives, described with 10 criteria of each group. The initial decision-making matrix is presented in (Appendix A, Tables A4–A6). The criteria were weighted with the help of pairwise questioner, in which representatives from different interest parties participated. The results of pairwise matrix were determined with the AHP method. The normalized and weighted decision-making matrix for COPRAS method's calculations, the normalized matrix for WASPAS method, and the normalized and weighted matrix for multiplication part are presented in Appendix A (Tables A7–A9).

The main results and rank of calculations are described and presented in Appendix A (Table A10). On the basis of the MCDM findings, results of Kaunas City Municipality, and research data, we found that 20% of the social housing buildings at the end of the priority queue were in the worst condition, namely, No. 8, No. 14, No. 15, and No. 16. The calculations included a detailed assessment of the alternatives for each criterion as well as the highest non-compliance. Considering the condition of social housing after conducting a technical assessment of buildings and prioritizing them, we present possible alternatives depending on the property's condition. We suggest three groups of social housing, after a multi-criteria assessment:

1. usable social housing;
2. the need for social housing;
3. social housing, which the municipality should disclaim.

Usable social housing refers to buildings that meets all the requirements but need minor repair or ongoing maintenance. Municipalities must evaluate the lack of social housing, consider possible alternatives, and choose only those that meet all the requirements after assessment. Social housing, which the municipality should disclaim, could be leased, sold, or rented.

According to each criterion's significance, it is necessary to identify the priorities and required investment, as well as decide which is suitable for social housing but require ongoing maintenance, renovation, or repair.

The following economic indices of the structures at the end of the priority queue is calculated after the assessment of municipal social housing on the basis of the selected criteria of the three groups: the construction value of the facility, the reconstruction cost (construction) value of the apartment, the amortization value, and the reconstruction value (Table 4).

Table 4. Economic indices of the alternatives (developed by the authors based on "*Sistela*" estimation prices for the construction of the structures as of 2020 and 2021) [35,36].

Alt. No	Volume, m^3 Social Housing	Reconstruction Price per 1 m^3	Construction Value of the Facility	Amortization (%)	Apartment Reconstruction Cost Value, EUR	Amortization Value, EUR	Apartment Reconstruction Value, EUR
	Apartment	Per Apartment					
A8	395 182	252.75 46,000.5	84,827.09	67	39,020.46	26,143.71	12,876.75
A14	4456 75	169.15 1286.25	828,994.24	37	16,579.88	6134.56	10,445.32
A15	656 159	222.24 35,336.16	128,241.44	72	31,034.42	22,334.78	8689.64
A16	7725 167	156.52 26,138.84	1,437,159	37	31,617.50	11,698.47	19,919.02

The economic indicators of the municipal social housing buildings that meet the system of criteria the least are calculated: construction, reconstruction costs, and amortization values to facilitate decision-making. These economic indices of facilities at the end of the municipal real estate priority que are computed by evaluating the municipal social housing on the basis of the selected three groups of criteria: construction value of the object, reconstruction price (construction) apartment value, depreciation value, and reconstruction value (Table 4). Buildings with a value of 61 to 100% of the essential requirements of the building fall into the third group—social housing, which the municipality should disclaim. Such real estate is in a state of emergency, unsuitable for use, and it is not profitable for municipalities to renovate it. The same is confirmed by the calculated economic indices presented in Table 4—for example, alternative 8. The amortization value of this property (26143.71 EUR) is twice as high as its reconstruction value (12876.75 EUR), and the apartment reconstruction cost value (39020.46 EUR) is only one-third higher than the amortization value.

4. Conclusions

In this study, a four-stage decision-making model for municipal buildings management was developed and demonstrated. The developed model is based on a decision-making methodology that identifies the worst-case real estate, for which strategic decisions have to be made in municipalities. The proposed model is based on 109 requirements of three groups for social housing buildings. Using expert assessment methods, we reduced the requirements to 30 (10 normative, 10 municipal, and 10 resident requirements) in order to simplify and speed up the decision-making process. After optimizing the building criteria system, the significance of residential building criteria is determined by the AHP method. In the third stage, the survey's compatibility is verified, and a system of evaluation criteria is developed for municipal residential buildings with calculated significances, which allow for assessing the importance of each criterion in a more detailed evaluation process. The last stage of the model is dedicated to the technical assessment of buildings according to the developed system of three groups of criteria used by the MCDM methods—WASPAS and COPRAS, in order to model the decision-making process in municipalities. The model developed in this study delivers informed decisions on sustainability aspects related to sustainable development goals (SDGs), including SDG 7 (affordable and clean energy), SDG 11 (sustainable cities and communities), SDG13 (climate action), and others.

According to the developed methodology, the inventory and monitoring of buildings can be simplified. The model allows for the evaluation of numerous aspects of real estate properties including the need for a property, suitability for its functions, efficiency, optimization measures, staff needs for property maintenance, and condition and maintenance costs. By optimizing real estate management, the need for buildings decreases, more efficient buildings better meet users' needs, less energy is used, and environmental pollution is mitigated. One of the main outcomes of the proposed model concerns recommendations for the management, use, and disposal of municipal buildings, in accordance with the principles of public law, rationality, management efficiency, and economic benefits.

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Appendix A

Table A1. Rankings of criteria for social housing requirements in normative documents according to 11 experts [17].

Expert No.	x_{n1}	x_{n2}	x_{n3}	x_{n4}	x_{n5}	x_{n6}	x_{n7}	x_{n8}	x_{n9}	x_{n10}	S
Expert 1	1	3	4	2	6	8	5	7	9	10	0.11434
Expert 2	1	2	4	3	6	8	5	7	9	10	0.066306
Expert 3	1	3	4	2	7	8	5	6	9	10	0.102355
Expert 4	1	3	4	2	5	7	6	8	9	10	0.093
Expert 6	1	10	4	2	5	6	3	8	7	9	0.058
Expert 7	1	3	4	2	6	8	5	7	9	10	0.096
Expert 8	1	4	3	2	6	7	8	5	9	10	0.068
Expert 16	1	8	3	2	6	5	7	4	9	10	0.092
Expert 17	1	3	4	2	7	8	5	6	9	10	0.101
Expert 18	1	3	4	2	5	6	7	8	9	10	0.091
Expert 32	1	4	3	2	5	6	7	8	9	10	0.104

Table A2. Municipal requirements for social housing and rank of their criteria according to 13 experts [17].

Expert No.	x_{m1}	x_{m2}	x_{m3}	x_{m4}	x_{m5}	x_{m6}	x_{m7}	x_{m8}	x_{m9}	x_{m10}	S
Expert 27	2	3	6	5	4	7	8	9	1	10	0.095
Expert 1	1	2	6	5	4	9	8	7	3	10	0.07
Expert 2	1	2	6	5	4	9	8	7	3	10	0.07
Expert 3	1	2	6	5	4	9	8	7	3	10	0.069
Expert 5	1	2	6	4	5	9	8	7	3	10	0.108
Expert 7	2	3	6	4	5	9	8	7	1	10	0.102
Expert 34	1	3	6	5	4	9	7	8	2	10	0.022
Expert 9	2	3	6	5	4	7	8	9	1	10	0.092
Expert 10	1	3	6	5	4	9	7	8	2	10	0.022
Expert 14	1	3	6	5	4	9	8	7	2	10	0.12
Expert 15	1	4	6	5	3	9	7	8	2	10	0.041
Expert 23	1	2	6	5	4	9	8	7	3	10	0.07
Expert 29	2	3	6	5	4	7	8	9	1	10	0.092

Table A3. Residents of social housing requirements and rank of their criteria according to 10 experts [17].

Expert No.	x_{r1}	x_{r2}	x_{r3}	x_{r4}	x_{r5}	x_{r6}	x_{r7}	x_{r8}	x_{r9}	x_{r10}	S
Expert 1	1	3	6	5	4	9	7	8	2	10	0.022
Expert 6	1	10	4	2	5	6	3	8	7	9	0.058
Expert 3	3	5	10	2	8	9	7	4	1	6	0.085
Expert 7	1	3	4	2	6	8	5	7	9	10	0.096
Expert 8	1	4	3	2	6	7	8	5	9	10	0.068
Expert 18	1	3	4	2	5	6	7	8	9	10	0.091
Expert 32	1	4	3	2	5	6	7	8	9	10	0.104
Expert 5	1	4	3	2	5	7	6	8	9	10	0.124
Expert 16	1	8	3	2	6	5	7	4	9	10	0.092
Expert 17	1	3	4	2	7	8	5	6	9	10	0.101

Table A4. The initial decision-making matrix, which presents the values of the criteria for social housing requirements in the normative documents and their significances q_j [17].

	Criteria									
	x_{n1}	x_{n2}	x_{n3}	x_{n4}	x_{n5}	x_{n6}	x_{n7}	x_{n8}	x_{n9}	x_{n10}
	max	**min**	**min**	**max**	**min**	**min**	**min**	**max**	**max**	**min**
q_j	0.309	0.113	0.114	0.148	0.07	0.066	0.068	0.069	0.025	0.018
A_1	75	10.42	15	125	10	45	21	6	4	2
A_2	84	8.32	20	125	41	21	20	7	3	1
A_3	70	10.42	30	125	49	51	19	7	3.5	1
A_4	92	10.81	10	125	25	21	15	6	4.5	1
A_5	81	8.69	27	125	40	35	10	7	3	1
A_6	91	7.24	10	125	21	20	15	8	3	1
A_7	66	9.54	40	125	40	35	15	5	2.5	1
A_8	33	18.32	90	65	75	100	51	3	2	1
A_9	93	11.98	10	125	21	10	15	7	3	2
A_{10}	93	11.98	10	125	21	10	15	7	3	2
A_{11}	93	11.98	10	125	21	10	15	7	3	2
A_{12}	93	11.98	10	125	21	20	15	7	3	2
A_{13}	99	7.24	5	125	21	20	15	8	2.5	1
A_{14}	63	16.68	60	125	61	40	40	4	3	1
A_{15}	28	18.98	85	125	65	61	41	3	4	1
A_{16}	63	14.67	60	125	40	41	41	6	3	1
A_{17}	69	15.97	75	125	40	55	35	6	2.5	1
A_{18}	100	7.18	5	100	10	2	1	9	3.5	1
A_{19}	100	7.38	5	100	10	2	1	9	3	1
A_{20}	99	7.6	5	100	10	2	1	9	3.5	1
OPT	100	7.18	5	125	10	2	1	9	4.5	1

Table A5. The initial decision-making matrix, which presents the values of the criteria for municipal requirements for social housing and their significance q_j [17].

	Criteria									
	x_{m1}	x_{m2}	x_{m3}	x_{m4}	x_{m5}	x_{m6}	x_{m7}	x_{m8}	x_{m9}	x_{m10}
	max	**min**	**min**	**min**	**min**	**min**	**min**	**min**	**min**	**max**
q_j	0.238	0.143	0.066	0.107	0.114	0.031	0.033	0.036	0.212	0.019
A1	75	0.47	1	1091	3	2	4	1	1	0.4
A2	84	0.37	1	367	7	1	4	1	1	0.7
A3	70	0.47	1	960	7	1	4	1	1	0.8
A4	92	0.49	1	324	7	1	4	1	1	0.8
A5	81	0.38	1	239	7	1	4	1	1	0.6
A6	91	0.33	1	830	7	1	4	1	1	0.7
A7	66	0.43	1	630	7	1	4	2	1	0.7
A8	33	0.71	3	52	7	1	3	1	1	1
A9	93	0.54	1	231	7	2	3	1	1	0.5
A10	93	0.54	1	233	7	2	2	1	1	0.5
A11	93	0.54	1	233	7	2	3	1	1	0.5
A12	93	0.54	1	270	7	2	4	1	1	0.6
A13	99	0.33	1	378	7	1	3	1	1	0.6
A14	63	0.76	1	381	7	1	4	1	1	0.6
A15	28	0.65	3	460	7	1	3	2	1	0.7
A16	63	0.67	1	590	7	1	3	1	1	0.6
A17	69	0.73	1	187	7	1	3	1	1	0.7
A18	100	0.25	1	1063	2	1	2	1	1	1
A19	100	0.25	1	1063	2	1	2	1	1	1
A20	99	0.26	1	1063	2	1	4	1	1	1
OPT	100	0.25	1	52	2	1	2	1	1	1

Table A6. The initial decision-making matrix, which presents the values of the criteria of social housing residents for social housing and their significance q_j [17].

	Criteria									
	x_{r1}	x_{r2}	x_{r3}	x_{r4}	x_{r5}	x_{r6}	x_{r7}	x_{r8}	x_{r9}	x_{r10}
	min	**max**	**min**	**max**	**max**	**min**	**min**	**min**	**min**	**min**
q_j	0.281	0.107	0.101	0.142	0.073	0.061	0.061	0.07	0.08	0.024
A1	169	8	1	7	0.4	5	5	1	25	4
A2	200	7	2	10	0.7	40	10	1	27	4
A3	146	5	1	8	0.8	30	5	1	40	4
A4	162	8	2	8	0.8	30	5	1	20	2
A5	106	7	3	8	0.6	60	5	1	28	4
A6	100	9	1	9	0.7	10	5	1	19	2
A7	63	5	5	7	0.7	55	5	2	30	3
A8	39	3	5	6	1	21	80	2	75	3
A9	104	9	1	9	0.5	21	1	1	15	2
A10	104	9	1	8	0.5	21	1	1	15	2
A11	104	9	1	8	0.5	21	1	1	15	2
A12	104	9	1	8	0.6	5	5	1	19	2
A13	100	9	1	9	0.6	5	5	1	19	2
A14	180	6	5	10	0.6	35	50	1	47	4
A15	65	2	2	10	0.7	5	80	1	56	4
A16	229	5	4	9	0.6	10	35	1	40	4
A17	168	6	3	9	0.7	45	35	2	43	4
A18	24	10	2	8	1	21	1	1	4	2
A19	26	10	2	8	1	21	1	1	4	2
A20	20	10	2	8	1	21	1	1	4	2
OPT	20	10	1	10	1	5	1	1	4	2

Table A7. Normalized and weighted decision-making matrix for COPRAS method (developed by the authors).

A1	0.01126183	0.0069217	0.00275	0.0109664	0.0028264	0.00248	0.0019701	0.0016364	0.0106	0.0005429
A2	0.01261325	0.005449	0.00275	0.003689	0.006595	0.00124	0.0019701	0.0016364	0.0106	0.0009500
A3	0.01051104	0.0069217	0.00275	0.0096496	0.006595	0.00124	0.0019701	0.0016364	0.0106	0.0010857
A4	0.01381451	0.0072163	0.00275	0.0032567	0.006595	0.00124	0.0019701	0.0016364	0.0106	0.0010857
A5	0.01216278	0.0055963	0.00275	0.0024023	0.006595	0.00124	0.0019701	0.0016364	0.0106	0.0008143
A6	0.01366435	0.0048599	0.00275	0.0083429	0.006595	0.00124	0.0019701	0.0016364	0.0106	0.0009500
A7	0.00991041	0.0063326	0.00275	0.0063326	0.006595	0.00124	0.0019701	0.0032727	0.0106	0.0009500
A8	0.00495521	0.0104562	0.00825	0.0005227	0.006595	0.00124	0.0014776	0.0016364	0.0106	0.0013571
A9	0.01396467	0.0079526	0.00275	0.0023219	0.006595	0.00248	0.0014776	0.0016364	0.0106	0.0006786
A10	0.01396467	0.0079526	0.00275	0.002342	0.006595	0.00248	0.0009851	0.0016364	0.0106	0.0006786
A11	0.01396467	0.0079526	0.00275	0.002342	0.006595	0.00248	0.0014776	0.0016364	0.0106	0.0006786
A12	0.01396467	0.0079526	0.00275	0.002714	0.006595	0.00248	0.0019701	0.0016364	0.0106	0.0008143
A13	0.01486562	0.0048599	0.00275	0.0037995	0.006595	0.00124	0.0014776	0.0016364	0.0106	0.0008143
A14	0.00945994	0.0111926	0.00275	0.0038297	0.006595	0.00124	0.0019701	0.0016364	0.0106	0.0008143
A15	0.00420442	0.0095726	0.00825	0.0046238	0.006595	0.00124	0.0014776	0.0032727	0.0106	0.0009500
A16	0.00945994	0.0098671	0.00275	0.0059305	0.006595	0.00124	0.0014776	0.0016364	0.0106	0.0008143
A17	0.01036088	0.0107508	0.00275	0.0018797	0.006595	0.00124	0.0014776	0.0016364	0.0106	0.0009500
A18	0.01501577	0.0036818	0.00275	0.0106849	0.0018843	0.00124	0.0009851	0.0016364	0.0106	0.0013571
A19	0.01501577	0.0036818	0.00275	0.0106849	0.0018843	0.00124	0.0009851	0.0016364	0.0106	0.0013571
A20	0.01486562	0.003829	0.00275	0.0106849	0.0018843	0.00124	0.0019701	0.0016364	0.0106	0.0013571

Table A8. Normalized and weighted matrix for summarizing part of WASPAS method (developed by the authors).

A1	0.1785	0.07606383	0.066	0.0050999	0.076	0.0155	0.0165	0.036	0.212	0.0076
A2	0.19992	0.09662162	0.066	0.0151608	0.0325714	0.031	0.0165	0.036	0.212	0.0133
A3	0.16660	0.07606383	0.066	0.0057958	0.0325714	0.031	0.0165	0.036	0.212	0.0152
A4	0.21896	0.07295918	0.066	0.0171728	0.0325714	0.031	0.0165	0.036	0.212	0.0152
A5	0.19278	0.09407895	0.066	0.0232803	0.0325714	0.031	0.0165	0.036	0.212	0.0114
A6	0.21658	0.10833333	0.066	0.0067036	0.0325714	0.031	0.0165	0.036	0.212	0.0133
A7	0.15708	0.08313953	0.066	0.0088317	0.0325714	0.031	0.0165	0.018	0.212	0.0133
A8	0.07854	0.05035211	0.022	0.1070000	0.0325714	0.031	0.0220	0.036	0.212	0.0190
A9	0.22134	0.06620370	0.066	0.0240866	0.0325714	0.0155	0.0220	0.036	0.212	0.0095
A10	0.22134	0.06620370	0.066	0.0238798	0.0325714	0.0155	0.0330	0.036	0.212	0.0095
A11	0.22134	0.06620370	0.066	0.0238798	0.0325714	0.0155	0.0220	0.036	0.212	0.0095
A12	0.22134	0.06620370	0.066	0.0206074	0.0325714	0.0155	0.0165	0.036	0.212	0.0114
A13	0.23562	0.10833333	0.066	0.0147196	0.0325714	0.031	0.0220	0.036	0.212	0.0114
A14	0.14994	0.04703947	0.066	0.0146037	0.0325714	0.031	0.0165	0.036	0.212	0.0114
A15	0.06664	0.05500000	0.022	0.0120957	0.0325714	0.031	0.0220	0.018	0.212	0.0133
A16	0.14994	0.05335821	0.066	0.0094305	0.0325714	0.031	0.0220	0.036	0.212	0.0114
A17	0.16422	0.04897260	0.066	0.0297540	0.0325714	0.031	0.0220	0.036	0.212	0.0133
A18	0.23800	0.14300000	0.066	0.0052342	0.1140000	0.031	0.0330	0.036	0.212	0.0190
A19	0.23800	0.14300000	0.066	0.0052342	0.1140000	0.031	0.0330	0.036	0.212	0.0190
A20	0.23562	0.137500000	0.066	0.0052342	0.1140000	0.031	0.0165	0.036	0.212	0.0190

Table A9. Normalized and weighted matrix for multiplication part (developed by the authors).

A1	0.933823	0.9136828	1	0.7220464	0.954829	0.9787417	0.9773858	1	1	0.9827411
A2	0.9593531	0.9454805	1	0.8113217	0.8669145	1	0.9773858	1	1	0.9932461
A3	0.9186146	0.9136828	1	0.7319971	0.8669145	1	0.9773858	1	1	0.9957692
A4	0.9803508	0.9082541	1	0.8222124	0.8669145	1	0.9773858	1	1	0.9957692
A5	0.9510852	0.9418817	1	0.8494225	0.8669145	1	0.9773858	1	1	0.9903413
A6	0.9778041	0.9610764	1	0.7434829	0.8669145	1	0.9773858	1	1	0.9932461
A7	0.9058399	0.9253786	1	0.7657428	0.8669145	1	0.9773858	0.9753555	1	0.9932461
A8	0.7680798	0.8613417	0.9300579	1	0.8669145	1	0.9867088	1	1	1
A9	0.9828765	0.8957217	1	0.8525226	0.8669145	0.9787417	0.9867088	1	1	0.9869165
A10	0.9828765	0.8957217	1	0.8517365	0.8669145	0.9787417	1	1	1	0.9869165
A11	0.9828765	0.8957217	1	0.8517365	0.8669145	0.9787417	0.9867088	1	1	0.9869165
A12	0.9828765	0.8957217	1	0.83841	0.8669145	0.9787417	0.9773858	1	1	0.9903413
A13	0.9976109	0.9610764	1	0.808762	0.8669145	1	0.9867088	1	1	0.9903413
A14	0.895866	0.8530001	1	0.8080782	0.8669145	1	0.9773858	1	1	0.9903413
A15	0.7386243	0.8722858	0.9300579	0.7919491	0.8669145	1	0.9867088	0.9753555	1	0.9932461
A16	0.895866	0.8685138	1	0.7711364	0.8669145	1	0.9867088	1	1	0.9903413
A17	0.9154742	0.8579268	1	0.8720177	0.8669145	1	0.9867088	1	1	0.9932461
A18	1	1	1	0.7240579	1	1	1	1	1	1
A19	1	1	1	0.7240579	1	1	1	1	1	1
A20	0.9976109	0.9944071	1	0.7240579	1	1	0.9773858	1	1	1

Table A10. The main results and rank of calculations (COPRAS and WASPAS) (developed by the authors).

	COPRAS	**WASPAS**
A1	0.046058	0.62113111
A2	0.054097	0.66920271
A3	0.044846	0.58805007
A4	0.0539	0.66802909
A5	0.054919	0.67705963
A6	0.050812	0.66349593
A7	0.04604	0.58265386
A8	0.040039	0.5683961
A9	0.053045	0.66267223
A10	0.053558	0.67195586
A11	0.053023	0.66228297
A12	0.052255	0.65216668
A13	0.057408	0.71326512
A14	0.044817	0.56761251
A15	0.035293	0.43893124
A16	0.044574	0.56598893
A17	0.048552	0.61885593
A18	0.057473	0.81064607
A19	0.057473	0.81064607
A20	0.055977	0.78744943

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Pricing ESG Equity Ratings and Underlying Data in Listed Real Estate Securities

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Abstract: By analyzing the adoption of the European Public Real Estate Association's (EPRA) Sustainability Best Practices Recommendations (sBPR), we examine and discuss the application of transparent environmental, social and governance (ESG) ratings and their interaction with public real estate performance across European markets. Due to increasing concerns about the environment and the impact of investment on society at large, public property companies have made significant progress in improving transparency and enhancing the protection of shareholder value by sharing and reporting ESG best practices. We explore and review the EPRA sBPR database, which is highly useful for investors who are already screening listed real estate companies. Hence, in this project, we carefully study the diffusion process of this new ESG metric as a tool to enhance informational transparency regarding public real estate investment management and assess the effects of this transparency and ESG performance for the real estate stock returns. We find evidence of a sustainability premium that investors are willing to pay to access companies with better sustainable ratings.

Keywords: ESG; real estate companies; ratings; sustainability; energy efficiency

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1. Introduction

Since the signing of the treaty during the United Nations COP21 meeting in Paris by 174 nations in 2015, the target of limiting global warming to well below 2 degrees versus pre-industrial levels by 2050 has moved up on the agenda. Institutional investors are under increasing pressure from governments, regulators and other stakeholders to contribute to this goal. We believe the listed real estate sector in particular could play a substantial role in achieving these aspirations, as real estate accounts for well over 30 percent of all greenhouse gas emissions. Ancillary and related activities such as infrastructure requirements arising from real estate add to this number, making the built environment the key source of greenhouse gas emissions. Furthermore, pension funds and other investors are looking for investment opportunities through which they can make a positive contribution to societal challenges. Large institutional investors have on average allocated 8 percent of their assets to real estate and are likely to further increase their allocation in the years ahead—see [1] for a full review of pension fund investments in real estate. Among the options of institutional investors to reach this allocation, publicly listed real estate investment firms are an attractive way of achieving this, as positions can be built quickly and without requiring large adjustments to the knowledge base in terms of trading and portfolio management. Contrary to other implementation forms, the listed market offers the opportunity to instantaneously achieve a full investment, whereas it would take a large amount of time to replicate this otherwise. However, this does require product availability. At the start of 2020, investors had the choice between over 800 publicly listed real estate investment firms to invest with globally, varying widely in portfolio size, focus and investment strategies.

During the selection process, investors are considering and screening for specific features that align with both their financial aims and their purpose. A wide range of environmental, social and corporate governance (ESG) metrics have become available to investors. These are metrics that can help them select investments that fit best with both their financial as well as their non-financial corporate aspirations and ambitions. However, an objective discussion and evaluation of the available ESG metrics in the listed real estate market is still largely missing. There is little evidence on the interlink between the variety of ESG metrics and financial performance in the public real estate market. For equities in general, reports show that ESG metrics between different providers of data do not correlate highly, suggesting that there are different interpretations of ESG attributes. It is therefore interesting to look at one specific sector with a material and comparable exposure to ESG risks to explore the financial materiality in terms of stock performance. This can help investors to see how the initial additional costs of ESG investments can be recovered in addressing the long-term risk of unsustainable stranded real estate assets. Due to a lack of evidence, opinions continue to differ about the net effect of ESG in real estate performance. Given the urgency of the ESG themes, it is crucial that empirical evidence is added to these opinions.

Thus far, the academic literature on public real estate has focused on the hypothesized relationship between energy efficiency (as part of the broader ESG) and real estate asset performance. The bulk of the research on the asset level is aimed at the commercial private real estate sector, which arguably represents a more efficient market with more rational agents (see Eichholtz et al., 2010). In contrast, portfolio level analysis on the sustainability within the real estate sector is confined to a few papers in the finance literature. In particular, since data availability on the subject has grown tremendously in recent years, the literature is becoming dated quite quickly and warrants further investigation. Another aspect of interest is that most of the available literature is based on the U.S. Real Estate Investment Trust (REIT) market, whereas internationally the requirements in terms of transparency and reporting on ESG move at different speeds. [2] studied the U.S. REIT market and discussed the link between energy efficiency and the sustainability of assets and the operating and stock performance of publicly listed REITs. Their study used building certification systems (e.g., Leadership in Energy and Environmental Design (LEED) and Energy Star) as a proxy for the greenness of a building. On the basis of this, they provided evidence that suggests that the level of greenness of the portfolio is positively correlated with three operating performance metrics, i.e., return on assets, returns on equity and the ratio of funds from operations to total revenues. Besides the operating performance, greener REITs also performed better in terms of stock performance.

In this paper, we broaden the analysis by focusing on ESG instead of environmental sustainability. Secondly, we revert to an international sample. We examine the unique database that underlies the newest ESG metric for European public real estate—the European Public Real Estate Association's (EPRA) Sustainability Best Practices Recommendations (sBPR). Our results show that both ESG completeness and ESG performance covary across firms. In other words, firms that score high on ESG completeness also tend to score higher than average on ESG performance. We also find that both ESG scores are higher for the larger firms in our sample, and among the sBPR gold award winners. Our return regressions offer evidence for a positive and significant return effects for ESG completeness and ESG performance, especially regarding the ESG aspects energy and greenhouse gasses. Furthermore, ESG completeness also increases returns regarding energy certification, social impact and governance scores. The more firms report on these matters, the better their subsequent stock returns turn out. Moreover, in our final analysis, we find evidence of a sustainable premium as investors are willing to accept a reduction in returns when they can choose to invest in companies with better sustainable ratings (sBPR).

We contribute to the literature by converting detailed firm level ESG data into objective measures for ESG transparency and ESG performance, tailored to the public real estate market. We start our analysis with a clear expose on EPRA's sBPR data, after we review the most relevant literature on ESG and ESG measurement. We then introduce and present the ESG metrics that we construct using the sBPR data, and we discuss the variation in these ESG scores within the European listed real estate market. The effects of these ESG scores on public real estate financial performance are studied both directly and indirectly through the sBPR ratings, and the most important results and their implications are summarized in our conclusions.

2. Literature Review

ESG refers to the three key factors for measuring the non-financial impact of a company. Including the impact on the environment and society at large into financial decisions has a long history, dating back to the 1950s and 1960s, when pension funds recognized the opportunity to affect their social environment using their capital assets, starting with smaller and more targeted initiatives such as affordable housing, and later extending into more ethical issues such as the condemnation of South African apartheid. Today, ESG has evolved into a wide collection of aims and goals, and at the same time a vast variety of means and manners have emerged to incorporate these issues into the investment process.

In the corporate finance literature, there have been various studies identifying the added value of ESG integration into financial decision-making. According to [3], companies with good ESG scores perform better in terms of operations and are also considered less risky. [4] also studied the impact of ESG issues in firm performance, especially in the case of engaging companies to improve their ESG scores via investor activism and reported evidence that active increases in ESG scores have been associated with enhanced operational performance. Regarding the link between ESG scores and stock returns, the literature is less conclusive. On the one hand, ESG criteria can reduce the investment universe and thereby increase the risk of ESG frontrunners. ESG efforts also introduce additional information and screening costs into the investment selection process. Costs have a clear footprint in the short-term profit and loss account, while many of the benefits of ESG practices are intangible, difficult to quantify, and materialize only in the longer term [5]. Long-term benefits should eventually also result in superior stock returns. An earlier study by [6] evaluated both the short- and long-term stock returns of US firms, using KLD Research & Analytics (from now on KLD) – a provider of environmental, social and governance (ESG) research and indexes for institutional investors – to distinguish between leaders and laggards. Their results show that while in the short term, low-scoring ESG firms outperformed, this return pattern does not persist in the longer run. In other words, enforcing high ESG standards may well weaken stock returns initially, but in the long run, these return differences vanish as high-ranking ESG firms tend to catch up. This result could be attributed to a learning curve of both the firm and the investor community. Moreover, a more recent study by [7] found compelling evidence for a sample of Eurostoxx50 firms, suggesting that the stock return appreciation for ESG excellence has grown steadily over time.

The lack of conclusive academic evidence on ESG scores and stock returns may well be due to ongoing debates on ESG measurement. The number of ESG rating providers has grown exponentially. A recent analysis of the rate-the-raters-survey [8] showed that the number of ESG rating providers increased five-fold from 2012 to 600 by the end of 2018. Rating providers often like to distinguish themselves by using self-developed criteria and weights for ESG factors. This situation translates into visible and hidden risks when relying only on one ESG rating provider for investment decisions. This is illustrated by research by [9] on alternative weighting schemes and the combination of individual and aggregate ESG scores, as well as by [10], demonstrating how subjective judgements within rating methodologies can lead to different portfolios and outcomes. This means that investors need to grasp the sometimes subtle differences between ESG scores and they need to be able to select ESG metrics that align with their corporate beliefs and ambitions.

Ref. [11] identified three factors that cause inherit biases of ESG scores: company size (large score better), country or type of market (developed or emerging) and sector (high versus low tangibility and visibility). After studying a vast set of metrics and scores, they concluded that, on average, half of a company's ESG score can be explained by these factors. This points out certain penalties that ESG raters might be imposing on highly profitable and sustainable but small companies that happen to be in an emerging market in a sector that has no ESG visibility. This is a concern which amplifies our interest in sector-specific ESG analysis. We focus our analysis on the European listed real estate market, which offers a sample of firms of similar midcap size, active in the same regions and industries.

Thus far, the available evidence on ESG scores is limited within the real estate literature. Instead, the underlying issues of E, -S and -G have been analyzed separately. Environmental sustainability has been studied frequently and internationally. For instance, [12] studied the performance effects of GRESB ratings for REITs in North America, Asia and Europe for the period 2011–2014. Although data coverage was still weak during this early period, [12] reported that high sustainability scores resulted in enhanced operational performance and lower stock market risks. [13] focused on the European listed real estate markets, using LEED and certifications as metrics for REIT sustainability, and discovered that high percentages of certified building in the European REITs portfolios have had a negative impact on return on assets (ROA), return on equity (ROE) and stocks' alphas, a finding that the authors account to the incremental costs related to the refurbishments needed to obtain the Building Research Establishment Environmental Assessment Method (BREEAM) and LEED certification.

Regarding the effects of corporate social responsibility (CSR)—the social aspects of ESG—the real estate literature is scarce. [14] applied the MSCI's Intangible Value Assessment (IVA) database to identify the voluntarily initiated aspects of CSR, and documented that CSR ratings are higher for companies with fewer agency problems. For real estate investments, [15] offered evidence for a positive relationship between CSR ratings and Tobin's Q, using the KLD data for a sample of US REITs. Although positive CSR scores had no effect on REIT returns, they documented that this Tobin's Q spread was mainly due to the negative effects for low-scoring REITs.

As far as the governance factor of ESG is concerned, [16] analyzed the performance effects of two competing governance structures in the market—the outperforming "self-administered" versus the underperforming "advisor" REITs. [17] built on this work and used the Corporate Governance Quotient Index (CGQ)—a metric developed by Institutional Shareholder Services (ISS) that rates publicly traded companies in terms of the quality of their corporate governance. They uncovered a significant and positive relationship, but only for US REITs with lower dividend payout ratios.

In all cases, studies have focused on certain aspects of ESG, and have been limited by their choice of metrics and data sources—see also [18]. In this study, we hope to profit from the emergence of EPRA's sBPR scores that have become available recently.

3. The EPRA sBPR Database

In this project, we make good use of the EPRA sBPR database. In Table 1, we give an overview of the different aspects of E, S, and G and how these are weighted across different metrics, including EPRA's sBPR. This directly yields an interesting first finding, as the weights that these metrics use differ significantly. For instance, the Thomson Reuters measure assigns equal weights to the three categories of E, S and G scores, while GRESB overweights the environmental impact as this accounts for 57 percent of the overall score. Instead, KLD assigns more importance to governance, with a score weight of 58 percent. This shows that when having to choose between the aggregate ESG score of Thomson Reuters, GRESB and MSCI KLD, one needs to be wary of the underlying variations, since these can result in very different outcomes using the same set of raw data.

Table 1. ESG metric weighting schemes.

	GRESB	Thomson Reuters	KLD MSCI	EPRA sBPR
E (Environmental)	57%	34%	17%	70%
Energy score	✓	✓	✓	✓
GHG score	✓	✓	✓	✓
Waste score	✓	✓	✓	✓
Water score	✓	✓	✓	✓
Technical building assessment	✓		✓	
Monitoring management system	✓	✓		
Building certifications	✓			✓
Raw material sourcing		✓	✓	
Biodiversity and land use		✓	✓	
Environmental policy				
Environmental supply chain incidents				
S (Social)	18%	36%	25%	20%
Sustainability community engagement process	✓			
Community engagement impact monitoring	✓	✓		✓
Tenants engagement and satisfaction	✓			
Employee's training and satisfaction	✓	✓	✓	✓
Product liability		✓	✓	
Controversial sourcing			✓	
Social opportunities			✓	
Policy on freedom of association		✓		
Policy on elimination of discrimination		✓		
Customer responsibility		✓		
Diversity				✓
G (Governance)	25%	30%	58%	10%
Management / Corporate governance	✓	✓	✓	✓
Policy and disclosure	✓	✓	✓	✓
Sustainability risk assessment	✓			
Tax transparency			✓	
Anti-competitive practice			✓	
Signatory of UN global compact				

Notes: In this table, we present the 2018 year-end summary statistics on our sample of 64 European firms. *Market value* (or market capitalization) is calculated by multiplying the number of its outstanding shares by the current share price, and is denominated here in million euros. *Total asset* refers to the total amount of assets owned by the companies in our sample, stated in million euros. *Debt/asset* is the debt to total assets ratio, and indicates a company's financial leverage. It tells you the percentage of a company's total assets that were financed by creditors. In other words, it is the total amount of a company's liabilities divided by the total amount of the company's assets. *Total return* refers to the average annualized total stock return of the firms in our sample, stated as a percentage over the period 31/12/2011–31/12/2018. *Fraction closely held shares* represent the percentage of outstanding shares held by insiders, which includes: corporate offices and directors, pension/benefit plans, and individuals who hold 5% or more of the outstanding shares. For each firm in our sample, we also examined their property portfolio composition. We classified firms as property type focused whenever at least 80 percent of their portfolio is invested in one property type. We classified firms as regionally focused whenever at least 80 percent of their portfolio is invested in one and the same (national) home market.

This issue is very different in EPRA's sBPR database. EPRA's sBPR was designed to raise the standards and consistency of sustainability reporting for listed real estate companies across Europe. First published in 2011, the third edition of the sBPR was published in September 2017 to align with established reporting initiatives in the real estate sector, and to establish common metrics to support companies with their reporting on wider social and governance issues as set out in Directive 2014/95/EU of the European Parliament and of the Council on the disclosure of non-financial and diversity information [For a full and detailed discussion of the EPRA sBPR Guidelines, we directly refer to: https://www.epra.com/application/files/3315/0456/0337/EPRA_sBPR_Guidelines_2017.pdf]. The sBPR complement the existing and well-established EPRA Financial BPR. Each year, a panel of sustainability reporting experts scores each eligible company's public disclosure against several areas of the EPRA sBPR Guidelines, including 28 different performance measures, consisting of environmental, social and governance items, and 10 overarching recommendations which underpin good quality disclosure and should be applied when reporting EPRA's sBPR Performance Measures—please see Appendix A for a full list.

EPRA has compiled a methodological framework that carefully assesses ESG transparency and yields an ESG disclosure score, which differs from other available ESG metrics in that it measures ESG transparency, not only ESG performance. Companies wishing to comply with EPRA's sBPR standard must disclose their sustainability data against the 28 EPRA's sBPR Performance Measures (16 on environmental, 9 on social, and 3 on governance) and a set of 10 guiding principles, i.e., the Overarching Recommendations which are the principles to apply to the disclosure of each performance metrics. Their disclosure must be made public in either their annual reports or corporate social responsibility report, or if preferred using a standalone documentation. The subsequent review of these sBPR data items occurs in a structured process, starting with a detailed primary review of annual reports, which is initiated by sustainability reporting experts at the end of the second quarter of the year, using a scorecard based directly on the EPRA sBPR. The total points are evenly distributed over the Performance Measures and the Overarching Recommendations (50%–50% weighting scheme). Within these two categories, different weighting schemes are applied, i.e., 70-20-10 weighting for the E, S and G impact categories within the Performance measures, while a 2.5%,10% range is used for the Overarching Recommendations. The score over the Performance Measures and the Overarching Recommendations is then aggregated into one ESG score at firm level. A second review by a different member of the team is then carried out to ensure data consistency. Any discrepancies between the primary and secondary review scores are double checked and addressed.

The increasing number of reporting companies and the progressing harmonization of them within the standard allowed EPRA to start a data collection exercise that became the sBPR database, launched in September 2019 and created with sBPR data of EPRA members reporting sBPR data since 2011. In order to be included in the sBPR database, companies must satisfy a threshold of quality disclosure, i.e., they must have been awarded a sBPR Award (Bronze, Silver or Gold). This principle has been set to ensure good quality and comparability of data of companies included in the scope of the database. Using the raw data on the sBPR data items collected for each company and included in the sBPR database, we define two measures of ESG compliance:

- The sBPR ESG completeness score, which represents the percentage of data items for which data are available. Even if this measure does not directly relate to the effectiveness of compliance, it indicates the ability of the company to provide data on ESG compliance. Therefore, it also represents a proxy for the emphasis each company gives to these themes, also collating appropriate data.
- The sBPR ESG performance score, which reflects the average percentage change in the data items. In particular, we firstly identify the following key items: energy efficiency (including energy intensity, proportion of renewables), greenhouse gas emissions (scope 1–3), water management, total waste by disposal route, energy performance certification (including BREAM, BRAVE and LEED), social impact score (including health and safety, diversity, employee turnover, and community engagement), and corporate governance impact score. We then count the number of items for which improvements (i.e., reduced energy intensity, increased proportion of renewable, etc.) have been achieved from year to the next. The percentage of improved data items forms our performance score.

For these public real estate firms, we collect firm characteristics (e.g., firm size, age, asset portfolio) from the Thomson Reuters and WRDS databases. For our analysis on real estate performance, we also collect time series on public real estate returns (both price and dividend) to assess any structural variations across our sBPR scores.

The sBPR database covers 64 different European listed companies, and we obtained data for the period 2011 to 2018. The sBPR panel is unbalanced both for companies—that entered and left the sample at different stages—, as well as for data items—with extension to S and G in 2017. Therefore, we limit our empirical analysis to the 2017 and 2018 data, when the panel is both consistent and balanced. In Table 2, we present relevant summary statistics on the sampled firms, which show that their 2018 year-end market value equaled EUR 3.18 B., an average leverage of 40 percent, and an annualized sample return of just over 12 percent. These statistics are above the total universe of the European listed real estate market—with a market value and leverage of EUR 2.51 B. and 31 percent, respectively—hence it appears that the 64 firms covered in the sBPR are in general terms a representative random sample of the total population of companies, but do tend to be somewhat larger. Around 60 percent of our sampled firms has a property portfolio that is invested in one single property type. We classified these firms as property type focused, and we incorporate this focus in our subsequent ESG analysis. In addition, regarding the regional spread of the property portfolio, we gathered information, and discovered that 70 percent of the firms in our sample are regionally focused, investing in one (national) home market. Apart from these mean values, Table 1 shows some disparities within this sample. The average total returns ranged between almost −43 percent and +44 percent. One may wonder whether the ESG performance of firms has had any influence on their position within this range. Therefore, we start our descriptive analysis with a simple visualization of the ESG-Return relation.

Table 2. Summary statistics (year-end 2018, n = 64).

	Our Sample		**The EPRA Universe**	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**
Market Value (mln. euros)	3178.48	1041.52	2509.90	3373.87
Total assets (mln. euros)	5322.86	10,925.760	5829.51	9160.23
Debt/assets	0.40	0.06	0.31	0.13
Total return (annualized)	12.03%	20.09%	12.29%	16.90%
Fraction closely held shares	0.24	0.06	0.18	0.20
Fraction property type focused firms	0.60	0.49	0.69	0.46
Fraction regionally focused firms	0.70	0.46	0.88	0.33

Notes: This table presents the summary statistics of key variables for our sample and the overall universe of companies covered by the European association of publicly listed real estate stocks (EPRA).

Figure 1 plots the pair of the 2018 ESG completeness scores and the annualized total return for each firm in the sample. We use different colors to indicate the sBPR Award that was handed out to each firm in 2018; green for gold, yellow for silver, and red for bronze. Let us start with the observation that award colors cluster in line with ESG scores, the bronze awards are found to the left of the chart, where ESG completeness scores are lowest, while the golden awards dominate the right half of the scatter plot. On the vertical axis, we have the total returns of each firm, and the fitted trend line reveals a slightly downward sloping trend. In other words, higher ESG completeness scores are not associated with superior returns. The negative relation that is shown instead ought to be handled with caution as the explanatory power of the trend line falls short of 5 percent, indicating that other omitted determinants are relevant and should be considered in the modelling part of the study.

Figure 2 plots the pair of the 2018 ESG performance scores and the size (logarithm of market value to rescale the dimension to a more homogeneous measure) of each firm in the sample. Again, we continue to use a different color to indicate the 2018 sBPR Award. Awards cluster in line with ESG scores; the bronze awards (with some exceptions) tend to belong to smaller sized firms, while silver awards show a slightly bigger dimension. Gold awards show a wide spread of sizes, even if the biggest companies in our sample tend to receive the highest award. Overall, the fitted trend line shows a slightly upward sloping trend, revealing a positive association between ESG score and company size. In other words, the bigger the company size, the higher the ESG completeness score tends to be. In this case too, the slightly positive relation ought to be handled with caution as the explanatory power of the trend line is just above 5 percent, indicating that other omitted determinants are relevant.

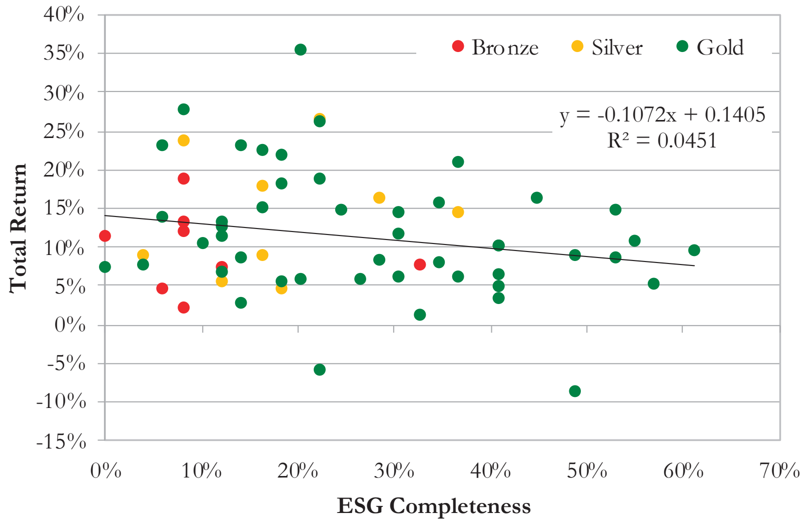

Figure 1. Scatter plotting total returns versus environmental, social and governance (ESG) completeness scores. (green = sBPR gold award winners, yellow = sBPR silver award winners, red = sBPR bronze award winners).

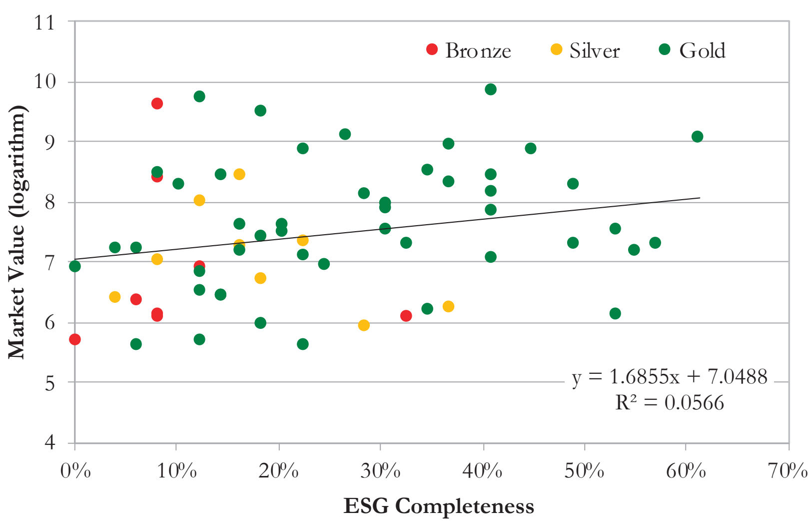

Figure 2. Scatter plotting size (market value) versus ESG completeness scores. (green = sBPR gold award winners, yellow = sBPR silver award winners, red = sBPR bronze award winners).

Therefore, we continue our descriptive analysis in Table 3 with a clustered overview of the key summary statistics across the three sBPR award categories. Although the debt-to-asset ratios and the fraction of closely held shares show little consistence, we do find evidence that market values covariate with sBPR awards—gold award winners are twice as large as bronze awards. This variation is meaningful as it suggests that companies need to have significant resources at their disposal to provide the transparency tested. This could either signal slack resources on the part of the firms that report or better governance. In the former case, it should have a negative relationship with financial performance, and in the latter, it should have a positive relationship. Given that the available finance literature has shown that firm size and other characteristics matter for return dynamics, we need to correct for these variations in a regression analysis of stock performance.

Table 3. Sum stats of award categories (year-end 2018).

	MV (Mean)	D/A (Mean)	TR	Closely Held
Gold	4355.05	0.39	8.44%	0.22
Silver	3360.79	0.37	12.09%	0.21
Bronze	2150.71	0.44	13.42%	0.25

Notes: *MV* refers to the mean market value, *D/A* to the mean debt to asset ratio, *TR* to the average annualized total stock return, and *Closely held* to the fraction of closely held shares.

Above, we present the estimation of our regression models. However, we must also compare our sBPR scores of completeness versus performance. The first counts the number of completed data cells across all 51 sBPR ESG items, while performance refers to the number of items recording an ESG improvement. In Table 4, we show that these scores align very well with each other and with the sBPR 2018 awards. Gold award winners score highest on both accounts, while bronze awards have been granted to the lowest ends of both metrics. Figure 3 also shows the scatter plot of the two ESG scores, which reveals a positive relationship, explaining more than 40 per cent of its variation. This finding suggests that a more complete questionnaire is normally associated with companies that are improving their ESG scores. Furthermore, this outcome reinforces our conjecture to measure ESG compliance via the completeness of the EPRA questionnaire as companies that are more aware and engaged in ESG activities also tend to monitor their position through data collection (and analysis).

Table 4. sBPR scores per award category (year-end 2018).

	ESG Completeness (% Filled in of Total)	ESG Performance (% Improvers)
Gold	0.513	0.280
Silver	0.421	0.192
Bronze	0.331	0.169

Notes: This table reports the average Completeness and Performance scores by sBPR rating.

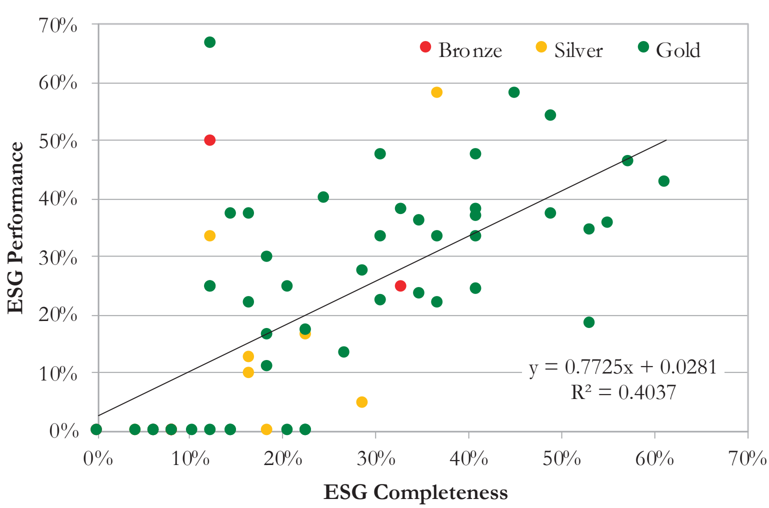

Figure 3. Scatter plotting ESG performance versus ESG completeness scores. (green = sBPR gold award winners, yellow = sBPR silver award winners, red = sBPR bronze award winners).

4. Return Analysis

Our pricing analysis starts with examining firm-specific returns using multivariate OLS regressions. These regressions are estimate on total returns for firm *i* ($return_i$) for the year 2018. We explain the cross-sectional variations in these returns using different combinations of factors as follows. In Equation (1), we estimate the pricing by evaluating firm characteristics (*Xji*) including size, LTV, ownership structure and portfolio, and fixed effects (*Zki*) including property type (specialized sector vs. diversified) and portfolio location (national vs. international exposure):

$$return_i = \alpha + \sum_{j=1}^{m} \beta_j * X_{ji} + \sum_{k=1}^{p} \delta_k * Z_{ki} + \varepsilon_i \quad (1)$$

In Equation (2), we then add the sBPR (completeness or performance) score information ($scores_{hi}$) to model specifications as follows:

$$return_i = \alpha + \sum_{j=1}^{m} \beta_j * X_{ji} + \sum_{k=1}^{p} \delta_k * Z_{ki} + \lambda_h * scores_{hi} + \varepsilon_i \quad (2)$$

Besides these return regressions, we also estimate the same model for return to risk (return over standard deviation) to assess the integral effects of sBPR scores on the risk adjusted stock returns. Earlier results by [16] demonstrated that SRI and ESG can differ depending upon the measure of return. To follow up on these findings we also control for risk by analyzing return to risk ratios as dependent variable, a method and metric discussed by [17].

In Table 5, we present the results of these multivariate regressions for the sBPR completeness scores. The regressions were executed and reported for key items within the sBPR framework, starting with 'energy' and 'greenhouse gasses', all the way to 'social impact', and 'corporate governance'. Before we discuss the results on the sBPR completeness scores, it is worth noting that control variables yield coefficients that are in line with expectations. Stock returns of the sampled listed real estate firms are higher for smaller (log total assets) companies, with a lower debt ratio (LTV) and larger real estate portfolios (log sqm). This confirms the common notion that investors prefer and appreciate investment firms in commercial real estate (higher square meters) with low leverage and a potential for growth. The fraction of closely held shares by inside investors appears to have no pervasive effect on stock returns.

Regarding the sBPR completeness score, we find positive and significant coefficients, indicating that firms more aware and active in sustainability issues (hence reporting more sBPR data) are associated with higher returns. This positive result is strongest for the data on social impact performance, but also statistically significant for other measures: energy usage, greenhouse gasses, energy performance certification and corporate governance. For the data categories water and waste management, results lack statistical significance. Therefore, we conclude that investors currently care most about the realized momentum regarding social impact, energy efficiency and corporate governance.

The same set of models are also estimated with the sBPR performance scores replacing completeness scores. In Table 6, we present our results, which confirm the main predictions of control variables but also tell a slightly different story as far as the sustainable measure is concerned.

Contrary to sBPR completeness, which is a monotonically increasing variable that is expected to have a positive effect on stock returns, sBPR performance requires more nuances. In the performance score, we count the number of reported data items for which an increase over the years has been reported. However, while an increase in one data item should be interpreted as a positive accomplishment—as for example the percentage of energy performance certification (column 5) within the property portfolio—the same increase in energy usage (column 1) or greenhouse gas emissions (column 2) reflects an ESG deterioration. Therefore, we include an expected coefficient sign at the top of each column in Table 6 to assist in the proper interpretation of results. In particular, we find significant results for energy usage and greenhouse gas emissions. In both cases, the coefficients are negative as expected, because a reduction should be interpreted as a positive ESG change, which will be rewarded by higher stock returns.

As far as other ESG performance measures are concerned, they do not seem to affect stock returns and coefficients lack statistical significance to allow for a proper economic interpretation. The fact that the results are strong and compelling for energy use and greenhouse gas emissions might indicate that investors currently care most about these ESG performance measures, which are also more prominent in the climate change debates and more prone to regulation. At the same time, we should note that the lack of significance among the other performance measures may well be due to the lack of data. We are estimating these effects on a small sample, which limits our degrees of freedom. It may well be that other ESG elements will also become more material for real estate stock performance in the near future, when more observations become available. Finally, even if other omitted factors in our modelling exercise may lead to a higher goodness of fit, the low R-squared is generally in line with results in the mainstream finance literature on asset pricing. They particularly reveal the attention investors give to the actual measurement of energy usage and gas emissions, where 20 to 30 percent of the variability in returns is explained with our models using performance scores.

Table 5. Stock return regressions, including sBPR ESG completeness scores.

	Energy	**GHG**	**Water**	**Waste**	**Certificate**	**Social**	**Governance**
Log(total assets)	−0.022 *	−0.022 *	−0.018 ′	−0.016	−0.017 ′	−0.014	−0.014
	0.058	*0.058*	*0.115*	*0.184*	*0.123*	*0.176*	*0.210*
LTV	−0.180 **	−0.153 **	−0.146 *	−0.135 *	−0.118′	−0.147 **	−0.124 ′
	0.023	*0.046*	*0.062*	*0.084*	*0.117*	*0.045*	*0.1*
Closely held shares	0.006	−0.010	−0.010	−0.002	0.009	−0.022	−0.018
	0.874	*0.784*	*0.808*	*0.954*	*0.820*	*0.554*	*0.637*
Log(sqm)	0.027 **	0.028 **	0.026 **	0.024 **	0.026 **	0.020 **	0.022 **
	0.011	*0.010*	*0.017*	*0.035*	*0.014*	*0.047*	*0.034*
Completeness score	0.073 *	0.070 *	0.028	−0.004	0.083 *	0.113 **	0.054 *
	0.056	*0.098*	*0.326*	*0.93*	*0.074*	*0.012*	*0.081*
Constant	0.065	0.055	0.041	0.049	0.009	0.065	0.023
	0.592	*0.652*	*0.743*	*0.702*	*0.939*	*0.582*	*0.853*
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Adjusted R-squared	0.10	0.09	0.06	0.04	0.09	0.15	0.09
F-stat	2.35 *	2.12 *	1.70 ′	1.48	2.23 *	3.02 **	2.20 *
DoF	51	51	51	51	51	51	51
Observations	60	60	60	60	60	60	60

Notes: In this table, we present our coefficient estimation for model (2) in which the variation in average stock returns is explained by the ESG completeness scores, while controlling for the four most important company characteristics: firm size, leverage, ownership, and property portfolio size. These controls are estimated by *Log(total assets)*, which refers to the natural log of a firm's total assets, *LTV*, which is the loan to value ratio, *Closely held shares*, which is the fraction of shares held by insiders, and *log(sqm)*, which is the natural log of the total square meterage of the property portfolio. The completeness score is estimated with several measures (energy usage, greenhouse gasses, water management, waste management, energy certification, social score and the governance score) and it should lead to higher performance (coefficients are expected to be positive). Coefficient estimates marked with (′) (*) (**) (***) are statistically significantly different from zero on an 85%, 90%, 95% and 99% confidence interval respectively. Below each coefficient, we also state in italics the corresponding p-value computed with robust standard error. Potential multicollinearity issues are not found to be significant (variance inflation factors VIF) and error terms are proved to be homoscedastic (White test) and normally distributed (normal probability plot and Jarque–Bera test). We also estimated models assuming clustered errors by property type and individual REIT, and the results remain consistent.

Table 6. Stock return regressions, including sBPR ESG performance scores.

	Energy (−)	GHG (−)	Water (−)	Waste (−)	Certificate (+)	Social (+)	Governance (+)
Log(total assets)	−0.007	−0.001	−0.02 ′	−0.016	−0.017	−0.021 ′	−0.018
	0.537	*0.917*	*0.105*	*0.208*	*0.153*	*0.126*	*0.167*
LTV	−0.147 *	−0.153 **	−0.157 **	−0.178 **	−0.157 *	−0.162 *	−0.151 ′
	0.051	*0.030*	*0.049*	*0.042*	*0.057*	*0.090*	*0.112*
Closely held shares	−0.006	−0.047	0.011	0.001	0.014	−0.02	−0.006
	0.879	*0.197*	*0.778*	*0.978*	*0.728*	*0.648*	*0.884*
Log(sqm)	0.02 *	0.014	0.025 **	0.021 *	0.027 **	0.028 **	0.028 **
	0.055	*0.164*	*0.022*	*0.077*	*0.014*	*0.016*	*0.019*
Performance score	−0.138 ***	−0.18 ***	0.012	0.003	−0.035	0.068	0.039
	0.003	*0.001*	*0.808*	*0.945*	*0.366*	*0.570*	*0.839*
Constant	0.013	0.035	0.09	0.108	0.041	0.069	0.034
	0.915	*0.753*	*0.482*	*0.402*	*0.752*	*0.625*	*0.801*
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Adjusted R-squared	0.21	0.31	0.05	0.04	0.08	0.06	0.05
F-stat	4.09 ***	6.1 ***	1.57	1.44	1.87 ′	1.66	1.56
DoF	49	49	46	39	45	43	43
Observations	58	58	55	48	54	52	52

Notes: In this table, we present our coefficient estimation for model (2) in which the variation in average stock returns is explained by the ESG performance scores, while controlling for the four most important company characteristics: firm size, leverage, ownership, and property portfolio size. These controls are estimated by *Log(total assets)*, which refers to the natural log of a firm's total assets, *LTV*, which is the loan to value ratio, *Closely held shares*, which is the fraction of shares held by insiders, and *log(sqm)*, which is the natural log of the total square meterage of the property portfolio. The performance score is estimated regarding different improvement measures: energy usage, greenhouse gasses, water management, waste management, energy certification, social score and the governance score. To indicate the expected sign for the ESG performance coefficient, we state (-) for hypothesized negative effects (e.g., higher use of energy or emissions of greenhouse gasses should reduce performance), and (+) for hypothesized positive effects (e.g., better social and governance scores should relate to higher performance). Coefficient estimates marked with (′) (*) (**) (***) are statistically significantly different from zero on an 85%, 90%, 95% and 99% confidence interval respectively. Below each coefficient, we also state in italics the corresponding p-value computed with robust standard error. Potential multicollinearity issues are not found to be significant (variance inflation factors VIF) and error terms are proved to be homoscedastic (White test) and normally distributed (normal probability plot and Jarque–Bera test). We also estimated models assuming clustered errors by property type and individual REIT, and the results remain consistent.

This combination of regression results tells us that sBPR transparency pays off. Overall, investors reward sBPR data completeness with a return premium, which can be justified as a reward for data transparency that helps them to better select listed real estate firms within their own ESG framework. As sBPR performance—measured as the percentage of data items that shows increasements over time—is only recognized and awarded when it relates to energy usage and greenhouse gas emissions, this can be part of a learning curve in the market, in which more investors need to recognize sBPR data opportunities, also for ranking and selecting listed real estate firms based on other ESG aspects.

In line with [16], we also want to control our return results for variations in risk. Hence, we also estimated model (2) with a return to risk ratio as dependent variable, and we present a succinct overview of our results in Table 7. Here we find results which are fairly similar to the main analysis using returns. While controlling for firm size, leverage, closely held share fraction, portfolio size, property- and location-fixed effects, we find a significantly positive net effect for sBPR completeness for energy, GhG, and social scores, and significantly negative effects for sBPR performance for energy and GhG. In other words, the effects on returns are associated with proportional returns on stock risk.

Table 7. Return to risk regressions.

	Energy	GHG	Water	Waste	Certificate	Social	Governance
Panel A: Return to Risk and Completeness Score							
Completeness score	0.578 **	0.486 *	0.264	−0.122	0.376	0.742 **	0.293
	0.254	*0.280*	*0.192*	*0.283*	*0.315*	*0.300*	*0.212*
Control variables	Y	Y	Y	Y	Y	Y	Y
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Observations	60	60	60	60	60	60	60
R-squared	0.245	0.215	0.198	0.172	0.191	0.258	0.199
Panel B: Return to Risk and Performance Score							
	Energy	GHG	Water	Waste	Certificate	Social	Governance
Performance score	−0.555 *	−0.546 *	0.137	0.262	−0.0945	0.175	−0.581
	0.329	*0.332*	*0.370*	*0.272*	*0.283*	*0.830*	*1.487*
Control variables	Y	Y	Y	Y	Y	Y	Y
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Observations	58	58	55	48	54	52	52
R-squared	0.232	0.23	0.183	0.289	0.191	0.223	0.209

Notes: In this table, we present our coefficient estimation for model (2) in which the variation in average stock returns over standard deviations is explained by the ESG completeness scores, while controlling for the four most important company characteristics: firm size, leverage, ownership, and property portfolio size. These controls are estimated by *Log(total assets)*, which refers to the natural log of a firm's total assets, *LTV*, which is the loan to value ratio, *Closely held shares*, which is the fraction of shares held by insiders, and *log(sqm)*, which is the natural log of the total square meterage of the property portfolio. The completeness (Panel A) and performance (Panel B) scores are estimated using several measures: energy usage, greenhouse gasses, water management, waste management, energy certification, social score and the governance score. Coefficient estimates marked with (*) (**) (***) are statistically significantly different from zero on a 90%, 95% and 99% confidence interval. Below each coefficient, we also state the corresponding robust standard error in italics. Potential multicollinearity issues are not found to be significant (correlation matrix and variance inflation factors VIF) and error terms are proved to be homoscedastic (White test) and normally distributed (normal probability plot and Jarque–Bera test). We have also estimated models assuming clustered errors by property type and individual REIT and results remain consistent.

As a final step in our analysis, we consider the sBPR ratings assigned by EPRA and test whether better rated companies deliver higher returns. The underlying information used for the ratings allows us to avoid endogeneity issues and we estimate our model using a two-stage approach. In the first stage estimation, we regress the sBPR rating against the underlying measure of completeness and performance scores as follows:

$$sBPR_{hpi} = \alpha + \beta * Completeness\ score_{hi} + \gamma * Performance\ score_{pi} + \varepsilon_i \tag{3}$$

We subsequently use the fitted values of the first stage regression ($s\hat{BPR}_{hpi}$)—i.e., sBPR rating explained by a combination of completeness score h ($Completeness\ score_{hi}$) and performance score p ($Performance\ score_{pi}$)—to explain company performance in the second stage. We replace the direct completeness/performance score in Equation (2) with $s\hat{BPR}_{hpi}$ as follows:

$$return_i = \alpha + \sum_{j=1}^{m} \beta_j * X_{ji} + \sum_{k=1}^{p} \delta_k * Z_{ki} + \lambda_{hpi} * s\hat{BPR}_{hpi} + \varepsilon_i \tag{4}$$

As the previous analysis reported in Table 6 shows that greenhouse gas emissions (GHG) and energy consumption (Energy) are the only significant performance scores to explain company returns, in the first stage regression—Equation (3)—we use a combination of each completeness score with each of the two aforementioned performance scores. As a robustness test, we also present the results of the second stage regression—Equation (4)—obtained by combining in the first stage regression each of the completeness scores with the GHG performance score (Table 8) and with the energy performance score (Table 9), which were found to be significant in the previous analysis.

Table 8. Second stage stock return regressions (GHG emissions for performance score in first stage regression).

Score Used in 1st Stage							
Completeness: Performance:	Energy GHG	GHG GHG	Water GHG	Waste GHG	Certificate GHG	Social GHG	Governance GHG
Log(total assets)	−0.0116	−0.0063	−0.0079	−0.0093	−0.0081	−0.0032	−0.0024
	0.0124	*0.0123*	*0.0118*	*0.0118*	*0.0117*	*0.0113*	*0.0111*
LTV	−0.142 *	−0.159 **	−0.184 **	−0.157 **	−0.187 **	−0.154 **	−0.160 **
	0.0786	*0.0751*	*0.0744*	*0.0750*	*0.0744*	*0.0705*	*0.0692*
Closely held shares	−0.0179	−0.0125	−0.0399	−0.00287	−0.0257	−0.0377	−0.0412
	0.0400	*0.0375*	*0.0397*	*0.0370*	*0.0380*	*0.0364*	*0.0358*
Log(sqm)	0.0222 **	0.0185 *	0.0178 *	0.0197 *	0.0165	0.0160	0.0148
	0.0108	*0.0107*	*0.0106*	*0.0105*	*0.0107*	*0.0010*	*0.0098*
Fitted sBPR	−0.0534 *	−0.0793 **	−0.0922 ***	−0.0674 **	−0.0813 ***	−0.130 ***	−0.139 ***
	0.0304	*0.0312*	*0.0329*	*0.0261*	*0.0288*	*0.0344*	*0.0339*
Constant	0.158	0.204	0.288 **	0.197	0.278 **	0.328 **	0.360 ***
	0.131	*0.130*	*0.140*	*0.128*	*0.138*	*0.130*	*0.130*
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Adjusted R-squared	0.198	0.244	0.262	0.247	0.263	0.333	0.358
Observations	58	58	58	58	58	58	58

Notes: In this table, we present our coefficient estimation for model (4) in which the variation in average stock returns is explained by the fitted value of sBPR rating obtained from the first stage regression with ESG completeness and performance scores (as indicated at the top of the table), while controlling for the four most important company characteristics: firm size, leverage, ownership, and property portfolio size. These controls are estimated by *Log(total assets)*, which refers to the natural log of a firm's total assets, *LTV*, which is the loan to value ratio, *Closely held shares*, which is the fraction of shares held by insiders, and *log(sqm)*, which is the natural log of the total square meterage of the property portfolio. In the first stage regression, the performance score is estimated with greenhouse gasses (*GHG*). Coefficient estimates marked with (*) (**) (***) are statistical significantly different from zero on a 90%, 95% and 99% confidence interval. Below each coefficient, we also state the corresponding robust standard error in italics. Potential multicollinearity issues are not found to be significant (correlation matrix and variance inflation factors VIF) and error terms are proved to be homoscedastic (White test) and normally distributed (normal probability plot and Jarque–Bera test). We also estimated models assuming clustered errors by property type and individual REIT, and the results remain consistent.

Table 8 shows a negative relationship between sBPR rating (fitted value from the first stage) and company returns, with better ratings associated with worse performing companies. This result is consistent across all completeness scores used in the first stage, with slightly stronger economic impact (−0.13 vs. −0.08) and explanatory power (c.ca 35% vs. 25%) when social and governance underlying scores are used in the first stage. Therefore, we find evidence that investors are willing to pay a sustainability premium (i.e., to accept a reduction in returns) to access more sustainable companies (i.e., companies with higher sBPR ratings). These results align with earlier findings by [5,6], and are most likely due to investment universe restrictions, sBPR costs, and, according to [7], because of a learning curve among investors.

Even though it has a slightly lower statistical significance and explanatory power, Table 9 generally confirms our findings when, alongside a completeness score, we use energy as the performance score in the first stage regression. The results still show a consistently negative coefficient of similar magnitude for sBPR rating, even if the statistical significance is slightly weaker if we exclude certification, social and governance as completeness scores in the first stage, in the last three columns.

Table 9. Second stage stock return regressions (energy consumption for performance score in first stage regression).

Score Used in 1st Stage							
Completeness: Performance:	Energy Energy	GHG Energy	Water Energy	Waste Energy	Certificate Energy	Social Energy	Governance Energy
Log(total assets)	−0.0169	−0.0129	−0.0145	−0.0151	−0.0125	−0.0092	−0.0083
	0.0124	*0.0124*	*0.0120*	*0.0119*	*0.0119*	*0.0118*	*0.0116*
LTV	−0.153 *	−0.159 **	−0.173 **	−0.158 **	-0.181 **	−0.148 *	−0.153 **
	0.0811	*0.0780*	*0.0777*	*0.0781*	*0.0770*	*0.0752*	*0.0738*
Closely held shares	−0.0004	0.0066	−0.0063	0.0116	−0.0059	0.0011	−0.0005
	0.0393	*0.0384*	*0.0388*	*0.0388*	*0.0381*	*0.0369*	*0.0364*
Log(sqm)	0.0259 **	0.0236 **	0.0237 **	0.0245 **	0.0208 *	0.0220 **	0.0209 **
	0.0109	*0.0108*	*0.0107*	*0.0107*	*0.0109*	*0.0103*	*0.0102*
Fitted sBPR	−0.0257	−0.0612	−0.0612	−0.0484	−0.0594 *	-0.111 **	−0.126 ***
	0.0335	*0.0399*	*0.0381*	*0.0322*	*0.0298*	*0.0430*	*0.0428*
Constant	0.114	0.180	0.210	0.165	0.221	0.275 *	0.318 **
	0.135	*0.141*	*0.149*	*0.137*	*0.142*	*0.142*	*0.143*
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Adjusted R-squared	0.160	0.187	0.191	0.186	0.211	0.247	0.271
Observations	58	58	58	58	58	58	58

Notes: In this table, we present our coefficient estimation for model (4) in which the variation in average stock returns is explained by the fitted value of sBPR rating obtained from the first stage regression with ESG completeness and performance scores (as indicated at the top of the table), while controlling for the four most important company characteristics: firm size, leverage, ownership, and property portfolio size. These controls are estimated by *Log(total assets)*, which refers to the natural log of a firm's total assets, *LTV*, which is the loan to value ratio, *Closely held shares*, which is the fraction of shares held by insiders, and log(sqm), which is the natural log of the total square meterage of the property portfolio. In the first stage regression, the performance score is estimated with energy usage (*Energy*). Coefficient estimates marked with (*) (**) (***) are statistical significantly different from zero on a 90%, 95% and 99% confidence interval. Below each coefficient, we also state the corresponding robust standard error in italics. Potential multicollinearity issues are not found to be significant (correlation matrix and variance inflation factors VIF) and error terms are proved to be homoscedastic (White test) and normally distributed (normal probability plot and Jarque–Bera test). We also estimated models assuming clustered errors by property type and individual REIT, and the results remain consistent.

As a final robustness test, we estimate the same two-stage model as from Equations (3) and (4), but this time using return to risk ratios as the dependent variable. Overall, we find similar, albeit weaker, outcomes as reported in Table 10. We show a negative coefficient for sBPR ratings in the second stage regression as for the results using returns. Either using the GHG or energy performance data does not affect our findings, and the fitted sBPR coefficient is significant only when we include waste and governance as completeness scores. This outcome may suggest that investors targeting less risky real estate companies may decide to invest in more ESG compliant firms which tend to be more conservative and allow them to reduce their overall risk exposure.

Table 10. Return to risk two-stage regressions.

Panel A: Return to Risk 2nd Stage Regression (GHG Performance).							
Score used in 1st stage							
Completeness:	Energy	GHG	Water	Waste	Certificate	Social	Governance
Performance:	GHG	GHG	GHG	GHG	GHG	GHG	GHG
Fitted sBPR	0.0063	−0.145	−0.0773	−0.432 **	−0.265	−0.0338	−0.454 *
	0.220	*0.231*	*0.194*	*0.209*	*0.245*	*0.227*	*0.266*
Control variables	Y	Y	Y	Y	Y	Y	Y
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Observations	58	58	58	58	58	58	58
R-squared	0.079	0.086	0.082	0.150	0.102	0.080	0.128
Panel B: Return to Risk 2nd Stage Regression (Energy Performance).							
Score used in 1st stage							
Completeness:	Energy	GHG	Water	Waste	Certificate	Social	Governance
Performance:	Energy	Energy	Energy	Energy	Energy	Energy	Energy
Fitted sBPR	0.0538	−0.173	−0.0606	−0.436 **	−0.287	−0.0257	−0.599*
	0.236	*0.285*	*0.231*	*0.208*	*0.271*	*0.266*	*0.319*
Control variables	Y	Y	Y	Y	Y	Y	Y
Property-type F.E.	Y	Y	Y	Y	Y	Y	Y
Portfolio location F.E.	Y	Y	Y	Y	Y	Y	Y
Observations	58	58	58	58	58	58	58
R-squared	0.080	0.086	0.081	0.151	0.099	0.080	0.138

Notes: In this table, we present our coefficient estimation for model (4) in which the variation in average stock returns over standard deviations is explained by the fitted value of sBPR rating obtained from the first stage regression with ESG completeness and performance scores (as indicated at the top of the table), while controlling for the four most important company characteristics: firm size, leverage, ownership, and property portfolio size. These controls are estimated by *Log(total assets)*, which refers to the natural log of a firm's total assets, *LTV*, which is the loan to value ratio, *Closely held shares*, which is the fraction of shares held by insiders, and *Log(sqm)*, which is the natural log of the total square meterage of the property portfolio. The performance score in the first stage is estimated with greenhouse gasses (*GHG*) in Panel A and energy usage (*Energy*) in Panel B. Coefficient estimates marked with (*) (**) (***) are statistical significantly different from zero on a 90%, 95% and 99% confidence interval. Below each coefficient, we also state the corresponding robust standard error. Potential multicollinearity issues are not found to be significant (correlation matrix and variance inflation factors VIF) and error terms are proved to be homoscedastic (White test) and normally distributed (normal probability plot and Jarque–Bera test). We have also estimated models assuming clustered errors by property type and individual REIT, and the results remain consistent.

5. Conclusions

ESG has become a standard for modern investment management. In an era where the literature on factor investing has inspired institutional investors around the world to tilt their portfolios towards small growth firms with stock momentum, the empirical evidence on the return effects of ESG performance is scarce. Yet, many investors consider and increasingly are required to consider ESG metrics when screening their investments.

In this paper, we add to this empirical literature by analyzing EPRA's sBPR database for the listed European real estate market. This is a database that covers a wide variety of ESG aspects and allows us to disentangle the return effects of each. In our analysis, we construct two ESG measures based on the sBPR data: ESG completeness—a measure of ESG transparency in which we report the fraction of filed data field—and ESG performance—the fraction of ESG data fields that shows an improvement of the years. Both are computed for a sample of 64 European listed real estate firms.

Our results show that both ESG measures covary across firms. In other words, firms that score highly on ESG completeness, also tend to score higher than average on ESG performance. There is perhaps a case of reverse causality, in which poorly performing firms shy away from reporting their ESG completely. Furthermore, we find that both ESG scores are higher for the larger firms in our sample, and among the sBPR gold award winners. The latter does not come as a surprise, because the sBPR awards are partially based on ESG completeness scores. The fact that ESG scores covary with firm size is important, as this means that we need to control for firm characteristics when properly examining the effects of ESG scores on listed real estate returns. We analyze this issue in a set of multivariate regressions on firm stock returns in which controls for firm size, leverage, ownership, and property portfolio size are added. In these regressions, we find a positive and significant effect for ESG completeness and ESG performance for the ESG aspects energy and greenhouse gasses. Apparently, stock investors already identify and appreciate the progress that European listed real estate firm make when it comes to their reduction in energy usage and greenhouse gas emissions. Moreover, ESG completeness also increases returns regarding energy certification, social impact and governance scores. The more firms that report on these matters, the better these subsequent returns evolve. Regarding whether the actual performance on the ESG measures is also related to to stock outperformance, it is still too soon to tell, as our data limitations do not allow for any significant estimations on these factors at this point in time. However, we find initial evidence of investors willing to pay a sustainable premium to access companies with better sustainability ratings (sBPR).

Our results are important for investors and fund managers, as we show that ESG not only matters, but also that thanks to EPRA's sBPR, it is swiftly evolving into a transparent quality of listed real estate firms. The extent to which firms cooperate in initiatives like the sBPR database can help them to improve their return profile. Given the successful but short history of EPRA's sBPR database, our analysis is still limited. We are certain that more data will soon become available and help to identify and measure the merits of ESG efforts within the European public real estate market. We therefore encourage future research on the matter and on this new and unique database.

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Abbreviations

BPR	Best Practices Recommendations (Financial)
BREEAM	Building Research Establishment Environmental Assessment Method
CDP	Carbon Disclosure Project
CGQ	Corporate Governance Quote
COP21	Conference of the Parties, UN Climate Conference held in 2015 in Paris
CSR	Corporate Social Responsibility
EPRA	European Public Real Estate Association
EPC	Energy Performance Certificate
ESG	Environmental, Social and Governance
IVA	Intangible Value Assessment
LEED	Leadership in Energy and Environmental Design
REITs	Real Estate Investment Trusts
ROA	Return on Assets
ROE	Return on Equity
sBPR	Sustainability Best Practices Recommendations

Appendix A. EPRA Sustainability Performance Measures, Codes, and Units of Measurement

Table A1. ESG Performance Measures.

Panel A: ENVIRONMENTAL SUSTAINABILITY PERFORMANCE MEASURES		
Code	**Performance Measure**	**Unit of Measure**
Elec-Abs	Total electricity consumption	annual kWh
Elec-LfL	Like-for-like total electricity consumption	annual kWh
DH&C-Abs	Total district heating and cooling consumption	annual kWh
DH&C-LfL	Like-for-like total district heating and cooling consumption	annual kWh
Fuels-Abs	Total fuel consumption	annual kWh
Fuels-LfL	Like-for-like total fuel consumption	annual kWh
Energy-Int	Building energy intensity	kWh/appropriate denominator
GHG-Dir-Abs	Total direct greenhouse gas (GHG) emissions	annual metric tonnes CO2e
GHG-Indir-Abs	Total indirect greenhouse gas (GHG) emissions	annual metric tonnes CO2e
GHG-Int	Greenhouse gas (GHG) emissions intensity from building energy consumption	tonnes CO2e/appropriate denominator
Water-Abs	Total water consumption	annual cubic metres (m3)
Water-LfL	Like-for-like total water consumption	annual cubic metres (m2)
Water-Int	Building water intensity	m2/appropriate denominator
Waste-Abs	Total weight of waste by disposal route	annual metric tonnes and proportion by disposal route
Waste-LfL	Like-for-like total weight of waste by disposal route	annual metric tonnes and proportion by disposal route
Cert-Tot	Type and number of sustainably certified assets	Total number by certification/
Panel B: SOCIAL PERFORMANCE MEASURES		
Code	**Performance measure**	**Unit of measure**
Diversity-Emp	Employee gender diversity	Percentage of employees
Diversity-Pay	Gender pay ratio	Ratio
Emp-Training	Employee training and development	Average hours
Emp-Dev	Employee performance appraisals	Percentage of employees
Emp-Turnover	New hires and turnover	Total number and rate
H&S-Emp	Employee health and safety	Injury rate, absentee rate and number of work related fatalities
H&S-Asset	Asset health and safety assessments	Percentage of assets
H&S-Comp	Asset health and safety compliance	Number of incidents
Comty-Eng	Community engagement, impact assessments and development programs	Percentage of assets
Panel C: GOVERNANCE PERFORMANCE MEASURES		
Code	**Performance measure**	**Unit of measure**
Gov-Board	Composition of the highest governance body	Total number
Gov-Selec	Process for nominating and selecting the highest governance body	Narrative on process
Gov-CoI	Process for managing conflicts of interest	Narrative on process

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Multi-Horizon Financial and Housing Wealth Effects across the U.S. States

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Abstract: We investigate for the presence of multi-horizon wealth effects across U.S. states over the period of 1975:Q2 to 2012:Q2 by utilizing multi-horizon non-causality testing and multi-horizon causality measurement. At the state/aggregate level, we document that housing wealth has more statistically significant and persistent impact on private consumption than financial wealth. We also find that state-level housing/financial wealth effects are present at long time horizons and exhibit heterogeneity across the U.S. From a policy perspective, we suggest that state-level policies may specifically utilize the housing market to support consumption and growth.

Keywords: consumption; housing wealth effect; financial wealth effect; multi-step causality

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1. Introduction

Evaluating the dynamics of the wealth effect on the U.S. economy has been growing in importance in the wake of the recent housing bubble. The literature reveals that income and wealth are the essential drivers of consumption, and fluctuations in the value of the wealth components, such as housing and financial wealth, result in some cyclical fluctuations in household consumption. Although there are some mixed results with respect to the selected sample, time period, and model specification, to name a few, there has been a growing consensus that the housing wealth effect is generally greater than the financial wealth effect in the U.S. (i.e., see, [1–6]). However, variations in financial wealth effect are also important for the countries that are characterized by a market-based financial system and a larger stock ownership such as in the case of the U.S. The wealth effect literature is already extensive. Most of the existing evidence on the wealth effect studies is based on a limited data set involving aggregate and micro (survey) data. This paper uses an expanded dataset with regional data to reinvestigate the classic research problem of wealth effect, or the link between wealth and consumption [7] in the U.S. In this respect, except for [8], no comprehensive systemic analysis has been conducted using data for the U.S. economy at the state-level. There are state-level wealth effect studies for the U.S. (i.e., [5,6,8,9]), but, to the best of our knowledge, our study is the first empirical attempt to analyze multi-horizon wealth effects across U.S. states over the period of 1975:Q2 to 2012:Q2 by utilizing multi-period non-causality testing [10] and causality measurement [11]. An analysis of the causality linkages between wealth and consumption across different prediction horizons and states provides a micro-level fresh perspective to the empirical literature.

This article contributes to the wealth effect literature in four aspects. First, we use a unique data set that allows us to document the presence of income, housing, and financial wealth effects across U.S. states. In addition to the aggregate-level evidence, our study provides state-level evidence to the role of housing and financial wealth effects in consumption by improving further on [5,8]. Second, our study is the first to classify U.S. states with respect to the relative importance of housing/financial wealth effects. This attempt may provide an interesting knowledge for federal and state-level policymakers in the U.S. Third, we apply a new methodological approach that enables us to compare the intensity of wealth effects at various time horizons in terms of predictability. This methodological improvement provides comparative evidence sensitive to the different model specifications. Fourth, based on our unique data set and application, we refine the scope of the wealth effect by comparatively analyzing aggregate and state-level income, housing, and financial wealth effects. Our main questions are addressed below.

The goal of this paper is to better understand the wealth effect-induced household consumption behaviors in the U.S. states, in particular: (i) whether state-level wealth effect dynamics in the U.S. differ from aggregate level dynamics, (ii) whether wealth effect upon consumption occurs at different time horizons at the state level, (iii) which wealth effect component is more intense in the short-run and long-run, (iv) whether the results are robust to different model specifications, and (v) whether the U.S. states can be classified with respect to which wealth effect is more dominant (housing or financial) based on some criteria such as short-/long-term persistency and magnitude of coefficient value of a wealth effect component. Eventually, by investigating these empirical questions, our study sheds more light on the field-classical research topic on which wealth effects matters the most for the household consumption in the U.S.

Causality measurement reveals that housing wealth constitutes the most crucial determinant of consumption growth changes from an economic viewpoint. Our evidence suggests that changes in housing wealth generate more intense, persistent, and widespread impacts on consumption growth at the aggregate and state level when compared with financial wealth. Moreover, although we document the presence of both financial and housing wealth effects upon consumption at long horizons, the results show that there is heterogeneity in the wealth effect patterns across U.S. states.

The remainder of the paper is organized as follows. The next section documents the literature review. Section 3 provides a discussion of our methodology. Data and empirical results are presented and discussed in Section 4. Finally, Section 5 concludes the paper.

2. Literature Review

The life cycle-permanent income [12–14] hypothesis is widely accepted as the proper application of the theory of the consumer to the problem of dividing consumption between present and future. According to the hypothesis, consumers form estimates of their ability to consume in the long run and then set current consumption to the appropriate fraction of the estimate. The estimate may be stated in the form of wealth, following [12], in which case the fraction is the annuity value of wealth, or as permanent income, following [14], in which case the fraction should be very close to zero [15]. Due to data constraints for pension and social security wealth, housing wealth studies have generally used financial and housing wealth data in their analyses [16].

Although the empirical literature presents some mixed evidence, common patterns of wealth effects are documented in different samples. First, in general, housing and financial wealth play a significant role in income, saving, consumption behaviors and in economic growth. Second, the business cycle of the economy is a determinative factor of the magnitude of the wealth effect. Namely, a rising (declining) stock/housing market may increase (decrease) wealth effect components to different degrees as observed before/after global financial crisis periods. There may also be parallel relations between real estate and business cycles for those countries/regions where real estate and the general economy have strong linkages. Ref. [17] argues that the real estate cycle amplified the business cycle significantly in the late 1980's in New England. The global financial crisis was the latest example of this relation for at least the U.S., UK, and Ireland. Ref. [18] indicate that increasing optimism in consumers is likely to increase consumption of housing and non-housing goods. Ref. [19] show that while the real house price generally leads real GDP per capita, both during expansions and recessions, significant feedback effect from the real GDP per capita onto the real house price also exists. These findings also occur during the recent financial crisis and Great Recession. Third, depending on the phase of the business cycle and the market, housing and financial wealth effects have some cyclical and non-asymmetrical features as well (i.e., [8,20–23]). Fourth, the importance of housing and financial wealth is determined by various factors such as the level of mortgage market completeness and financial development, the ownership level/structure in housing/stock markets, and market-specific policies (i.e., protection of rights, transaction cost, information asymmetry etc.). Although it is generally difficult to make a generalization among countries from a housing/wealth effect perspective, it seems that while financial wealth may become a primary wealth effect source in Anglo-Saxon and/or market-based economies, housing wealth effect may become a primary source in bank-based and some developing countries (i.e., [24–27]).

The variations in household consumption sensitivity to wealth effects depends on various factors such as liquidity conditions [28], utilities derived from the property right and the role of bequest [29], distributions of wealth among income groups, expected permanency of changes, measurement biases of wealth [30,31], housing/stock market features of the analyzed country/province, the policies, and behaviors and demographics of asset owners. However, ref. [32] discusses that standard measures of wealth may not adequately reflect newly emerging economic concerns such as sustainability.

Differences of marginal propensity to consume in housing/stock markets are generally explained by the well-documented differences in nature and risk characteristics of housing/stock as the asset classes (see, [25,33]). For example, ref. [34] provide evidence that imperfect knowledge of households with respect to their financial wealth may result in them reacting instantaneously to changes in wealth. Ref. [35] discuss that the psychology of framing may dictate that certain assets are more appropriate to use for current expenditures, while others are earmarked for long-term savings. Ref. [8] note that the emotional impact of accumulating stock market wealth may be quite different from that of real estate wealth. People are likely to be less aware of the short-run changes in real estate wealth since they do not receive regular updates on its value. Stock market wealth can be tracked daily online. Ref. [36] argue that housing and stock markets respond rather differently to negative shocks when the stock market is more volatile, but price rigidity is found in the housing market. From the micro-analysis perspective, the magnitude of the wealth effect is also related to demographic features. From the housing market perspective, ref. [37] discuss that house price appreciation increases the net worth and consumption of all homeowners, while it only improves the welfare of older homeowners. Ref. [8] underline that the importance of housing market wealth and financial wealth in affecting consumption is an empirical matter. For example, in an earlier study, using aggregate data in explaining U.S. consumer expenditures over the period of 1960 to 1977, ref. [38] finds that fluctuations in the net value of household holdings of consumer durables and real estate do not associate significantly in consumer spending and values of expenditure elasticity of stock price change with mean values in the 0.030–0.055 range. Empirical work, such as [20,39], suggests at best a weak link between house price changes and nonhousing consumption. Refs. [40,41] find similar housing/stock wealth elasticities in their estimations. Ref. [29] discusses that house price fluctuations possibly trigger smaller consumption changes than do stock market fluctuations. The extent to which an unanticipated increase in house prices raises a household's real wealth depends on the time horizon over which the household plans to live in their current home. It is noted from the U.S. Survey of Consumer Finances, in 1998 and 2001, that more than two-thirds of households are homeowners, while only half owned stock, bonds, and mutual funds concentrated in pension/retirement accounts, ref. [1] argue that the level of marginal propensity to consume in real estate or financial wealth is a determinative factor in economic stabilization.

The recent empirical literature provides a large body of evidence on the larger and persistent source of housing wealth in general and for the U.S., in particular. For example, ref. [42] indicate that change in household net worth caused by a change in house prices is larger than the change from similar variation in stock values for the vast majority of households. By estimating the consumption function for the U.S. economy with real estate and financial wealth for quarterly data for 1952:Q1–2001:Q4, ref. [1] find that an additional dollar of real estate wealth increases consumption by 8 cents, as compared with only 2 cents for financial wealth. Ref. [2] finds that the effect of housing wealth is somewhat smaller than that of financial wealth for most of the investigated countries, but not for the U.S. and the UK [43], consistent with several recent studies, find a housing wealth effect that is substantially larger than the stock wealth effect for the U.S. Ref. [3] find that overall wealth effect from housing is stronger than the effect from financial wealth for all countries involving the U.S. Housing wealth effect is consistently stronger for the oldest group in Canada and the late middle-aged groups in Finland and Italy. Authors suggest that policymakers should keep an eye on housing market developments separately from financial markets. Ref. [4] research findings indicate relatively large housing wealth effects for the U.S. Among homeowners, the housing wealth elasticities are estimated in the range of 0.06 over the 1989–2001 period. Ref. [43] suggest that it is not certain that the housing wealth effect is substantially larger than the financial wealth effect for the U.S., but monetary policies should follow housing markets separately from equity markets due to its significantly higher MPC from housing wealth. Ref. [9] find a strong association between consumption and housing wealth declines in the period after the real estate bubble burst in the U.S. Ref. [44] document that the housing wealth effect is more intense than the stock wealth effect for a panel of countries involving the U.S. over the period from 1970:Q1 to 2015:Q4. They argue that housing is a powerful asset transmission channel irrespective of the size, financial structure, and geographic location of the analyzed economies. By employing a multistep non-causality test [10] and causality measures [11,45] investigate the nature of the intertemporal relationship between household wealth and private consumption across the G7 countries. The authors document the absence of short-horizon causality and the presence of long-horizon causality across variables.

Analyses of the role of housing wealth in the determination of consumption spending have used one of three types of information: aggregate time-series data at the state or national level, micro-data from household-level surveys, and data based on refinance activity [4]. It seems that studies are mostly focused on aggregate and micro-level data [46]. From a regional data perspective, by following [31] and using a state-level panel for the Australian economy, ref. [30] find larger effects for financial wealth, but smaller effects for housing wealth. Using threshold regression to explore the asymmetric effects of housing price on consumption, ref. [47] investigate the linkage for 35 major Chinese cities. The authors argue that the housing market is indeed equally or even more important to the transmission channels from housing wealth to consumption in China. Based on China Family Panel Studies, ref. [48] find that urban housing price influences some nonessential expenditure items like education, medical, and transportation.

In parallel to studies for other countries, wealth effect studies based on state-level data (and region, city) are also scarce for the U.S. Using aggregate data, ref. [17] finds evidence of a significant consumption effect during the real estate price boom in the late 1980's for New England. Ref. [8] estimate stock market wealth, housing market wealth and consumption for each U.S. state, quarterly, for the period 1982–1999. They find at best weak evidence of a stock market wealth effect and strong housing wealth effect. Ref. [5] use similar data sources to [8] while they estimate regression models in levels, first differences and in error-correction form over the period of 1975 through 2012:Q2 for U.S. states. They document a statistically significant and rather large effect of housing wealth upon household consumption. Among others, they argue that a decline of 35% in housing wealth would lower consumer spending by 3.5% in the U.S. The authors further indicate that changes in housing wealth and stock market wealth do not move closely with per capita income across states. The most dramatic cyclical pattern is in California and the patterns in Florida and Arizona are much like that in Texas. Ref. [33] examine the nature and causal direction of the relationship between house prices and economic growth proxied by per capita personal income for a panel of 351 U.S. metropolitan statistical areas. The authors find a long-run relationship between local house prices and per capita personal income and also the existence of a bi-directional causality between real house prices and real per capita personal income over both long and short-horizons. Ref. [49] investigate the presence of causal linkages between asset prices and output per capita across the 50 U.S. states and DC over the period 1975–2012:Q2 by implementing a bootstrap panel causality framework. Their findings indicate when controlling for cross-state dependency, heterogeneity and asset market interconnections, causality runs from asset prices (both housing and stock prices) to output, not only at the level of individual states, but also taking together all the agricultural and industrial states. Using geographically linked microdata, ref. [50] finds that a USD 1 increase in home values in the U.S. leads to a USD 0.047 increase in spending for homeowners, but a negligible response for renters. By analysing the 1978–2017 period for the city-level data of the U.S., time-varying estimates of [51] indicate that housing wealth effects were not particularly large in the 2000s. Ref. [6] provide evidence that the elasticities of consumption with respect to financial wealth and housing wealth vary considerably across U.S. states, with housing wealth effects being larger than financial wealth effects in 37 cases.

Overall, not surprisingly, housing and financial wealth effects may exhibit heterogeneity across regions involving U.S. states/cities if we account for the differences in ownership level in financial/housing assets, demographics, income-wealth level/distribution, consumption behaviours shaped by socio-econonomic/cultural structures, access to finance and credit constraints, etc.

3. Methodology

The traditional concept of [52,53] causality is defined in terms of incremental predictability one period-ahead. It is by now a commonplace observation that this concept does not take into account the possibility that the predictive ability of a variable for another may vary over different time periods into the future. Refs. [54,55], argue that even if there is no causality between two variables one period-ahead, causal links may be present at subsequent time periods. In a multivariate framework, a set of auxiliary variables, say Z, can induce an indirect influence of X on Y at higher prediction horizons than one. Ref. [55] are the first to present a theoretical multivariate framework, referred as long (or short) horizon non-causality, which allows one to disentangle potentially different Granger causality relations over different forecast horizons. The authors provide definitions and a set of conditions which ensure the equivalence between standard Wiener-Granger type one-step ahead non-causality and non-causality at any forecast period. Their multivariate framework defines conditions on non-causality between two variables of interest at a forecast horizon greater than one in terms of multi-linear zero restrictions on the VAR model parameter coefficients.

Testing such hypotheses using likelihood ratio or Lagrange multiplier tests is problematic due to the difficulty of estimating parametric models that encompass the multi-linear coefficient zero restrictions. The use of a Wald test is a feasible alternative to this problem. However, a regularity condition states that the asymptotic distribution of a standard Wald test is valid only when the matrix of the first partial derivatives of the VAR coefficient restrictions is of full rank. Ref. [56] argue that the matrix of the first partial derivatives of [55] VAR coefficient restrictions may be of reduced rank because these restrictions have a multilinear form. Therefore, the Wald statistic may fail to be asymptotically distributed as chi square under the null, and as a consequence, the use of the asymptotic chi square critical values may lead to misleading inference. Refs. [56,57] propose modified Wald statistics to test the noncausality hypothesis at a specific horizon h. These tests are shown to have a valid asymptotic distribution under the null hypothesis even when these highly nonlinear zero coefficient restrictions violate the regularity condition of a usual Wald test. However, the proposed tests yield a poor finite sample performance. An alternative test procedure is proposed by [10]. Their methodology requires the estimation of parametric mean regressions denoted as "(p,h)-autoregressions". Inference is conducted by testing simple zero coefficient restrictions on the parameters of the "(p,h)-autoregressions" via an asymptotic chi-square Wald test. The authors also introduce a parametric Monte Carlo procedure to calculate p-values to ensure enhanced finite sample properties.

3.1. Testing for Granger Non-Causality at Time Horizon h

Testing for multi-horizon non-causality (see [10]) involves estimating the conditional vector autoregressive model of order p (VAR(p)),

$$V_t = \mu + \sum_{k=1}^{p} \theta_k V_{t-k} + \mu_t, \ \ t = 1, 2, \ldots, \ T, \tag{1}$$

where $V_t = (v_{1t}, v_{2t}, \ \ldots, v_{mt})$ is an $m \times 1$random vector, μ is an $m \times 1$ vector of intercepts, and μ_t is the vector of uncorrelated residuals with $E\left(u_t u_t'\right) = \Omega$. The model in Equation (1) can be rewritten for the time period $t + h$:

$$V_{t+h} = \ \mu^{(h)} + \sum_{k=1}^{p} \theta^{(h)} V_{t+1-k} + \sum_{\tau-1}^{h-1} \Psi_t u_{t+h-\tau}, \ \ t = 0, 1, \ \ldots, T-h, \tag{2}$$

where Ψ_t is the matrix of impulse response coefficients. Estimators for the parameter coefficients of model (2), which is denoted by the authors as "(p,h)-autoregression", are presented in [10,55]. Suppose we want to test the null hypothesis that the variable v_{jt} does not Granger cause variable v_{it} at time horizon h. The null hypothesis is defined in terms of specific zero coefficient restrictions on the parameters of model (2):

$$H_0^{(h)} : \theta_{ijk}^{(h)} = 0, \ \ k = 1, 2, \ldots, p, \tag{3}$$

where $\theta_k^{(h)} = \left|\theta_{ijk}^{(h)}\right|, \ \ i, j = 1, \ldots, m.$

The authors propose an asymptotic chi-square Wald test statistic to test the null hypothesis in (3). Evidence from Monte Carlo simulations indicates that inference based on the asymptotic chi-square critical values may be misleading due to size distortions. Therefore, they introduce a simulation method to calculate the p-value of the Wald test which ensures enhanced finite sample properties of the test procedure. The simulated p-values of the Wald test results are calculated using the method described at page 351 of [10].

3.2. Measuring Granger Non-Causality at Time Horizon h

While testing for Granger non-causality at multiple time horizons may yield interesting insights, this approach by construction cannot help the researcher to conclude whether a statistically significant causal effect at a specific time horizon may lead to enhanced forecastability of the series. Quantifying the degree of multi-horizon conditional mean codependence between the data would give a richer and more comprehensive picture than just documenting the presence of a causality relation. Ref. [11] propose measures for Granger multi-horizon non-causality that quantify the strength of a causality relation between two random variables at a specific time horizon h. Their method is an adaptation of [58–60] framework for the assessment of one-period ahead conditional mean dependence between multivariate series, but generalized for multi-horizon causality measurement.

Ref. [11] quantify the intensity of causality from Y to X at horizon h by means of the mean-square based causality measure:

$$C_L(Y \to X_h|I) = ln\left[\frac{\det\{\Sigma[X_{t+h}|I_{X,t}]\}}{\det\{\Sigma[X_{t+h}|I_{XY,t}]\}}\right] \tag{4}$$

where $\sum[X_{t+h}|I_t]$ is the covariance matrix of the prediction error $u[X_{t+h}|I_t] = X_{t+h} - P[X_{t+h}|I_t]$, with $P[X_{t+h}|I_t]$ denoting the best linear forecast of X_{t+h}. The causality measure (5) is applied for multivariate ARMA–type processes in the context of infinite vector autoregressive models (VAR(∞)) or infinite vector autoregressive moving average models (VARMA(∞)). Estimation of expression (5) involves the following steps:

Assume that we want to measure the intensity of causality from v_{1t} to v_{2t} at forecast period h. Let the stationary and invertible process V_t be partitioned into $V_t = (v_{1t}, v_{2t},\ v_{qt})$, where v_{1t}, v_{2t} are two $T \times 1$ vectors and v_{qt} is a $T \times (m-2)$ matrix with auxiliary variables. The process V_t can be approximated by a VAR (p) model (see Equation (1)), while the variance-covariance matrix of the forecast error of v_{2t+h} is estimated as:

$$\hat{\Sigma}_h = \sum_{z=0}^{h-1} R\,\hat{\Psi}_z\,\hat{\Sigma}_z\,\hat{\Psi}'_z R', \tag{5}$$

where $R = (0,1,0,\ldots,0)$ is a $1 \times m$ vector, $\hat{\Psi}_z = \hat{\theta}_1^{(z)}\ \hat{\theta}_1^{(z+1)} = \hat{\theta}_2^{(z)} + \hat{\theta}_1^{(z)}\hat{\theta}_1$, $\hat{\theta}_1^{(1)} = \hat{\theta}_1$, $\hat{\theta}_1^{(0)} = I_m$ for $z \geq 1$, $\hat{\theta}_k = [\hat{\theta}_{1k}, \hat{\theta}_{2k}, \ldots, \hat{\theta}_{kk}]$ is the matrix of the least-squares estimators of the coefficients θ_k, and $\hat{\Sigma} = \hat{u}_t\hat{u}'_t/(T-p)$ with $\hat{u}_t$ denoting the estimated residuals from model (1). Subsequently, consider the marginal process $V_t^* = (v_{2t}, v_{qt})$. Let V_t^* evolve as a VAR(p) process, while the variance-covariance matrices of the forecast errors of v_{2t+h} are estimated as:

$$\hat{\Sigma}^*_h = \sum_{z=0}^{h-1} R^*\,\hat{\Psi}^*_z\,\hat{\Sigma}^*_z\,\hat{\Psi}^{*\prime}_z R^{*\prime}, \tag{6}$$

where the quantities $\hat{\Psi}^*_z$, $\hat{\Sigma}^*_z$ are estimated similarly with those of Equation (5) and $R^* = (1,0,\ldots,0)$ is a $1 \times (m-1)$ vector.

Then, the expression in (4) is estimated as

$$\hat{C}_l(v_{1t} \to v_{2th}|I) = ln\left[\frac{\det\{\hat{\Sigma}^*_h\}}{\det\{\hat{\Sigma}_h\}}\right].. \tag{7}$$

The causality measure at horizon h indicates how strong the causal relationship is between the two time series at the specific forecast period. Therefore, a large value of the causality measure is interpreted as an indication that the variable v_{1t} induces a severe effect on the conditional mean of variable v_{2t} at horizon h. On the other hand, non-causality from v_{1t} to v_{2t} at horizon h is equivalent to a zero-causality measure.

The causality measure estimator in (7) is shown to be consistent and asymptotically normal by [11]. Estimation of the asymptotic variance of the measure involves difficult calculations since it requires the analytical differentiation of the causality measure with respect to θ_k. To circumvent this problem, the authors introduce a residual-based bootstrap procedure to construct confidence intervals. In this paper, the bootstrap method of [11] is used to compute the 95% confidence intervals for each h-horizon causality measure. The order p of the autoregressive specifications used for testing and measuring multi-horizon causality is set arbitrarily to be four quarters.

4. Data and Empirical Results

4.1. Data

We use state-level per capita owner-occupied real housing wealth, per capita real financial wealth and per capita real household consumption, as imputed in [5,8]. This is virtually the only data set that has both the financial wealth and housing wealth disaggregated to the state-level (including the District of Columbia (DC)); the imputation covers a significant period of time, from 1975:Q2 to 2012:Q2. We aggregate all these variables across the 50 states and for DC to obtain the corresponding values for overall United States. One issue with this dataset is that per capita consumption is approximated at the state level by total retail sales. Further, note that [5,8] restricted the growth rate in household financial wealth solely to the growth rate in households' holdings of mutual funds due to data availability. Various unit root tests are implemented to test whether the variables are non-stationary at both the aggregate and the state level. Our findings indicate that all variables are nonstationary (the results are available upon request from the authors). Therefore, we calculated the logarithmic first differences of the data to ensure that the series are stationary. Throughout the empirical analysis that follows, the testing and measurement procedures are applied to the differenced data.

4.2. Test Results

4.2.1. Multi-Horizon Non-Causality Measure Test Results and Implications

Tables 1–3 report the results when we implement the multi-horizon non-causality test of [10] described in Section 3.1 to investigate for multi-horizon wealth effects on private consumption growth for 50 U.S. States and DC. Each table exhibits the simulated *p*-value of the Wald test statistic over the range one to eight quarters ahead. Following [10], we used 1000 replications for each simulation to calculate the *p*-value.

We observe in Table 1 that in 37 states housing wealth growth Granger causes on consumption growth at multiple forecast horizons at levels of statistical significance 1%, 5%, and 10%. In some states, housing wealth effect occurs one or two quarters ahead (Florida, Idaho, Illinois, Kansas, Maine, Montana, New York, and Wisconsin). In some other states, we document the presence of long horizon causalities exclusively (Alaska, Arizona, Arkansas, Connecticut, Delaware, Indiana, Maryland, Michigan, Nebraska, North Dakota, Rhode Island, South Dakota, and Texas). Causality from housing wealth to consumption is also found at both short and long horizons (California, Colorado, Iowa, Massachusetts, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, Ohio, Oklahoma, Oregon, Pennsylvania, Tennessee, Vermont, and Virginia). On the aggregate level in the U.S., we find highly significant housing wealth effects upon consumption in one, two, four, five, six, and eight quarters ahead.

Table 2 demonstrates the presence of statistical significance of income effects upon consumption at different time horizons in 21 states at levels 1%, 5%, and 10%. We document cases of causality from income growth to consumption growth at short horizons (Alaska, Florida, Kansas, Maine, North Carolina, and Virginia), at long horizons (Arizona, Connecticut, District of Columbia, Illinois, Iowa, Kentucky, Louisiana, North Dakota, Ohio, and Washington), and at both short and long horizons (Delaware, Hawaii, Maryland, Oklahoma, South Dakota, and Texas). On the aggregate level in the U.S., we find that income does not cause consumption over any time horizon.

We see in Table 3 that the null hypothesis of non-causality from stock holdings growth to consumption growth is rejected at multiple time horizons in 43 states at levels 1%, 5%, and 10%. This evidence suggests a significant state-level financial wealth effect according to non-causality measure. Causal effects from stock holdings to consumption occur up to two quarters ahead (Arizona, California, Colorado, Connecticut, Delaware, District of Columbia, Hawaii, Maine, Massachusetts, Michigan, Ohio, and Virginia), several distant quarterly periods-ahead (Alabama, Arkansas, Idaho, Illinois, Mississippi, Montana, New Hampshire, Oklahoma, South Carolina, Texas, Vermont, West Virginia, and Wyoming), and over the range between one and eight quarters ahead (Florida, Georgia, Indiana, Minnesota, Missouri, Nevada, New Jersey, New Mexico, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Tennessee, Utah, Washington, and Wisconsin). On the aggregate level, causality is statistically significant in one quarter-ahead at level 5% and eight quarters ahead at level 10%.

Table 1. Causality from housing wealth growth to consumption growth at different time horizons.

Time Horizon h	1	2	3	4	5	6	7	8
Alabama	0.193	0.696	0.453	0.268	0.091	0.203	0.574	0.509
Alaska	0.485	0.412	0.234	0.022 **	0.009 ***	0.004 ***	0.010 **	0.061 *
Arizona	0.207	0.215	0.900	0.206	0.128	0.007 ***	0.071 *	0.034 **
Arkansas	0.375	0.722	0.884	0.665	0.582	0.798	0.035 **	0.017 **
California	0.003 ***	0.027 **	0.583	0.001 ***	0.001 ***	0.006 ***	0.603	0.033 **
Colorado	0.006 ***	0.398	0.693	0.102	0.056 *	0.077 *	0.414	0.393
Connecticut	0.566	0.959	0.970	0.296	0.432	0.339	0.190	0.025 **
Delaware	0.361	0.488	0.681	0.133	0.090 *	0.131	0.038 **	0.007 ***
District of Columbia	0.636	0.826	0.633	0.307	0.731	0.317	0.508	0.206
Florida	0.046 **	0.329	0.515	0.334	0.500	0.585	0.241	0.179
Georgia	0.941	0.825	0.914	0.713	0.796	0.780	0.724	0.221
Hawaii	0.991	0.959	0.389	0.420	0.881	0.799	0.712	0.671
Idaho	0.144	0.079 *	0.142	0.397	0.226	0.437	0.465	0.775
Illinois	0.024 **	0.074 *	0.392	0.085	0.284	0.700	0.602	0.519
Indiana	0.157	0.307	0.367	0.008 ***	0.044 **	0.126	0.132	0.016 **
Iowa	0.081 *	0.276	0.304	0.150	0.556	0.756	0.938	0.001 ***
Kansas	0.067 *	0.422	0.826	0.170	0.280	0.276	0.879	0.670
Kentucky	0.162	0.935	0.818	0.348	0.498	0.248	0.192	0.100
Louisiana	0.618	0.550	0.893	0.852	0.661	0.528	0.192	0.303
Maine	0.087 *	0.091 *	0.597	0.581	0.966	0.917	0.658	0.188
Maryland	0.214	0.834	0.871	0.491	0.442	0.306	0.418	0.081 *
Massachusetts	0.027 **	0.122	0.790	0.128	0.112	0.087 *	0.145	0.016 **
Michigan	0.184	0.848	0.970	0.355	0.069	0.229	0.339	0.003 ***
Minnesota	0.047 **	0.565	0.709	0.117	0.035 **	0.042 **	0.023 **	0.029 **
Mississippi	0.065 *	0.165	0.199	0.025 **	0.021 **	0.003 ***	0.017 **	0.535
Missouri	0.011 **	0.148	0.305	0.404	0.225	0.076 *	0.204	0.084 *
Montana	0.009 ***	0.058 *	0.398	0.575	0.404	0.738	0.886	0.818
Nebraska	0.111	0.597	0.539	0.520	0.793	0.148	0.484	0.041 **
Nevada	0.366	0.393	0.677	0.365	0.766	0.286	0.377	0.359
New Hampshire	0.015 **	0.949	0.792	0.605	0.483	0.099 *	0.508	0.059 *
New Jersey	0.007 ***	0.169	0.275	0.009 ***	0.001 ***	0.957	0.811	0.263
New Mexico	0.438	0.847	0.694	0.268	0.177	0.335	0.258	0.166
New York	0.018 **	0.005 ***	0.528	0.441	0.757	0.772	0.437	0.732
North Carolina	0.154	0.427	0.323	0.139	0.174	0.136	0.188	0.125
North Dakota	0.796	0.677	0.853	0.465	0.768	0.250	0.205	0.094 *
Ohio	0.082 *	0.660	0.861	0.233	0.107	0.194	0.374	0.029 **
Oklahoma	0.023 **	0.022 **	0.668	0.416	0.151	0.100	0.060 *	0.019 **
Oregon	0.011 **	0.065 *	0.191	0.169	0.092 *	0.190	0.219	0.328
Pennsylvania	0.113	0.501	0.695	0.053 *	0.088 *	0.091 *	0.062 *	0.050 *
Rhode Island	0.154	0.329	0.016 **	0.020 **	0.006 ***	0.983	0.759	0.147
South Carolina	0.700	0.764	0.967	0.591	0.252	0.285	0.486	0.692
South Dakota	0.068 *	0.037 **	0.111	0.096*	0.218	0.275	0.493	0.635
Tennessee	0.043 **	0.388	0.859	0.230	0.017 **	0.055 *	0.103	0.036 **
Texas	0.344	0.540	0.984	0.788	0.603	0.035 **	0.005 ***	0.009 ***
Utah	0.349	0.699	0.752	0.499	0.426	0.282	0.353	0.254
Vermont	0.115	0.164	0.004 ***	0.185	0.380	0.443	0.015 **	0.146
Virginia	0.005 ***	0.013 **	0.335	0.069 *	0.080 *	0.472	0.537	0.204
Washington	0.236	0.917	0.999	0.248	0.191	0.145	0.215	0.121
West Virginia	0.839	0.588	0.626	0.300	0.432	0.201	0.351	0.328
Wisconsin	0.002 ***	0.002 ***	0.892	0.274	0.132	0.186	0.229	0.129
Wyoming	0.858	0.664	0.283	0.219	0.288	0.370	0.602	0.530
United States	0.014 **	0.032 **	0.870	0.005 ***	0.005 ***	0.010 **	0.206	0.006 ***

Note: The table reports the simulated *p*-values of [10] test procedure on non-causality from housing wealth growth to consumption growth for forecast horizons (h) 1–8 quarters ahead. The sample covers a period from 1975:Q2 to 2012:Q2, a total of 149 observations. ***, ** and * refers to a 1%, 5% and 10% significance, respectively.

Table 2. Causality from income growth to consumption growth at different time horizons.

Time Horizon h	1	2	3	4	5	6	7	8
Alabama	0.284	0.338	0.285	0.301	0.314	0.281	0.619	0.754
Alaska	0.052 *	0.023 **	0.189	0.849	0.739	0.296	0.198	0.309
Arizona	0.561	0.393	0.795	0.697	0.898	0.660	0.083 *	0.042 **
Arkansas	0.800	0.385	0.740	0.706	0.439	0.787	0.681	0.548
California	0.223	0.125	0.336	0.645	0.813	0.674	0.377	0.112
Colorado	0.189	0.225	0.971	0.476	0.504	0.141	0.569	0.158
Connecticut	0.783	0.593	0.500	0.727	0.608	0.566	0.575	0.029 **
Delaware	0.022 **	0.012 **	0.039 **	0.092 *	0.686	0.441	0.266	0.190
District of Columbia	0.914	0.979	0.997	0.354	0.068 *	0.027 **	0.008 ***	0.036 **
Florida	0.461	0.003 ***	0.463	0.513	0.849	0.591	0.731	0.865
Georgia	0.185	0.200	0.295	0.298	0.361	0.219	0.432	0.416
Hawaii	0.218	0.063 *	0.025 **	0.294	0.827	0.882	0.574	0.557
Idaho	0.576	0.379	0.386	0.418	0.892	0.999	0.991	0.955
Illinois	0.468	0.398	0.398	0.358	0.117	0.329	0.043 **	0.137
Indiana	0.760	0.906	0.709	0.365	0.249	0.136	0.233	0.234
Iowa	0.953	0.628	0.270	0.036 **	0.018 **	0.134	0.166	0.294
Kansas	0.041 **	0.062 *	0.420	0.289	0.302	0.344	0.178	0.179
Kentucky	0.279	0.654	0.481	0.204	0.718	0.778	0.780	0.086 *
Louisiana	0.835	0.939	0.791	0.030 **	0.129	0.074 *	0.050 *	0.406
Maine	0.068 *	0.088 *	0.176	0.296	0.515	0.389	0.309	0.326
Maryland	0.050 *	0.034 **	0.038 **	0.028 **	0.106	0.155	0.502	0.325
Massachusetts	0.598	0.407	0.530	0.645	0.803	0.995	0.538	0.146
Michigan	0.336	0.502	0.340	0.157	0.543	0.447	0.751	0.392
Minnesota	0.404	0.411	0.283	0.657	0.997	0.896	0.816	0.707
Mississippi	0.668	0.589	0.761	0.814	0.803	0.751	0.109	0.235
Missouri	0.655	0.570	0.683	0.451	0.350	0.364	0.241	0.371
Montana	0.322	0.388	0.311	0.252	0.212	0.293	0.535	0.766
Nebraska	0.912	0.956	0.969	0.959	0.967	0.999	0.448	0.632
Nevada	0.754	0.406	0.490	0.539	0.877	0.612	0.552	0.636
New Hampshire	0.420	0.257	0.256	0.336	0.846	0.500	0.476	0.841
New Jersey	0.361	0.410	0.457	0.346	0.676	0.257	0.155	0.323
New Mexico	0.840	0.546	0.623	0.179	0.199	0.277	0.155	0.574
New York	0.414	0.379	0.999	0.661	0.193	0.169	0.145	0.439
North Carolina	0.071*	0.275	0.443	0.457	0.680	0.497	0.636	0.695
North Dakota	0.197	0.177	0.900	0.938	1.000	0.420	0.075 *	0.229
Ohio	0.485	0.456	0.605	0.832	0.559	0.882	0.355	0.035 **
Oklahoma	0.199	0.032 **	0.063 *	0.072 *	0.008 ***	0.629	0.025 **	0.001 ***
Oregon	0.910	0.236	0.763	0.930	0.669	0.651	0.426	0.240
Pennsylvania	0.671	0.389	0.812	0.685	0.982	0.946	0.749	0.275
Rhode Island	0.603	0.644	0.754	0.810	0.869	0.943	0.915	0.543
South Carolina	0.291	0.533	0.463	0.583	0.998	0.995	0.757	0.450
South Dakota	0.221	0.098 *	0.402	0.531	0.814	0.409	0.118	0.001 ***
Tennessee	0.921	0.962	0.965	0.869	0.816	0.813	0.740	0.481
Texas	0.253	0.085 *	0.574	0.462	0.447	0.618	0.274	0.045 **
Utah	0.626	0.313	0.540	0.186	0.334	0.702	0.326	0.528
Vermont	0.333	0.277	0.159	0.232	0.738	0.896	0.649	0.656
Virginia	0.131	0.062 *	0.225	0.609	0.960	0.927	0.455	0.433
Washington	0.400	0.470	0.193	0.290	0.389	0.511	0.017 **	0.044 **
West Virginia	0.154	0.506	0.559	0.650	0.849	0.451	0.122	0.458
Wisconsin	0.806	0.642	0.619	0.452	0.390	0.556	0.711	0.539
Wyoming	0.976	0.937	0.975	0.939	0.786	0.379	0.351	0.409
United States	0.540	0.187	0.902	0.829	0.854	0.485	0.570	0.262

Note: The table reports the simulated *p*-values of [10] test procedure on non-causality from housing wealth growth to consumption growth for forecast horizons (h) 1–8 quarters ahead. The sample covers a period from 1975:Q2 to 2012:Q2, a total of 149 observations. ***, ** and * refers to a 1%, 5% and 10% significance, respectively.

Table 3. Causality from stock holdings growth to consumption growth at different time horizons.

Time Horizon h	1	2	3	4	5	6	7	8
Alabama	0.172	0.158	0.905	0.916	0.842	0.032 **	0.075 *	0.083 *
Alaska	0.555	0.463	0.833	0.769	0.836	0.268	0.030 **	0.395
Arizona	0.037 **	0.131	0.752	0.295	0.150	0.458	0.151	0.162
Arkansas	0.440	0.498	0.597	0.492	0.656	0.590	0.034 **	0.017 **
California	0.041 **	0.024 **	0.564	0.188	0.122	0.202	0.127	0.166
Colorado	0.019 **	0.248	0.951	0.898	0.267	0.256	0.157	0.125
Connecticut	0.039 **	0.288	0.918	0.836	0.425	0.571	0.445	0.400
Delaware	0.006 ***	0.024 **	0.933	0.703	0.784	0.776	0.371	0.369
District of Columbia	0.063 *	0.337	0.887	0.422	0.110	0.388	0.471	0.422
Florida	0.022 **	0.002 ***	0.915	0.998	0.030 **	0.286	0.122	0.294
Georgia	0.030 **	0.093 *	0.625	0.758	0.998	0.317	0.045 **	0.003 ***
Hawaii	0.021 **	0.014 **	0.755	0.511	0.277	0.376	0.176	0.229
Idaho	0.392	0.625	0.403	0.381	0.303	0.253	0.089 *	0.117
Illinois	0.257	0.195	0.447	0.716	0.763	0.885	0.095 *	0.002 ***
Indiana	0.039 **	0.063 *	0.715	0.452	0.501	0.130	0.139	0.066 *
Iowa	0.213	0.279	0.964	0.871	0.311	0.314	0.202	0.184
Kansas	0.391	0.778	0.997	0.932	0.723	0.856	0.526	0.387
Kentucky	0.332	0.166	0.898	0.302	0.956	0.635	0.156	0.120
Louisiana	0.277	0.440	0.831	0.437	0.695	0.238	0.252	0.566
Maine	0.018 **	0.032 **	0.978	0.960	0.996	0.782	0.146	0.133
Maryland	0.108	0.250	0.717	0.788	0.478	0.317	0.101	0.281
Massachusetts	0.002 ***	0.103	0.692	0.124	0.128	0.582	0.559	0.492
Michigan	0.054 *	0.261	0.816	0.754	0.372	0.633	0.219	0.191
Minnesota	0.029 **	0.085*	0.756	0.725	0.081 *	0.025 **	0.009 ***	0.047 **
Mississippi	0.506	0.473	0.751	0.902	0.997	0.338	0.001 ***	0.002 ***
Missouri	0.023 **	0.237	0.468	0.499	0.199	0.091 *	0.155	0.381
Montana	0.103	0.109	0.658	0.316	0.046 **	0.402	0.481	0.137
Nebraska	0.185	0.617	0.720	0.731	0.569	0.197	0.226	0.227
Nevada	0.043 **	0.071 *	0.447	0.728	0.893	0.140	0.142	0.094 *
New Hampshire	0.239	0.518	0.661	0.634	0.530	0.232	0.023 **	0.066 *
New Jersey	0.049 **	0.255	0.679	0.046 **	0.053 *	0.173	0.206	0.121
New Mexico	0.065 *	0.429	0.999	0.956	0.906	0.423	0.061 *	0.042 **
New York	0.003 ***	0.039 **	0.812	0.346	0.097 *	0.141	0.299	0.249
North Carolina	0.023 **	0.037 **	0.722	0.742	0.902	0.138	0.226	0.025 **
North Dakota	0.200	0.290	0.780	0.700	0.463	0.300	0.134	0.127
Ohio	0.093 *	0.336	0.741	0.515	0.317	0.686	0.340	0.250
Oklahoma	0.853	0.729	0.761	0.756	0.617	0.442	0.050 *	0.080 *
Oregon	0.004 ***	0.024 **	0.887	0.831	1.000	0.278	0.037 **	0.034 **
Pennsylvania	0.002 ***	0.066 *	0.942	0.434	0.094 *	0.219	0.222	0.075 *
Rhode Island	0.120	0.071 *	0.935	0.226	0.216	0.322	0.066 *	0.519
South Carolina	0.176	0.363	0.969	0.791	0.857	0.017 **	0.009 ***	0.036 **
South Dakota	0.273	0.339	0.238	0.179	0.149	0.278	0.292	0.172
Tennessee	0.160	0.065*	0.575	0.423	0.445	0.386	0.225	0.028 **
Texas	0.133	0.458	0.965	0.945	0.903	0.478	0.011 **	0.027 **
Utah	0.020 **	0.040 **	0.856	0.790	0.826	0.089 *	0.014 **	0.072 *
Vermont	0.546	0.340	0.474	0.471	0.517	0.461	0.066 *	0.070 *
Virginia	0.038 **	0.111	0.503	0.326	0.410	0.394	0.214	0.272
Washington	0.015 **	0.259	0.934	0.782	0.549	0.382	0.019 **	0.081 *
West Virginia	0.442	0.151	0.844	0.757	0.729	0.901	0.046 **	0.038 **
Wisconsin	0.043 **	0.107	0.979	0.608	0.780	0.179	0.182	0.074 *
Wyoming	0.426	0.373	0.138	0.837	0.652	0.420	0.361	0.001 ***
United States	0.019 **	0.141	0.925	0.756	0.260	0.699	0.137	0.086 *

Note: The table reports the simulated *p*-values of [10] test procedure on non-causality from housing wealth growth to consumption growth for forecast horizons (h) 1–8 quarters ahead. The sample covers a period from 1975:Q2 to 2012:Q2, a total of 149 observations. ***, ** and * refers to a 1%, 5% and 10% significance, respectively.

The evidence of aggregate/state-level non-causality test results of housing/financial wealth effects are comparatively summarized in below. As far as it concerns the aggregate results of non-causality test, while causality from stock holdings growth to consumption growth is statistically significant at (1; 8) quarters ahead with corresponding simulated *p*-values (0.019; 0.086), causality from housing wealth growth to consumption growth is statistically significant at (1; 2; 4; 5; 6; 8) quarters ahead with corresponding *p*-values (0.014; 0.032; 0.005; 0.005; 0.010; 0.006). At the state level, we document that in Alaska, Minnesota, Mississippi, and Pennsylvania there are statistically significant housing wealth effects on consumption in all eight quarterly-periods-ahead. These states are classified as the states that exhibit the most persistent housing wealth effects upon consumption. Furthermore, among these states, we observe that the most persistent long-term housing wealth effect takes place in Pennsylvania, and Minnesota, which are well above the aggregate level averages at the corresponding time horizons. A different state classification in terms of the intensity of housing wealth effects would be also possible based on the magnitude of the *p*-values. So, the test results of Table 1 suggest that higher housing wealth effect on consumption occurs in the following states (where the largest *p*-value and its corresponding quarterly prediction period are in the parenthesis): Arizona (0.071; 7), Colorado (0.077; 6), Delaware (0.090; 5), Idaho (0.079; 2), Illinois (0.074; 2), Iowa (0.081; 1), Maine (0.091; 2), Maryland (0.081; 8), Massachusetts (0.087; 6), Missouri (0.084; 8), New Hampshire (0.099; 6), Ohio (0.081; 1), Pennsylvania (0.091;6), South Dakota (0.096; 4), and Virginia (0.080; 5). At the same time, financial wealth effects upon consumption occur at most 5 quarters ahead in Minnesota and Utah. We observe in Table 3 that the most profound financial wealth effect upon consumption is found in the following states (where the largest simulated *p*-value and its corresponding quarterly prediction period are in the parenthesis): Alabama (0.083; 8), District of Columbia (0.063; 1), Georgia (0.093; 2), Illinois (0.095; 7), Michigan (0.054; 1), Minnesota (0.085; 2), Nevada (0.094; 8), New Hampshire (0.066; 8), New Mexico (0.061; 7), Ohio (0.093; 1), Oklahoma (0.080; 8), Pennsylvania (0.075; 8), Utah (0.089; 6), Vermont (0.070; 8), Washington (0.081; 8), Wisconsin (0.074; 8).

Finally, multi-horizon non-causality test results indicate that at short, long, and simultaneous short-/long-horizon causality from housing (financial) wealth to consumption are found in 9 (12), 11 (12), and 17 (19) states, respectively, suggesting the presence of short-/long-horizon housing/financial wealth effects upon consumption in the majority of states (Tables 1 and 3).

Overall, the multi-horizon non-causality test results of Dufour et al. (2006) [10] suggest that (i) housing/financial wealth effects are equally important in the short-/long-run at the state level; (ii) at the aggregate level, financial wealth appears to have stronger short-/long-term impact on consumption, but housing wealth induces more persistent short-/long-run effects; (iii) wealth effects occur across different time horizons for different states, but our evidence indicates the presence of simultaneous short-/long-horizon housing/financial wealth effects in the majority of the states; (iv) Minnesota and Pennsylvania are the two states where housing/financial wealth growth have the strongest and the most persistent impact on private consumption growth.

4.2.2. Multi-Horizon Causality Measure Test Results and Implications

Tables 4–6 report the results when we implement the multi-horizon causality measure of [11] described in Section 3.2 to quantify the intensity of wealth effects on private consumption growth at different prediction periods for 50 U.S. states and DC. Each table exhibits the causality measure described in Equation (7) over the range one to eight quarters ahead. The bootstrap 95% confidence interval for each measure is calculated by using 5000 bootstrap samples. We report only the statistically different from zero causality measures based on the bootstrap confidence interval.

Table 4. Causality measurement from housing wealth growth to consumption growth at different time horizons.

Time Horizon h	1	2	3	4	5	6	7	8
Alabama	0.061						0.010	0.010
Alaska								
Arizona					0.036	0.030	0.022	0.019
Arkansas	0.056	0.039	0.024	0.025	0.021	0.021	0.020	0.020
California	0.085	0.063			0.044	0.033	0.022	0.021
Colorado	0.095	0.034	0.028	0.027	0.035	0.026	0.020	0.018
Connecticut								
Delaware					0.030	0.021	0.020	0.017
District of Columbia								
Florida	0.066							
Georgia								
Hawaii								
Idaho								
Illinois	0.104				0.065	0.036	0.035	0.036
Indiana								
Iowa								
Kansas	0.095	0.042	0.033	0.040	0.030	0.023	0.018	0.019
Kentucky	0.046			0.017	0.014		0.006	0.006
Louisiana						0.011	0.011	0.010
Maine								
Maryland	0.050	0.038	0.018					
Massachusetts	0.101	0.055	0.030	0.044	0.046	0.040	0.039	0.039
Michigan	0.039							
Minnesota	0.065							
Mississippi	0.109	0.073		0.019	0.020	0.014	0.013	0.014
Missouri	0.110				0.062			
Montana	0.110	0.113			0.030		0.019	0.019
Nebraska	0.088	0.048	0.046	0.045	0.035	0.033	0.032	0.031
Nevada								
New Hampshire	0.115				0.023	0.028	0.028	0.026
New Jersey	0.146				0.042			
New Mexico								
New York								
North Carolina	0.048	0.029						
North Dakota								
Ohio	0.072	0.036	0.024	0.026	0.031	0.020	0.016	0.012
Oklahoma								
Oregon								
Pennsylvania	0.076				0.051	0.041	0.039	0.038
Rhode Island					0.057	0.055	0.055	0.049
South Carolina								
South Dakota								
Tennessee	0.060	0.047						
Texas					0.029	0.025	0.023	0.023
Utah								
Vermont								
Virginia	0.093	0.079	0.060	0.071	0.065	0.055	0.043	0.041
Washington	0.034							
West Virginia								
Wisconsin	0.140	0.135						
Wyoming								
United States	0.094	0.059	0.027	0.031	0.033	0.025	0.018	0.018

Note: The table presents the causality measure from housing wealth growth to consumption growth for forecast horizons (h) 1–8 quarters ahead. We only report the statistical significant causality measures based on the 95% bootstrap confidence interval. The sample covers a period from 1975:Q2 to 2012:Q2, a total of 149 observations.

Table 5. Causality measurement from income growth to consumption growth at different time horizons.

Time Horizon h	1	2	3	4	5	6	7	8
Alabama								
Alaska	0.059							
Arizona					0.014	0.013	0.011	0.010
Arkansas								
California		0.049						
Colorado								
Connecticut								
Delaware	0.087	0.082	0.079	0.074				
District of Columbia								
Florida		0.054						
Georgia	0.053	0.051	0.042	0.046				0.018
Hawaii	0.052	0.051	0.039					
Idaho								
Illinois								
Indiana								
Iowa								
Kansas	0.070	0.075	0.046	0.022	0.019	0.014	0.012	0.012
Kentucky	0.038							
Louisiana								
Maine								
Maryland	0.049	0.048	0.042	0.038	0.034	0.032	0.027	0.023
Massachusetts		0.029	0.021	0.018				0.012
Michigan								
Minnesota								
Mississippi								
Missouri								
Montana	0.089	0.093	0.085	0.077	0.025	0.020	0.018	0.018
Nebraska								
Nevada								
New Hampshire								
New Jersey								
New Mexico								
New York	0.033	0.033						
North Carolina	0.064	0.060						
North Dakota								0.009
Ohio								
Oklahoma								
Oregon								
Pennsylvania								
Rhode Island			0.026	0.028		0.016	0.017	0.012
South Carolina								
South Dakota	0.038	0.046	0.041	0.035	0.030	0.027	0.025	0.022
Tennessee								
Texas	0.067	0.068						
Utah								
Vermont								
Virginia	0.049	0.052	0.053					
Washington								
West Virginia	0.041							
Wisconsin								
Wyoming								
United States		0.047						

Note: See notes of Table 4.

Table 6. Causality measurement from stock holdings growth to consumption growth at different time horizons.

Time Horizon h	1	2	3	4	5	6	7	8
Alabama								
Alaska								
Arizona	0.069	0.058						
Arkansas								
California								
Colorado								
Connecticut								
Delaware								
District of Columbia								
Florida								
Georgia								
Hawaii								
Idaho								
Illinois								
Indiana								
Iowa	0.044	0.035						
Kansas								
Kentucky								
Louisiana								
Maine	0.079	0.079						
Maryland	0.107	0.101	0.030					
Massachusetts								
Michigan								
Minnesota								
Mississippi	0.033	0.031						
Missouri	0.065	0.033						
Montana								
Nebraska								
Nevada								
New Hampshire								
New Jersey								
New Mexico								
New York								
North Carolina								
North Dakota								
Ohio	0.057	0.042						
Oklahoma								
Oregon	0.128	0.117						
Pennsylvania	0.085	0.059						
Rhode Island								
South Carolina								
South Dakota								
Tennessee								
Texas								
Utah								
Vermont								
Virginia								
Washington								
West Virginia								
Wisconsin								
Wyoming								
United States								

Note: See notes of Table 4.

The results of Table 4 show that causality measures on housing wealth effects are statistically significant at different forecast periods in 30 states. Our results indicate that causality measures are statistically different from zero up to two quarters ahead (Florida, Kentucky, Michigan, Minnesota, North Carolina, Tennessee, Washington, Wisconsin), over the range from five quarters to eight quarters ahead (Arizona, Delaware, Louisiana, Rhode Island, and Texas), and over the range from one to eight quarters ahead (Alabama, Arkansas, California, Colorado, Illinois, Kansas, Kentucky, Maryland, Massachusetts, Mississippi, Missouri, Montana, Nebraska, New Hampshire, New Jersey, Ohio, Pennsylvania, and Virginia). The majority of the measure estimates are relatively large since they range from 0.010 to 0.14. These findings indicate the presence of strong housing wealth effects. The intensity of these linkages diminishes as h increases, especially after the fifth quarter. Therefore, we document that in the U.S. the causality measures running from housing wealth to consumption are relatively large and statistically different from zero at all horizons.

In Table 5, we see that the estimates of measures of Granger causality-in-mean from income growth to consumption are not statistically equal to zero at short horizons (Alaska, California, Florida, Kentucky, New York, North Carolina, Texas, Virginia, and West Virginia), at long horizons (Arizona and North Dakota), and at both short and long horizons (Delaware, Georgia, Hawaii, Kansas, Maryland, Massachusetts, Montana, Rhode Island, and South Dakota). We document only significant short horizon causality from income to consumption. The income wealth effects appear to be weaker than housing wealth effects in terms of the causality measure size. Still, the impact of income growth to consumption is relatively large up to four quarters ahead approximately (the estimates at $h = 4$ range from 0.018 to 0.077).

In the case of causality measurement from stock holdings growth to consumption (Table 6), we document a very small number of statistically significant causality measures. In particular, changes in stock holdings growth induce a strong effect on the conditional mean of consumption in nine states up to two quarters ahead approximately. The magnitude of the stock effect on consumption is relatively large since the estimates of the measures vary from 0.030 to 0.128. Our results also indicate that stock holdings do not anticipate changes in consumption on an aggregate level.

Overall, at the aggregate level causality measurement from housing wealth growth to consumption is statistically important for all quarters with the measure values ranging from 0.094 to 0.018. On the other hand, financial wealth has virtually no aggregate-level effect upon private consumption. At the state-level, causality measurement shows that strong housing wealth effects on consumption are present at all 8 quarterly periods-ahead in Arkansas, Colorado, Kansas, Massachusetts, Nebraska, Ohio, and Virginia. We also document that housing wealth is a strong impact on private consumption at six prediction periods in California and seven prediction periods in Mississippi. We may classify these states as the ones which exhibit the most persistent housing wealth effects on consumption in terms of predictive intensity. Moreover, Massachusetts, Virginia, and Nebraska have the largest and the most persistent long-term causality measure estimates that are generally above the aggregate level averages in relevant time horizons. Interestingly, comparing state-level non-causality test results and causality measurement results (Tables 1 and 4), we find that Mississippi has the most persistent short-/long-horizon housing wealth effects upon consumption. Moreover, Table 4 shows that the causality measures for the direction from housing wealth growth to consumption growth seem statistically meaningful and also relatively higher in the following states (where the largest causality measure value and its corresponding quarterly prediction period are in parenthesis): California (0.085; 1), Colorado (0.095; 1), Illinois (0.104; 1), Kansas (0.095; 1), Massachusetts (0.101; 1), Mississippi (0.109; 1), Montana (0.013; 2), New Hampshire (0.115; 1), New Jersey (0.146; 1), Virginia (0.093; 1), and Wisconsin (0.140; 1). The results of both methods collectively suggest (Tables 1 and 4) that housing wealth has a big impact on consumption in Colorado, Illinois, Massachusetts, New Hampshire, and Virginia. These states may be classified as the states which experience the most intense housing wealth effects upon consumption.

At the state level, intense financial wealth effects upon consumption exist up to two quarters ahead in eight states and up to three quarters ahead only in Maryland (Table 6). The estimates of the causality measures for the direction from stock holdings growth to consumption growth reveal that the most profound financial wealth effects upon consumption can be found in the following states (the largest causality measure value and its corresponding quarterly prediction period are in the parenthesis): Arizona (0.069; 1), Missouri (0.065; 1), Oregon (0.0128–0.117; 1–2) and Pennsylvania (0.085; 1). Comparing the results of Tables 2 and 6, we document that Pennsylvania is the state that enjoys the strongest financial wealth influence on consumption for different time horizons.

On the other hand, multi-horizon causality measurement results highlight that short, long, and simultaneously short-/long-horizon causalities from housing wealth to consumption are present in 9, 6, and 16 states, respectively. This finding suggests that the majority of states experience intense housing wealth effects upon consumption at both short and long time horizons (Table 4). However, we find evidence of only short horizon for financial wealth effect (Table 6).

To sum up, the results from the application of the multi-horizon causality measure of [11] suggest that (i) at the aggregate level, although housing wealth induces economically significant effects on consumption for all time horizons, financial wealth has no economically significant effect on consumption, (ii) at the state level, housing appears to be a clearly dominant and persistent wealth effect component at multiple time horizons, and (iii) housing wealth effect upon consumption exists across different time horizons and in different states, but financial wealth influences consumption only at short-time horizons. Moreover, (i) Colorado, Illinois, Massachusetts, New Hampshire, and Virginia experience the most intense housing wealth effects upon consumption while Mississippi presents the most persistent influences of housing wealth effect, (ii) no housing wealth effects are documented in Hawaii, Utah and Wyoming, and (iii) Pennsylvania has the strongest financial wealth effects at different time horizons. (We also conducted the analyses with 99% confidence intervals and our main results, which are available upon request from the authors, do not change).

From the methodological perspective, one interesting result is that causality measurement does not always confirm the findings of causality testing. For instance, test results of Table 3 indicate the presence of statistically highly significant causalities from stock holdings to consumption at long horizons in several states. On the other hand, the estimates of the measures are statistically equal to zero at these prediction horizons for all states. Hence, the output of causality measurement shows that long horizon financial wealth effects are economically weak, which in turn implies that there is no gain in predictive power at these horizons. Similar contradictory results are also found in the cases of housing and income wealth effects upon consumption in some states at specific time horizons, but to a lesser degree. These findings highlight the importance of testing implementation in conjunction with the measurement to distinguish among the statistically important and economically important causal linkages.

5. Conclusions

The housing and financial wealth effects on consumption have been widely analyzed for the U.S. economy due to housing and stock market-centered policies since the mid-1990s. Stock and housing market boom-bust episodes during almost the entire 2000's have also highlighted the importance of a better understanding of the foundations of wealth effects. While the magnitude and drivers of wealth effects have been broadly analyzed for the U.S. economy at the aggregate level, questions remain about the intertemporal co-behavioral patterns between housing/financial wealth and consumption growth at the state level. This paper provides new evidence that sheds more light on the dynamics of housing and financial wealth effects in the U.S. states.

The major findings of our investigation can be summarized as follows. First, based on the multi-horizon non-causality test of [10], our empirical results suggest that (i) housing (financial) wealth growth Granger cause consumption growth in 37 (43) States implying that both effects are simultaneously important at the state level, (ii) at the aggregate level, although financial wealth induces stronger short-/long-run effects upon consumption, changes in housing wealth trigger more persistent effects both in the short and long run,

(iii) housing and financial wealth effects occur at both short and long time horizons in the majority of states, and (iv) we find in Minnesota and Pennsylvania the strongest and most persistent housing/financial wealth effects upon consumption. Second, the application of the multi-horizon causality measure of [11] at the state level indicates that the causality measure from housing (financial) wealth growth to consumption growth is statistically significant at different forecast periods in 31 (9) states. Ref. [11] test results also suggest that (i) while financial wealth has no statistically significant effect, housing wealth has statistically significant effects upon consumption at all time horizons at the aggregate level; (ii) housing is the dominant and the most persistent wealth effect component at the state level across different time horizons; and (iii) while housing wealth effects occur at both short and long time horizons across many states, financial wealth effects are found only at short-time horizons. Third, we document the most intense housing wealth effects occur in Colorado, Illinois, Massachusetts, New Hampshire, and Virginia in terms of the magnitude of the causality measure estimate. Again, no housing wealth effects are documented in Hawaii, Utah and Wyoming, and Pennsylvania has the strongest multi-horizon financial wealth effect. It is also important to note that we document significant wealth effects across different prediction horizons in the remaining states.

Our results lead to various implications. Housing/financial wealth effects show heterogeneity across U.S. states depending on the scope of the data (state vs. aggregate) and employed methodology. Furthermore, while non-causality testing suggests that financial wealth is as important as housing wealth, causality measurement clearly indicates that housing wealth has more statistically significant, persistent, and widespread impacts on consumption growth than financial wealth at both the state and the aggregate level. Our evidence of stronger state-level housing wealth effect confirms the results of [5,6,8]. Our evidence is in line with the findings of [1–4,43], among others, at the aggregate level. The dominance of the housing market in generating wealth effects upon consumption at the state level may be attributed to the relatively more uniform increase in housing value across regions compared to the quite unequal geographical distribution of stock market wealth across households in the U.S. (see, [8]). This evidence has important implications for monetary policies aiming to develop a strategy combining asset prices, consumption, and price stability (see [61]). Moreover, our findings suggest that federal/state level economic policies may define specific targets for consumption, saving, and economic growth depending on the magnitude of the wealth effect of the relevant state. For example, while housing economy may not be a priority in Hawaii, Utah, and Wyoming, both housing/financial ownership may be specifically supported in Pennsylvania. Moreover, the evidence on the presence of housing wealth effects upon consumption at long horizons is in line with the result of [45], suggesting that housing markets are positively sensitive to long-run state-level policymaking.

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Retirement Age and Housing Consumption: The Case of South Korea

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Abstract: South Korea became an aging society in 2000 and will become a super-aged nation in 2026. The extended life expectancy and earlier retirement make workers' preparation for retirement more difficult, and that hardship might lead to poorer living conditions after retirement. As annuity payments are, in general, not enough for retirees to maintain their previous standard of living after retirement, retired households would have to liquidate their financial and real assets to cover household expenditures. As housing takes the biggest share of households' total assets in Korea, it seems to be natural for retirees to downsize their houses. However, there is no consensus in the housing literature on housing downsizing, and the debate is still ongoing. In order to understand whether or not housing downsizing by retirees occurs in Korea, this paper examines the impact of the timing of retirement on housing consumption using an econometric model of housing tenure choice and the consumption for housing. The results show that the early retirement group living in more populated region does not downsize the house, while the timing of retirement is negatively associated with housing consumption for the late retirement group living in the peripheral region.

Keywords: retirement; housing downsizing; housing consumption; housing tenure choice

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1. Introduction

Aging is a global issue. According to the definition of the United Nations, when people aged 65 or older account for 7–14 percent of the population, it is called an aging society; when the proportion is between 14 and 20 percent, it is called an aged society; when it is over 20 percent, it is called a super-aged society. For example, Japan, where aging has been taking place more rapidly, became an aging society in 1970, entered an aged society in 1994, and has been a super-aged society since 2005 [1]. South Korea (hereafter, "Korea") is also one of the most rapidly aging countries, with a decreasing birth rate. Korea became an aging society in 2000 and an aged society in August 2017, and will become a super-aged country in 2026.

In 2015, the residual expected life at 65 in Korea was 18.2 years for men and 22.4 years for women. Those numbers have increased over the past 10 years [2]. On the contrary, workers tend to retire earlier prior to the age of 60, even though 60 marks formal retirement. This extended life expectancy and earlier retirement make workers' preparation for retirement more difficult, and that hardship might lead to poorer living conditions after retirement [3,4]. In Korea, only 6.7 percent of retired households have "enough" provisions for living expenses, while 42.2 and 20.9 percent have "insufficient" and "very insufficient" provisions, respectively [5]. In addition, the relative poverty rate for households with household heads aged 66 or older is 53.1 percent. These figures reveal that a significant portion of retired households encounter financial difficulties after retirement. Most retired people rely on annuity income instead of earned income, but annuity payments are generally not high enough to prepare for a satisfactory standard of living after retirement [6–8]. In Korea, 45.3 percent of people aged 55 to 79 received an annuity of KRW (South Korean won) 520,000 (about USD 444 as of 20 September 2020) per month in 2016, and 73 percent received less than 500,000 won [9]. This means that most elderly face difficulties in living a financially stable life. Owing to this insufficient annuity, some retirees who own multi-unit properties let a portion of their residential properties to earn rental incomes [10–12].

There are many people who do not save enough money in preparation for retirement, and they are thus not likely to have the essential financial resources required to maintain their standard of living in retirement [13]. This reality seems to be more significant for the early retirement group. Fisher et al. [14] expected that people who retire early are more likely to spend their wealth compared to individuals who work longer. Retiring early might mean that people have to rely upon their previously accumulated wealth for a longer amount of time.

As houses are the largest assets owned by most households, do retirees downsize their houses? Among these retirees, who downsizes their houses? There is no consensus in the housing literature on housing downsizing, and the debate is still ongoing. On the one hand, retired households downsize their homes for the consumption of non-durable goods after retirement. Those households plan properly for retirement, which supports the life-cycle income hypothesis and the notion of consumption smoothing. According to this premise, in retirement, accumulated assets are decumulated to achieve the desired level of consumption of non-durable goods and services. On the other hand, there is an opposing strand of literature which found a sharp decline in consumption during the early years of retirement. One reason for this "retirement-consumption" puzzle might be the unwillingness or failure to downsize financial and real assets.

This study contributes to the existing literature on the demand for housing by comprehensively considering the simultaneous linkage of housing tenure choice and housing consumption using a rigorous statistical treatment. Specifically, we first calculated the likelihood of owning a house using a logit model. Then, the estimated propensity of home ownership was included in the housing consumption regression equation as an explanatory variable, in order to deal with the simultaneity between housing tenure choice (owning versus renting) and the consumption for housing (dwelling size). We used the 2014 Survey of Household Finances and Living Conditions (SFLC) dataset provided by Statistics Korea. The dataset contains socio-demographic and financial information for households of all generations. We extracted a sample of retired households from the data. Our analysis was divided into four sub-categories by retirement group and region. We posit that retirees show different housing consumption patterns with respect to the timing of retirement. We estimated the housing downsizing equations for the capital region (Seoul, Gyunggi, and Incheon) and for the non-capital region separately, due to the spatial heterogeneity of the housing market in Korea.

This paper is organized as follows. Section 2 discusses the previous literature on retirement and housing. Section 3 describes the data, variables, and research methodology. Section 4 presents the results from housing tenure choice and housing consumption regressions by retirement group and region. In Section 5, we discuss the results of housing downsizing and their implications for the formation of housing policies for older or retired households. Finally, Section 6 provides some brief concluding remarks and the limitations of the research.

2. Related Literature

2.1. Definition of Retirement

Studies on retirement have employed different definitions of retirement. It can be defined by whether one participates in an economic activity. If one provides a positive answer to the question "Have you completely stopped working or looking for a job?", one is considered to be a retiree [15]. Another definition is related to a significant change in working hours or wages. When one's working hours or wages drastically drop below a certain threshold, one is considered to be a retiree [16,17]. This can also be defined by whether one has left one's primary workplace. If a worker has left the workplace in which he or she has worked for the longest period of time, the person is considered to be a retiree, regardless of current job activities [18–21]. Whether or not one receives a retirement annuity can also define the status of retirement. When one receives a public or private annuity, one is a retiree [22]. Finally, retirement is defined by one's subjective assessment. If one provides a positive answer to the question "Are you currently retired?", one is considered to be a retiree [23,24].

The SFLC data used in this study contain the respondents' subjective assessment. Additionally, retirement is formally defined in South Korea as "the state of being retired from one's business or occupation." First, this study defines retirees as those who answered "yes" to the question "Are you currently retired?" in the SFLC. As for the age cut-off, we also included the early retirement group. Korea's effective age of retirement is around 68 for men and 67 for women. These figures are much higher in many other OCED (Organization for Economic Co-operation and Development) nations. Firms, however, tend to be reluctant to employ older workers. Accordingly, many employers in Korea often set the "mandatory retirement" policy, by which they lay off older workers below the age of 60, as low as 55 [25]. In the SFLC, we observed that some retirees listed their retirement ages as being below 60. We chose to include retirees whose retirement age was equal to or greater than 50, following the study by Kim and Son [26]. The formal retirement age in Korea is 60, similar to many countries. Therefore, we define retirees whose retirement age ranges from 50 to 59 as the "early retirement group", and retirees from the age of 60 to 80 as the "late retirement group". We excluded retirement ages of 81 or above from the analysis.

2.2. Literature on Housing and Retirement Timing

There are a handful of studies in retirement literature that explore the role of housing in retirement timing. Szinovacz et al. [27] studied the effects of wealth and investment on retirement timing, and found that a decrease in home value is positively related to expectations to work after the age of 62, although the effect is modest relative to other determinants, such as debts and the work environment [28,29]. Farnham and Sevak [30] investigated the effect of the change in housing wealth using the Health and Retirement Study (HRS). They found that a 10 percent increase in housing wealth is associated with a decrease in the expected retirement age of between 3.5 and 5 months. Hartig and Fransson [31] assessed the association between housing tenure and early retirement, and found that housing circumstances have an impact on retirement timing. On the other hand, Gorodnichenko et al. [32] found that home values in the United States have nothing to do with retirement timing, while unemployment rate and inflation are important factors. Similarly, Disney et al. [33] found little evidence of any wealth (housing prices or share prices) effects on retirement timing from the British Household Panel Survey.

2.3. Literature on the Consumption for Housing of Retirees

Home ownership is a major way to accumulate assets for later life in Korea. Some elderly people might earn rental incomes by holding assets other than houses. Kim and Jeon [34] found that this phenomenon is observed above a certain income decile in South Korea. They showed that the probability of owning additional houses for lease income increases when the household head is married and has school-age children. Similarly, Lin et al. [35] suggested that those who have a higher price-to-income ratio can buy housing for investment purposes in Taiwan. Disney et al. [36] found that there is a strong connection between asset evolution and retirement behavior for later cohorts of retirees in Britain.

The biggest portion of the portfolio of retirees comprises housing assets compared to financial assets in many countries [37]. In Latin America, 90 percent of householders aged 64 or older live in their own houses, whereas only 4 percent live in rented housing [38]. In Taiwan, the older the household head is, the more he or she prefers to buy housing [39].

People aged 60 or older in Hong Kong desire to live in their own housing [40]. This preference for housing assets results from the tendency of the middle-aged and elderly to hedge the risk associated with rent changes in the future by possessing their own housing [41]. In addition, those middle- to old-aged people with real estate assets are more financially well off and better prepared for retirement than those without such assets [10,12]. In Japan, the number of aged people who have their own housing is rising because of the government policy to increase housing welfare by promoting the possession of housing in the postwar period [42].

On the other hand, some studies show that retirees switch from owning to renting or downsize their homes, which is in accordance with the life-cycle income hypothesis [43–46]. Chiuri and Jappelli [47] found that home ownership declines after the age of 70 in most countries by using an international cross-sectional dataset. Older Americans adjust their housing size by around 0.7 of a room smaller than their previous residence [48]. Yogo [49] found that the housing portfolio is negatively related to health for retirees and falls significantly as they age. On the contrary, other studies suggest that such downsizing or reduction is not closely related to aging and retirement [17,50–55].

According to the traditional life-cycle model, retired households who want to reduce the consumption of housing services can liquidate their housing assets through housing downsizing. Artle and Varaiya [56] extended the life-cycle hypothesis to housing, assuming that older households would consume their share of housing after retirement, and predicted that homeowners would convert to rent after retirement. In addition, in the study by Jones [57], the possibility of shifting owning to renting displays a negative relationship with the amount of savings, which is interpreted to support the life-cycle hypothesis. Furthermore, he proposed a revised life-cycle hypothesis, which addresses the fact that housing assets can be liquidated after a significant portion of non-housing assets have been consumed.

However, as many older households were observed to behave differently from the prediction of the life-cycle hypothesis, several alternative hypotheses were suggested. For example, it is argued that socio-demographic changes can lead to tenure transition by reducing the preference for home ownership [52]. They found that the more liquid assets elderly households retain, the lower the probability of housing size reduction becomes.

Venti and Wise [58] conducted a regression analysis of the relationship between the characteristics of moving to owning and the value of housing assets. They found that households with a low income and high housing assets reduce housing assets, while those with a high income and low housing assets increase housing assets. This study revised the life-cycle hypothesis, arguing that homeowners are not moving in order to alleviate liquidity constraints. Some Korean studies, however, found that the liquidity of real estate assets of retirees would be of great importance for their retirement preparation [23,59–61].

2.4. Summary

In summary, the concept of retirement is somewhat ambiguous, and the definition of retirement is context-dependent. The status of retirement can be judged by an abrupt change in the working hours or wages, by a change of a person's prior major workplace, or by whether or not he or she is in receipt of a retirement pension. The retirement literature is not conclusive about the role of housing in the timing of retirement. A decrease in the housing value might accelerate the timing, and that effect would be less significant, relative to other economic conditions, such as unemployment and inflation. Older households might end up with a bigger housing asset or owning a house. In some cases, they eventually downsize their houses. There are, however, other studies that found little evidence on housing downsizing.

3. Research Methodology

3.1. Data and Variables

The SFLC is an annual survey that has been jointly conducted by Statistics Korea, the Financial Supervisory Service, and the Bank of Korea since 2012. The purpose of the SFLC is to support policymaking and research on finance and welfare by comprehensively identifying households' standards of living and the factors affecting their size composition and distribution of assets, debt, and income [2]. This study used the SFLC 2014 data because the sampling design was altered from a fixed panel to a rotating panel in 2015. For our data, 8907 of the 10,000 households provided a complete response for the "Welfare" section of the survey in SFLC 2014. Among those 8907 households, 1454 stated that "the household head has retired." After applying our definition of retirement, we obtained 1337 observations as the effective sample for the analysis.

The dataset was further processed in several ways, in accordance with the purpose of the research. The observations, the retirement age of which is less than 50 and greater than 80, were removed. Then, if the household head was not married or divorced, those households were excluded from the study so that only households with the household head being married or widowed were included. This removal was conducted because there are only 13 and 90 cases for unmarried and divorced households in the data, respectively, and the numbers are thus too small to represent those household groups. Furthermore, cases were removed where other household members (except for the household head and his or her partner) were living with the household head. If a retiree is living with other people (such as his or her children or other relatives), the housing consumption for those households should be systematically different, even after controlling for the timing of retirement. As a result of narrowing the scope of household formation, we ended up focusing on households in one of the following two cases: (i) two-person households with one household head with his or her partner, or (ii) one-person households with one widowed household head without any other family member living together with the household head.

The definitions and measurements of the variables used in this study are presented in Table 1. The housing tenure type (*HTENURE*) is a dummy variable, which takes on the value of 1 if a retired household owns a house. The dwelling size per household member (*AREAPM*) represents the consumption for housing. Clark and Deurloo [62] used the housing size per household member to examine the housing over-consumption behavior for retired households. The dwelling size variable was logged to be used in the regression equations. The probability of owning a house (*OWNPROB*) was estimated using demographic and financial variables, and the likelihood variable was then used as an explanatory variable in the housing consumption equation. *AGE* is the age of the household head in years. *AGERE* represents the retirement age of the household head, indicating the timing of retirement. We wanted to observe the relationships between the retirement age variable and the consumption for housing by region and retirement group. *MSTATUS* indicates the marital status of the household head, which takes on a of value of 1 if a retiree is married and lives with his or her partner, and 0 if he or she is widowed and lives alone. Other types of household member formations were not considered in this research. *NETINC* is the net income variable. We calculated it by subtracting the retired household's expenditures from the total income. The expenditures include consumption expenditures (groceries, residence, education, healthcare, transportation, communication, and family events) and non-consumption expenditures (tax and social insurance fees). *NETASSET* is the net asset variable. A retired household's assets consist of financial and real assets. The financial assets include savings and security deposits. The real assets comprise real estates, automobiles, golf and/or resort membership, jewelry, antiques, and artworks.

Table 1. Definitions of variables.

Variable	Variable Definitions
HTENURE	Housing tenure type (1: Own; 0: Rent)
log(*AREAPM*)	Logarithm of dwelling size per household member (m^2)
OWNPROB	Probability of owning a house
AGE	Age of the household head (years)
AGERE	Retirement age of the household head (years)
MSTATUS	Marital status of the household head (1: Married and living with the partner; 0: Widowed and living alone)
NETINC	Yearly net income of the household
NETASSET	Net asset of the household
CAPITAL	Location of the household (1: National capital region; 0: Remainder of the region)
APT	Housing type of the household (1: Apartment; 0: Other types)

3.2. Empirical Strategy

We recognize that choosing whether to own or rent a house involves an endogenous decision-making process with regard to consumption for housing. King [63] constructed an econometric model of the joint tenure and consumption decision, where both discrete (tenure choice) and continuous (the quantity of housing services) variables are considered using cross-section data. Goodman [64] estimated a joint tenure choice-housing demand model. Ahmad [65] utilized a similar approach for the Karachi housing market. Those studies suggest that ignoring the simultaneity can result in biased elasticity estimates in the equation of housing services. Some studies employed Heckit-type models in regard to the remedy for the simultaneity problem. This study utilized a more direct and intuitively appealing approach, suggested by Fan and Yavas [66], which used the method to study the effect of having a mortgage on household expenditure. In order to tackle the endogeneity problem between housing tenure choice and the level of housing consumption, we first estimated the probability of owning using a logit model. Then, the *estimated* probability was entered into the housing consumption regression equation as an explanatory variable. The two-step process is as follows:

$$\begin{aligned} Prob(owning_i = 1|X_i) = \hat{owning}_i = F(X_i^T \gamma) \\ \log(AREAPM) = \beta_0 + \beta_1 \hat{owning}_i + \beta_2 AGERE + \beta_3 \Omega_i + \varepsilon_i, \end{aligned} \tag{1}$$

where $owning_i$ indicates whether or not a retired household owns a house and X_i is a vector of independent variables that affect the household's decision on owning a house. These variables include household demographic and financial characteristics (age of household head, age of retirement, marital status, and net asset), the type of house (apartment or not), and the location of a house (capital area or not). X_i^T is the transpose of the matrix X_i, and γ is a vector of parameters for X_i. F is the cumulative distribution of the logistic distribution. $\hat{owning}_i$ denotes the estimated probability of home ownership. $\log(AREAPM)$ indicates the natural log of the level of housing consumption, which is measured as the log of the dwelling size of a house per household size—the number of household members. Ω_i is a vector of explanatory variables that include the same variables as in X_i, plus the current net income stream. The two-step procedure enables us to test whether or not the probability of owning is significantly associated with the consumption for housing by checking the significance of β_1. Concerning the robustness for the housing consumption equation, a propensity score matching (PSM) analysis was conducted (see Appendix A).

We chose not to include current income in the housing ownership equation because many housing economics studies suggest that housing ownership is more likely to be determined by the level of the long-run expected income, rather than the current or transitory income. On the other hand, the consumption for housing services was estimated for both owners and renters. A renter's housing consumption is more likely to be affected by fluctuation of the current income, relative to owners, because owning involves a higher search cost and pursuing a new house for owning is relatively costly. Therefore, a higher current income does not necessarily ensure a higher level of housing consumption for owners. Changing the level of housing consumption within the rental market, however, is relatively less costly, so the current net income still might be a responsive factor for the change. Consequently, the current net income can plausibly be included in the housing consumption equation, but not in the tenure choice model. If retirees downsize their houses, the retirement age ($AGERE$) should be negatively related to the quantity of housing services.

4. Results

4.1. Descriptive Analysis

The descriptive statistics for the discrete and continuous variables are shown in Tables 2–5. After processing the data in line with the purpose of the research, we obtained 780 households for the whole sample. Among them, the number of households who live in the capital region is 229, and it is 551 for the non-capital region. The ownership rate is 74.62 percent for the whole sample. The rate is slightly lower for the capital region (65.07 percent) in comparison with that for the non-capital region (78.58 percent). The result is reasonable because the difference in housing prices between the two regions outweighs the income differential. We cannot calculate the exact ratio of the number of one-person households to the number of households with two or more household members because this study, by design, eliminated the households with three or more family or non-family members. Among households with one or two members, 50.90 percent are one-person households and 49.10 percent are two-person households. As for the type of housing, retired households in the non-capital region are more likely to live in non-apartment houses, such as single, detached houses or town houses. Breaking the whole sample down into retirement groups with respect to the retirement age, the late retirement group shows a higher home ownership rate in comparison with the early retirement group nationwide (75.00 percent versus 73.17 percent, respectively). For both retirement groups, the home ownership rates in the non-capital region are higher than those in the capital region. A similar pattern can be observed for the percentages of one-person households and non-apartment houses: They are higher in the non-capital region for both groups.

Table 2. Descriptive statistics for nominal variables (all retirees).

		Nationwide		Capital		Non-Capital	
		Freq.	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
Panel A: All retirees							
HTENURE	0	198	25.38	80	34.93	118	21.42
	1	582	74.62	149	65.07	433	78.58
MSTATUS	0	397	50.90	104	45.41	293	53.18
	1	383	49.10	125	54.59	258	46.82
APT	0	488	62.56	111	48.47	377	68.42
	1	292	37.44	118	51.53	174	31.58
Panel B: Early retirement group							
HTENURE	0	44	26.83	18	31.58	26	24.30
	1	120	73.17	39	68.42	81	75.70
MSTATUS	0	76	46.34	25	43.86	51	47.66
	1	88	53.66	32	56.14	56	52.34
APT	0	86	52.44	24	42.11	62	57.94
	1	78	47.56	33	57.89	45	42.06
Panel C: Late retirement group							
HTENURE	0	154	25.00	62	36.05	92	20.72
	1	462	75.00	110	63.95	352	79.28
MSTATUS	0	321	52.11	79	45.93	242	54.50
	1	295	47.89	93	54.07	202	45.50
APT	0	402	65.26	87	50.58	315	70.95
	1	214	34.74	85	49.42	129	29.05

Table 3. Descriptive statistics for continuous variables (all retirees).

	N	Mean	S.D.	Min	Max
Nationwide					
AREAPM [1]	780	54.02	37.20	9	601
AGE	780	74.35	7.09	53	93
AGERE	780	64.06	7.08	50	80
NETINC	780	0.17	0.69	−7.37	4.10
NETASSET	780	17.30	19.69	−0.80	97.72
Capital					
AREAPM	229	53.63	37.36	9	301.50
AGE	229	74.94	6.75	53	93
AGERE	229	62.99	6.80	50	80
NETINC	229	0.09	0.89	−7.37	2.75
NETASSET	229	26.01	24.08	0.01	97.72
Non-capital					
AREAPM	551	54.19	37.16	10	601
AGE	551	74.10	7.22	54	91
AGERE	551	64.50	7.15	50	80
NETINC	551	0.21	0.58	−3.13	4.10
NETASSET	551	13.68	16.25	−0.80	92.31

[1] *AREAPM* indicates the dwelling size per household member (m^2).

Table 4. Descriptive statistics for continuous variables (early retirement).

	N	Mean	S.D.	Min	Max
Nationwide					
AREAPM [1]	164	54.00	33.94	10	198
AGE	164	70.26	7.65	53	89
AGERE	164	55.15	2.93	50	59
NETINC	164	0.27	0.58	−1.02	4.10
NETASSET	164	18.42	19.08	−0.80	91.82
Capital					
AREAPM	57	49.54	29.39	11.50	188
AGE	57	72.16	7.24	53	86
AGERE	57	55.11	2.79	50	59
NETINC	57	0.29	0.55	−0.96	1.79
NETASSET	57	26.63	23.71	0.01	91.82
Non-capital					
AREAPM	107	56.38	36.03	10	198
AGE	107	69.25	7.70	54	89
AGERE	107	55.17	3.01	50	59
NETINC	107	0.25	0.60	−1.02	4.10
NETASSET	107	14.04	14.39	−0.80	78.55

[1] *AREAPM* indicates the dwelling size per household member (m^2).

Table 3 presents the demographic and financial information for the retired households by region for all retirees. The average age was 54.02 at the time of the survey, and they retired at the age of 64.06 on average. Two important financial variables in investigating the consumption for housing are the current net income (*NETIC*) and the net asset (*NETASSET*). Those variables are measured in KRW 10 million. On average, retired households' yearly net income is KRW 1.7 million. It seems that some households' expenditure exceeds the yearly income (the minimum value of net income is −7.37). According to Kim [67], two out of five elderly households receive financial support from their adult children on a regular basis in Korea. The exact amount of monetary support obtained from their children or other relatives is generally hidden and not fully reported. Taking a close look at the regional difference, retirees living in the non-capital region obtain a higher net income than those living in the capital region on average (mean = 0.21 versus 0.09, respectively). However, the net incomes for the capital region are more dispersed (S.D. = 0.89 versus

0.58, respectively). The average net asset value retained by the capital region's retirees, however, is almost twice as high as the one in the non-capital region (26.01 versus 13.68, respectively). The combination of the relatively lower level of net income with a higher deviation and the higher level of net asset in the capital region might demonstrate that (i) real estate values are higher in the central area and (ii) the income distribution in the capital area is more skewed to the right, relative to the peripheral region. Another explanation for the lower income in the capital region could be that a fraction of retirees with a higher income move to the non-capital region upon retirement. The Korea Research Institute for Human Settlements [68] reported that, from 2005 to 2010, the number of baby boomers in the non-urban areas increased by around 23,000, whereas the number in major urban areas and in the capital region continuously fell. Lim [69] found that older households are more likely to move from capital to non-capital areas.

Table 5. Descriptive statistics for continuous variables (late retirement).

	N	Mean	S.D.	Min	Max
Nationwide					
AREAPM [1]	616	54.03	38.04	9	601
AGE	616	75.44	6.52	60	93
AGERE	616	66.43	5.86	60	80
NETINC	616	0.15	0.71	−7.37	3.96
NETASSET	616	17.00	19.85	0.00	97.72
Capital					
AREAPM	172	54.99	39.63	9	301.5
AGE	172	75.87	6.33	61	93
AGERE	172	65.60	5.62	60	80
NETINC	172	0.02	0.97	−7.37	2.75
NETASSET	172	25.80	24.27	0.05	97.72
Non-capital					
AREAPM	444	53.66	37.45	10	601
AGE	444	75.27	6.59	60	91
AGERE	444	66.75	5.92	60	80
NETINC	444	0.20	0.57	−3.13	3.96
NETASSET	444	13.59	16.68	0.00	92.31

[1] *AREAPM* indicates the dwelling size per household member (m^2).

Regardless of the location, the early retirement group retains higher levels of financial resources than the late retirement counterpart (Tables 4 and 5). Nationally, the average net income and the net asset for the early retirement group are KRW 2.7 and 184.2 million, respectively. For the early retirement group, those numbers become smaller (1.5 and 170.0 million won, respectively). For the capital region, the net income for the early retirement group is KRW 2.9 million, on average, whereas it is only 0.2 million won for the late retirement group. We suspect that the significant difference between these figures is due to the fact that the older population spend more on medical expenses, and medical treatments in the capital area deliver better services but are much more expensive.

4.2. Housing Tenure Choice of Retirees

Tables 6–8 exhibit the results from the logistic regressions for housing tenure choice. Table 6 shows the results for all retirees, for retirees living in the capital region, and for retirees living in the non-capital region, without dividing the whole sample into the retirement groups by retirement age. The models for home ownership are further estimated for early and late retirement (Tables 7 and 8). Regarding the result from the whole sample nationwide, the retirement age (*AGERE*), marital status (*MSTATUS*), housing type (*APT*), and regional dummy variable (*CAPITAL*) significantly affect the decision on owning a house. Retirement age is positively related to the probability of owning a house at the alpha level of 0.05. As the positive effect is derived after controlling for the effect of the age of a retiree, we can conclude that retirees who retired later are more likely to own a house. The positive effect of marital status on home ownership indicates that two-person households are more likely to possess housing property in comparison with one-person households. Net asset is strongly related to the home ownership. Housing type (*APT*) is also strongly associated with the probability of having a home. Retirees in the capital region are more likely to rent a house than those in the non-capital area. The coefficient of *AGERE* is not statistically significant for the capital region. For the non-capital region, this is significant, and the magnitude of the effect is greater than that for the whole sample. For both regions, the coefficients of net asset are positively related to the home ownership probabilities. Housing type is not a determinant for home ownership in the capital region.

Table 6. Housing tenure choice (whole retirees).

	Nationwide		Capital		Non-Capital	
Variables	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**
AGE	0.0000	0.017	−0.0203	0.030	0.0297	0.022
AGERE	0.0327 **	0.016	−0.0209	0.028	0.0522 **	0.020
MSTATUS	0.5817 **	0.230	0.7229 *	0.372	0.3486	0.309
NETASSET	0.1766 ***	0.019	0.1088 ***	0.017	0.3345 ***	0.041
APT	−1.0376 ***	0.236	−0.4145	0.373	−1.5932 ***	0.333
CAPITAL	−1.8647 ***	0.259				
Constant	−2.0584	1.262	1.4439	2.297	−6.0738 ***	1.669
N	780		229		551	
Chi^2	299.45		111.17		214.87	
Prob > Chi^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.3388		0.3751		0.3754	
Log likelihood	−292.16		−92.59		−178.76	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7. Housing tenure choice (early retirement group).

	Nationwide		Capital		Non-Capital	
Variables	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**
AGE	0.0224	0.037	0.0923	0.076	−0.0099	0.046
AGERE	0.0929	0.086	0.0772	0.209	0.0663	0.102
MSTATUS	−0.0950	0.555	0.0657	1.143	−0.0568	0.668
NETASSET	0.3093 ***	0.063	0.2651 ***	0.089	0.3890 ***	0.099
APT	−1.3429 **	0.558	−1.5703	1.185	−1.3790 **	0.702
CAPITAL	−1.8879 ***	0.651				
Constant	−7.0816	5.741	−12.7180	13.599	−3.6747	6.775
N	164		57		107	
Chi^2	97.35		43.91		55.71	
Prob > Chi^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.5103		0.6177		0.4695	
Log likelihood	−46.70		−13.59		−31.48	

** $p < 0.05$, *** $p < 0.01$.

As for the early retirement group nationwide, except for the net asset, demographic and financial characteristics are not significant factors for home ownership (Table 7). The retirement age and marital status variables are statistically significant for the non-capital region. Moreover, the magnitudes of those variables in the non-capital region become greater than those for the whole sample. On the other hand, for the late retirement group, retirement age has a significant impact on home ownership nationwide and in the non-capital region (Table 8).

Table 8. Housing tenure choice (late retirement group).

Variables	Nationwide		Capital		Non-Capital	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
AGE	−0.0067	0.020	−0.0574	0.037	0.0463 *	0.026
AGERE	0.0535 **	0.021	−0.0227	0.037	0.0878 ***	0.029
MSTATUS	0.7526 ***	0.258	0.8894 **	0.419	0.4814	0.355
NETASSET	0.1559 ***	0.020	0.0940 ***	0.018	0.3470 ***	0.048
APT	−0.9512 ***	0.264	−0.2095	0.416	−1.7715 ***	0.391
CAPITAL	−1.8974 ***	0.288				
Constant	−2.9372 *	1.671	4.4456	3.127	−9.9045 ***	2.288
N	616		172		444	
Chi^2	214.60		77.86		167.51	
Prob > Chi^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.3098		0.3463		0.3697	
Log likelihood	−239.10		−73.50		−142.79	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In logistic regression, an odds ratio indicates the constant effect of the independent of interest on the likelihood of an event occurring. In this study, the regression coefficient for *AGERE* is the estimated increase in the natural logarithm of odds of owning a house per unit increase in the retirement age. Therefore, the exponentiated value of the regression coefficient is the odds ratio related to a one-unit increase in the retirement age. Table 9 presents the odds ratios of housing ownership for retirement age by the retiree group and region. For all retirees nationwide, the odds ratio is 1.033, meaning that one-unit increase in the retirement age contributes to a 3.3 percent increase in the likelihood of home ownership at any value of the retirement age. The odd ratio for the late retirement group is greater than that for all retirees (1.055). As for the spatial differential of the odds ratio for all retirees, the ratio for the non-capital is greater than that for the entire area (1.054 versus 1.033, respectively). Furthermore, the ratio for the late retirement group living in the non-capital region is the highest in magnitude (1.092). In sum, the effect of the increase in the odds of home ownership for the late retirement group in the peripheral area is almost three times as high as that for all retirees for the whole nation (a 9.2 percent increase versus a 3.3 percent increase, respectively).

Table 9. Odds ratios of housing ownership for retirement age.

Sample	Region		
	Nationwide	Capital	Non-Capital
All retirees	1.033	n.a. [1]	1.054
Early retirement group	n.a.	n.a.	n.a.
Late retirement group	1.055	n.a.	1.092

[1] The odds ratios are not reported here because the corresponding coefficients are not statistically significant at the alpha level of 0.05.

Figure 1 depicts the probabilities of owning a house for the values of retirement age by region. Figure 1a is derived from the nationwide sample, and Figure 1b from only the late retirement group. The results suggest that the non-capital retirees show higher probabilities for the same levels of retirement age, regardless of the timing of retirement. In Figure 1a, the probability of home ownership for the retirement age of 50 for the entire nation is 87.9 percent with the rest of the predictors being set to their mean values, whereas the probability for the same level of retirement age for the non-capital region is 95.1 percent, which is 7.2 percent higher than that for the whole country. The probability curves for both regions are slightly concave, so the probability differentials become smaller as the values of the retirement age increase. Interestingly, across the non-capital probability curves in Figure 1a,b, the home ownership probabilities are higher for the entire sample than for the late retirement group, up to the retirement age of around 65. From the age of

65, the probabilities for the late retirement group apparently start to exceed those for the entire sample.

4.3. Housing Consumption of Retirees

In accordance with the empirical design, the relationships between retirement age and the consumption for housing services were finally tested by retirement group and region, after controlling for each retired household's propensity of home ownership (Tables 10–12). From the Breusch–Pagan tests for heteroskedasticity, we could not reject the null hypothesis that the error terms are homoscedastic for all regressions, so we did not estimate robust standard errors for the predictors. The adjusted R^2 figures range from around 0.45 to 0.51, suggesting that the limited sets of variables in this study were satisfactorily selected, without causing further multicollinearity problems.

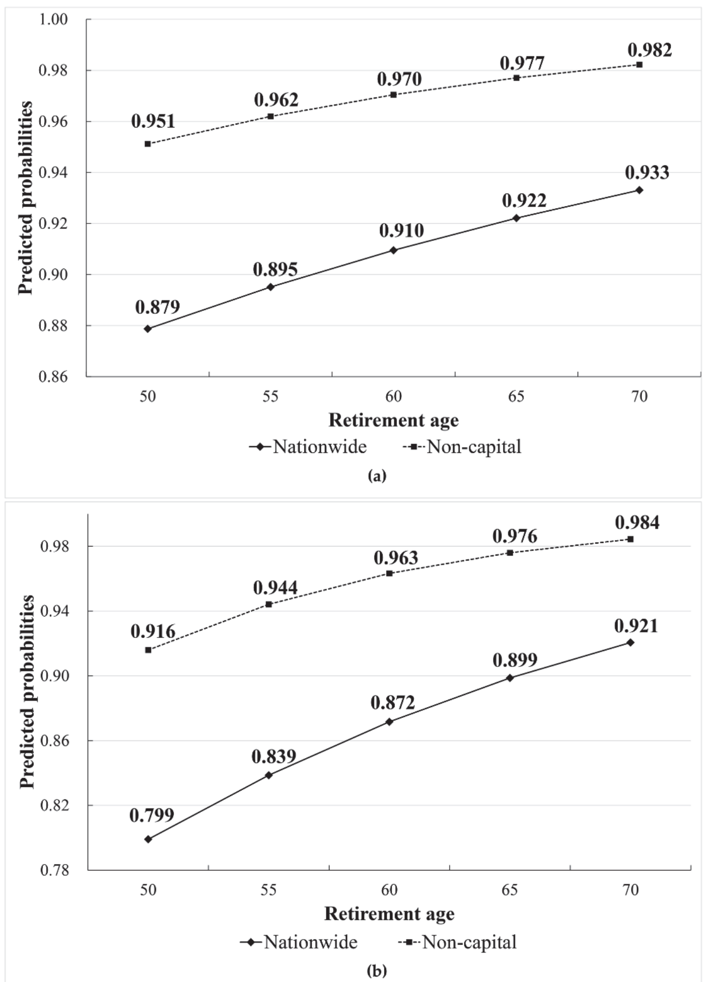

Figure 1. Predicted probabilities of owning a house for retirement age by region: (**a**) All retirees; (**b**) Late retirement group.

Table 10. Housing consumption (whole sample).

	Whole Sample		Subsample: Capital Region		Subsample: Non-Capital Region	
Variables	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**
OWNPROB	0.0124 ***	0.001	0.0136 ***	0.002	0.0105 ***	0.001
AGE	−0.0017	0.002	0.0001	0.004	−0.0022	0.003
AGERE	−0.0079 ***	0.002	0.0007	0.004	−0.0094 ***	0.003
MSTATUS	−0.6779 ***	0.034	−0.7338 ***	0.067	−0.6415 ***	0.038
NETINC	0.0282	0.021	0.0183	0.031	0.0329	0.030
NETASSET	0.0032 ***	0.001	0.0021	0.002	0.0047 ***	0.001
APT	−0.0373	0.033	−0.0358	0.057	−0.0669 *	0.040
CAPITAL	0.1338 ***	0.040				
Constant	3.7899 ***	0.181	3.2260 ***	0.384	4.0458 ***	0.205
Breusch–Pagan test for heteroskedasticity						
Chi^2	0.98		0.49		0.60	
Prob > Chi^2	0.3229		0.4828		0.4403	
N	780		229		551	
Adjusted R^2	0.4482		0.4878		0.4330	

* $p < 0.1$, *** $p < 0.01$.

Table 11. Housing consumption (early retirees).

	Early Retirement Group		Subsample: Capital Region		Subsample: Non-Capital Region	
Variables	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**
OWNPROB	0.0091 ***	0.002	0.0053 **	0.002	0.0102 ***	0.002
AGE	−0.0009	0.004	−0.0042	0.007	0.0030	0.006
AGERE	−0.0128	0.012	−0.0228	0.020	0.0012	0.015
MSTATUS	−0.5749 ***	0.070	−0.5628 ***	0.106	−0.6045 ***	0.091
NETINC	0.0015	0.057	0.1401	0.092	−0.0261	0.071
NETASSET	0.0055 **	0.003	0.0077 **	0.003	0.0074 *	0.004
APT	−0.0186	0.067	0.1911 *	0.105	−0.1279	0.086
CAPITAL	−0.0735	0.080				
Constant	4.1750 ***	0.678	4.9240 ***	1.165	3.0964 ***	0.870
Breusch–Pagan test for heteroskedasticity						
Chi^2	0.01		0.20		0.00	
Prob > Chi^2	0.9218		0.6523		0.9635	
N	164		57		107	
Adjusted R^2	0.4413		0.5013		0.4614	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

All regressions suggest that the likelihood of having a home increases the level of housing consumption. The sample of the late retirement group for the capital region exhibits the highest effect (0.0143), meaning that a 1 percent point increase in the probability of home ownership leads to a 1.44 percent increase in dwelling size ($100 \times [\exp(0.0143) - 1] = 1.44\%$) for the retirees who retired at the age of 60 or later living in the non-capital region. It is worth noting that none of the *AGE* variables exert significant impacts on the dwelling size across different retiree groups and regions. The marital status (*MSTATUS*) variables are negatively associated with the dwelling size in all regressions. As the dependent variable is the living area per person, retired households with two persons consume less dwelling area per person than those with one-person households. While the coefficients for net asset (*NETASSET*) variables are positive and significant in some subsamples, those for net income turned out to be irrelevant to the variation of housing consumption.

Table 12. Housing consumption (late retirees).

	Late Retirement Group		Subsample: Capital Region		Subsample: Non-Capital Region	
Variables	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**
OWNPROB	0.0133 ***	0.001	0.0143 ***	0.003	0.0098 ***	0.001
AGE	−0.0014	0.003	0.0055	0.006	−0.0044	0.003
AGERE	−0.0115 ***	0.003	−0.0033	0.006	−0.0093 **	0.004
MSTATUS	−0.7136 ***	0.039	−0.7684 ***	0.085	−0.6526 ***	0.043
NETINC	0.0362	0.023	0.0266	0.035	0.0456	0.034
NETASSET	0.0029 **	0.001	0.0034	0.003	0.0046 ***	0.001
APT	−0.0460	0.038	−0.1377 *	0.070	−0.0541	0.046
CAPITAL	0.2010 ***	0.047				
Constant	3.9565 ***	0.240	3.0903 ***	0.579	4.2656 ***	0.269
Breusch–Pagan test for heteroskedasticity						
Chi^2	1.01		1.66		0.67	
Prob > Chi^2	0.3156		0.1971		0.4127	
N	616		172		444	
Adjusted R^2	0.4447		0.4759		0.4187	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The retirement age (*AGERE*) variables are negatively associated with the consumption for housing in the following samples: (i) the all-retiree sample for the whole country; (ii) the non-capital region for the entire retirement group; (iii) the late retirement group sample for the whole country; (iv) the late retirement group sample for the non-capital region. Therefore, we can conclude that later retirement results in a higher degree of economizing on housing consumption.

Finally, Table 13 reports the percentage change in the housing consumption of retirees for a one-unit and five-unit increase in the retirement age. For example, the coefficient of the retirement age variable for the entire retirement group for the whole country is −0.0079, so the consumption for housing decreases by about 0.787 percent as the retirement age increases by one year ($100 \times [\exp(-0.0079) - 1] = -0.787\%$). The effect becomes −3.873 percent when the retirement age increases by five years ($100 \times [\exp(-0.0079 \times 5) - 1] = -3.873\%$. As the retired household's average dwelling size is 54.02 m^2 per person for all retirees nationwide (shown in Table 3), the amount of housing consumption per person for this group on average is expected to decrease by 0.43 m^2 if retirement occurs one year later, ending up with the dwelling size of 53.6 m^2. A five-year delay in retirement is associated with a decrease in housing consumption of 2.1 m^2 per person, and the resulting level of housing consumption becomes 51.9 m^2 per person.

Table 13. Effects of retirement age on housing consumption.

Sample	Region		
	Nationwide	**Capital**	**Non-Capital**
Panel A: 1 year-increase in retirement age			
All retirees	−0.787%	n.a. [1]	−0.936%
Early retirement group	n.a.	n.a.	n.a.
Late retirement group	−1.143%	n.a.	−0.926%
Panel B: 5 year-increase in retirement age			
All retirees	−3.873%	n.a.	−4.591%
Early retirement group	n.a.	n.a.	n.a.
Late retirement group	−5.588%	n.a.	−4.544%

[1] The effects are not reported here because the corresponding coefficients are not statistically significant at the alpha level of 0.05.

The magnitude of the economization of housing consumption for one-unit increase in the retirement age for all retirees is greater for the non-capital area than for the entire nation

(0.936 percent versus 0.787 percent in terms of absolute values, respectively). As the effects are broken down into subsamples in regard to the timing of retirement, the late retiree group shows a higher degree of sensitivity of retirement timing to the adjustment for housing consumption for the entire nation (1.143 percent versus 0.787 percent in terms of absolute values, respectively). For the non-capital region, the effect for all retirees is greater than that for the late retirement group (0.936 percent versus 0.926 percent in terms of absolute values, respectively). The early retirement group does not show any impact of retirement timing on housing consumption adjustment. This irrelevance between retirement age and dwelling size also applies to the retired households living in the capital region.

5. Discussion

5.1. Housing Downsizing and Retirement-Consumption Puzzle

Downsizing homes is defined as "a residential move to smaller quarters and the necessary reduction of personal possessions" [70]. This study provides cross-section evidence that housing consumption by retired households decreases with the age of retirement, supporting the hypothesis of housing downsizing. However, our analysis, in terms of housing downsizing, shows different results when we segment the analysis by retirement group and region: Retired households in the capital region and in the early retirement group do not show the downsizing pattern. Therefore, our results do not follow the notion by Fisher et al. [14], which suggests that early retirement induces a higher degree of liquidation of housing wealth than late retirement.

Our results are partly in line with the so-called "retirement-consumption puzzle" with respect to housing consumption. According to the life-cycle hypothesis, even though income discontinuously decreases with retirement, consumption should not be significantly different from the pre-retirement level with respect to lifetime utility maximization and the resulting consumption smoothing. However, some studies found that, in the case of retired households, not only the income level, but also the consumption level, decreases compared to that before retirement. This phenomenon has been referred to as the retirement-consumption puzzle because it is not satisfactorily explained by the permanent income hypothesis that forms the theoretical basis in exploring household consumption behavior. There are various opinions on what the cause is, to what extent the decline occurs, or whether the phenomenon is common to all retirement groups or specific to certain groups or consumption items.

The paper by Hamermech [71] is a pioneering study presenting evidence on the relationship between consumption and assets using the US Retirement History Survey (RHS). The study found that the average consumption of households in their early retirement period exceeded their income level by about 14%. Furthermore, it was found that these households increased their net financial wealth by sharply reducing the level of consumption within a short period of time after retirement. This means that, if it is difficult to maintain the level of consumption enjoyed at the beginning of retirement because their assets are insufficient, their real consumption is reduced in order to cover the gap. A study by Bank et al. [72] analyzed income and expenditure patterns before and after retirement by retirement age cohort, using the British Family Expenditure Survey data, to explore whether households are saving enough for retirement. The results show that there was a significant decrease in consumption around the time of retirement, which was different from the consumption smoothing framework. Even after taking into account job-related expenses, changes in consumption that may be related to the risk of death, and other determinants, the consumption decline predicted by the model was about 2 percent, while the actual consumption decline in the retirement period was 3 percent. The authors concluded that this behavior results from the decrease in consumption due to unexpected negative shocks. Bernheim et al. [73] also reported similar results. This study estimated consumption patterns for the Panel Study of Income Dynamics (PSID) for 430 households between 1978 and 1990. The authors found that consumption decreased by 14 percent on average at the time of retirement. They interpreted the rapid decline in consumption at the time of retirement as an action taken by households after inspecting their retirement preparation status. It could be the case that those households reduce consumption in response to future negative shocks.

The puzzle is pertinent to housing. According to the life-cycle hypothesis suggested by Ando and Modigliani [74], households withdraw accumulated financial and housing assets for consumption after retirement. Therefore, they increase housing assets when they are young, and reduce those assets when they are getting older. However, there are studies that have tried to modify or refute existing predictions by the life-cycle model related to housing when it comes to the changes in residential status of middle-aged households. Although it has been recognized that older households retain large housing assets and their income levels cannot satisfactorily cover household expenditures, alternative hypotheses have suggested that the possibility of downsizing housing is low if demographic shocks, such as death, illness, or divorce, do not occur, or if people want their children to inherit the housing assets. Beblo and Schreiber [75] found that the strict consumption-smoothing hypothesis is violated for the subgroup of non-home owners for German tenants. Even though our study cannot identify the exact reasons, the results suggest that consumption for housing after retirement *discontinuously* declines. In other words, a decline in housing consumption does not occur through the entire time path after retirement in a smooth way: the reduction in housing consumption does not happen in early retirement, but in late retirement.

5.2. Housing Policy Recommendations

As the retirement of the baby boomers begins, much attention is being paid to the prediction that older households put their homes on the market through downsizing. In Korea, retiring households' income sources are rapidly decreasing, in part due to the immaturity of public and private pension systems. It is argued that housing represents a high proportion of household assets, and there are relatively few liquid assets that can be used for daily consumption [26]. According to the Korea Housing Finance Corporation [76], 30 percent of the elderly, who own their own homes, had accumulated debts of about KRW 44 million; 20% covered their monthly expenditures with public pensions, such as the national pension, and 40.9% answered that their average income is insufficient.

A reverse mortgage system enables the elderly who own a house to receive a stable monthly income through liquidating housing wealth in the form of a pension. In July 2007, the Korea Housing Finance Corporation launched a reverse mortgage program called "Housing Pension" for the purpose of alleviating the problems of public and private pensions, which are thought to be inefficient in coping with the trend of a rapidly aging society. However, the subscription rate is still low. According to the Korea Housing Finance Corporation, as of January 2017, the 10th year since its inception, the number of subscribers is 40,586. This is less than 1% of 4,969,773 people, which is the population of those aged 60 or older, as of the 2015 Population and Housing Census. The reasons for the low rate include house bequest motivation, expectations for house price appreciation, and the low level of receivable income from the program [77].

The poverty rate of the elderly aged 65 or older in Korea is 43.8%, which is more than triple the average of 14.0% in OECD members [78]. South Korea has a high population density around its capital, which causes housing costs to continuously rise around the area. Therefore, it is difficult for retirees who generally have a relatively low income to own a house in the urban area [79,80]. It turns out that the elderly living in the Seoul metropolitan area are more satisfied with reverse mortgages than the elderly living in non-Seoul areas, as they use such mortgages to cover their relatively high living expenses in the highly dense area [77]. It is thus necessary for the reverse mortgage program to be redesigned, to be expanded, or to be made more accessible to those who retire earlier in the capital region because some retired households might over-consume housing involuntarily [62]. Another concern arises: the reverse mortgage program only supports older home owners. As for the renters, we need to devise policy measures to lower the rental costs, such as the provision of public housing or direct assistance, that are tailored to those who did not accumulate enough housing wealth to prepare for the later stage of life or to those who experience difficulty moving to a smaller housing unit in the rental housing market.

6. Concluding Remarks

This paper has investigated the impact of the timing of retirement on housing consumption. Incorporating the endogeneity of housing tenure choice, this study found that households whose household heads retire at the age of 60 or later living in the non-capital region exhibit a negative relationship between the age of retirement and the level of housing consumption, which corresponds to housing downsizing. On the other hand, the early retirement group living in the more populated region does not downsize their house. If the differential impacts of the timing of retirement on housing consumption indicate that the elderly who retire early in the capital region have difficulty reducing their dwelling size in a timely manner, housing policies should pay more attention to revising the current reverse mortgage program or assisting renters through a combination of direct support and the supply of affordable housing.

Three limitations should be addressed. First, we only used the SFLC dataset for one year (2014) because Statistics Korea provides the dwelling size variable as discrete, not continuous, starting from the 2015 dataset, for the sake of increasing confidentiality. As a result, we could not obtain a sufficient number of cases, especially for the early retirement group. Second, we could not add the price variable in the housing consumption regression. We need to estimate the user cost of owning, the rent, and the ratio of those two (the relative price). We could not observe both the value and rent for each observation. In addition, in order to estimate those metrics, we need detailed information on the variables for the hedonic pricing model. The data used in this study lack such information. Finally, because of the limited usability of the data, we could not construct the data as a longitudinal dataset, which has advantages over the one-year data in that we could capture the changes in the retirement status from repeated observations and compare them with the changes of housing consumption. However, given some of the difficulties in using the data, our approach and the results shed some light on the impact of the timing of retirement on housing consumption. We look forward to more studies that examine the spatial heterogeneity of the housing downsizing behaviors for different retirement groups and derive relevant housing policy directions.

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Appendix A. Propensity Score Matching

As a robustness check, we employed the propensity score matching (PSM) method in order to remove the possible systematic difference of dwelling size between owning and renting. The PSM technique matches observations using the predicted probability of owning from the binary logistic regression. Once the probability is calculated for all households, households with owning are matched with those with renting that have the closest probability. Then, regression equations are re-estimated for the matched samples to ensure the elimination of the systematic bias. This study ended up using the "nearest neighborhood matching with a caliper" algorithm, where the caliper size is a quarter of the standard deviation of the estimated propensity scores.

The matching procedure satisfactorily removed the previous imbalances of dwelling size between owning and renting. Most variables exhibited significant reductions in the differences in means (Table A1). The covariates as a whole also became more balanced after the matching (Table A2). After employing PSM, the coefficient of *AGERE* was not statistically significant (Model 1 in Table A3). We suspected that this result is due to the high level of collinearity between *AGE* and *AGERE*. After removing *AGE* from the model, the coefficient of *AGERE* was significant at the level of $\alpha = 0.1$ (p-value = 0.050) (Model 2 in Table A3). We did not employ PSM for other subsamples because the numbers of observations are too small to conduct valid PSM procedures.

Table A1. Mean differences of dwelling size between owning and renting.

Variable	Unmatched Matched	Mean Owning	Mean Renting	%Bias	%Reduct ∣bias∣	*t*-test *t*	*t*-test $p > \mid t \mid$
AGE	U	74.033	75.278	−17.7		−2.14	0.033
	M	74.955	75.245	−4.1	76.6	−0.30	0.765
AGERE	U	64.278	63.419	12.0		1.48	0.140
	M	63.164	64.636	−20.7	−71.4	−1.54	0.124
MSTATUS	U	0.565	0.273	62.0		7.35	0.000
	M	0.282	0.336	−11.6	81.4	−0.87	0.384
NETASSET	U	21.462	5.055	102.0		10.86	0.000
	M	7.662	7.617	0.3	99.7	0.03	0.973
APT	U	0.361	0.414	−10.9		−1.34	0.181
	M	0.400	0.282	24.3	−121.7	1.86	0.065
CAPITAL	U	0.256	0.404	−31.8		−3.99	0.000
	M	0.336	0.218	25.4	20.2	1.97	0.051

Table A2. Mean and median standardized differences for all covariates.

Sample	Pseudo R^2	LR χ^2	$p > \chi^2$	Mean Bias	Median Bias	Rubin's B	Rubin's R
Unmatched	0.300	264.83	0.000	39.4	24.8	133.4 *	2.41 *
Matched	0.047	14.22	0.027	14.4	16.1	51.2 *	1.35

* if B > 25%, R outside [0.5; 2].

Table A3. Regression results for the whole sample after PSM.

Variables	Model 1 Coeff.	Model 1 S.E.	Model 2 Coeff.	Model 2 S.E.
OWNPROB	0.0109 ***	0.003	0.0114 ***	0.003
AGE	−0.0049	0.005		
AGERE	−0.0063	0.005	−0.0088 *	0.004
MSTATUS	−0.7192 ***	0.075	−0.7218 ***	0.075
NETINC	0.0959 *	0.052	0.0936 *	0.052
NETASSET	−0.0009	0.007	−0.0014	0.007
APT	0.1391 *	0.081	0.1504 *	0.080
CAPITAL	0.2441 **	0.116	0.2464 **	0.116
Constant	3.9511 ***	0.361	3.7095 ***	0.282
Breusch–Pagan test for heteroskedasticity				
Chi^2	0.01		0.01	
Prob > Chi^2	0.9092		0.9035	
N	220		220	
Adjusted R^2	0.3244		0.3239	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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House Prices in the Peripheries of Mass Rapid Transit Stations Using the Contingent Valuation Method

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Abstract: With the implementation of growth management planning in urban areas and the realization of sustainable development visions, transit-oriented development has become a form of mainstream urban development. Relevant studies have verified that the market prices of houses in the peripheries of public transit stations are higher than those of regular houses. However, when buying a house, people make price decisions on the basis of their levels of identification with the amenities and environmental qualities of residential locations. The question arises whether current housing price levels in the peripheries of public transit stations properly reflect or over-reflect this consideration. To clarify this, this study selected the peripheries of mass rapid transit (MRT) stations in the Taipei metropolitan area in Taiwan as the research area and designed a willingness-to-pay questionnaire for houses in the peripheries of MRT stations by using the contingent valuation method. Subsequently, a Tobit regression model was established to estimate the prices that people are willing to pay for such houses. The results revealed that after the respondents had considered the advantages and disadvantages of the amenities and environmental qualities of the peripheries of MRT stations, they were willing to pay higher prices for a house in those areas than for a regular house. For houses in the peripheries of elevated stations, the respondents were willing to pay approximately 7.89% more than the average market price of the entire administrative district per square meter. For houses in the peripheries of underground stations, the respondents were willing to pay approximately 5.9% more than the average market price of the entire administrative district per square meter. However, in the peripheries of both elevated and underground stations, the current market house prices are higher than the price levels the respondents were willing to pay. In the peripheries of elevated stations, the market house prices are 33.55% higher, and those in the peripheries of underground stations are 14.82% higher than what the respondents were willing to pay.

Keywords: growth management; sustainable development; transit-oriented development; housing price; contingent valuation method

1. Introduction

In the development of urban areas, the land demand from industrial development, commercial activities, and resident behaviors results in suburbanization. Furthermore, lack of control regarding development locations and the consideration of land use efficiency have resulted in landscape patterns with low density, fragmentation, and leapfrogging. This is the so-called urban sprawl phenomenon [1–7]. As experienced in Europe and North America, the negative impacts of sprawl in urban spaces far outweigh the benefits. Furthermore, urban sprawl violates the principle of sustainable development. Relevant studies have supported such discourse on the aspects of land use, environmental resource preservation, urban and rural development, transportation, and public sector finance [1,4,8–12]. Consequently, the planning concept of growth management emerged, which is a systematic strategy and proposed solution for targeting the effects of this development trend of urban areas. Planning departments in the public sector intend to help urban areas achieve sustainable development through growth management. After 2000, this planning concept evolved into smart growth with the introduction of elements of urban design and building design to strengthen the habitability and attractiveness of downtown areas. People's willingness to move back from suburbs to downtown areas is expected to increase, and urban centers are encouraged to adopt a land use pattern of compactness and mixed use [13]. With the emergence of smart growth, transit-oriented development (TOD) has become a form of mainstream urban development in modern times. TOD is the use of a land development pattern with high density and mixed residential and commercial use along the corridors and stations of public transit systems. This improves the lifestyle amenities of the surrounding areas as well as the convenience of public transit systems. The purpose of this development is to centralize the activities of work, residence, commerce, and recreation to the areas surrounding public transit stations in addition to reducing the improper consumption of land resources as well as air and noise pollution.

Further studies on the major price-related characteristics of housing markets in these areas have indicated that the convenience of transport and great amenities in the peripheries of mass transit stations have positive effects on house prices in the area [14–20]. Benjamin and Sirmans (1996), Workman and Brod (1997), and Dueker and Bianco (1999) have conducted research on the peripheries of subway stations in Washington D.C., New York, and Portland in the United States, respectively. Their results have all indicated that the unit price of houses is higher closer to stations [21–23]. Mulley and Tsai (2016) verified that the unit price of houses within 400 m of metro stations was higher than those of houses in other areas after the metro started operations in Sydney, Australia [24]. Debrezion and Rietveld (2006) measured the influence of Dutch rail transit on house prices, and their results revealed that because of the noise caused by the stations, houses within 250 m of the stations had a unit price 5% lower than that of houses 500 m from the stations [16]. Deng and Nelson (2016) investigated the influence of the Beijing subway system on house prices in China and discovered that subway stations have positive effects on housing prices in the surrounding areas. The established characteristic price model demonstrated that the houses within 100 m of public transit stations are influenced the most [25]. In Taiwan, studies by Liou et al. (2016), Shyr et al. (2013), Chiang (2013), and Peng et al. (2009) have verified that the mass rapid transit (MRT) system has positive effects on the prices of surrounding houses [26–29].

TOD strategies aim to solve the predicament of development imbalance in urban areas and attain sustainable development of the environment. The results of market mechanisms indicate that because of the planning actions implemented by the government with all its available resources, the houses in the peripheries of mass transit stations are considered a special house type. Studies have verified that market prices of such a special house type are higher than those of regular house products. The price discrepancy mainly occurs because people enjoy the living environments built in accordance with this special type of land use and are willing to pay higher prices for houses in the peripheries of mass transit stations. However, under the market mechanism, whether factors such as market price gouging cause real market prices to exceed the prices that people are willing to pay to enjoy the living environment is unclear. If urban development policies and strategies proposed by the public sector lead to an increase in people's costs for purchasing houses under price gouging, the favorable intention of such governmental policies may be compromised.

Developmental sprawl has appeared in the overall spatial structure of the Taipei metropolitan area in Taiwan [30]. To reverse this urban land use pattern, which violates sustainable development, and solve the conventional land use problem of the inability of zoning controls to respond to the rapid changes in industrial development and commercial activities, governmental urban planning agencies have gradually introduced growth management into planning systems at different levels and are actively implementing TOD strategies. However, the developmental characteristics of the Taipei metropolitan area and US metropolises differ. In the United States, severe spatial sprawl has caused the middle class to move to live in suburban areas, minimizing the number of residences in downtown areas. Therefore, TOD strategies are introduced to reinforce downtown public transport accessibility. The adoption of mixed use in the peripheries of mass transit stations can attract people to reside in downtown areas [31–33]. Under the special spatial structure in Taiwan, the developable land area and ratio are small. Combined with the development context of mixed use and common dense residential communities, Taipei features compact city characteristics according to US standards [30]. Urban sprawl occurs in the Taipei metropolitan area mainly because of high housing prices in the downtown areas, loopholes in land change systems, and population migration to suburbs promoted by public construction projects led by the governmental sector. Despite the urban sprawl, housing in downtown areas remains highly attractive [7]. Therefore, the Taipei metropolitan area implements TOD to reduce dependency in private transport and further improve urban living conditions. The planning department of the Taipei metropolitan area has made adjustments in urban planning, urban design, and land use control and developed the systems of floor area incentives and transfer of development rights to strengthen the land use intensities and mixed-use levels in the peripheries of MRT stations. However, whether the different causes and purposes of metropolitan development characteristics and the introduction of TOD for planning result in different profiles of housing markets in the peripheries of mass transit stations in Taipei and US metropolises remains unclear.

Consequently, the peripheries of MRT stations in the Taipei metropolitan area in Taiwan were selected as the research area in this study. After people's perceived satisfaction with the amenities and environmental qualities of the peripheries of the stations was clarified, the prices they were willing to pay to buy houses in the areas were calculated. In addition, actual market transaction prices were compared with the prices people were willing to pay, and the differences between the two were analyzed. In accordance with the study's purpose, we conducted an empirical analysis based on the contingent valuation method (CVM) to design a willingness-to-pay (WTP) questionnaire to assess the prices people were willing to pay to buy houses in the peripheries of MRT stations. Subsequently, a Tobit regression model was established, and the additional prices people were willing to pay for houses in the areas surrounding MRT stations compared with those for regular houses were calculated. Thus, the interactions among the living environment, residents' feelings, and the housing market derived from the planning concept of growth management could be understood. In addition, a novel price evaluation framework could be provided for this special house type.

2. Research Area

This study selected the Taipei metropolitan area in Taiwan as the research area. The Taipei metropolitan area consists of Taipei City, New Taipei City, and Keelung City and has an area of 2457 km^2 and a population of 7,048,851. It is the largest metropolitan area in Taiwan. The Taipei metropolitan area is a highly concentrated political, economic, and cultural metropolis with 42 administrative districts. In 1996, the MRT system started operation in the Taipei metropolitan area. Currently, it has six lines with a total operating length of 167.2 km and a total of 119 stations. Different forms of stations have different influences on the surrounding environment, including landscape views, crowds, congregation of commercial activities, available open space, and noise and vibration generated by the MRT system's operation. Thus, the house prices are influenced. Consequently, the target area in this empirical study included the peripheries of elevated and underground MRT stations. Thus, whether people's WTP additional house prices differs based on different station forms can be further clarified.

To fit the scope of the study, the zoning of the selected peripheries of stations mostly comprises residential districts. In addition, these peripheries have commercial facilities that residents require in their daily lives. Consequently, the surrounding areas of six MRT stations were selected as the research area through the digital land use zoning inquiry system of Taipei City Government and New Taipei City Government as well as Google Maps. They were the peripheral areas of Mingde, Qilian, Beitou, Wanlong, Dapinglin, and Xindian District Office Stations. Among them, the first three stations are elevated MRT stations, and the latter three are underground MRT stations. The details are shown in Figure 1.

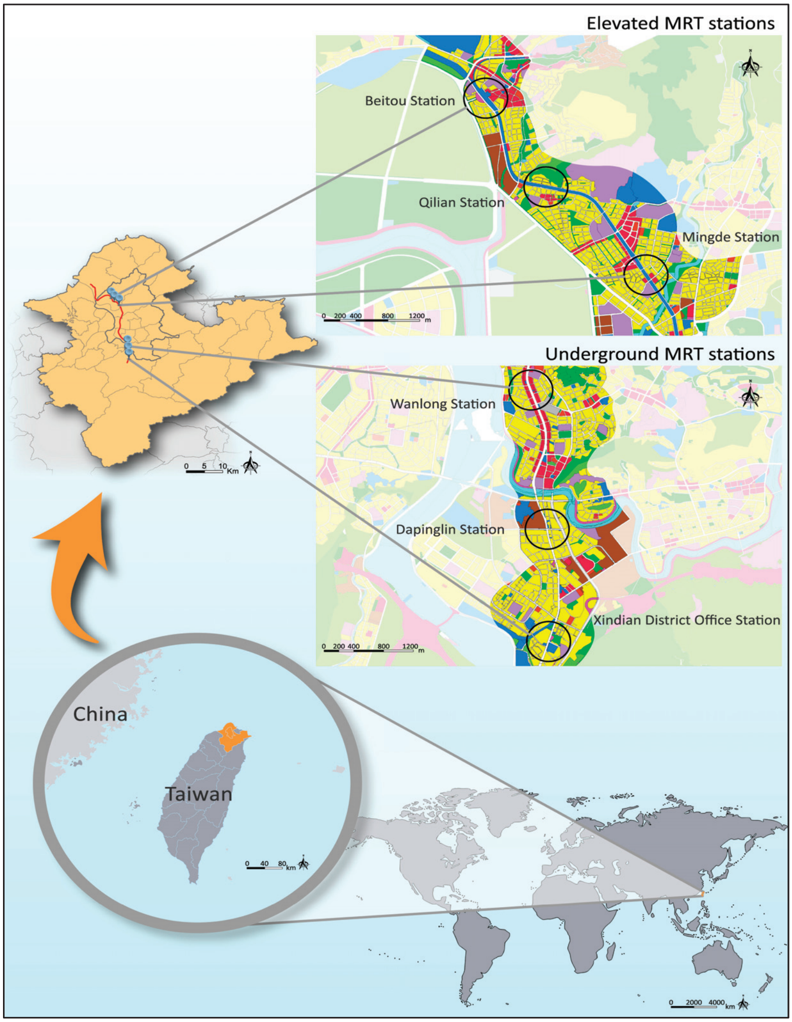

Figure 1. Locations of the study area (courtesy of Free Vector Maps).

3. Study Design

This study determined the value of houses in the areas surrounding stations as perceived by people by using objective evaluation models. Thus, two study hypotheses were proposed and verified. The first hypothesis is that because elevated and underground stations have different effects on their peripheries, the advantages and disadvantages of resulting amenities differ. Therefore, the prices people are willing to pay to purchase different types of houses in the peripheries of MRT stations differ. The second hypothesis was that although people are willing to pay higher prices to buy houses in the peripheries of MRT stations than they are to buy regular house products, the market prices of houses surrounding stations are higher than the prices people are willing to pay after considering the effects. Figure 2 presents the framework of the study design. After the empirical research area was determined, the system of factors influencing house prices in the peripheries of MRT stations was established. Subsequently, a questionnaire was designed on the basis of the CVM. Finally, a Tobit regression model of the areas surrounding elevated and underground stations was established. The additional prices that people are willing to pay for this special house type were estimated. The steps involved in each stage are presented in Figure 2.

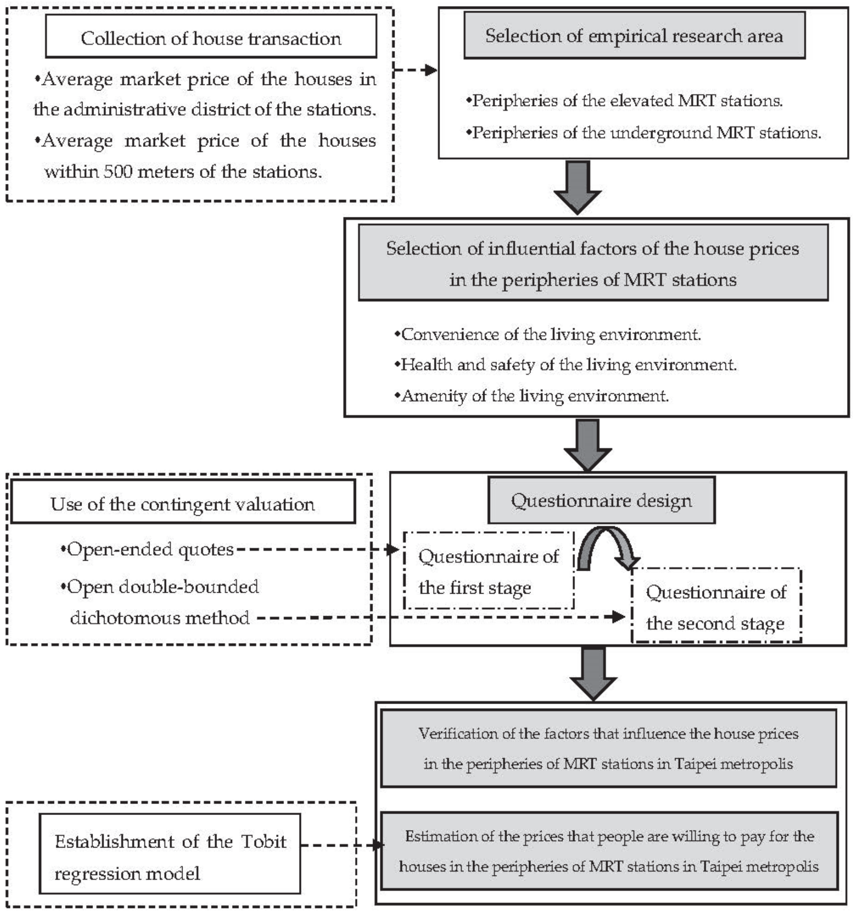

Figure 2. Research procedure.

3.1. Selection of Factors that Influence House Prices in the Peripheries of MRT Stations

Factors influencing real estate prices include real estate characteristics, neighboring environments, and location [34]. Factors associated with location include distances to workplaces, schools, shopping districts, and public transit stations [35]. If houses are closer to public transit stations, including those for trains, buses, and subways, the commute cost will be reduced. Consequently, according to the compensation principle, people must spend relatively more to live in the peripheries of transit stations. In other words, real estate prices are closely related to the accessibility of public transit systems. Because convenient public transit systems provide people with greater transport convenience, the commute time cost is naturally transferred to the cost of buying or renting houses. In addition, houses near transit stations often have higher selling rates in the real estate market [16,17]. Belzer and Autler (2002) explored the housing markets in the peripheries of public transit stations in New York, Boston, Chicago, and San Francisco and concluded that such areas have high-quality amenities of abundant commerce and convenient transportation. Consequently, people prioritize such areas when selecting living locations, even if they must pay relatively higher rents and house prices [36]. Cervero and Duncan (2002) indicated that if an area within 400 m of a station has fine mixed land use pattern, the house prices in the surrounding areas will increase [20]. Bae et al. (2003) found that line 5 of the Seoul Metropolitan Subway in South Korea exerted a significant positive influence on the house prices of the surrounding areas even before it started operation. The reason was that people living in crowded urban environments with intensive development hope that public transit systems translate to superior transportation convenience and an enhanced living environment. Consequently, the value increase is reflected in advance in the housing market in the peripheries of the stations [19]. Lund (2006) explored the reasons that influence people living in the areas surrounding public transit stations in the three regions of the San Francisco Bay Area, Los Angeles, and San Diego and revealed family income to be a significant influencing factor [18]. Diaz and Mclean (1999) asserted that pedestrian-oriented street pattern designs are introduced more actively in areas surrounding public transit stations. As a result, the quality of life for residents in these areas improve, which becomes a factor positively influencing house prices. Conversely, noise pollution and privacy concerns negatively influence house prices [15]. Mulley et al. (2016) conducted research in Brisbane, Australia, and found that public transit stations exert positive influences (e.g., attracting the aggregation of commercial activities) and negative influences (e.g., causing noise and increasing crime rates near the stations) [14].

In sum, compared with regular house products, houses in the peripheries of public transit stations allow residents to enjoy more convenient transportation functions and abundant commercial functions. In addition, the aggregation of people and vehicles might exert negative impacts such as noise, unclean environments, and insufficient public security. Thus, the present study reviewed related literature and considered the development characteristics of the Taipei metropolitan area. The factors influencing house prices in the peripheries of MRT stations were determined from the three major dimensions of living environment convenience, resident health and safety, and living environment amenity. Thereafter, under the premise of people considering lifestyle amenities and environmental qualities, whether they are willing to pay more to buy houses in the peripheries of public transit stations was investigated. In addition, the amount that they would be willing to pay was estimated. A total of 13 influential factors under the 3 major dimensions were identified, as shown in Table 1. Among them, six positive influenced house prices (GQ1 to GQ6) and seven had negative influences (BQ1 to BQ7).

Table 1. Factors influencing house prices in the peripheries of mass rapid transit (MRT) stations.

Dimension	Influential Factor	Expectation Sign
Convenience of the living environment	Well-developed public transit network provides fast and convenient transportation services (GQ1).	+
	Diverse public transportation provides fast and convenient transfer functions (GQ2).	+
	Mixed land use provides abundant and convenient commercial functions (GQ3).	+
	Traffic congregation results in insufficient parking space (BQ1).	−
Health and safety of the living environment	Traffic congregation influences the air quality of the living environment (BQ2).	−
	Crowds influence the safety of the living environment (BQ3).	−
	Crowds influence the cleanliness of the living environment (BQ4).	−

Table 1. *Cont.*

Dimension	Influential Factor	Expectation Sign
Amenity of the living environment	Additional open space at the stations improves the recreational functions of the living environment (GQ4).	+
	Pedestrian walking systems around the stations improve the convenience of the overall walking space (GQ5).	+
	Additional public art installations to the stations improve the esthetics of the living environment (GQ6).	+
	Traffic congregation influences the serenity of the living environment (BQ5).	−
	The noise and vibrations produced by the MRT systems influence the serenity of the living environment (BQ6).	−
	The buildings and additional facilities of MRT stations influence the landscapes of the living environment (BQ7).	−

3.2. Utilization of the CVM

The theoretical CVM was first proposed by Ciriacy-Wantrup in 1947 as a method for eliciting market valuation of a nonmarket good. The method was practically applied in 1963 by Davis to estimate the value hunters and tourists placed on a particular wilderness area [37]. The CVM is generally used in the estimation of the value of nonmarket goods. The principle of the CVM involves using various methods to elicit respondents' WTP for nonmarket goods. The CVM involves the following steps: establishing hypothetical markets, selecting survey methods (interviews, phone survey, and postal survey), selecting elicitation methods, estimating WTP, calibrating models, and inferring prices [38,39]. The CVM has been developed into a commonly used valuation method; however, some researchers have expressed concerns regarding its use, including respondents' hypothetical bias and testing for scope effects when respondents respond to a questionnaire. The reliability and validity of the final estimated WTP is also questionable. By contrast, some researchers have verified that the CVM is a reliable valuation method [40–45]. Mitchell and Carson (1989) and Hutchinson et al. (1995) indicated that with a rigor questionnaire structure, the CVM can be a trustworthy model to valuate nonmarket goods [46,47]. List (2001) claimed that hypothetical bias can be reduced by providing more information to respondents and encouraging them to imagine that they are actually engaged in a monetary transaction [48]. Fransico (2010) claimed that using an open double-bound dichotomous choice method to design questionnaires can increase their statistical validity [49].

The CVM can also be used for market goods for which prices are currently unavailable [50]. Mattia et al. (2013) indicated that conventional real estate can be appraised using the market comparative approach, cost approach, and capitalization approach. Appraisers determine real estate prices according to experience, values, data, and market conditions. However, the reliability of related data and information on the real estate market remains unclear in the appraisal process. Therefore, if the CVM can be used to determine the prices that people are willing to pay, the reliability of the appraised prices can be increased, and the influential factors as well as their influence levels on real estate prices in different submarkets or regional environments can be clearly understood [51]. Roddewig and Frey (2006) also believed that the CVM can be used to determine the real estate prices that buyers are willing to pay or the price levels that sellers are willing to accept [52].

In a related study, Mundy and Mclean (1998) studied the litigation case of American Smelting and Refining Company. The plaintiff claimed that the smelter exhaust gases contained arsenic, lead, and other heavy metals. Under the premise of impacts on the health of nearby residents and decreasing real estate values, the CVM was used to estimate that the house prices of the surrounding areas would decrease by 10–18% [53]. Simons and Throupe (2005) surveyed homeowners in South California through random sampling and used the CVM to demonstrate that the potential damage caused by toxic mold on house prices was as high as 60% [54]. Simons and Geideman (2005) surveyed the influence of leaks in the underground oil storage equipment of gas stations on house prices in eight

US states. The results indicated that the CVM can help analyze the reasons for reduced house prices from the residents' perspective [55]. Lipscomb et al. (2011) verified that the CVM has an effect on the appraisal of real estate value affected by pollution under circumstances in which market data are difficult to use as a reference or when market failure occurs. However, this valuation method has its advantages and limitations [56]. In addition, Kiel and McClain (1985), Chattopadhyay (2000), Beron et al. (2001), and Brasington and Hite (2005) targeted changes in the prices that people are willing to pay for houses if the air quality of the living environment improves [57–60]. Furthermore, Jim and Chen (2006) conducted questionnaire surveys on house buyers in Guangzhou City, China, and found that they were willing to pay more to purchase houses in communities with favorable living environmental qualities. For communities with green landscapes, house buyers were willing to pay an additional 7.1%, whereas for communities with favorable and sufficient water sources, they were willing to pay an additional 13.2% [61]. Another survey study on Klang, Malaysia, concluded that home buyers were willing to pay an additional 20.3% for houses within a commute time of 20 min. If communities had adequate property management mechanisms and pleasant landscapes, they were willing to pay an additional 3.5% [62].

Generally, methods that employ the CVM principle to explore WTP prices include the open-ended CVM, closed-ended CVM, sequential bids method, and payment card method. These methods are described as follows:

3.2.1. Open-Ended CVM

The first CVM to be used was the open-ended CVM proposed by Davis in 1963. In the open-ended CVM, respondents are directly asked the prices they are willing to pay under different circumstances without any related information or restrictions. This is considered the most direct price inquiry method because the respondents receive no hints. Consequently, respondents are allowed to reflect on the prices they have in mind with no restrictions. However, the major dispute regarding this method is that respondents do not have the basis for an overall understanding of the event, and the results are not objective. In addition, the prices proposed by respondents are often too high or too low. With no reasonable explanation, subsequent analysis and price valuation becomes difficult [49,63].

3.2.2. Closed-Ended CVM

The closed-ended CVM can be further divided into the single-bounded dichotomous choice method and double-bounded dichotomous choice (DBDC) method. The single-bounded dichotomous choice method involves directly asking respondents whether they agree on a random price. Carson, Hanemann, and Mitchel further proposed the DBDC method in 1986. The statistical efficiency of the contingent evaluation is increased with the use of dichotomous choices because it involves two inquiry steps. Specifically, respondents are first allowed to understand the reason for the price inquiry before being asked whether they agree to a first offer. The second inquiry depends on the respondents' responses to the initial offer. If they are willing to pay for the first offer, then the second offer is set higher than the first. If they are unwilling to pay, then the second offer is set lower than the first [64].

3.2.3. Sequential Bids Method

The sequential bids method is similar to auction bidding, and its goal is to determine the final price that people are willing to pay. The inquirer first proposes an initial price. If the respondent does or does not accept the price, the price will be gradually increased or reduced until the respondent is unwilling to further negotiate the price. Although the method may be influenced by the starting point deviation, the respondents are allowed sufficient time for consideration in the inquiry process. To a certain level, this method has higher validity than the open-ended and closed-ended CVMs [63,65].

3.2.4. Payment Card Method

In this method, the inquirer provides a price list and asks respondents for the highest amount they are willing to pay. The method avoids using a single inquiry point. In contrast to the open-ended CVM, this method allows respondents to understand the inquiry reason. Because the prices of the highest and lowest limits must be provided, the inquiry method can reduce the deviation problems arising from different starting prices [63,64].

The four aforementioned methods have advantages and disadvantages. The empirical results by Mattia et al. (2013) indicated that the DBDC method yields prices with smaller differences from actual market prices [51]. However, the DBDC method involves directly asking respondents whether they agree on a random price. Thus, the awareness and decision-making of respondents may be limited to that price. The deviations derived from this method influence the accuracy of the final estimated prices [65,66]. To solve this problem, the open DBDC method can be used, which combines the open-ended CVM and DBDC method. After two inquiries, the questionnaire allows respondents to freely fill out the prices they are willing to pay. Thus, the problems of limited WTP price intervals as well as limited willingness of respondents can be solved [49]. Consequently, this study adopted the open DBDC method of CVM. After two inquiries, respondents were guided to answer with the amount they were willing to pay. They only needed to answer if they were willing to pay a certain amount to buy the houses in the peripheries of MRT stations. Thus, the difficulty in answering was reduced, and the valuation results were reliable. In addition, to solve the problem of the initial prices proposed by respondents being too low, before designing the questionnaire, this study first conducted a pretest questionnaire survey. Subsequently, the model of the open-ended method was used to determine the price basis for the official questionnaire.

Empirical studies that adopt the CVM for elicitation mostly use a general continuous regression model for calibration. Although the calibration results can help determine the respondents' WTP, low explanatory power of the model is frequently obtained because WTP is a constrained continuous variable rather than a general continuous variable. Therefore, this study adopted a Tobit regression model with WTP as a constrained continuous variable within a given range. The use of the Tobit model for analysis can prevent measurement or sample errors caused by unobservable factors. The WTP function is expressed as follows:

$$WTP_i = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_2 + \beta_3 \times X_3 + \cdots + \beta_n \times X_n + \varepsilon_i \tag{1}$$

where WTP_i represents the *WTP* additional prices per square meter for houses in the peripheries of MRT stations; this variable is assumed to be continuous. $\beta_0 \ldots . \beta_n$ represent the calibration coefficients; $X_1 \ldots . X_n$ represent the independent variables affecting WTP; ε_i presents the random error term; n represents the number of independent variables; and i represents the sample size. The *WTP* of individual respondents and average *WTP* are expressed in Equations (2) and (3), respectively.

$$W\hat{T}P_i = \beta_0 + \beta_1 \times X_1 + \cdots + \beta_n \times X_n + \varepsilon_i \tag{2}$$

$$\overline{WTP} = \frac{\sum_{i=1}^{N} W\hat{T}P_i}{N} \tag{3}$$

3.3. Estimation of the WTP Prices for Houses in the Peripheries of MRT Stations

After the questionnaire survey was completed, basic statistical tests (correlation analysis, tolerance analysis, and variance inflation factor calculation) were performed to verify whether the factors influencing house prices in the peripheries of stations collected in this study were appropriate. Subsequently, LIMDEP was used to establish Tobit regression models for elevated and underground stations. The factors influencing house prices in the peripheries of MRT stations in the Taipei metropolitan area were clarified. Then, the prices that respondents were willing to pay to buy such houses compared with regular houses were estimated.

4. Questionnaire Design and Survey

The questionnaire survey in this study was divided into two stages. In the first stage, through the inquiry model of the open-ended method, the initial price basis was determined for use in the official questionnaire in the second stage. For the second-stage questionnaire, the respondents' opinions regarding the factors that influence house prices in the peripheries of stations were collected. Later, the respondents were guided step by step to propose additional prices they would be willing to pay to buy the houses in the peripheries of the MRT stations by using the inquiry model of the open DBDC method designed in this study. The details are provided in the following subsections.

4.1. First-Stage Questionnaire

The contents of the first-stage questionnaire first allowed respondents to assess the positive and negative conditions of amenities and environmental qualities in the areas surrounding MRT stations. Subsequently, they were provided with the average price per square meter of the administrative district of the MRT station as well as the average price per square meter of the houses within 500 m of that MRT station. Then, the respondents were asked how much money they would be willing to pay per square meter to buy a house in the peripheries of the MRT stations based on the average unit price of the houses in that administrative district.

The house prices in the administrative districts where the six MRT stations are located as well as the prices of houses within 500 m of these stations from October 2016 to October 2018 were obtained from the Real Estate Actual Price Inquiry website of the Ministry of the Interior, Taiwan. A total of 2857 house transaction data items were found for these 2 years in Shilin and Beitou Districts, where the elevated MRT stations (Mingde, Qilian, and Beitou Stations) are located, with an average house price of US$3847 per square meter. Within 500 m of these 3 MRT stations, 46 house transaction data items were found, with average house prices per square meter of US$4854 (Mingde Station), US$6026 (Qilian Station), and US$5750 (Beitou Station). For Wenshan and Xindian Districts, where the underground MRT stations (Wanlong, Dapinglin, and Xindian District Office Stations) are located, 8416 house transaction data items were recorded in the recent 2 years, with an average house price of US$4506 per square meter. Within 500 m of these 3 MRT stations, 84 house transaction data items were recorded, with average house prices per square meter of US$5201 (Wanlong Station), US$5566 (Dapinglin Station), and US$5002 (Xindian District Office Station). The surrounding areas of the six stations were included in the survey in this study. Thus, the related price information of these six areas differed in the questionnaire. An example of an item of the first-stage questionnaire for Wanlong Station, an underground MRT station, is presented as Box 1.

Box 1. Questions of the first-stage questionnaire.

> According to the house prices announced by the government, the average unit price of houses in Wenshan District, Taipei City, from October 2016 to October 2018 was US$4015 per square meter. Considering the amenities and environment qualities of the peripheries of the MRT station, how much money per square meter would you be willing to pay additionally on the basis of the average unit price of US$4015 to buy a house within 500 m of Wanlong Station?

When questionnaires designed with the CVM are used, individuals who object to the survey may not respond to any questions; some may provide positive responses, but invalid bids (outliers); whereas others may state a value of zero for a good that they actually value (protest zero bids) [67]. The questionnaire used in this study focused on identifying the respondents' WTP additional prices for houses in the peripheries of mass transit stations based on the prices of regular house after they considered the amenities and environmental qualities in these areas. Therefore, if the respondents believed that living in the special area provided no benefit, the WTP additional price would be zero, indicating that the respondents were only willing to purchase house products with regular housing prices. Given the characteristics of this study, the responses were acceptable.

The first-stage questionnaire survey was conducted from 6 to 12 November 2018. After invalid samples with omissions or contradictions were omitted, 277 valid questionnaires were retrieved from the surrounding areas of the 6 stations. Subsequently, to avoid respondents' positive but invalid bids and subsequent bias in WTP estimation, we ranked the WTP prices of the six stations from high to low. The highest 10% of prices for houses in the peripheries of each station were considered outliers and removed. The remaining 90% of the sample was calculated using quantiles and organized into five price groups for each of the six stations (as shown in Table 2). The five price groups were used as the initial price basis for the second-stage questionnaire. The halved prices of the five groups were used as the basis for price increment or decrement for the second elicitation in the second stage.

Table 2. Willing-to-pay price distribution in the first-stage questionnaire (unit: US$/m^2).

Group \ Station Amount	Elevated MRT Stations		
	Mingde Station	**Qilian Station**	**Beitou Station**
1	100	500	500
2	200	1000	800
3	400	1600	1200
4	700	1800	1300
5	1000	2200	1800
Group \ Station Amount	**Underground MRT Stations**		
	Wanlong Station	**Dapinglin Station**	**Xindian District Office Station**
1	300	200	200
2	500	250	250
3	600	300	300
4	800	500	400
5	1000	800	500

Data source: Prepared by the authors.

4.2. Second-Stage Questionnaire

The items in the second-stage questionnaire were rated using a five-point Likert scale. The respondents were asked their opinions on the factors influencing the house prices in the peripheries of an MRT station. Subsequently, according to the five sets of WTP prices obtained from the first-stage questionnaire, each respondent was guided to provide the additional prices they would be willing to pay to purchase a house in the area surrounding the MRT station studied. The collected data were used in the Tobit regression models to confirm the WTP prices of respondents for houses near each MRT station by using the respondents' perceived factors affecting prices of such houses. An example of the item of the second-stage questionnaire for Wanlong Station, an underground MRT station, is presented subsequently.

According to the results of the first-stage survey, five sets of inquiry amounts were confirmed for each area; the amounts were separately included, thus yielding five versions of questionnaire for each MRT station. The second-stage survey was conducted from 28 November to 7 December 2018. In the surrounding area of each station, 200 questionnaires were distributed, totaling 1200 questionnaires for the surrounding areas of all stations. After invalid samples with omissions or contradictions were eliminated, 526 valid questionnaires remained for the peripheries of the elevated MRT stations, whereas 567 valid questionnaires remained for the peripheries of the underground MRT stations, is presented as Box 2.

Box 2. Questions of the Second-stage questionnaire.

According to the house prices announced by the government, the average unit price of houses in Wenshan District, Taipei City from October 2016 to October 2018 was US$4015 per square meter. The average unit price of houses within 500 m of MRT Wanlong Station was US$5200 per square meter, which is US$1185 higher than the average unit price in Wenshan District.
Considering the amenities and environmental qualities of the peripheries of MRT stations, are you willing to pay US$500 per square meter in addition to the price of US$4515 per square meter to buy a house in the periphery of MRT Wanlong Station, based on the average unit price of the houses in Wenshan District being US$4015 NTD per square meter?

□ Yes

→ Would you be willing to pay the additional amount of money if it were increased to US$750 (at US$4765 per square meter)?
□ Yes □ No

□ No

→ Are you willing to pay the additional amount of money if it were reduced to US$250 (at US$4265 per square meter)?
□ Yes □ No

If the aforementioned amount is not what you have in mind, please fill out the blank below with the amount you are willing to pay. On the basis of the average house price being US$4015 per square meter in Wenshan District, the maximum amount of money you are willing to pay additionally to buy a house in the periphery of MRT Wanlong Station is US$_______ per square meter.

5. Empirical Results

5.1. Basic Statistical Tests

In this study, basic statistical tests were conducted on the 13 factors influencing house prices in the peripheries of MRT stations obtained from the second-stage questionnaire survey. Thus, it was determined whether these factors were suitable for incorporation in the Tobit regression model. In addition, the factors that needed to be eliminated in model calibration to prevent deviations in the model results were determined.

The tolerance value and variance inflation factors were determined. For the questionnaire data of the peripheries of both the elevated and underground stations, the tolerance values of all 13 influencing factors were larger than 0.1, and the variance inflation factors for all 13 influential factors were less than 10. This indicated that none of these factors had multicollinearity. The results of the correlation analysis indicated that for the questionnaires in the peripheries of the elevated stations, the r value between "pedestrian walking systems around the stations improve the convenience of the overall walking space (GQ5)" and "traffic congregation influences the serenity of the living environment (BQ5)" was 0.827, indicating a strong correlation. For the peripheries of the underground stations, the r value between "additional public art installations to the stations improve the esthetics of the living environment (GQ6)" and "traffic congregation influences the air quality of the living environment (BQ2)" was 0.811, indicating that the two factors exhibited a strong correlation. The results served as a reference for the deletion of influencing factors in the calibration of the Tobit regression model.

5.2. Calibration Results of the Tobit Regression Model

Tobit regression models for the peripheries of the elevated and underground MRT stations were established, and the likelihood–ratio indexes (ρ^2) were 0.2257 and 0.2509, respectively. This indicated that the two models had favorable goodness of fit and significant explanatory power.

As shown in Table 3, the factor "diverse public transportation provides fast and convenient transfer functions (GQ2)" exhibited a significant positive effect in the model of elevated stations; specifically, elevated MRT stations can lead to the congregation of related transportation facilities (e.g., bus stations, public bicycle rental stations, and taxi stops). The higher the recognition levels respondents had for this transportation transfer function, the more they were willing to pay to buy houses in the peripheries of these stations. However, this factor was not significant in the model of underground stations. This may be because the MRT routes in the Taipei metropolitan area pass through areas with narrow roads and dense buildings. Consequently, a construction method wherein both the rails and station facilities were set up underground had to be adopted. Only the entrances and mechanical and electrical facilities were established above the ground. Thus, the land areas on the ground are insufficiently large for supportive transportation transfer facilities. For elevated stations, land areas of a certain range must be used for the tracks. In addition, the land on the ground or elevated levels must be used by the stations. Consequently, more space is available for transportation transfer facilities; residents in the peripheries of elevated stations are not limited to using the MRT system alone, and the convenience of using other transportation for residents is high. By contrast, underground MRT stations do not have these functions. The factor "additional open space at the stations improves the recreational functions of the living environment (GQ4)" showed a significant positive effect in the models of both types of stations. This was because both elevated and underground stations, particularly elevated stations, have open spaces around them. These recreational facilities directly create benefits of amenities for people and thus increase their willingness to pay higher house prices. Notably, the factor "mixed land use provides abundant and convenient commercial functions (GQ3)" was not significant in both the elevated and underground station models. These results indicate that the commercial functions of the peripheries of MRT stations in the Taipei metropolitan area are insufficient for respondents to pay an additional price for houses in the areas. This can be attributed to the highly concentrated and mixed land use pattern in Taiwan's urban development, in contrast to that of Western countries. In the Taipei metropolitan area, people's needs for commercial services are satisfied easily and conveniently. Consequently, people do not particularly desire to live in the surrounding areas of stations to obtain superior daily life services.

Table 3. Regression model results for the additional willing-to-pay prices for houses in the peripheries of MRT stations.

Station Type Variable	Elevated MRT Station		Underground MRT Station	
	Coefficient	*p*-Value	Coefficient	*p*-Value
Constant	64.1115	0.8561	307.5472	0.4933
GQ1	−82.4639	0.3209	81.6459	0.1424
GQ2	244.1896 ***	0.0044	48.4192	0.2498
GQ3	−39.0976	0.5336	−35.2468	0.4407
GQ4	169.7697 **	0.0103	108.6497 ***	0.0095
GQ5	76.2604	0.1528	−26.8994	0.4967
GQ6	−83.8331	0.1500	56.7177	0.2156
BQ1	−36.7867	0.4031	−51.9199*	0.0739
BQ2	0.4426	0.9941	0.6542	0.1785
BQ3	3.6184	0.9367	48.9747	0.1424
BQ4	−97.5535 *	0.0595	−32.7417	0.4285
BQ5	−62.6702	0.3564	−48.6202	0.2525
BQ6	−46.5519	0.4162	−65.2189 *	0.0645
BQ7	86.4634	0.1110	−86.3589 **	0.0101
USE	−30.7837	0.7044	67.2104	0.2282
AGE	34.0040	0.3640	−60.6347	0.2290
COU	193.3824 **	0.0168	166.7056 ***	0.0041
CT	−95.0298	0.1152	86.4056	0.2011
EDU	26.5146	0.5989	127.3080	0.1310
INC	110.7526 ***	0.0009	107.7989 ***	0.0000
ρ^2	0.2257		0.2509	

Data source: Prepared by the authors. Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Regarding negative influential factors, the factor "crowds influence the cleanliness of the living environment (BQ4)" exhibited a significant negative effect only in the elevated station model. This is because elevated stations have larger hinterlands and have corridor space under the elevated rails. Consequently, vendors often gather there for business, and relatively busy commercial activities have negative effects on surrounding areas in terms of environmental cleanliness. Regarding the underground station model, the three factors "traffic congregation results in insufficient parking space (BQ1)," "noise and vibrations produced by the MRT system influence the serenity of the living environment (BQ6)," and "buildings and additional facilities of MRT stations influence the landscapes of the living environment (BQ7)" exhibited significant negative influences. These findings indicate that the stronger the perception of these three factors among the respondents, the less willing they are to pay more for houses in the peripheries of underground stations. Such results are clearly related to the structural patterns of underground stations. As mentioned earlier, underground stations require a small land area at ground level. Consequently, parking space is insufficient, which results in inconvenient parking in the peripheries of underground stations. In addition, because of the space problem, transformer boxes and ventilation facilities can be set only next to streets. Thus, the respondents had negative feelings toward the landscapes of underground stations. Generally, the established impression of elevated stations is that the tall stations and tracks affect the visual landscapes of the surrounding areas. However, the empirical results indicated otherwise possibly because in the construction design phase of elevated stations in the Taipei metropolitan area, the fusion of station forms with the surrounding buildings was already valued. Thus, inharmony between station forms and the surrounding environment was avoided. In addition, the stations and corridor space under the tracks increase residents' accessibility to green space and street furniture. Thus, residents do not have negative feelings toward the visual landscapes. In addition, underground stations are mostly in areas with narrow roads and concentrated buildings. Low-frequency noise and vibrations created when MRT trains pass through also caused respondents to doubt the serenity of the living environment.

Regarding personal social economic conditions, family income exhibited a significant positive effect in the models of both station types. This indicates that the higher the family income, the more willing respondents are to pay more for houses in the peripheries of stations. This result is consistent with that of Lund (2006), who conducted investigations in the San Francisco Bay Area, Los Angeles, and San Diego [18]. People who currently lived within 500 m of an MRT station also exhibited a significant positive effect on the results of both models. This indicates that people currently living in the peripheries of stations (in their own houses or rented housing) are willing to pay more for houses also in the said peripheries. This result can be interpreted as indicating that respondents who currently live in the peripheries of stations still believe that houses in those areas are worth more after experiencing the advantages and disadvantages of living there.

5.3. WTP Prices for Houses in the Peripheries of MRT Stations

The Tobit regression model established in this study is shown in Equation (4). WTP_i presents the WTP additional prices per square meter for houses in the peripheries of MRT stations; $\beta_0 \ldots \beta_{20}$ represent the calibration coefficients; ε_i represents the random error term; $GQ_{1\ldots}GQ_6$ represent the positive factors influencing house prices in the peripheries of MRT stations. $BQ_{1\ldots}BQ_7$ represent the negative factors influencing house prices in the peripheries of MRT stations. USE, AGE, COU, CT, EDU, INC represent the factors of personal social economic conditions.

$$\begin{aligned} WTP_i = \beta_0 + \beta_1 GQ1 + \beta_2 GQ2 + \beta_3 GQ3 + \beta_4 GQ4 + \beta_5 GQ5 + \beta_6 GQ6 + \beta_7 BQ1 \\ + \beta_8 BQ2 + \beta_9 BQ3 + \beta_{10} BQ4 + \beta_{11} BQ5 + \beta_{12} BQ6 + \beta_{13} BQ7 \\ + \beta_{14} USE + \beta_{15} AGE + \beta_{17} COU + \beta_{18} CT + \beta_{19} EDU + \beta_{20} INC + \varepsilon_i \end{aligned} \quad (4)$$

According to Equation (4), this study establishes WTP estimation models for elevated and underground stations in Equations (5) and (6) respectively. This can be used to estimate the extra price people would be willing to pay to buy the houses in the peripheries of the MRT, compared with regular houses.

$$\begin{aligned} W\hat{T}P_i = 64.1115 + 244.1896 \times GQ2 + 169.7697 \times GQ4 - 97.5535 \times BQ4 \\ + 193.3824 \times COU + 110.7526 \times INC + \varepsilon_i \end{aligned} \quad (5)$$

$$\hat{WTP}_i = 307.5472 + 108.6497 \times GQ4 - 51.9199 \times BQ1 - 65.2189 \times BQ6 \\ -86.3589 \times BQ7 + 166.7056 \times COU + 107.7989 \times INC + \varepsilon_i \quad (6)$$

As shown in Table 4, the average market price of the houses in the peripheries of the elevated MRT stations is US$5543 per square meter. This is up to US$1696 higher than the average market price of houses in the administrative district where the stations are located, with a difference of more than 40%. The estimation results indicated that when the average market price in the entire administrative district was US$3847, the respondents were willing to pay an additional US$304 per square meter to purchase houses in the peripheries of elevated stations, that is, they were willing to pay up to US$4151 per square meter. The average market price of the houses in the peripheries of the underground MRT stations is US$5295 per square meter. The difference between this price and the average market price of houses in the districts where the stations are located is US$941, which is 21.6% higher. This study estimated that after considering the advantages and disadvantages of the amenities and environment qualities of the peripheries of stations, the respondents were willing to pay an additional US$257 per square meter for houses, with the average house price of all administrative districts as their basis for judgment. Specifically, the respondents were willing to purchase houses in the peripheries of underground MRT stations at a price of US$4611 per square meter. Accordingly, the TOD-based living fields caused the housing submarket in the peripheries of mass transportation stations to develop differently from the housing submarket in ordinary regions, affecting individuals' willingness to pay for housing. Specifically, the empirical results of this study revealed that, in the Taipei metropolitan area, the establishment of mass transit stations changed the amenities and environmental qualities of the adjacent peripheries. After consideration of the advantages and disadvantages of living in such regions, individuals were more willing to pay higher prices in such housing submarkets than in ordinary ones.

Table 4. Prices that the respondents were willing to pay and the market prices of houses in the peripheries of the MRT stations.

Item		Elevated Station	Underground Station
House market price	Average market price of houses in the administrative districts in which the stations are (US$/m^2)	3847	4354
	Average market price of houses in the peripheries of the stations (US$/m^2)	5543	5295
	Price difference of houses between the peripheries of the stations and the administrative districts (US$/m^2)	1696	941
	Price difference ratio of houses in the peripheries of the stations and in the administrative districts (%)	44.10	21.60
Respondents' WTP price	WTP price of respondents living in the peripheries of the stations	476	471
	WTP price of respondents not living in the peripheries of the stations	214	136
	WTP price of houses in the peripheries of the stations (US$/m^2)	304	257
	Average price of houses in the peripheries of the stations (US$/m^2)	4151	4611
-	Ratio of respondents' WTP price to the average market price in the administrative districts (%)	7.89	5.91
-	Price difference between the average market price of houses in the peripheries of the stations and the respondents' WTP price (%)	33.55	14.82

Data source: Prepared by the authors.

In addition, perceptions regarding the advantages and disadvantages of the amenities and environmental qualities derived from the surrounding areas varied among respondents for different station types. Consequently, the additional WTP prices also differed when respondents made purchase decisions for houses in these areas. For houses near elevated stations, the respondents were willing to pay approximately an additional 7.89% above the average market price of houses in the entire district per square meter. For those near underground stations, the respondents were willing to pay approximately an additional 5.9% above the average market price of houses in the entire district per square meter. The results of the Tobit regression models were further used to explain the reasons for these findings. In the constructed models, transportation transfer convenience as well as the open and recreational space near the elevated stations generated positive effects, thereby increasing the respondents' willingness to pay more. Only the factor of unfavorable cleanliness of the environment surrounding the stations negatively influenced the WTP prices. Underground stations have more factors that negatively influence WTP prices, including traffic congregation causing insufficient parking space, noise and vibrations generated by the MRT system influencing the amenity of the living environment, and buildings and additional facilities of the MRT station influencing the landscapes of the living environment. Consequently, the houses in the peripheries of elevated stations were slightly more attractive to respondents compared with those in the peripheries of underground stations. To conclude, the respondents were willing to pay prices higher than those of average houses to own houses in the peripheries of the MRT stations to enjoy more diverse transportation services, open space, and recreational facilities. Therefore, the first study hypothesis was supported.

The differences in the current residential locations of respondents were further observed. For both elevated and underground stations, the respondents currently living in the peripheries of stations were willing to pay more than those who did not live in such areas. In addition, the price differences were up to 1.22 and 2.45 times higher for houses near elevated and underground stations, respectively. Compared with respondents who did not live in the peripheries of stations, who offered more conservative prices, the respondents already living in those areas were willing to pay more for houses in those areas. This was because they were already dependent on the additional advantages of the surrounding areas of stations in their daily lives.

However, in the peripheries of both the elevated and underground stations, the current house market prices were higher than those that the respondents were willing to pay. In the peripheries of the elevated stations, the market prices of houses were 33.55% higher than the house prices respondents were willing to pay. For houses in the peripheries of underground stations, the market prices were 14.82% higher than the prices respondents were willing to pay. Since the MRT started operation in the Taipei metropolitan area in 1996, the expansion of MRT routes has been ongoing. When land development and urban renewal are conducted in the peripheries of stations, the marketing of house products mostly emphasizes the advantages derived from being near MRT stations. Thus, the particularity of houses in the peripheries of MRT stations is gradually being established. Under such market trends and the registration system for the actual selling prices of real estate effective since 2012, sellers must report the actual transaction prices of house products to competent authorities. This credible price information system has an anchoring effect on the market. Although prospective house buyers have their suitable WTP price for a house product, they must accept existent transaction prices on the market to obtain market-oriented special houses. Consequently, the market prices for this special housing type increase gradually, even to a level beyond the value that home buyers assume. This result verified the second hypothesis.

6. Conclusions

Growth management refers to the introduction of urban growth activities to suitable areas at the appropriate time. Moreover, public transit is used to connect land use activities and construct urban residential living environments with a concentrated mixed use of residential and commercial zoning. Thus, the urban sprawl of a metropolis is slowed. In addition, the efficiency of land and environmental use is increased, thus increasing construction investment. Based on this idea of sustainable development, local governments can use the TOD strategy to reconstruct land use patterns in the peripheries of public transit stations (including increasing the efficiency of the mixed use of residence and commerce, increasing building height, and renewing pedestrian walkways). Thus, people's dependence on vehicles for personal transport is expected to decrease, and the problems of worsening traffic congestion, air pollution, and noise pollution will be subsequently reduced. The sustainable planning of this type of metropolis also allows houses in the peripheries of public transit stations to become a special product in the housing market. In this study, the Taipei metropolitan area was used as an example, and a questionnaire was designed using the open DBDC model based on the CVM. After the respondents considered the advantages and disadvantages of the amenities and environmental qualities of the peripheries of MRT stations, the additional prices they would be willing to pay to purchase houses in those areas compared with those for regular houses were estimated. Thus, the present research clarified whether the living environment shaped by the land use patterns that fit sustainable development are popular. Additionally, the results reflect the actual housing prices and the presence of price gouging. The findings are described in three aspects as follows:

First, CVM is generally used to estimate the value of nonmarket goods. However, the method can also be used for market goods for which prices are currently unavailable. Studies regarding real estate prices have mostly used the CVM to explore the effect of environmental pollution on housing prices [50–54,56–61,68]. This study applied CVM to explore the WTP of houses in the peripheries of mass transit stations. It is different from other studies that focus on the housing market price level changes before and after the operation of mass transit stations, the scope of effect, and their causes [15–31]. This study is the first to use the CVM to estimate the house prices of the peripheries of public transit stations. The respondents were allowed to consider their positive and negative feelings toward amenities and environmental qualities if they lived in these areas and determine the house prices they would be willing to pay. An empirical analysis was used to demonstrate the differences between the market prices of houses in the peripheries of MRT stations and the prices that the respondents were willing to pay. This organized empirical design framework may serve as a reference for relevant future studies.

Second, the empirical results suggested that the recreational functions of peripheries are improved by the additional open space near both elevated and underground MRT stations. Thus, people are willing to pay more for houses in these areas compared with regular houses. Next, the introduction of TOD strategies in urban planning entails using mixed land use to improve the commercial functions and convenience of residents' daily lives. Thus, the attractiveness of the areas surrounding public transit stations is increased. This is the main reason for the higher housing prices in the peripheries of public transit stations in European and North American countries. However, current land use patterns in urban areas in Taiwan are already concentrated with a mix of residence and commerce. Therefore, people can satisfy their needs for commercial services easily and conveniently with the shops near their houses without the demand of living in the peripheries of public transit stations to obtain superior commercial services. Therefore, abundant commercial function is not why people are willing to pay more to purchase houses in these areas. This finding is different from the development characteristics of urban areas in European and North American countries. In the Taipei metropolitan area, both elevated and underground stations provide open space that can improve the leisure functions of the peripheries, thus increasing people's WTP for house products in the peripheries of the stations than regular house products. Apart from the positive factors that affect housing prices in the peripheries of mass transit stations in the Taipei metropolitan area, factors such as insufficient parking space and the compromised tranquility of the residential environment due to noise and vibrations resulting from the MRT system negatively affect people's decisions to purchase houses in the peripheries of MRT stations. Because elevated stations feature greater hinterland areas and corridor spaces beneath the elevated railways, the relatively more active commercial activities and intense crowds negatively affect the environment; this effect is reflected in people's house purchase decisions. The negative factors affecting the housing prices of the peripheries of the stations are similar to those in European and North American metropolitan areas [14–16].

Third, respondents were willing to pay more for houses in the peripheries of both elevated and underground stations after considering the advantages and disadvantages of living in these areas. However, they perceived the advantages and disadvantages of living in the surrounding areas of different types of MRT stations differently, leading to different additional prices that they were willing to pay for houses near those stations. The additional amount people were willing to pay per square meter was approximately 7.89% and 5.9% more than the average market price of houses in the entire administrative district for houses in areas surrounding elevated stations and underground stations, respectively. In addition, in daily life, people already living in the peripheries of stations were dependent on the additional advantages of such areas. Thus, their WTP price was higher than that of people who did not live in such areas. Furthermore, this study verified that the market prices of the houses in the peripheries of MRT stations were higher than the prices people were willing to pay after considering the advantages and disadvantages of amenities and environmental qualities. Specifically, the market price of houses in areas surrounding elevated stations was 33.55% higher, and that of houses in areas surrounding underground stations was 14.82% higher, indicating that the market prices of this type of house product already surpass the values they should have.

To conclude, people are willing to pay more to purchase this type of house product in the Taipei metropolitan area compared with regular houses. This indicates that the TOD-based living fields are popular to some degree. However, the factors affecting amenities and environmental qualities of the areas surrounding transit stations differ between Taiwan and European and North American countries. Subsequent studies can use the analytical framework established in this study to further discuss the situations of Asian metropolises such as Shanghai, Hong Kong, Seoul, and Tokyo. The results of the study systematically present the characteristic differences in urban development between Asian and Western countries. Thus, current planning ideas and strategic systems created according to the characteristics of urban areas in Western countries can be further examined to clarify the required adjustments for the implementation of such ideas and strategies in Asian cities. In addition, similar to Western countries, the prices of houses in the peripheries of MRT stations are higher than those of regular houses. For middle-class and young populations, buying houses in such areas is difficult. However, according to the social development characteristics of the Taipei metropolitan area, Taipei residents comprise the major population that commutes using the MRT. Individuals living a certain distance from MRT stations continue to use private vehicles for their commutes or other transfer transportation. Thus, to increase the benefits of TOD and implement growth management in the Taipei metropolitan area, the structural predicament caused by current market mechanisms should be gradually improved by adjusting related policies and establishing complementary measures. Regarding housing policy adjustment, the supply of affordable housing and social housing in the peripheries of MRT stations should be increased with a floor area incentive mechanism. Thus, opportunities for middle-class and young populations to buy or rent houses in the areas surrounding stations can be increased. In other words, new buildings must be composed of certain ratios of affordable or social housing to obtain additional floor area. Moreover, regarding the adjustment of land use projects, transit-oriented corridors should be introduced in TOD for urban renewal projects or large-scale block remodeling should be adapted in the peripheries of MRT stations in the future. The planning of space corridors should be combined with the development of areas surrounding multiple MRT stations. A basis for pedestrian-oriented space should be created through overall network connections, walking corridor configuration, and reinforcement of commercial facilities along streets.

Finally, by using data such as the house price-to-income ratio, future studies can identify whether housing price levels in the peripheries of the stations exert an excessive load on prospective house buyers. Furthermore, questionnaires can be used to obtain detailed demographic data of prospective house buyers, such as household compositions and the area of houses to be purchased. In this way, the variance on the affordability of houses for buyers with different socioeconomic backgrounds will be analyzed. In addition, in the entire MRT network, differences in station scale, relative location, and functional orientation generate various types of stations. The market characteristics of houses in the peripheries of stations also differ, thereby forming different housing submarkets and engendering different levels of attractiveness to prospective house buyers. Future studies should set different types of stations as targets to compare the characteristics of prospective house buyers' house purchase decisions and WTP prices in different housing submarkets.

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The Unequal Impact of Natural Landscape Views on Housing Prices: Applying Visual Perception Model and Quantile Regression to Apartments in Seoul

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Abstract: Natural landscape views have positive sides, such as providing restorative effects to urban residents, and negative sides, such as deepening wealth inequality. Previous studies have mainly focused on the positives and rarely on the negatives. From this perspective, this study aimed to analyze the unequal impact of natural landscape views on housing prices for apartments in Seoul. We proposed a visual perception model to analyze natural landscape views and, based on a hedonic price model, we used ordinary least squares and quantile regression to estimate the marginal impacts on housing prices. The results show that: (1) natural landscape views had positive impacts on housing prices, but their impacts did not reach the level of structural and locational characteristics such as apartment area and the distance to subway stations; (2) natural landscape views had different marginal impacts by housing price range and, in particular, had much higher value-added effects on higher-priced apartments, meaning that if old apartment complexes are redeveloped into high-rise ones, the improvement in natural landscape views generates great profit for apartment owners and intensifies wealth inequality; (3) the geographic information system-based visual perception model effectively quantified the natural landscape views of wide areas and is thus applicable for the rigorous analysis of various landscape views.

Keywords: natural landscape; views; visual perception; housing price; hedonic price model; quantile regression; marginal impact; wealth inequality

1. Introduction

A natural landscape consists of a collection of landforms such as mountains, rivers, and lakes as well as natural vegetation [1]. Views of such landscapes have restorative effects and provide psychological comfort to urban residents [2,3]. Therefore, consumers are willing to pay more for homes with good natural landscape views [4]. In light of this, researchers have attempted to analyze the impacts of natural landscape views on housing prices, generally using hedonic price models [5]. A hedonic price refers to the unit price of structural, locational, and environmental characteristics of housing, such as area, floor level, and proximity to a primary school [6]. The hedonic price is typically estimated by using ordinary least squares (OLS) regression, and the estimated coefficient is also described as a marginal impact [7]. The marginal impact of a natural landscape view refers to the change in housing price for a unit change of the view variable, all other independent variables being constant. Most studies have found that the marginal impact of the natural landscape view had positive values, supporting that natural landscape views positively affect urban residents [4,8–23].

Based on the mean of price distribution, OLS regression estimates marginal impacts equally for all housing. However, this is not an appropriate analysis method for segmented markets, such as low-, mid-, and high-end housing markets [7,24]. Several studies have indicated quantile regression as an alternative to OLS regression, as quantile regression coefficients are estimated differently across the conditional distribution of housing prices [7,19,25–30]. OLS minimizes the sum of squared residuals, whereas quantile regression minimizes the sum of asymmetric weighted absolute values [31]. Indeed, several studies have used quantile regression to analyze the impact of natural landscape views on housing prices. Some showed that natural landscape views had a much higher value-added impact on higher-priced housing than on lower-priced housing [32], whereas others found the opposite [7,28]. To draw definite conclusions, a complementary study using quantile regression should be performed. Moreover, previous studies have focused mainly on measuring the marginal impacts of natural landscape views, and have not been concerned with the related social problems. Considering the public nature of natural landscape views, it is necessary to examine the related social issues. In the study, we tried to address these issues by examining the Seoul housing market.

In Seoul, the capital of Korea, housing prices have risen significantly in recent years. As housing prices rose, wealth inequality between homeowners and non-owners deepened, and as the prices of expensive housing rose even further, wealth inequality among homeowners grew as well [33]. In particular, the housing prices of apartment complexes preparing for redevelopment rose significantly. In Korea, an apartment is a self-contained housing unit and a type of residential real estate. An apartment complex consists of one or more buildings, with more than five floors, divided into units that are owned and sold individually. The rise in the housing prices of old apartment complexes along the Han River has attracted particular attention. The reason for this lies in the expectation that redeveloping the old apartment complex into a high-rise one with a good view of the Han River will provide great benefits to apartment owners. This expectation is based on the fact that new apartments along the Han River are the most expensive in Seoul [34]. The Seoul Metropolitan Government strictly controls such redevelopment projects, as profits are attributed to apartment owners. For these reasons, natural landscape views are often criticized as being a cause of deepening wealth inequality.

The situation in Korea shows us that natural landscape views have both positive sides, such as providing restorative effects to urban residents, and negative ones, such as deepening wealth inequality. Despite the importance of reducing wealth inequality in terms of sustainability, previous studies have focused mainly on the positives, and rarely on the negatives. Quantile regression can be effectively used as an analytical method to examine these negative sides. When analyzing the marginal impact by housing price range through quantile regression, it is possible to determine which price ranges get premiums from natural landscape views. From this perspective, this study aimed to analyze the impact of natural landscape views on housing prices for apartments in Seoul. First, we analyzed the marginal impacts of natural landscape views using OLS regression analysis. Next, we analyzed the variation of marginal impacts by price range using quantile regression. Based on the analysis results, we discuss the impact of natural landscape views on deepening wealth inequality.

In order to effectively analyze the impact of natural landscape views on housing prices, it is necessary to measure such views accurately. In many studies, views were analyzed using dummy variables, and categorized as visible and invisible, or visible, partially visible, and invisible [4,5,9,10,15,35–37]. However, these studies did not show an objectively testable method of measuring views; it is difficult to know how the view was measured and how much was measured. To overcome this limitation, the quantification of views is being attempted. Viewing is possible when there is line-of-sight between the viewpoint and the target object, and visibility analysis is based on this nature of viewing. Viewshed analysis is performed by accumulating visibility analysis for target objects within a certain radius around a viewpoint. As for landscape analysis, various methods have been developed using Geographical Information System (GIS) or Computer-Aided Design (CAD) software as well as a digital elevation model (DEM), which comprises numerical information on terrain topography.

Two major groups of studies on landscape quantification have been performed. One concerned calculating the area of various objects that can be viewed using viewshed analysis [12,17,38–41], and the other involved determining a visual perception using the spatial relationship between a specific target object and a viewpoint to determine the psychological effect of the target object on the observer [42–47]. The former group involved evaluating the landscape by calculating the planimetric area for each target object, although recent studies have improved the accuracy of the analysis by using more precise three-dimensional data [17,41]. The area to be viewed is obtained by overlaying the results of viewshed analysis and land use or land cover information. This analysis technique is limited in that it is impossible to quantify the human visual perception of view by using the planimetric area of the landscape included in the visual field. The latter group of studies quantified the view analysis results using the concept of visual perception. However, the study [42] only evaluated openness among factors affecting property value, and [43] did not analyze irregular topography. Studies [44] and [45] attempted to quantify exact visual perceptions using a solid angle as a viewing unit, but it is necessary to improve the algorithm for applying it to a large area, as these were experimental studies on a small research site. By considering only the vertical view of an object, the entire view and visual perception are not appropriately integrated and analyzed [46]. Since the algorithm in [47] evaluated the landscape using the depth view obtained by projecting the view onto a cylinder, not a hemisphere, it was not able to evaluate the correct visual perception.

As such, conclusive studies have not yet been conducted to evaluate the value of landscapes using the results of view analysis based on visual perception targeting large urban areas where natural and artificial features are mixed. In the study, to analyze the value of natural landscapes in the Seoul metropolitan area, an analysis method was proposed to apply visual perception-based view analysis to wide areas.

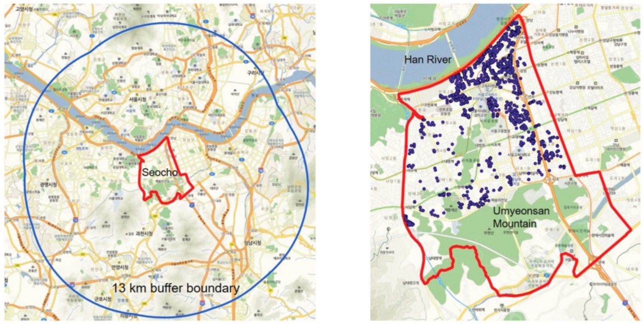
The rest of this paper is organized as follows. Section 2 introduces study area and data, discusses research methods focused on the visual perception model, the hedonic price model, and the quantile regression model, and describes independent variables such as natural landscape view variables and other independent variables. Section 3 presents and discusses the results of an empirical analysis using OLS and Quantile regression. Section 4 discusses wealth inequality, which is the negative side of natural landscape views in connection with apartment redevelopment in Seoul, and additionally discusses the utility of the visual perception model. The final section summarizes the key findings and suggests policy implications.

2. Data and Methods

2.1. Data

In the study, we focused on natural landscape views such as views of greenery and the Han River, excluding views of artificial facilities. Seoul is made up of 25 local government districts called "gu". For the purpose of the study, Seocho-gu was selected due to its relative abundance of natural landscapes and its having the highest ratio of apartments (57.9% compared to 42.0% for the entirety of Seoul [48]). As shown in Figure 1, Seocho-gu has Umyeonsan Mountain to its south, Han River to the north, and the large Seoripul Park in the center. In a GIS-based viewshed analysis, natural landscapes both outside and inside Seocho-gu were analyzed. As shown in Figure 1a, the range for natural landscapes outside Seocho-gu was set to 13 km.

To analyze the impacts of natural landscape views on housing prices, we used apartment transaction data in Seocho-gu in 2013. These data, which were provided by the Seoul Metropolitan Government, consist of 1260 apartments in 193 complexes, and the locations of the apartments are shown in Figure 1b. The data include basic transaction information such as address, area, transaction date, and sale price. Using the addresses of apartments, we were able to locate them in three-dimensional space, which is a necessary prerequisite for GIS-based viewshed analysis.



(**a**) (**b**)

Figure 1. Study area and the distribution of apartments: (**a**) Seocho-gu boundary (red line) and the 13 km buffer boundary (blue line) of the visible range of viewshed analysis; (**b**) the locations of apartments used for the study (blue points).

The structural characteristics of the apartment complex, such as the number of apartments and dwelling age, were extracted from the data provided by R114, a real estate consulting company. The locational characteristics of apartment complexes, such as the distances to subway stations and primary schools, were measured using the near function of ArcGIS.

In Korea, various kinds of spatial information are distributed through the National Spatial Data Infrastructure (NSDI). In the study, the DEM, building, and land cover information from the NSDI's spatial information distribution site [49] was used. A digital surface model (DSM) with a 2-m resolution was constructed using the DEM for Seoul and neighboring areas as well as the height values of the building map (Figure 2). The view of each land cover was analyzed to evaluate the landscape using the sub-class land cover map (2-m resolution) for Seoul and the mid-class land cover map (10-m resolution) for the neighboring regions. Land cover classes such as paddy fields, fields, broadleaf forests, coniferous forests, mixed forests, natural grassland, artificial grassland, and barren land were extracted for evaluation of natural landscape views, and inland wetland and inland water items were extracted for evaluation of the view of the Han River.

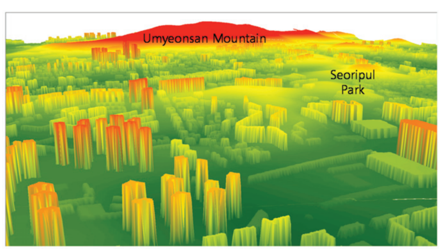


Figure 2. Part of the digital surface model (DSM) from the north.

2.2. Methods

2.2.1. Visual Perception Model

As humans perceive different landscapes differently, they also value them differently. To quantify the human perception of landscapes, all views in the viewshed must be converted into a single unit based on visual perception. Among studies on visual perception, the experimental studies [44,45] have quantified visual perception using a viewing angle. Based on this, we tried to develop a model for evaluating a visual perception in the study.

The visual field corresponds to the viewing angle of the camera, and is about 200° horizontally and 135° vertically in humans. All visible objects occupy a certain region on the retina to form the entire visual field. When an object forms an image on the human retina, it forms a three-dimensional angle proportional to the size of the object and inversely proportional to the square of the distance from the retina, as shown in Equation (1) [50]. As described above, if the area of the retina occupied by the object is converted into a solid angle, the visual angle can be quantified, based on which the value of the landscape can be evaluated.

$$\Omega \sim \frac{A}{r^2} \tag{1}$$

where Ω is the solid angle (in steradian), A is the projected area of the object, and r is the distance between the retina and the object.

Factors involved in visual perception include size, color, and texture, but color and texture are difficult to model because they are affected by irregularities such as weather and season. Therefore, in the study, we tried to quantify the viewing angle only in terms of size, which can be measured using a solid angle. In addition, we proposed a visual perception quantification model that can fully utilize the spatial analysis function of GIS to evaluate landscapes in metropolitan areas such as Seoul. While the viewshed analysis in previous studies did not rely on visual perception, the visibility of the entire area subject to landscape evaluation is still important, so the viewshed was extracted to limit the scope of the visual perception evaluation. As such, this study presented a general visual angle measurement model that can be applied to landscape evaluations by integrating viewshed analysis and visual angle quantification by solid angle. The proposed model is as follows:

(1) Viewshed analysis using a DSM. In an urban space where artificial features such as buildings interfere with the view, a DSM that includes the height information of buildings should be used, rather than a simple DEM. The viewshed analysis uses a distance and a viewing angle that can sufficiently include target objects required for landscape evaluation from a viewpoint. Viewshed analysis uses the raster analysis function of GIS;

(2) Using Equation (2), calculate the actual surface area from the angle of inclination, and generate raster data with the value of surface area only for the ground pixels on which a line of sight is created in the DSM. The angle of inclination is calculated using the slope function of GIS, and the calculation of the surface area uses the raster calculator function

$$A' = \frac{A''}{cos\theta} \tag{2}$$

where A' is the actual surface area, A'' is the planimetric area of pixel, and θ is the inclination angle of the ground surface;

(3) Using the dot product as in Equation (3), calculate the area where the actual surface area is projected in the direction of the viewing point, and create raster data. The normal vector of the ground surface is calculated using the elements of the aspect and slope of the DSM, the aspect is calculated using the raster analysis function of GIS, and the calculation of the projected area uses the raster calculator function

$$A = \overrightarrow{OP} \cdot \overrightarrow{A'} \times A' \tag{3}$$

where A is the projected area, $\overrightarrow{OP}$ is the direction vector of the line-of-sight with the target object as the origin and the viewpoint as the end point, and $\overrightarrow{A'}$ is the normal vector of the ground surface;

(4) The solid angle at which a pixel on the visible ground surface is perceived by a person is calculated by dividing the projected area by the square of the range of sightline using Equation (1). The distance from the observation point to the ground pixel to be analyzed is calculated as the Euclidean distance from the coordinates of the two points, and the raster calculator function is used to calculate the solid angle and generate raster data;

(5) The visibility angle is calculated by summing the solid angle of the raster data created in (4) for each natural landscape item of the land cover to be analyzed. Among the raster analysis functions of GIS, the zonal statistics function is used to sum solid angles.

2.2.2. Hedonic Price Model

A hedonic price model has been widely used to explore the determinants of housing prices. According to [6], the market price of a heterogeneous good like housing is determined by the sum of prices of its characteristics. As these characteristics are not transacted individually but in a bundle, these prices are not individually observed, unlike housing prices that are explicitly revealed. The characteristic price is described as the equilibrium price in the implicit market and is estimated by regressing housing price on the quantity of the characteristic [24]. The hedonic price model typically estimates coefficients using OLS regression. To test the impact of natural landscape views on the housing price P, we assume hedonic price model as the following form

$$P = \alpha + \sum \beta_i V_i + \sum \gamma_j S_j + \sum \delta_k L_k + \sum \theta_m T_m + \varepsilon \quad (4)$$

where V_i are the characteristics of natural landscape views, such as views of greenery and the Han River; S_j are structural characteristics, such as net area of housing and dwelling age; L_k are the locational characteristics, such as distance to subway stations and primary schools; T_m is dummy variables representing the season of transaction; ε is the error term; α, β_i, γ_j, δ_k and θ_m are coefficients to be estimated.

The estimated coefficient refers to the expected value of the partial derivative of the dependent variable with respect to an independent variable, depending the functional form of the hedonic price model. Linear, semi-log, and log–log forms are generally used as functional forms. In the linear form, both the dependent and independent variables go into regression without any transformation [24]. The estimated coefficient indicates the change in the dependent variable for a one-unit change of the independent variable when all other independent variables are held constant. This linear form has an advantage when interpreting the estimated coefficient because it means a marginal impact. In the semi-log form, a dependent variable is logged form and independent variable is linear [24]. The coefficient indicates the rate at which the housing price increases at a certain level, given an independent variable [24]. Marginal impact is found to be somewhat more complex than the linear form in that marginal impact is calculated by multiplying the estimated coefficient by the corresponding values for the mean of independent variables [7]. Since there is no economic theory that informs the selection of a functional form, it is generally selected by considering the research objective and comparing the goodness of fit [26]. In this study, the log–log form in which the dependent and independent variables are in logged form were excluded because the marginal impact is more complexly calculated. The appropriate functional form would be selected between linear form and semi-log form by comparing the goodness of fit.

2.2.3. Quantile Regression Model

Based on the mean of price distribution, the OLS regression assumes that the marginal impacts of physical characteristics are constant across the conditional distribution of housing prices. However, recent studies have shown that marginal impacts are not constant because high-end home buyers value physical characteristics differently from low-end home buyers [29]. Several studies have identified significant variations in the marginal impacts across the conditional distribution of housing prices using quantile regression [7,19,26–29,51]. We assume that the marginal impacts of natural landscape views would vary differently across the conditional distribution of housing prices, in particular being much higher in higher-priced housing. Considering Equation (4), housing price for the quantile τ can be written as

$$P_\tau = \alpha_\tau + \sum \beta_{i\tau} V_i + \sum \gamma_{j\tau} S_j + \sum \delta_{k\tau} L_k + \sum \theta_{m\tau} T_m + \varepsilon \quad (5)$$

where τ represents a quantile point in the distribution of housing prices; and α_τ, $\beta_{i\tau}$, $\gamma_{j\tau}$, $\delta_{k\tau}$, and $\theta_{m\tau}$ are coefficients to be estimated.

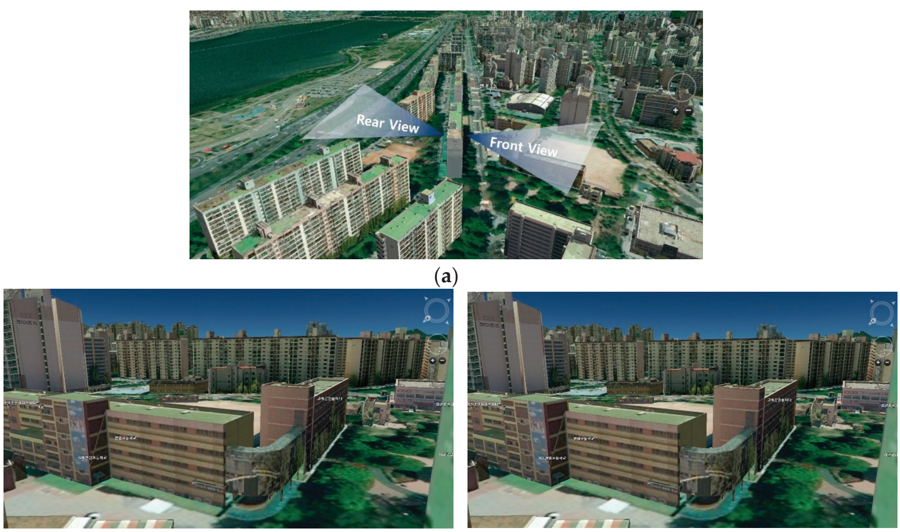
Quantile regression minimizes weighted absolute deviations to estimate conditional quantile functions [31]. For the median ($\tau = 0.5$), symmetric weights are used; for all other quantiles, asymmetric weights are used [7]. The standard errors of coefficient estimates can be feasibly estimated using bootstrapping [52].

2.3. Independent Variables

2.3.1. Natural Landscape Views

To analyze the impact of natural landscape views on housing prices, a database was constructed of the view characteristics. The view characteristic data were constructed by applying the visual perception measurement model described in Section 2.2.1 to the DSM and land cover, and the model was automated using the ArcGIS model builder.

First, a viewshed analysis was performed using ArcGIS. The primary viewpoint for the viewshed was set in the front of the living room, and a secondary viewpoint was set to be spaced apart by the width of the building. The reason for having two viewpoints is that most apartments in Seoul are flat-type, and the views of the front and the rear are greatly different, as shown in Figure 3. As Korean culture values sunlight, the living room is usually located towards the south. As the study area is south of the river, to use Han River views as a variable for the landscape evaluation, both the front view and the rear view must be considered at the same time. In the study, the sum of the viewing angles of the natural landscape, quantitatively calculated for two or more viewsheds according to the shape of the apartment building, was used as the natural landscape view variable.



(**a**)

(**b**) (**c**)

Figure 3. Front and rear views of an apartment in Seocho-gu, Seoul [53]: (**a**) two views of an apartment; (**b**) Part of the front view of (**a**); (**c**) Part of the rear view of (**a**).

Next, viewshed analysis is performed so that the visual perception model can be applied to quantify natural landscape views. Viewshed analysis conditions were set as follows. The height of the viewpoint was given as an offset value considering the floor level of traded apartment. The visible range of the viewshed analysis was set to 13 km, the average visible range of Seoul (Figure 1a), as suggested in the annual air environment report [54], the observation orientation angle was set to the façade direction of the building, and the viewing angle was set to 180° for both the top, bottom, left, and right. Figure 4 shows an example of a viewshed analysis.

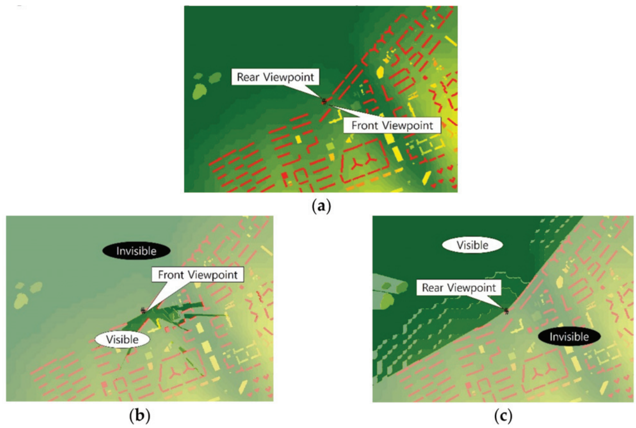


Figure 4. Example of viewshed analysis results: (**a**) Viewpoint overlay with the DSM; (**b**) Viewshed analysis result of front view; (**c**) Viewshed analysis result of rear view.

The slope and aspect of the DSM and the azimuth angles from viewpoints to target points were analyzed using the Spatial Analyst function of ArcGIS. Since the resolution of the DSM is 2 m, the planimetric area of one pixel is 4 m^2. Slope, aspect, and azimuth angle are input into Equations (2) and (3) in ArcGIS Map Algebra to calculate the surface area (Figure 5a) and the projected area (Figure 5b), respectively. The surface area increases in proportion to the ground slope, and the projected area depends on the angle between the viewpoint and the surface.

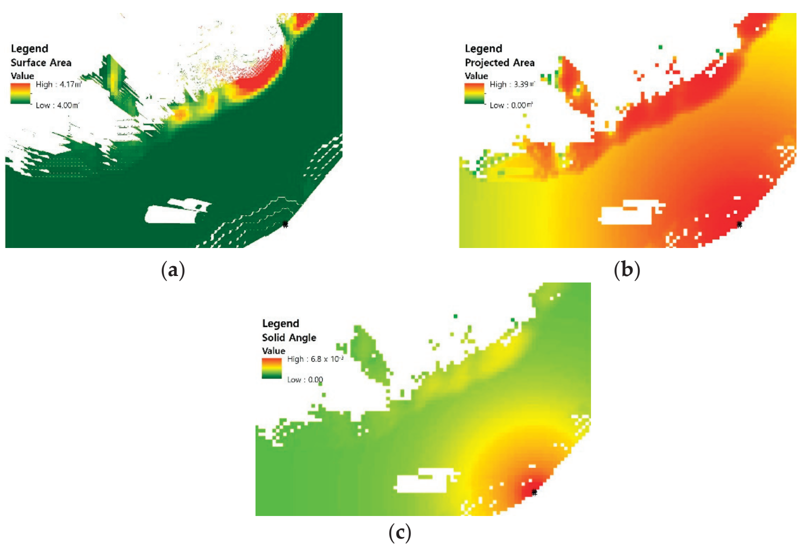


Figure 5. Example of the calculation result for the rear viewpoint in Figure 4: (**a**) surface area; (**b**) projected area; (**c**) solid angle.

The distance of the target object from the viewpoint was calculated by using the three-dimensional coordinates of the two points. The solid angle of the visible pixels, as seen from the viewpoint, was calculated using Equation (1) in ArcGIS Map Algebra (Figure 5c). The sum of the solid angles for each land cover class within the viewshed was calculated using the Zonal Statistics function of ArcGIS. The GREENVIEW variable is the sum of the solid angles for land covers including paddy fields, fields, broadleaf forests, coniferous forests, mixed forests, natural grassland, artificial grassland, and barren land. The RIVERVIEW is the sum of the solid angles for the Han River.

2.3.2. Other Independent Variables

The structural characteristics were divided into apartment-level variables and complex-level variables. The independent variables of apartment-level include the net area of the apartment, AREA, floor level on which the apartment is located, FLOOR, and being south-facing, SOUTH. AREA was adopted as an independent variable because housing price generally increases with an increase in apartment area [4,10,15,18]. Likewise, higher floor levels have a better view, so their sale prices are also higher. For this reason, we adopted FLOOR as an independent variable, but this differs from the natural landscape view variables GREENVIEW and RIVERVIEW because both artificial and natural landscapes are included in the view object, and some apartments have poor views even if the floor level is high. Finally, previous studies show that the facing direction of housing has a significant impact on housing prices [25]. In Korea, south-facing housing commands higher prices due to advantages in heating, laundry drying, sterilization, and so on [55], so SOUTH was introduced as a dummy variable. As this is mainly related to sunlight, this variable was analyzed by classifying apartments facing south, southeast, and southwest into the same group, the south-facing.

Regarding the complex-level variables, we introduced dwelling age, AGE, age squared, AGESQ, and the number of total apartments in the complex, TUNIT. In general, the older the dwelling age, the lower the apartment price due to the negative impact of depreciation. However, as the dwelling age approaches the point when redevelopment is possible, old apartment prices turn and rise due to the expectation of redevelopment [56,57]. This phenomenon can be described effectively using a quadratic function on the AGE and AGESQ variables [56]. The turning point refers to the point that has a minimum apartment price and can be calculated by taking the partial derivative of housing price with respect to the AGE variable [57]. In the study, AGE is calculated by subtracting the year of apartment completion from 2013. Finally, the larger the complex, the better the housing service, so the price tends to increase [34]. TUNIT was adopted to test this hypothesis.

Regarding the locational characteristics, we introduce independent variables for the distance of the apartment complex from the boundary of Gangnam-gu, DGANGNAM, the distance to a subway station, DSUBWAY, the distance to a primary school, DPRIMARY, and the distance to a middle school, DMIDDLE. As Gangnam-gu is the commercial center of the southern area of the Han River, DGANGNAM was adopted to test the hypothesis that the closer the apartment complex is to Gangnam-gu, the higher the price of apartments will be. DSUBWAY is adopted to measure the impact of proximity to public transportation, as several studies have found such a relationship [34,55]. As Koreans highly value education, several studies have shown that the closer an apartment complex is to a primary or middle school [34,56], the higher the price of apartments. DPRIMARY and DMIDDLE were adopted to test this. The distance was measured to the nearest target from the apartment complex using ArcGIS, at 100-m measurement increments for convenience in analysis.

Korea has four distinct seasons that also affect housing transactions; for example, there are many in spring when the new school year begins due to the high interest in education. To test this, we introduced seasonal dummy variables with winter as the reference group. Given that Korea's real estate transaction reports had a time lag of 1-2 months, January to March was counted as winter, April to June as spring, July to September as summer, and October to December as fall.

Table 1 summarizes the definitions and basic statistics for the variables used in the study. The average and maximum of GREENVIEW were 0.063 and 0.320 steradians; viewshed in all directions was analyzed, so the possible maximum is 4π steradians. As the view from the zenith to the horizon forms one hemisphere, and the view from the horizon to the nadir forms the other, on average, both the blue sky and the landscape have 2π steradians. Therefore, the maximum of GREENVIEW, 0.32 steradians means that 5.1% (= 0.320/2π) of all view fields seen from the front and rear are the view of greenery. Looking the mean values of seasonal dummy variables, the most apartments were sold in spring (32.5%), and the least in summer (17.1%).

Table 1. Definition and statistical summary of variables.

Variable	Definition	Mean	S.D.	Min.	Max.
PRICE	Sale prices of apartments as dependent variable (million KRW) [1]	849.386	384.716	188.000	2850.000
Views					
GREENVIEW	Solid angle of the visible pixels for green views (steradians)	0.063	0.057	0.000	0.320
RIVERVIEW	Solid angle of the visible pixels for Han River views (steradians)	0.011	0.031	0.000	0.166
Structure					
AREA	Net area of the apartment (square meters)	98.850	37.697	23.700	254.450
FLOOR	Floor level on which the apartment is situated (story)	7.131	4.905	1.000	29.000
SOUTH	1 if the apartment is south-facing, otherwise 0 (dummy)	0.780	0.414	0.000	1.000
AGE	Subtracting the year of apartment completion from 2013 (years)	21.913	10.999	4.000	37.000
AGESQ	AGE squared (years squared)	601.044	458.871	16.000	1369.000
TUNIT	Number of total apartments in the complex	844.579	875.893	9.000	3410.000
Location					
DGANGNAM	Distance from the complex to Gangnam-gu boundary (100 m)	14.261	10.310	0.687	46.521
DSUBWAY	Distance from the complex to subway station (100 m)	4.433	1.920	0.242	9.428
DPRIMARY	Distance from the complex to primary school (100 m)	3.566	1.697	0.623	8.724
DMIDDLE	Distance from the complex to middle school (100 m)	4.076	1.982	0.259	9.553
Transaction					
SPRING	1 if reported from April to June, otherwise 0 (dummy)	0.325	0.469	0.000	1.000
SUMMER	1 if reported from July to September, otherwise 0 (dummy)	0.171	0.377	0.000	1.000
FALL	1 if reported from October to December, otherwise 0 (dummy)	0.220	0.414	0.000	1.000

Notes: [1] The average exchange rate in 2013 was USD 1.00 = KRW 1095.04 [58].

3. Results

3.1. OLS Regression Analysis Results

Table 2 shows the estimation results of OLS regression with linear and semi-log forms. When comparing the goodness of fit of two models, the R^2 of the linear form model is 0.8604 and that of the semi-log form model is 0.8403, indicating that the linear form model is better. In addition, comparing the significance of independent variables, SUMMER and FALL are not significant in the linear form model, while DMIDDLE, SPRING, SUMMER and FALL are insignificant in the semi-log form. The linear form model is superior in both the goodness of fit and the number of significant variables, so this study selects the linear form model.

Table 2. Analysis results of ordinary least squares (OLS) regression.

Variable	Linear: Dependent Variable = PRICE				Semi-Log: Dependent Variable = Ln(PRICE)			
	Unstandardized Coefficient	S.E.	Standardized Coefficient	VIF	Unstandardized Coefficient	S.E.	Standardized Coefficient	VIF
CONSTANT	341.474 ***	37.054			6.069 ***	0.041		
GREENVIEW	378.359 ***	80.715	0.056	1.259	0.226 **	0.088	0.033	1.259
RIVERVIEW	324.706 **	139.561	0.026	1.149	0.444 ***	0.153	0.035	1.149
AREA	7.253 ***	0.115	0.711	1.124	0.008 ***	0.0001	0.729	1.124
FLOOR	4.888 ***	0.939	0.062	1.278	0.006 ***	0.001	0.080	1.278
SOUTH	41.963 ***	10.395	0.045	1.117	0.055 ***	0.011	0.057	1.117
AGE	−15.854 ***	2.471	−0.453	44.446	−0.013 ***	0.003	−0.375	44.446
AGESQ	0.321 ***	0.058	0.383	42.942	0.0003 ***	0.0001	0.368	42.942
TUNIT	0.118 ***	0.006	0.269	1.800	0.0001 ***	0.00001	0.251	1.800
DGANGNAM	−0.792 *	0.475	−0.021	1.441	−0.002 ***	0.0005	−0.042	1.441
DSUBWAY	−34.427 ***	2.496	−0.172	1.383	−0.031 ***	0.0027	−0.150	1.383
DPRIMARY	−18.515 ***	2.997	−0.082	1.557	−0.023 ***	0.0033	−0.101	1.557
DMIDDLE	−5.890 **	2.594	−0.030	1.591	−0.004	0.0028	−0.020	1.591
SPRING	19.855 *	10.522	0.024	1.464	0.015	0.0115	0.017	1.464
SUMMER	3.130	12.644	0.003	1.368	−0.002	0.0138	−0.002	1.368
FALL	−11.577	11.711	−0.012	1.417	−0.014	0.0128	−0.015	1.417
R^2	0.8604				0.8403			
Adj. R^2	0.8587				0.8384			
N	1260				1260			

Notes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

As the difference between R^2 and adjusted R^2 are small ($R^2 = 0.8604$; Adj. $R^2 = 0.8587$), it can be said that there are no multicollinearity among the independent variables. This is also confirmed through the variance inflation factor (VIF), which tests for multicollinearity: it is less than 2.0 for all variables except AGE and AGESQ, so it can be concluded that there is no multicollinearity. AGE and AGESQ can have high VIFs because although AGE and AGESQ are highly correlated, AGESQ is nonlinear functions of AGE [59]. Based on these observations, the GREENVIEW, RIVERVIEW, and FLOOR variables can be put into the model at the same time without worrying about multicollinearity.

Both GREENVIEW and RIVERVIEW had significantly positive impacts on housing prices. As both are measured in steradian, their marginal impacts can be directly compared. The marginal impacts of GREENVIEW and RIVERVIEW are KRW 378.4 million and KRW 324.7 million, respectively. Given that the averages of GREENVIEW and RIVERVIEW are 0.063 and 0.011 steradians, respectively, the former has a greater impact. However, this interpretation must consider the location of apartments in Seocho-gu, as the views of the Han River were analyzed as the rear view of the apartment and the views of greenery as the front view in the study. Nevertheless, the fact that the values of their impacts are not very different supports the significant impact of the views of the Han River on housing prices.

Among the structural characteristics, AREA, FLOOR, TUNIT, and SOUTH had positive impacts on housing prices. Despite the limitation that floor level cannot directly express the level of the view, the fact that FLOOR had a positive impact can be seen as a result of the general perception that the higher the floor height, the better the view. Specifically, the floor level of the apartment has a limitation in that it cannot directly represent views. Nevertheless, the fact that FLOOR coefficient has a positive value can be seen as a result of reflecting the general perception that the view is better as floor level increases. Comparing south-facing apartments and non-south-facing apartments, the price of a south-facing apartment was about KRW 42.0 million higher.

With respect to AGE and AGESQ, the hypothesis of dwelling age assumes that the curve of housing prices represents a quadratic function, so the AGE coefficient should be negative and the AGESQ coefficient should be positive, and this is borne out by the results in Table 2. As a result of taking the partial derivative of housing price with respect to the AGE variable to find the turning point at which the housing price has the minimum value, the point was calculated as 24.8 years. This means that the housing price decreases over time up to about 25 years of dwelling age due to depreciation effect, but after 25 years, prices increase as the magnitude of the positive redevelopment effect overtakes the negative depreciation effect.

Among the locational characteristics, DGANGNAM, DSUBWAY, DPRIMARY, and DMIDDLE all had negative impacts on housing prices. Housing price decreases with greater distance between the apartment complex and Gangnam-gu (KRW 0.8 million per 100 m), the nearest subway station (KRW 34.4 million per 100 m), primary school (KRW 18.5 million per 100 m), and middle school (KRW 5.9 million per 100 m). When comparing primary and middle schools, the impact of primary schools is much higher because parents generally feel more needed to protect younger students from traffic accidents. When looking at the difference in housing prices by season, spring showed a statistically significant difference from winter, but summer and fall showed no significant difference from winter.

Comparing the marginal impacts using standardized coefficients, the following order is obtained, from greatest effect to smallest: AREA, TUNIT, DSUBWAY, DPRIMARY, FLOOR, GREENVIEW, SOUTH, DMIDLE, RIVERVIEW, SPRING and DGANGNAM. In summary, apartment area, complex size, and proximity to subway stations and primary schools, and floor level are important characteristics that determine housing prices. It can be seen that though the views of greenery and the Han River do not reach the impacts of these characteristics, they are significantly important characteristics.

3.2. Quantile Regression Analysis Results

In the OLS regression analysis, it was assumed that the marginal impact of the natural landscape was constant regardless of housing prices. To test our hypothesis that marginal impacts differ by housing price range, we used quantile regression. Table 3 shows the estimation results for the quantile regression. The results are summarized by increasing the quantile points by five percent to effectively represent the variation in marginal impact.

All GREENVIEW coefficients were positive but were not significant at quantile points 0.05, 0.15–0.4, and 0.8–0.85. As shown in Figure 6, the coefficients have similar values up to quantile point 0.85 and exhibit a sharp uptrend from quantile point 0.9. RIVERVIEW coefficients were significantly positive at all quantile points, showing a sharp uptrend from quantile point 0.85. Specifically, when comparing the marginal impact of the quantile point 0.95 and that of the quantile point 0.5, GREENVIEW was 4.0 times and RIVERVIEW was 4.3 times. The results indicate that natural landscape views have unequal impacts on housing prices by price range, in particular, having a greater positive impact on higher-priced apartments. In other words, this means that higher-priced apartments have a premium on natural landscape views compared to lower- and medium-priced apartments. Compared to the OLS estimate, GREENVIEW has less impact on lower- and medium-priced apartments, but has a much greater impact on higher-priced apartments. RIVERVIEW has less impact on medium-priced apartments, but has a greater impact on lower-priced apartments and much greater impact on higher-priced apartments. Methodologically, the results show that OLS regression underestimated marginal impacts on higher-priced apartments.

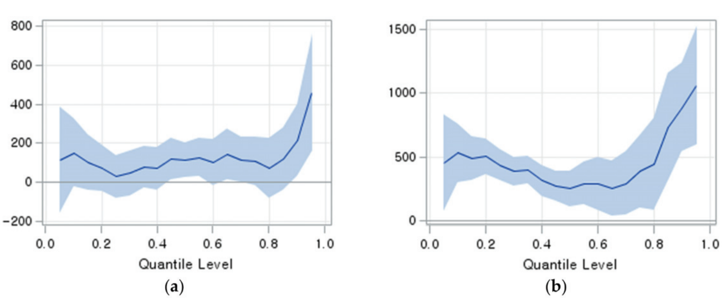


Figure 6. Quantile regression coefficients with 95% confidence limits: (**a**) GREENVIEW; (**b**) RIVERVIEW.

Table 3. Analysis results of quantile regression.

	OLS	Q0.05	Q0.1	Q0.15	Q0.2	Q0.25	Q0.3	Q0.35	Q0.4	Q0.45
CONSTANT	341.47 ***	45.94	76.27 *	138.54 ***	200.58 ***	271.76 ***	267.76 ***	289.66 ***	287.13 ***	298.36 ***
	(37.054)	(46.660)	(41.432)	(37.951)	(38.555)	(30.915)	(29.056)	(25.422)	(28.775)	(29.322)
GREENVIEW	378.36 ***	112.74	151.25 *	101.63	71.50	29.64	46.23	77.47	71.56	118.79 **
	(80.715)	(137.804)	(88.912)	(72.978)	(60.065)	(56.297)	(57.585)	(53.347)	(55.674)	(54.228)
RIVERVIEW	324.71 **	456.31 **	530.04 ***	486.33 ***	504.64 ***	438.63 ***	386.95 ***	401.38 ***	312.90 ***	271.82 ***
	(139.561)	(193.396)	(117.513)	(87.212)	(72.244)	(61.054)	(58.254)	(54.915)	(60.666)	(59.397)
AREA	7.25 ***	5.26 ***	5.54 ***	5.90 ***	6.25 ***	6.46 ***	6.78 ***	6.97 ***	7.17 ***	7.28 ***
	(0.115)	(0.183)	(0.141)	(0.141)	(0.142)	(0.140)	(0.164)	(0.144)	(0.139)	(0.134)
FLOOR	4.89 ***	2.66 **	5.31 ***	4.70 ***	5.10 ***	4.33 ***	4.27 ***	4.20 ***	4.69 ***	4.66 ***
	(0.939)	(1.163)	(1.027)	(0.925)	(0.731)	(0.688)	(0.678)	(0.644)	(0.642)	(0.536)
SOUTH	41.96 ***	78.87 ***	46.53 ***	32.72 ***	27.38 ***	21.29 ***	24.29 ***	20.49 ***	24.15 ***	24.23 ***
	(10.395)	(22.576)	(13.873)	(9.746)	(8.197)	(7.138)	(6.766)	(5.918)	(5.631)	(5.729)
AGE	−15.85 ***	7.09 ***	6.09 ***	4.72 **	−0.54	−6.91 ***	−8.81 ***	−10.28 ***	−11.40 ***	−12.63 ***
	(2.471)	(2.450)	(2.267)	(2.343)	(2.358)	(1.972)	(1.837)	(1.542)	(1.597)	(1.490)
AGESQ	0.32 ***	−0.14 **	−0.11 **	−0.10 *	0.01	0.13 ***	0.17 ***	0.20 ***	0.22 ***	0.24 ***
	(0.058)	(0.061)	(0.052)	(0.053)	(0.050)	(0.043)	(0.041)	(0.035)	(0.036)	(0.033)
TUNIT	0.12 ***	0.11 ***	0.11 ***	0.11 ***	0.11 ***	0.12 ***	0.12 ***	0.12 ***	0.11 ***	0.11 ***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
DGANGNAM	−0.79 *	−1.42 **	−1.41 ***	−1.94 ***	−2.22 ***	−2.26 ***	−2.08 ***	−2.03 ***	−2.15 ***	−1.88 ***
	(0.475)	(0.681)	(0.534)	(0.428)	(0.364)	(0.428)	(0.380)	(0.330)	(0.373)	(0.408)
DSUBWAY	−34.43 ***	−20.00 ***	−21.63 ***	−24.12 ***	−26.19 ***	−25.03 ***	−24.67 ***	−24.95 ***	−24.44 ***	−22.86 ***
	(2.496)	(4.376)	(3.032)	(2.457)	(2.114)	(1.697)	(1.729)	(1.642)	(1.955)	(2.080)
DPRIMARY	−18.51 ***	−7.94 *	−12.02 ***	−15.45 ***	−15.83 ***	−14.23 ***	−12.28 ***	−12.33 ***	−12.16 ***	−12.53 ***
	(2.997)	(4.413)	(3.474)	(2.648)	(2.274)	(2.107)	(2.444)	(2.375)	(2.435)	(2.567)
DMIDDLE	−5.89 **	−9.10 ***	−6.35 ***	−4.62 *	−5.11 **	−5.72 ***	−7.25 ***	−8.96 ***	−8.18 ***	−9.32 ***
	(2.594)	(2.623)	(2.380)	(2.374)	(2.251)	(2.182)	(2.039)	(1.719)	(1.898)	(2.093)
SPRING	19.85 *	17.74 *	19.12 *	12.43	9.62	6.59	8.02	5.88	9.10	10.67 *
	(10.522)	(10.168)	(9.943)	(10.005)	(8.333)	(7.572)	(7.074)	(7.185)	(6.973)	(6.444)
SUMMER	3.13	−8.46	21.13*	18.14 *	5.85	−0.35	3.08	2.43	1.63	2.56
	(12.644)	(22.069)	(12.721)	(9.809)	(9.251)	(9.181)	(8.769)	(8.062)	(7.209)	(6.914)
FALL	−11.58	13.85	17.67	12.30	4.44	0.94	−1.79	−2.61	−1.43	−1.58
	(11.711)	(21.190)	(12.129)	(8.706)	(7.454)	(6.956)	(7.307)	(7.003)	(6.926)	(6.659)

Table 3. *Cont.*

	Q0.5	Q0.55	Q0.6	Q0.65	Q0.7	Q0.75	Q0.8	Q0.85	Q0.9	Q0.95
CONSTANT	325.83 ***	342.60 ***	356.89 ***	383.15 ***	405.68 ***	424.72 ***	455.81 ***	440.41 ***	382.23 ***	395.90 ***
	(30.054)	(28.363)	(27.220)	(28.868)	(25.624)	(31.272)	(37.001)	(37.001)	(40.229)	(70.511)
GREENVIEW	114.74 **	127.95 ***	100.94 *	145.51 **	116.64 **	107.73 *	72.77	120.02	213.48 **	458.71 ***
	(45.034)	(48.643)	(60.593)	(65.955)	(57.354)	(62.947)	(78.983)	(78.983)	(92.476)	(151.891)
RIVERVIEW	249.66 ***	290.57 ***	286.47 ***	254.96 **	293.53 **	385.23 ***	445.58 **	730.81 ***	890.29 ***	1062.23 ***
	(69.545)	(85.274)	(105.407)	(111.051)	(127.246)	(146.622)	(184.104)	(184.104)	(179.130)	(237.457)
AREA	7.45 ***	7.59 ***	7.75 ***	7.89 ***	8.15 ***	8.27 ***	8.44 ***	8.59 ***	8.93 ***	9.75 ***
	(0.145)	(0.153)	(0.152)	(0.143)	(0.129)	(0.115)	(0.125)	(0.125)	(0.157)	(0.232)
FLOOR	4.72 ***	4.84 ***	5.11 ***	4.60 ***	4.40 ***	3.84 ***	3.26 ***	3.86 ***	3.39 ***	2.63 *
	(0.592)	(0.638)	(0.696)	(0.761)	(0.710)	(0.781)	(0.866)	(0.866)	(1.080)	(1.523)
SOUTH	21.13 ***	18.86 ***	14.69 ***	10.75 *	7.09	6.64	7.20	4.35	−1.20	−6.68
	(5.611)	(5.976)	(5.906)	(6.310)	(6.035)	(6.563)	(7.609)	(7.609)	(9.998)	(14.391)
AGE	−14.49 ***	−15.27 ***	−16.20 ***	−17.51 ***	−18.70 ***	−19.76 ***	−21.79 ***	−21.04 ***	−18.15 ***	−22.08 ***
	(1.599)	(1.531)	(1.578)	(1.545)	(1.428)	(1.676)	(2.161)	(2.161)	(3.021)	(5.282)
AGESQ	0.27 ***	0.28 ***	0.30 ***	0.32 ***	0.34 ***	0.35 ***	0.37 ***	0.35 ***	0.28 ***	0.34 ***
	(0.035)	(0.034)	(0.035)	(0.034)	(0.032)	(0.036)	(0.048)	(0.048)	(0.067)	(0.116)
TUNIT	0.11 ***	0.10 ***	0.10 ***	0.10 ***	0.10 ***	0.10 ***	0.10 ***	0.09 ***	0.10 ***	0.08 ***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.009)	(0.018)
DGANGNAM	−1.58 ***	−1.26 ***	−1.46 ***	−1.14 ***	−1.11 ***	−0.89 *	−0.56	0.82	3.13 ***	4.73 ***
	(0.454)	(0.437)	(0.428)	(0.430)	(0.413)	(0.495)	(0.734)	(0.734)	(0.888)	(1.073)
DSUBWAY	−23.44 ***	−24.51 ***	−25.21 ***	−25.85 ***	−29.44 ***	−30.43 ***	−32.22 ***	−32.71 ***	−31.61 ***	−30.40 ***
	(2.087)	(2.009)	(2.205)	(2.442)	(2.237)	(2.533)	(2.569)	(2.569)	(2.768)	(4.211)
DPRIMARY	−12.91 ***	−13.62 ***	−14.47 ***	−16.29 ***	−19.52 ***	−20.28 ***	−21.00 ***	−20.83 ***	−17.16 ***	−12.80 **
	(2.500)	(2.199)	(2.109)	(2.198)	(2.056)	(2.349)	(2.316)	(2.316)	(3.518)	(5.255)
DMIDDLE	−9.08 ***	−8.51 ***	−8.11 ***	−7.70 ***	−4.78 **	−3.69 *	−1.35	−1.87	−6.34 *	−12.38 **
	(2.308)	(2.249)	(2.223)	(2.238)	(2.060)	(2.234)	(2.602)	(2.602)	(3.712)	(5.232)
SPRING	9.16	6.14	8.97	5.54	11.47 *	13.62 **	15.60 *	20.90 **	21.89 *	32.60
	(6.543)	(6.760)	(6.576)	(6.512)	(6.425)	(6.518)	(8.117)	(8.117)	(11.929)	(20.018)
SUMMER	−4.47	−6.16	−3.03	−5.40	−1.99	4.87	5.57	3.18	2.17	8.05
	(7.296)	(7.567)	(7.633)	(8.018)	(7.618)	(7.891)	(8.860)	(8.860)	(9.946)	(13.576)
FALL	−5.36	−10.72	−9.28	−10.46	−2.96	−1.19	7.54	2.43	−1.86	8.19
	(6.342)	(6.718)	(6.877)	(7.444)	(6.869)	(7.199)	(7.269)	(7.269)	(9.413)	(12.286)

Notes: Standard errors in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

All FLOOR coefficients had significantly positive impacts on housing prices like OLS estimate. Specifically, the coefficients of lower- and medium-priced apartments were larger than those of higher-priced apartments. This result is believed to have been influenced by the fact that the low- and mid-rise apartments being redeveloped were sold at high prices.

Redevelopment and natural landscape views are closely related. The owners of old apartments along the Han River are making great efforts to redevelop them into apartments with good views. In the study, the possibility of redevelopment is represented by the dwelling age of the apartment. According to the hypothesis that the curve of housing prices has a quadratic function with respect to the dwelling age, the AGE coefficient should be negative and the AGESQ coefficient should be positive. However, the signs of the coefficients up to quantile point 0.2 did not agree with the hypothesis, whereas they did from quantile point 0.25 onward. As in the OLS regression analysis, we took partial derivative of housing price with respect to the AGE variable to find the turning point at which the housing price has the minimum value. The turning points were found to be between 25 and 33 years longer than the 25 years of OLS regression. In particular, the turning points grow as quantile point increases, meaning that higher-priced apartments are redeveloped relatively later. This is related to the fact that higher-priced apartments are mainly located along the Han River and their redevelopment is strictly regulated by the Seoul Metropolitan Government.

Looking at other independent variables, the marginal impacts of AREA also increase as quantile point increases. The marginal impact at quantile point 0.95 of AREA is 1.6 times the marginal impact at quantile point 0.5. The marginal impacts of DSUBWAY also increase as quantile point increases. These results mean that the higher the price of the apartment, the more the price is affected by apartment size and the distance to subway stations. In other words, higher-priced apartments have a premium on apartment size and the distance to subway stations compared to lower-priced apartments. On the contrary, the marginal impacts of SOUTH and TUNIT decrease as quantile point increases, indicating that the higher the price of the apartment, the less the price is affected by apartment direction and the number of apartments in the complex. Except for these variables, other variables did not show notable trends with increasing quantile point. Compared to the OLS estimate, AREA has less impact on lower-priced apartments, but has much greater impact on medium- and higher-priced apartments. DSUBWAY, SOUTH and TUNIT have less impacts overall. Methodologically, the OLS regression overall underestimates the marginal impact of DSUBWAY, SOUTH, and TUNIT. For AREA, the OLS regression underestimates the marginal impact of medium- and higher-priced apartments, but rather overestimates that of lower-priced apartments.

4. Discussion

4.1. Natural Landscape Views and Wealth Inequality

As discussed in the introduction, natural landscape views have both positive sides, such as providing restorative effects to urban residents, and negative sides, such as deepening wealth inequality. According to the results of our OLS regression analysis, natural landscape views such as the views of greenery and the Han River have significant positive impacts on housing prices, namely positive marginal impacts (Section 3.1). Based on the hedonic price model, this result is in line with several studies that suggest the positive value of natural landscape views. This also supports the common wisdom that natural landscape views positively affect urban residents. However, by comparing the standardized regression coefficients, we confirmed that the marginal impacts of natural landscape views did not reach the level of the effects of structural and locational characteristics such as the area of the apartment unit, the number of apartments in the complex, and the distance to subway stations and primary schools. OLS regression analysis is limited in that it is not able to effectively explain negative sides such as the deepening of wealth inequality, only estimating average marginal impacts on housing prices. Therefore, the only conclusion that can be drawn from these estimates is that housing prices rise with better natural landscape views. To overcome this limitation, we used quantile regression to estimate the impacts of natural landscape views on housing prices by price range.

According to the results of the quantile regression analysis, this study showed that the coefficients of natural landscape views have a sharp uptrend in higher price ranges, as shown in Figure 6 (Section 3.2). This means that natural landscape views have unequal impacts on housing prices depending on price range; specifically, the marginal impacts are higher for higher-priced apartments compared to lower- and medium-priced apartments. As discussed in the introduction, previous studies have found different results: one showed that natural landscape views had a much higher value-added effect on higher-priced housing than on lower-priced housing [32], and the others showed the opposite [7,28]. The results in the current study support the former group. The results also support that the Seoul housing market is segmented by housing level, such as the low-, mid- and high-end housing, which can respond to the needs of buyers by income level. This shows that "rich" households who can buy high-end housing have a high preference for housing with good natural landscape views, and they also appreciate the future value of such housing very high.

Linking natural landscape views to apartment redevelopment can allow us to address one aspect of deepening wealth inequality. Apartment prices tend to rise when dwelling age nears the time when redevelopment is permitted; however, the higher the housing price, the more severe the government's redevelopment regulation, so there is a tendency to delay the turning point at which prices increase in higher-priced apartment (Section 3.2). Nevertheless, the rise in the prices of old apartments is stronger in apartments along the Han River, as most buyers believe that redevelopment will provide more views of the Han River. It can be said that the prices of old apartments along the Han River reflect the average value of Han River views that will be secured in the future, plus a premium for higher-priced apartments. Redevelopment projects that improve natural landscape views result in a deepening of wealth inequality if development profits are attributed to homeowners. Improvement in natural landscape views is determined by urban planning activities such as height deregulation, but such decisions can worsen the views of neighboring houses and the city skyline. In this respect, natural landscape views should be strictly managed, and the development profits generated by improvement of the views need to be recouped to the public sector.

4.2. Visual Perception Analysis

Previous studies to analyze the impacts of landscape views on property value have considered the visible area by simply combining the results of viewshed analyses with information on land cover. However, the size of objects in the landscape as perceived by humans directly affects the value of the landscape. In the studies of [44,45], a method of quantifying the visual perception of a specific object was suggested, but it was difficult to use for general analysis work in metropolitan areas, such as real estate value modeling. We proposed the following analysis procedure to quantify the visual perception of the natural landscape views of wide areas. Using the spatial analysis function of GIS:

(1) Analyze the slope and aspect of the DSM, the azimuth between the viewpoint and the DSM pixel;
(2) Calculate the surface area using the slope of the DSM pixel where the visibility line is created;
(3) Calculate the projected area by applying directional cosine using slope, aspect, and azimuth angle to the surface area;
(4) Calculate the solid angle corresponding to the visual perception by dividing the projected area by the square of the distance between the viewpoint and the target pixel;
(5) Quantify the visual perception of the natural landscape by summing the solid angle for each land cover item included in the viewshed.

In the study, we constructed a GIS database using public data. By applying the proposed analysis procedure to the GIS database, the viewshed was analyzed for 843 km^2 including Seoul City and adjacent areas, and the visual perception area of each target object could be calculated from the results. By using the proposed method, it is possible to calculate the visual perception area for natural landscapes in a large urban area, rather than only a specific target, and analyze a large number of viewpoints. Using this visual perception-based landscape analysis, a more rigorous analysis of the impact of natural landscape views on property value is possible.

5. Conclusions

Natural landscape views have both positive and negative sides. From this perspective, we analyzed the impacts of natural landscape views on housing prices, and applied a visual perception model, OLS regression, and quantile regression to apartments sold in Seocho-gu, Seoul. The results are as follows. First, natural landscape views have a positive marginal impact, indicating that natural landscape views have positive sides. However, their marginal impacts did not reach the level of structural and locational characteristics such as apartment area and the distance to subway stations. Second, the study found that natural landscape views unequally affect housing prices by price range; the marginal impacts are higher in higher-priced housing than in lower- and medium-priced housing, indicating that natural landscape views have negative sides such as deepening wealth inequality. In particular, when old apartments along the Han River are redeveloped into high-rise apartments, the impact of natural landscape views on the housing prices is higher. Therefore, such redevelopment should be accompanied by efforts to recoup development profits to the public sector rather than leaving it in the hands of homeowners, to reduce wealth inequality. In addition, governments should consider how to properly impose property taxes to reduce wealth inequality caused by natural landscape views. In Korea, property taxes are levied on the basis of officially appraised prices. Despite the significant differences in natural landscape views, the appraised prices do not properly reflect this. It is necessary to introduce the visual perception model and quantile regression model used in the study as a valuation tool.

In the study, the research data were obtained using a GIS-based viewshed model, which effectively quantified the visual perception of natural landscape views in wide areas, unlike the similar model used in previous studies. However, this has a limitation in terms of analysis methods. The psychological effect of landscape on humans largely relates to its openness, along with the sense of stability given by natural landscape views of greenery and the river. We evaluated the natural landscape views only using viewshed analysis. However, unlike the viewshed, openness should be analyzed using a modified method of the daylight availability analysis represented by visual perception, which will require further research in the future.

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The Economic Viability of a Progressive Smart Building System with Power Storage

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Abstract: The increased smartness of the built environment is expected to contribute positively to climate change mitigation through energy conservation, efficient renewable energy utilization, and greenhouse gas emission reduction. Accordingly, significant investments are required in smart technologies, which enable the distributed supply of renewables and increased demand-side energy flexibility. The present study set out to understand the cash flows and economic viability of a real-life smart system investment in a building. The data collection process was threefold: First, a case building's level of (energy) smartness was estimated. Second, the semi-structured interviews were held to understand the building owner's motives for a smart investment. Third, the investment's profitability was analyzed. The study found that the progressive smartness investment was technically feasible, and surprisingly also economically profitable. The original EUR 6 million investment provided over 10% return-on-investment and, thus, increased the property value by more than EUR 10 million. Moreover, the commercial partners also emphasized the strategic value gained by renewable energy and environmental performance. The high level of smartness with a good return on investment was accomplished mainly through new income generated from the reserve power markets. However, the results implied that financial profitability alone was not enough to justify the economic viability of a smart building system investment.

Keywords: smart building; smart energy system; renewable energy resources; energy storage; reserve power system; investor motives; investment profitability; smart readiness indicator; discounted cash flow analysis

1. Introduction

The world's population is estimated to increase by one-third in the next 30 years, to 9.7 billion in 2050. By then, an estimated 6.7 billion people will live in urban areas [1]. This predicted rapid urbanization could be considered as an opportunity, but it also presents a challenge to making cities resilient and sustainable in line with the United Nations' sustainable development goals [2]. Furthermore, such rapid socio-economic development will significantly affect the long-term outlook of energy, as the demand for space heating and cooling, for instance, will rise [3]. Therefore, it is vital to make buildings, both directly and indirectly, less energy- and carbon-intensive in the future [4].

The greatest challenges to achieving a decarbonized energy system and, indirectly, for the building stock are the efficient deployment of renewable energy sources (RES) and the use of the most efficient generation technologies [5,6]. The most promising solution for the sector appears to be the integration of the electricity network into buildings' energy systems [7,8]. The integration of information and communication technologies (ICT) in the energy system may be the key to achieving a decarbonized building stock and accelerating the energy system transformation [3]. The adoption of ICT will enable a faster energy market operation that is more responsive to the balancing needs of a power system with less inertia and faster rates of change [9,10].

To support the energy system transformation, and to enhance the uptake of RES, the European Commission has strongly directed European Union (EU) members to engage in activities that promote the adoption of digital solutions in the built environment. One such activity is the development of a smart readiness indicator (SRI) [11]. The objective of the indicator is to provide an equal rating system for EU members and raise awareness of the benefits of grid flexibility enabled by distributed and fast-responding electricity and thermal storages, electric vehicles (EVs), and demand response. In alignment with the scope of the proposed framework, the SRI aims to evaluate a building's potential to optimize the overall energy consumption, provide occupants with more accurate information about their consumption, and enable the central system operators to manage the grid more effectively based on demand [12]. The SRI for buildings is not, naturally, an indicator of the maximum level of smartness in a building system. Nevertheless, it aims to provide a way to support the cross-sectorial integration of the building sector into (future) smart energy systems by enhancing the role of the building, the user, and the grid.

One of the key goals behind the development work of the SRI is to make the added value of building smartness more tangible for property owners. So far, however, evaluations of holistic smart energy investments, that support real estate investment valuations, are still lacking in the literature. Previous studies, such as [13–15], have mainly concentrated on measuring economic aspects of various stand-alone smart energy systems. In these studies, the financial profitability of the investment in a smart system has been estimated from a technology project perspective by using traditional economic analysis methods, including internal rate of return (IRR), return on investment (ROI), and payback period. However, even though the investments as such have appeared appealing, these frequently applied valuation methods do not consider the possible impact of such investments on property value.

From the real estate investment point-of-view, the property is evaluated as an entity with the focus on its total value [16]. The value of professionally managed investment properties is often evaluated using a discounted cash flow (DCF) analysis. In a DCF analysis, the present value of a property is based on the estimated cash flows and exit value, which are discounted to the present with a suitable discount rate [17]. The most important parameters forming the cash flow of a property are rental income, rental growth, vacancy rate, operating expenses, capital expenditure, depreciation, and a discount rate that reflects the relevant risks [17]. Depreciation includes both physical deterioration and obsolescence [18]. Thus, to understand the real estate investors' perspective and capture the value of smart building investments for them, DCF analysis should be applied in evaluating the economic profitability of such investments.

In the current literature, there is only a limited number of studies, if any, that consider the property value aspect of a smart (energy) system investment in a building. On the other hand, existing research that considers the property value aspect focuses purely on energy efficiency improvements (i.e., does not consider the system smartness). However, these studies mainly apply statistical analysis [19–21], which does not explain the value influencing mechanism of such investments in detail. Christersson et al. [16] and Leskinen et al. [22] seem to be the only practitioners who have considered the value-influencing mechanism of energy efficiency improvement investments of on-site energy production in a DCF framework. Additionally, Vimpari et al. [23,24] and Kontu et al. [25] considered the potential property value increase in their profitability analysis of rooftop solar and ground source heat pump investments. Interestingly, hardly any studies have estimated the financial feasibility of the technological shift towards smart energy systems at the property level.

The present study was designed as a novel case study that examines the economic viability and impact on the property value of a real-life smart building system investment. The implemented energy system generated not only traditional energy savings but also new income for the property through the participation in the frequency containment reserve (power) markets. This is the first study known that has used empirical cash flow data and utilized property investment analysis to reveal the added property value of such a smart energy system in buildings.

The present study provides insight into a smart energy system investment in a case building through a technology description, investor interviews, and an investment's profitability analysis. First, the case building's smartness, i.e., its technological readiness to support the energy system transition, was assessed using the EU-driven SRI rating system. Second, the economic and strategic motives of the investment were identified through interviews with representatives of the case building's owner. Third, investment analysis with case-specific data was performed. To the best of the authors' knowledge, this is the first study to apply a property investment analysis to a real-life smart energy system investment.

The study found that the building system was highly advanced in terms of its energy smartness, signified by a near-maximum score on the smartness rating scheme (SRI). The core technologies for achieving a high score was the system's microgrid functionality, on-site energy capacity, and advanced demand management capabilities. In the interviews, representatives of the building's owner implied that the investment was justified mainly by decreased operating costs and income related to participating in the frequency containment reserve market, which improved the net cash flow of the property. However, the improved net cash flow and the lucrative internal rate of return (IRR) were not enough to make the investment appealing. Besides, the smart energy system supplier's, i.e., service supplier's, active, and service-oriented attitude appeared essential in investment decision-making. Finally, a government subsidy made the investment even more lucrative. The additional strategic value of "being smart and environmentally excellent" was also considered an important factor in executing the investment. The explicit reasoning of the more sophisticated drivers, such as branding and image benefits, were recognized, but their influence on investment's profitability was difficult to evaluate in financial terms.

The present paper is structured as follows: Section 2 describes the research design of the study, including the case description and empirical data collection methods. Section 3 reviews the empirical research results comprising the energy smartness assessment, semi-structured interviews, and investment's profitability analysis. Section 4 further discusses the results, and Section 5 presents the conclusion.

2. Research Design

The present study was designed as a descriptive case study to examine a real-life smart energy system investment that supports the cross-sectorial integration of the building sector into smart energy systems. This study aimed to investigate the value creation of investment from a real estate market perspective. In this section, the case building and data collection methods are introduced.

2.1. Case Building

The study case was chosen based on an extensive smart energy system investment implemented in the building in recent years. The system consisted of substantial energy storage, software development, and energy conservation technologies. The investment was funded by the consortium of three Finnish institutional investors. The case building, considered to be a prime investment property, was located in southern Finland, which is one of the few EU countries where smart technologies have been systematically implemented into the built environment [26]. In 2015, the case building was the first European shopping center to receive LEED Platinum certification for existing buildings. The key characteristics of the case building are shown in Table 1.

Table 1. Characteristics of the case building.

Year of Constr.	Area [m^2]	Building Type	Year of Smart Energy Investment	Smart Technologies
2003	100,000	Commercial building	2018	PV system, battery storage, active LEDs, EV charging, advanced demand management (software development)

The data collection process for the case study was threefold: First, the building system's level of (energy) smartness was measured using the EU-driven SRI rating scheme [12]. Second, semi-structured interviews were held with representatives of the case building's owner. Third, the investment's profitability was calculated using widely applied investment evaluation methods. In the present study, the profitability of the investment was additionally evaluated through the impact of the savings in operating expenses and additional income (generated by the investment) on the property value. In the following sections, the data collection methods are further reviewed.

2.2. Energy Smartness Assessment

The energy smartness of the case building was evaluated by using the EU-driven SRI rating scheme. Today, the SRI is still under development; therefore, the most recent scheme [12], which was available at the time of the assessment, was applied to measure the energy smartness of the building system. Here we will introduce briefly the applied assessment methodology of the rating scheme as well as describe the assessment setup. A more detailed description of the assessment methodology is provided by Janhunen et al. [27].

2.2.1. Assessment Methodology

The SRI rating scheme is based on the assessment of a predefined list of smart services, which are enabled by a set of smart (ready) technologies. The practical, i.e., streamlined, version of the service list is divided into 10 distinct main domains, which are the following:

1. Heating
2. Domestic hot water (DHW)
3. Cooling
4. Controlled ventilation (MV)
5. Lighting
6. Dynamic building envelope (DBE)
7. On-site renewable energy generation (EG)
8. Demand side management (DSM)
9. Electric vehicle charging
10. Monitoring and control (MC).

In the version, which was applied in the present study, these domains contain altogether 52 smart services, which are inspected as part of the assessment. Each service has been given various degrees of smartness, i.e., functionality levels, where the lowest functionality, level 0, refers to non-smart service implementation and the highest level refers to an adaptive functionality with a demand-based service control. Hence, the highest functionality level varies from service to service. Additionally, each listed service in the SRI scheme has a potential (positive or negative) impact on the building occupants, and/or the building itself, and/or the grid. These impacts have been categorized into eight categories: energy savings on-site, flexibility for the grid and storage, self-generation, comfort, convenience, wellbeing and health, maintenance and fault prediction, and information to available occupants.

The final SRI score, i.e., the level of energy smartness, is a result of a multi-criteria assessment, which leads to an explicit percentage expressing how close (or far) the building is from its theoretical maximum smartness. The maximum smartness is individual for each building. The multi-criteria assessment method, which was applied to calculate the case building's level of energy smartness, followed the methodology provided in the final report of the SRI's first technical support study [12].

2.2.2. SRI Case Assessment

The energy smartness assessment was conducted within the premises of the case building in March 2019. The assessment was performed in a workgroup consisting of the property manager, the representative of the service supplier, and the SRI evaluation team members. The first author of this paper acted as the SRI assessment evaluator. In alignment with the SRI methodology [12], the assessment of those services, which were SRI compatible but not relevant, i.e., applicable, in the case building, did not affect the final scoring.

The assessment session began with a presentation of the SRI rating scheme. The assessment was performed using a qualitative checklist approach. The representative of the service supplier performed the role of a technical building systems (TBS) specialist in the assessment. The TBS specialist indicated the implemented functionality levels for the applicable smart ready services. The evaluation team inputted the scores into an excel-based calculation tool, which aggregated the overall SRI scores. The calculation tool was developed by the evaluation team following the applied SRI methodological framework [12]. Because the smart energy system was recently implemented and currently being operated by the service supplier, the TBS specialist was able to determine almost all of the functionality levels without consulting technical documents. Only a few service levels had to be checked on the documents, which were inputted into the calculation tool afterward. The workshop took approximately 1.5 h. The assessment did not include a walk-through inspection in the building's technical facilities.

2.3. Semi-Structured Interviews

Altogether, six semi-structured interviews were held with representatives of the case building's owner. The interviewees for the study were chosen based on their involvement in and knowledge of the investment decision-making and/or management phase of the smart energy system. The interviewee descriptions are visible in Table 2.

Table 2. Interviewee descriptions.

Interview	Title of the Interviewee	Role in the Investment
A	Real Estate Portfolio Manager (former)	Primary owner, involved in the decision-making
B	Real Estate Investment Director (former)	Primary owner, involved in the decision-making
C	Real Estate Investment Manager	Primary owner, involved in the management phase
D	Sustainability Manager	Primary owner, involved in the management phase
E	Business Development Director	Owner, involved in the decision-making and management phase
F	CEO	Shopping center manager

Four interviews were held with the primary owner of the case building. Two interviews (A and B) were held with the representatives involved in the investment decision-making phase, and two (C and D) with the representatives who had the best knowledge of the management phase of the smart energy system. To increase the validity of the interviews, one interview (E) was held with an owner representative who was involved both in the decision-making and management phases of the investment. The last interview (F) was held with a representative of the shopping center manager to obtain insights regarding the smart energy system's operational side.

The interviews were held by the first and second authors of this paper in February 2020, after the first full operational year of the smart energy system. Interview A was an exception: it was held in January 2018. Interview A provided evidence of the investment decision-making process before the smart energy system was fully operational and was applied as a preliminary research dataset for the present study. The interviews were conducted in Finnish.

The application of the interviews as a data collection method was twofold. First, the interviews were used to identify the key themes supporting the investment decision-making process. Second, the interviews were used to confirm the results of the conducted investment analysis calculations.

At the beginning of each interview, the SRI rating system was briefly introduced and the case building's assessment results were summarized. Thereafter, the interviewees were asked to describe the investment decisions and management phase of the smart energy system. Finally, the investment's profitability calculations described below were shown and the interviewees were asked to comment on both the collected input data and the outcome of the calculations.

All the interviews were semi-structured and took approximately 1h each. The interview questions were not delivered to the interviewees beforehand. The interviews were recorded, and both interviewers made notes along with the discussion. Afterward, the notes were accumulated in a SharePoint environment, and the second author conducted a content analysis of the data set and categorized the results into themes. The first author validated the results by referring to the recordings and confirmed the substance of the key findings that arose from the analysis.

2.4. Investment's Profitability Analysis

The investment's profitability analysis was based on real investment data and new cash flows generated by the smart energy system. In this section, we introduce the applied investment data and describe the conducted analysis with a case-specific example.

2.4.1. Investment Data

The total investment cost amounted to approximately EUR 6 million. The investment was financially supported by a government subsidy of EUR 2 million. The implemented smart system consisted of the main technologies of the rooftop PV, energy storage, and system integration (including the software development of the advanced demand management capabilities). The investment generated both savings and new income.

The rooftop PV investment amounted to approximately EUR 600,000. Aligned with the recent researches, the life cycle of the PV system was assumed to be 30 years [28,29]. In economic analysis, the inverter replacement costs are often included in the operating expenses of a PV system, as explained by Vimpari and Junnila [23]. It is assumed that the life cycle of the battery was 20 years [6,30]; after that, the owner would invest in a new battery, the investment cost of which totals EUR 2 million [30].

Due to confidentiality reasons, real maintenance cost data was not available. In this paper, the maintenance costs were estimated from Finnish data [31] based on the relationship between technical property maintenance costs and investment costs. Based on this data, the maintenance costs of the system amounted to 1% of the investment costs. In addition to yearly maintenance costs, this estimate included insurance and repair costs.

The annual estimates of the savings and new income generated by the investment were based on 10 months of actually running the smart energy system. The savings were generated from the energy efficiency improvements and the new income from the reserve power markets enabled by the battery. The investment dataset, which was applied in the financial analysis, is summarized in Table 3.

Table 3. A summary of the investment data.

Smart Energy System		Investment [EUR]	Life Cycle [yr.]	Maintenance [EUR/yr.]	Savings [EUR/yr.]	New Income [EUR/yr.]
Total		6M	30	60,000	180,000	480,000
	Rooftop PV	600,000	30	N/A	60,000	N/A
	Battery	2M	20	N/A-	N/A	480,000
	System integration	3.4M	N/A	60,000	120,000	N/A

Note: system integration means development, design, integration, and maintenance.

2.4.2. Description of the Analysis

The financial profitability of the smart energy system investment was first evaluated from a technological project perspective by applying the static investment metrics of payback period and ROI. However, as these metrics do not capture the time value of money nor the lifetime of the investment, the IRR was calculated using a spreadsheet program with a 30-year life cycle. A 30-year life cycle was selected based on the typical life cycle of the installed technical elements. The payback period, ROI, and IRR were calculated with and without the government subsidy using the equations explained below.

The payback period was calculated using the following equation [32]:

$$Payback\ period = \frac{Investment\ costs}{Annual\ net\ cash\ flow} \tag{1}$$

where investment costs equal the total cost of the investment, and the annual net cash flow equals the yearly amount of income and savings in operating costs generated by the investment.

The ROI was calculated using the following equation [33]:

$$Return\ on\ investment = \frac{Profit}{Investment\ costs}, \tag{2}$$

where profit equals the income and net savings generated by the investment, and investment costs equal the total cost of the investment.

The IRR of the investment was calculated using a spreadsheet program that uses the following equation [34]:

$$Net\ present\ value\ (NPV) = \sum_{i=1}^{30} \frac{CF_t}{(1+d)^i} = 0, \tag{3}$$

where CF_t denotes to cash flows (i.e. the net savings and income) in different years; and d is the discount rate, which equals the IRR when NPV is zero.

Even though the payback period, ROI, and IRR are widely applied investment evaluation methods, they do not consider the positive impact of a smart energy system investment on property value. Thus, in the present study, we applied a DCF framework to support the conducted investment analysis. By applying the DCF framework, the profitability of the investment was evaluated based on the new cash flows (generated by the smart energy system) on property value. The cash flows consisted of the savings in operating expenses and additional income (associated with the battery). By using the DCF framework, the present value of a property can be expressed as follows with a 30-year life cycle [35]:

$$Present\ value\ of\ property = \sum_{i=1}^{30} \frac{(Gross\ income - operating\ expenses)}{(1+property\ yield)^i} \tag{4}$$

The above equation clearly shows that a decrease in operating expenses leads to an increase in the value of the property through the capitalization of the improved net cash flow, as the International Valuation Standards suggest [35]. Leskinen et al. [36] described the impact of the value-influencing mechanism of on-site energy investment (which can be assimilated into smart building investments) on property values and justified the use of property yields as discount rates in these kinds of investments. Accordingly, the increase in property value generated through the savings in the operating expenses and additional income can be expressed as follows:

$$Property\ value\ increase = \sum_{i=1}^{30} \frac{CF_t}{(1+property\ yield)^i} \tag{5}$$

Between 2000 and 2018, electricity prices increased faster than inflation in Finland. From the property owners' perspective, the faster increase in energy prices compared to the rental growth rate motivated investment in self-generated energy production to protect the property from the risk of rising energy prices. Between the period, the increase in electricity prices amounted to 4.1% p.a. [37], while the increase in consumer price index totaled 1.5% p.a. [38]. In the analysis of this paper, 1.5% was used as the inflation rate. As cash flows included the expected inflation, the net savings and income of the property value increase function were discounted with the sum of the area's prime retail yield of 4.5% [39] and an inflation rate of 1.5% [38]. The electricity price growth rate, instead, was used as the inflation rate when estimating the savings generated by the PV system. The applied discount rate variables, which were applied to calculate the property value increase, are shown in Table 4.

Table 4. The applied discount rate variables for calculating the property value increase.

	PV Savings	Battery Income	System Int. Savings	Maintenance Costs	Total CF_t
Discount rate (d)	4.1%	1.5%	1.5%	1.5%	6%

For the sake of clarity, we show the property value increase equation by using the investment data (Table 3) and the applied discount rate variables (Table 4) Although the investment consisted of different parts (PV system, battery, and system integration), the investment was evaluated as one entity as suggested by the interviewees. The expected property value increase generated by the smart energy system investment was calculated as follows:

$$\begin{aligned}
&\text{Property value increase} = CF_0 + \sum_{i=1}^{30} \frac{CF_t}{(1+d(CF_t))^i} - \text{Battery capex}(i=20) \\
&= (\text{PV savings} + \text{battery income} + \text{system int. savings} - \text{maintenance costs}) \\
&+ \sum_{i=1}^{30} \frac{\text{PV savings} * (1+0.041)^i + (\text{battery income} + \text{system int.savings} - \text{maintenance costs}) * (1+0.015)^i}{(1+0.06)^i} \\
&- \frac{\frac{\text{investment (battery)}}{(1+0.015)^{20}}}{(1+0.06)^{20}} \\
&= (60{,}000 + 480{,}000 + 120{,}000 - 60{,}000) \\
&+ \sum_{i=1}^{30} \frac{60{,}000 * 1.041^i + (480{,}000 + 120{,}000 - 60{,}000) * 1.015^i}{1.06^i} - \frac{\frac{2M}{1.015^{20}}}{1.06^{20}} \\
&= 600{,}000 + \sum_{i=1}^{30} \frac{60{,}000 * 1.041^i + 540{,}000 * 1.015^i}{(1.06)^i} - \frac{\frac{2M}{1.015^{20}}}{1.06^{20}}
\end{aligned} \tag{6}$$

3. Results

In this section, the results from the case study are introduced. First, the results from the SRI assessment are presented. Second, the key investment motives that arose from the semi-structured interviews are introduced. Third, the investment's profitability analysis results are shown.

3.1. Smartness Evaluation of the Building and Relevant Technologies

In this study, the SRI rating system was applied to identify the energy smartness of the building. In this section, the results from the energy smartness assessment are reviewed.

The case building's final score was 92% of the maximum on the SRI rating scale, which indicated that the building was indeed exceptionally smart in terms of its technological implementations. From 10 domains listed in the SRI framework, nine were identified as present in the case building. Only the main domain of DBE was not implemented in the building. In total, 39 smart (ready) services from the list of 52 were identified as applicable in the assessment. The applicable services, their levels of energy smartness (%), and brief descriptions of primary technologies are shown in Table 5.

Table 5. The energy smartness of the applicable smart services.

Service	Smart Technology	Score	Service	Smart Technology	Score
Heating-1a	Individual room control with communication and presence control	100%	MV-2d	Variable set point with load-dependent compensation	100%
Heating-1c	Demand based control	100%	MV-3	Free cooling	67%
Heating-1d	Variable speed pump control (external demand signal)	100%	MV-6	Real-time information of indoor air quality available to occupants and suggesting triggers to action	100%
Heating-1e	Automatic control with demand evaluation	100%	Lighting-1a	Automatic detection (manual on/dimmed or auto-off)	100%
Heating-1g	Program heating schedule in advance	50%	Lighting-2	Scene-based light control	100%
Heating-2a	Variable temperature control depending on outdoor temperature	50%	EG-2	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	100%
Heating-2c	Load prediction-based sequencing	100%	EG-3	Dynamically operated storage which can also feedback into the grid	100%
Heating-3	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	100%	EG-4	Long term optimization including predicted generation and/or demand	100%
DHW-3	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	100%	DSM-18	Building energy systems are managed and operated depending on grid load; demand side management is used for load shifting	100%
Cooling-1a	Individual room control with communication between controllers and to building automated control system	75%	DSM-19	Smart appliances, DHW, heating, and cooling subject to DSM control	100%
Cooling-1c	Demand based control	100%	DSM-21	Reporting information on current, historical and predicted DSM flows and controls	100%
Cooling-1d	Variable speed pump control (external demand signal)	100%	DSM-22	Scheduled override of DSM control and reactivation with artificial intelligence	100%
Cooling-1e	Automatic control with demand evaluation	100%	EV-2	Medium charging capacity	67%
Cooling-1f	Total interlock	100%	EV-16	One-way (controlled charging)	50%
Cooling-2a	Variable temperature control depending on the load	100%	EV-17	Communication with a back-office compliant to ISO 15118	100%
Cooling-3	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	100%	MC-3	Individual setting following a predefined schedule; adaptation from a central room; variable preconditioning phases	67%
MV-1a	Demand control based on air quality sensors	100%	MC-4	With central indication of detected faults and alarms/diagnosing functions	100%
MV-1b	Variable control	100%	MC-9	Occupancy detection for individual functions, e.g., lighting	50%
MV-1c	Automatic flow or pressure control (without reset)	75%	MC-13	Real-time indication of sub-metered energy use or other performance metrics for all main TBS	100%
MV-2c	Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control	100%			

The case building scored 100% in 30 (out of 39) smart ready services on the SRI rating scheme. It scored less in nine services, scoring between 50% and 75%. The average SRI score was 91% (Table 5). In the service categories in which the building scored less than maximum, the upgrade to the maximum would have required the implementation of the following smart technologies: thermostat self-learning user behavior (Heating-1g), load-based control (Heating-2a), presence control (Cooling-1a), control with reset (MV-1c), H,x-directed control (MV-3), high charging capacity (EV-2), two-way balancing (EV-16), control of run-time management by artificial intelligence (MC-3), and centralized detection feeding into several TBS, such as lighting and heating (MC-9). The more sophisticated explanations of the listed SRI compatible smart services and their related technologies can be found in the final report of the first technical support study [12].

3.2. Investor Motives Regarding the Smart Building System Investment

The semi-structured interviews elucidated on the decision-making process of the smart energy system investment. The investor motives were assigned to key categories as identified in the content analysis of the interviews. The analysis delivered the following key themes, along with the improved net cash flow of the property and appealing IRR: image benefits, mitigation of the environmental and energy price risks, and solid trust in the long-lasting collaboration with the service supplier. The investment was also found to have some risks, which are shortly described in this section.

3.2.1. Enhanced Image

A majority of the interviewees mentioned that the strategy of the shopping center was to be a forerunner in environmental issues. Both of the interviewed investor representatives confirmed that they had signed a responsible investment commitment at the company level. However, the enhanced image was not only seen as an important means of engaging visitors to the shopping center, but also as a way to attract new tenants and improve the likelihood of renewing leases with the current tenants.

3.2.2. Future Price Risk Mitigation

All the interviewees mentioned that the investment could also be seen as cutting long-term maintenance costs and following liabilities to repair the property. Mitigating environmental and energy price risks was also seen as an important reason for the investment. Protecting the property from the risk of rising electricity prices was mentioned by some of the interviewees. In addition to electricity price growth risk, some of the interviewees mentioned that enhancing sustainability and energy self-sufficiency protects the cash flow and exit value of the case property from tightening environmental regulation. For instance, a possible future carbon tax might apply directly to properties and increase maintenance costs. The investment was seen as a means of protecting the property rising electricity prices and the financial consequences of possible environmental regulation. Two of the interviewees mentioned that the electricity price growth risk and possibly changing energy fee structures and taxes might affect the estimated profitability of the investment. However, they felt that it was more likely that environmental regulations would tighten, causing taxes and energy fees to rise, which would improve the profitability of the investment.

3.2.3. Long-Lasting Collaboration with the Service Supplier

All the interviewees mentioned that the investment was originally introduced to the owners by the service supplier, whose active role was one of the most important factors driving the owners to execute the investment. Furthermore, the supplier actively aimed to increase the owners' confidence in the investment by committing to the project in the form of a long-term service agreement and sharing the (economic) risks with the owner. The active role of the shopping center manager was also mentioned during the interviews. The interviewees noted that the previous nearly 10-year working relationship with the service supplier (related to energy management of the case property), the supplier's credible track record, and resources were important parameters in the investment decision-making process.

3.2.4. Investment Risks

The interviewees were also asked to analyze the most significant obstacles and the most relevant risks related to the investment. All the interviewees mentioned the risk of new technology and risks related to the estimated savings and profitability of the investment. Income-related to participating in the frequency containment reserve market (later referred to as battery income) was seen as a central source of uncertainty. One of the interviewees mentioned that one major risk (measured by its consequences) was whether the national main grid operator would allow the shopping center to participate in the frequency containment reserve market. All the interviewees mentioned that there was great uncertainty related to the (yearly) amount of battery income. Furthermore, the reputational risk was mentioned. Interviewees saw that reputational risks mainly consisted of the consequences of possibly realizing technical risks. Juridical risks related to the service agreement with the smart system supplier were carefully considered before the final investment decision was made. Although the investment was relatively small compared with the total annual maintenance costs of the property, consultants with expertise in the fields were asked for a second opinion regarding the technical and juridical risks.

3.3. Financial Profitability of the Smart Building System Investment

From the investor interviews, it was found that investment's profitability was the most important decision-making rationale. Hence, an analysis was done to justify the profitability of the investment. The calculation results were validated as part of the semi-structured interviews, where the interviewees were first asked to describe their investment analysis and then to comment on the analysis performed by the authors. Due to uncertainty related to the electricity price growth rates, battery income, and the maintenance costs of the system, a sensitivity analysis was performed for the conducted property value increase evaluation. This section introduces and describes the results of the financial investment analysis.

3.3.1. Base Scenario

The investment's profitability was analyzed using three widely used investment evaluation methods in real estate economics: payback period, ROI, and IRR. Based on the economic analysis, two scenarios for the investment's profitability were formulated. The first scenario was calculated without the EUR 2 million government subsidy, and the second one with the subsidy. The resulted investment's profitability metrics of both scenarios are shown in Table 6.

Table 6. Investment's profitability metrics.

Without the Subsidy			With the Subsidy		
IRR	**ROI**	**Payback Time**	**IRR**	**ROI**	**Payback Time**
5%	10%	10yr.	11%	15%	6.7yr.

Two of the interviewees mentioned that the payback period of the investment was under 10 years, which is in line with our results. Due to confidentiality reasons, the interviewees could not comment on the exact profitability metrics that were estimated in the investment decision phase. However, two of the interviewees mentioned that the IRR was appealing compared to the return of the property. This would be fulfilled in both of the scenarios, as the retail property yield (return) in the area was 4.5%.

Additionally, the investment's profitability was evaluated based on the capitalized value of the savings in operating expenses and the income related to the system by applying the DCF framework. Based on the analysis, the property value would increase by EUR 10.2 million. This means that the owner of the case property would immediately gain a benefit of over EUR 4 million from the investment. Next, we further reflect on some uncertainties that were found to concern the conducted property value increase analysis.

3.3.2. Sensitivity Analysis

To increase the validity of the primary financial analysis, i.e., the base scenario, a sensitivity analysis was performed for the expected property value increase. The sensitivity analysis concerned the savings generated by the PV system, the new income generated by the battery, and the maintenance costs.

First, an analysis of different electricity price scenarios was conducted to address the uncertainty related to the increase in electricity prices. The electricity price scenario was relevant to the savings generated by the rooftop PV system as it was the only element that was tied to energy price increase (and not inflation). In the base scenario, electricity prices were assumed to grow at the same rate as they did between 2000 and 2018. In the high electricity price scenario prices were assumed to grow 2%-point faster than in the base scenario.

Another important source of uncertainty was caused by the income associated with energy storage. In the base scenario, it was assumed that the battery would generate the estimated income for the whole life cycle of the investment. In the low-income scenario, it was assumed that only 80% of the estimated income would be received. In the high-income scenario, it was assumed that the income was 20% higher than estimated.

Finally, as the maintenance costs were estimated based on Finnish data [31], the appraise presented noteworthy uncertainty. In the low-costs scenario, the estimated maintenance was 80% of the estimated costs. In the high-cost scenario, the estimated maintenance was twice as much as estimated. The expected property value increase scenarios are summarized in Table 7.

Table 7. The results from the sensitivity analysis.

Scenario	Property Value Increase [MEUR]			IRR (with the Subsidy)		
	PV Savings	Battery Income	Maintenance Costs	PV Savings	Battery Income	Maintenance Costs
Base	10.2	10.2	10.2	11%	11%	11%
Low	9.8	8.5	10.4	11%	8%	11%
High	10.6	11.8	9.2	11%	13%	9%

4. Discussion

This study was designed as a descriptive case study to examine the viability of a progressive smart building solution that supports the cross-sectorial integration of the building sector into smart energy systems. The solution, including energy storage, software development, and energy conservation technologies, was considered as a real-life smart energy system. The viability of the investment was observed from the real estate market perspective, as evaluations of holistic investments in smart building solutions are still lacking in the literature. The study aimed to show the technological implementations, investor motives, and investment profitability of a smart energy system, using a market-driven case example with real-life data. The study found that investment in progressive smart building systems is already an economically viable option for contributing to the transition towards future smart and renewable energy systems. However, it was also found that the investment's profitability alone was not enough to justify such an investment.

In this study, the case building system's level of energy smartness was verified using the EU-driven SRI framework. Based on the energy assessment results, the case building was considered to be a real-life example of a viable smart energy system. The building's final score, over 90% of the maximum on the SRI scale, implied that sophisticated TBS appliances and technologies—which positively affect the building, the occupant, and the grid—have been implemented in the building [12]. Other smart technologies, including the PV system, active LED lighting, and EV charging were found to support the high SRI score significantly. Nevertheless, the power storage with the smart building's advanced demand management capabilities was considered to be at the core of the high scoring, as the relevance of grid flexibility has been strongly emphasized in the SRI development work [27,40]. Namely, the SRI rating scheme appears to increasingly favor demand response related features in buildings [40]. As has been shown, an integrated demand management system enables the efficient utilization of available resources within the building system; it also integrates the building into the national energy system by acting as a reserve power system for the grid [41–43].

In this study, the economic viability of the investment was analyzed both from the qualitative and quantitative perspectives. The investor interviews revealed that the financial profitability of the investment was the most important rational in decision-making, but surprisingly not enough to justify the investment. As the investment's profitability analysis results implied, the owner of the case property would immediately gain a benefit of over EUR 4 million from the investment. Accordingly, compared to traditional investment evaluation metrics, the investment seemed to be highly appealing. Based on the interviews, the conducted analysis was seen as relevant and interesting. However, surprisingly this kind of property value increase analysis, which was performed in this paper, was not performed in the owner's investment decision-making phase.

In alignment with the EU's vision for future energy systems, buildings will have a crucial role as active energy prosumers in the transition to a decarbonized energy system by 2050 [44]. Hence, to support the transition and the efficient deployment of distributed RES, it will be critical that buildings all over the world be built according to the highest energy efficiency standards [3,45]. Based on the results of the present study, one of the key obstacles to the transition, however, appears to be the property investors averse to take a risk in smart investments.

Overall, the new technology-related risk is generally known to be one of the barriers of smartness in buildings [46,47]. In the present study, the motives to implement the smart technologies and advanced demand management system were found to be rather energy- and sustainability-driven, and the smartness itself was not considered as a value driver. Despite the improved net cash flow and lucrative IRR (compared to the area's retail property yield) generated by the investment, the most crucial part in the investment decision-making appeared to be the service supplier's active role and commitment to the management and development of the system, as well as their willingness to share part of the risk.

In the present study, the value increase of the case property was analyzed from the perspective of decreased operating expenses and new income generated by the battery. The value-influencing mechanism of a similar investment that enhances sustainability and decreases the operating expenses of properties was confirmed by surveyors in a study by Leskinen et al. [22]. In addition to the capitalization of operating expense savings, the value of a property can increase through other improvements in a property's cash flow parameters. Based on earlier research, property owners can benefit from investments that enhance the sustainability of properties through increased rent levels, rental growth, and occupancy rates, as well as decreased risks [48]. These enhancements can increase the property value even more than the capitalization of operating expense savings. However, earlier studies found that surveyors did not fully transfer these benefits into property values [22,49,50].

Although in the present study the smart energy system investment appears to be very appealing from a property value perspective, investors might not be able to execute the investment based solely on the estimated increase in the value. First, the value increase is hypothetical unless the investor sells the property, or an objective surveyor confirms the value. In practice, surveyors might not be able to reflect the decrease in operating expenses fully in the value of the property. They might need actual data on the decreased operating expenses for several years to verify the justified amount of savings. Irrespective of the investment, other cash-flow parameters might change, which could diminish the value increase resulting from the decreased operating expenses.

Secondly, investors traditionally focus on managing the income side of cash flow rather than optimizing operating costs. The share of operating costs amounts to approximately 5–15% of total cash flows [16], of which energy costs represent some 30% [51]. Although energy costs are a significant factor in the operating expenses of a property and have huge savings potential, they represent only a small share of the overall cash flow. Hence, the value increase potential is rather small compared to the overall value forming of the property.

Third, investing in and maintaining smart technology systems require special expertise that property investors might not have. Therefore, even though in this study the reserve power system was found to generate a significant potential for value increase, the uncertainty related to the income and new technology-related risk negatively affected the investors' expectations and willingness to invest in smartness. This should, however, create new business opportunities for technology service providers, as their relevance in maintaining and developing smart building systems can be expected to increase in the future.

In the case property, lease agreements follow a net lease structure, which means that tenants pay rent for maintenance on top of capital rent. Due to the savings in operating expenses, tenants might be able to pay higher capital rent, as it is the total amount of rent that matters from the tenants' perspective. However, the length of time needed for the rent levels to rise in practice is unclear. In a gross lease structure, where the owner of a property is responsible for operating expenses, the owner will immediately gain the benefits of the savings in operating expenses. In the end, the owner of the property will extract the same value from the property if the difference between net and gross rents equals the difference in operating expenses [52].

To the best of the authors' knowledge, this paper was the first study to apply a property investment analysis to a real-life smart energy system investment in a building. Hence, some limitations and uncertainties related to the results of the case study were identified. The greatest uncertainties and limitations were found to be related to the financial profitability of the smart energy investment. The annual savings were based on 10 months of actually running the system and on estimates provided by the service supplier. Actual savings can be very different from the estimate and can vary year to year. The most uncertain part of the savings is the income associated with the battery. This uncertainty was reflected in the sensitivity analysis, which contained three scenarios for the battery income. Furthermore, the electricity growth rate and inflation utilized in this study were based on the historical yearly average between 2000 and 2018. These growth rates can change over time.

Accordingly, a sensitivity analysis was added to show how the work could be improved and how a more realistic picture could be captured from the profitability analysis of the investment. In addition to growth rates, electricity prices and taxes can change over time, which might affect profitability. Besides, there were likely service charges paid by the owner to the service supplier that was not available for this study. These service charges might decrease the profitability of the investment. However, these kinds of charges might also include all the fees related to the maintenance of the technical system; therefore, this might have a minor or no impact on the results of the case study. Furthermore, this study did not consider possible enhancements in other cash flow parameters (a potential increase in rent, rental growth, and occupancy, as well as a decrease in discount rate) that could increase the value of the property even more than the decreased operating expenses.

Some limitations were found to concern also the other data collection methods. First, the SRI rating system applied to evaluate the case building's smartness is still under development; thus, the predefined list of smart services, as well as the functionality levels and impact weightings, are expected to change in the final version of the rating scheme. Additionally, the subjective decision-making related to the selection of an applicable service may affect the reliability of the assessment, as it has been explained by Janhunen et al. [27]. Secondly, some limitations were linked to semi-structured interviews. A majority of the interviewed investors were representatives of the primary owner, which might bias the results. However, the selected interviewees were considered to have the best understanding of the investment. To increase the validity of the results, one interview was also held with an independent secondary owner representative, who was involved both in the decision-making and management phase of the investment.

5. Conclusions

This study examined the economic viability of a real-life smart energy system investment in a building. The implemented system, including energy storage, advanced demand side management (i.e., software development), and energy conservation technologies, was considered as an exemplary smart system solution that supports the future energy system transformation. The results of this study revealed that buildings' have the economic capability of becoming extremely smart to promote the cross-sectoral integration of the building sector into (future) energy systems.

From a real estate market perspective, there are multiple reasons to invest in smart technologies, including energy efficiency and lower operating costs with a predictable decrease in maintenance costs. However, the current study was the first in the smart building literature to evaluate the potential impact of smartness on property value through savings in operating expenses and additional income, specifically in the context of energy storage systems and new cash flows from the reserve power markets. The study found that even a progressive smart building system investment was economically profitable, and the investment generated over 10% return-on-investment along with over EUR 10 million increase in property value. However, the investment decision-making in smartness was not justifiable solely based on the appealing investment metrics, as the new cash flow opportunities were found to contain investment risks and practical challenges. For example, it is still uncertain how the property valuators approach the expected increase in the property value of such an investment.

Overall, due to the symbiotic nature of smart energy systems, the present study suggests that investment cash flows on a property level should be evaluated as one entity, instead of being broken down into subsystems based on smart technologies. Furthermore, the profitability of smart building investments should be evaluated through the impact of the savings in operating expenses and additional income (generated by the investment) on the property value to reveal the added value of smartness for property owners. However, further studies that consider the financial gains of the total smart energy system should be conducted to enhance the viability of the proposed solution as an option towards a renewable and sustainable energy system.

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Abbreviations

The following abbreviations were used in the paper:

DBE	dynamic building envelope
DCF	discounted cash flow
DHW	domestic hot water
DSM	demand side management
EG	renewable energy generation
EV	electric vehicle
ICT	information and communication technologies
IRR	internal rate of return
MC	monitoring and control
MV	controlled ventilation
NPV	net present value
PV	photovoltaics
RES	renewable energy sources
ROI	return on investment
SRI	smart readiness indicator
TBS	technical building systems

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An Innovative GIS-Based Territorial Information Tool for the Evaluation of Corporate Properties: An Application to the Italian Context

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Abstract: The financial transmission of the USA's housing price bubble has highlighted the inadequacy of the valuation methods adopted by the credit institutions, due to their static nature and inability to understand complex socio-economic dynamics and their related effects on the real estate market. The present research deals with the current issue of using Automated Valuation Methods for expeditious assessments in order to monitor and forecast market evolutions in the short and medium term. The paper aims to propose an evaluative model for the corporate market segment, in order to support the investors', the credit institutions' and the public entities' decision processes. The application of the proposed model to the corporate real estate segment market of the cities of Rome and Milan (Italy) outlines the potentialities of this approach in property big data management. The elaboration of input and output data in the GIS (Geographic Information System) environment allowed the development of an intuitive platform for the immediate representation of the results and their easy interpretation, even to non-expert users.

Keywords: mass appraisal techniques; evaluation model; hedonic price method; geographically weighted regression; evolutionary polynomial regression; market value

1. Introduction

In the last decade, the economic and financial crisis in Europe, triggered by the USA subprimes, has led to a relevant cogency of evaluation tools able to provide 'slender' and reliable mass appraisals [1–3]. The inability to update properties' market values over time with respect to the current selling prices trend, and the inadequacy of the methodologies used to assess market values, mainly based on direct estimates that require long processes and lead to results influenced by significant approximations [4–8], are the main causes of the global economic crisis that started in 2008. Moreover, the negative effects triggered by inappropriate valuations have highlighted the need for adequate professional skills in property appraisals. In this context, the International Valuation Standards define uniform and shared guidelines in order to guarantee a unique code based on the same principles and rules among professionals and the public interest in the valuation models [9].

The need to control the uncertainty is aimed at avoiding or, at least, reducing the likelihood of systemic financial and economic market crises, like that of the USA subprimes in 2007. With reference to Covid-19 and the resulting global pandemic, the emergence has also created a huge amount of uncertainty around the world in terms of the enormous market volatility that could have impacts on the real estate sector from the point of view of sales and prices. In fact, the current Covid-19 crisis is of non-financial or economic origin, is not consequent to a war period, and is causing a global upheaval in all sectors. The impacts are affecting all fields, starting from the collapse of global and national Gross Domestic Product. Phases of recessions, a slowdown in national and international trade, an increase in unemployment with consequent lower spending power and income impoverishment, an increase in crime and an overall modification of social relationships are the main effects. Inevitably, this will have a significant impact on individuals' availability to pay rent, mortgages and various household expenditures [10–12].

In the context of real estate evaluations, the main impacts derive from the need to limit travel and contacts, and from the introduction of drive-by assessments, which only provide for the external inspection of the property to be valued. In the case of bank lending, this typology of preliminary investigation aimed at exploring the property does not ensure the necessary guarantee to lending institutions [13]. In this sense, Aronsohn A. (IVSC Technical Director) underlines that uncertainty, already present in 'normal' times, is inherent in most market valuations, since there is rarely a single price with which it is possible to compare the valuation [14]. In this scenario, such as the one marked by the current health and economy emergency in progress, the only way to make predictions is to proceed by hypothesis [15].

In recent years, the static nature of the traditional valuation methods and their inability to consider the complex and changing socio-economic dynamics, and their effects on the real estate market, have generated the experimentation and diffusion of innovative mass appraisal models (genetic algorithms, spatial analysis models, fuzzy logic, artificial neural networks, etc.).

Starting from the spread of spatial big data, i.e., large amounts of data from heterogeneous sources, the innovative assessment techniques are supported by elaborated computing technologies, which are able to automate the implementation processes that, otherwise, would require more time. The Automated Valuation Methods (AVMs) are characterized by a strong theoretical and methodological basis, and are able to: (i) automatically capture the causal functional links between explanatory variables and selling prices; and (ii) obtain reliable forecasts of property market values over the medium-long term [16–18].

In the framework outlined, the use of innovative statistical valuation methods has become necessary for the different market operators (buyers, sellers, institutions, real estate funds, insurance companies, banks, etc.) in order to determinate more appropriate and objective property values, and to effectively monitor the evolution of property values [19,20].

In the sector of real estate valuations, the widespread interest in these techniques testifies to the growing central role played by AVMs in the support of evaluation processes and the periodic updates of the public and private assets values [21–23].

The present research proposes a contribution to the debate on the use of AVMs through the definition of, and experimentation with, an evaluation model for corporate properties, i.e., for those properties characterized by large size, with non-residential intended uses and the widespread interest of professional and/or institutional investors. In particular, two different techniques have been implemented in order to identify the functional relationships between the selling prices and the considered factors. In this research, a GIS-based Territorial Information Tool that processes the properties selling prices and the explanatory variables was developed. A Geographic Information System (GIS) is a tool that aims to receive, store, process, analyse, manage and represent geographic data. Many studies have used the potentialities of GIS tools to investigate different economic phenomena, such as dynamics related to per capita income in Europe [24], the links between urban morphology and economic growth [25], and the relationship between human capital, represented through the level of education, and productivity in the different areas of Europe [26]. The common goal of all the applications is to identify, through spatial analysis, the links between a deductive theoretical system and an inductive empirical one. The GIS environment can support: (i) the analysis of spatial variables and interdependencies; (ii) the identification of the value of the spatial component variables; and (iii) the definition of predictive models. The use of GIS-based systems allows us to investigate the influence of spatial elements in determining the price of a property [27], and to effectively define a series of spatial variables, increasing the objectivity of the process and also supporting the user through an intuitive graphic representation [28].

The model proposed constitutes an expeditious assessment tool that allows the Public Administration to identify the potential future value of public assets following enhancement processes. In particular, the model could be useful in the initial evaluation phases of redevelopment initiatives, which can also be integrated through multi-criteria analysis [29]. At the same time, the proposed tool can be used by private investors to identify the areas where the market is most dynamic, in terms of the number of transactions occurring in the short term and where there are the highest profit opportunities, and by independent experts to formulate reliable value judgments on the properties. The appraisers and the core valuation of the Asset Management Companies could implement the model as a comparison tool with the classic assessment procedures in order to verify the congruity of the values assessed by independent experts. Finally, for the institutional subjects involved (banks, Public Administrations, insurance companies, etc.) the proposed model can be applied to monitoring directly and in a more transparent way the evolution over time of the market value of the Fund's asset, and consequently the progress of their investment. The proposed tool could also be used for the representation of alternative scenarios related to different intended uses, in order to enhance abandoned or under-utilized property assets and, with reference to the current crisis trigged by Covid-19, to analyse the market trend of relevant and large assets.

This work is organized as follows. In Section 2, the main mass appraisal methods and their respective predictive potentialities are illustrated. In Section 3, the proposed method and the two assessment techniques implemented are explained: the first is a non-linear regressive procedure, named Evolutionary Polynomial Regression, the other one is a linear spatial regressive procedure, named Geographically Weighted Regression. In Section 4, the two different techniques are applied to two sample corporate properties, respectively, located in the cities of Rome and Milan (Italy), in order to determine their market value, taking into account a series of factors; the results of the two implemented techniques are then compared. The elaboration of the input and output data in the GIS environment allowed the development of an intuitive platform for the immediate representation of the results, and their easy interpretation, even to non-expert users. In Section 5, the conclusions are discussed by describing the results of the research and identifying the limits, the innovative elements and the possible lines of development for future research.

2. Background on Mass Appraisal Techniques

In the real estate valuations sector, the role of mass appraisal techniques has become strategic: (i) to define the urban policies aimed at the enhancement of exiting property assets [30]; (ii) to develop technical and economic refunctionalization initiatives [31]; (iii) to evaluate the risk related to the provision of mortgage loans by the credit institutions [32]; and iv) to assess the urban planning choices carried out by Public Administration for territorial strategic programs definition [33,34]. According to the International Association of Assessing Officers [35], mass appraisal concerns 'the process of valuing a group of properties as of a given date and using common data, standardized methods, and statistical testing'. In fact, with reference to an appropriate spatial and temporal horizon, mass appraisal methods concern large samples of properties similar to each other, collected in a systematic way, to be assessed through the implementation of mathematical algorithms.

Mass appraisal is a statistical procedure for the definition of a representative sample of a larger database in order to assess the overall value of the database [36] through an inferential approach. The Appraisal Institute Foundation defines mass appraisal techniques as including the following steps: (i) the identification of the property being assessed; (ii) the definition of the market trade area relating to the property to be assessed; (iii) the selection of the factors (demand and supply) that influence the value formation in this trade area; (iv) the elaboration of the model that returns the value formation by starting from the characteristics of the trade area; (v) the application of the model and assessment of the property value; (vi) the analysis of the model's results (statistical error, more significant variables, etc.) [37].

In the international reference literature, numerous contributions demonstrate the potentialities of mass appraisal techniques and the wide interest for this issue [38–40]. In particular, in these applications, the 'advanced' mass appraisal procedures have been primarily implemented to assess the influence of locational, productive, technological and socio-economic factors on properties' selling prices. In this sense, the aim of mass appraisal techniques concerns the analysis of the contribution of each component in the market value formation processes, in order to support public subjects in the planning decision-making phases.

In the framework outlined, Pagourtzi et al. [19] proposed the following mass appraisal technique classifications:

- The Hedonic Price method;
- Artificial Neural Networks;
- Fuzzy logic methods;
- ARIMA (autoregressive integrated moving average) models;
- Spatial analysis methods.

The Hedonic Price (HP) method allows the assessment of the marginal contributions of the influencing factors on property price, taking into account that this value depends on the utilities obtainable from the qualitative and quantitative characteristics that compose it [41]; therefore, according to the hedonic price method, the value of the property can be expressed as the sum of the contributions of its characteristics. In fact, the aim of the HP model is to estimate the price of a property as a function of its characteristics [42]. In theory, the price paid for the property purchase can be decomposed into the hedonic prices (implicit prices) of the individual attributes that constitute the whole unit. The resulting regression coefficients provide the assessment of the individual property features value.

The main application fields in which the HP method has been most used, classified by Capello [43], concern the assessment of the negative environmental externalities in urban areas [44–46] and of the ex post urban planning policies in order to analyse the effects of initiatives already carried out through land rent variation [47,48]. Moreover, through the HP method, it has been possible to determine the effects of social, environmental and urban factors on real estate values [49–52], highlighting the importance of the proximity to urban-type services [53–55] and environmental attractors such as green areas [56,57]. The major limitation of the hedonic price method is represented by the impossibility of considering the combination of the variables among them, as they are based on multivariate regression techniques. Another HP method weakness concerns the likelihood of the omission of significant model variables. In fact, this technique requires a detailed database of each property variable (intrinsic and extrinsic variables). In addition, it is necessary to collect a large number of data—which is not always available—in order to obtain a study sample that is sufficiently wide and representative of the phenomena, and to reliably analyse the weight of each factor on selling prices.

Artificial Neural Networks (ANN) constitute complex systems [58] composed of a set of elementary units (neurons) combined in an opportune manner in a netting structure made of layers that have an elevated interconnection degree that is able to associate an output y to a set of inputs $(x_1, x_2, \ldots x_n)$. The input layer represents the first level, and includes neurons which contain the exogenous information, translated in pulse for the neurons of the upper level. The output layer, instead, is formed by the neurons that return the result generated by the network's implementation. In the intermediate levels, called the hidden layers, the information deriving from the input layer is developed and transformed into outputs.

The complexity of the ANN structure depends on the number of neurons and existing connections. The ANN have been widely used both for the prediction of real estate values in the short and medium term [59–63] and for the determination of market micro-zones [64,65]. The limit of the ANN is that its depends on the exact information of the system under study, and the methods of training that must be used, as the algorithm of the ANN has the ability to identify unnecessary data during its training [66]. ANN models require that the structure of the neural network (e.g., model inputs, transfer functions, the number of hidden layers, etc.) is exogenously defined. Furthermore, other disadvantages are related to the over-fitting problems that are frequent in parameter estimation, and to the inability to incorporate known economic laws into the learning processes.

Fuzzy logic constitutes a linguistic-mathematical approach useful for describing 'vague' concepts through a formal logical support that allows us to create analytically treatable models [67,68]. In particular, the fuzzy rules are able to translate the mechanism which the decision maker adopts to assume the choice into formal models [69] by associating an input linguistic relationship with an output linguistic expression [70]. A fuzzy rule describes, in words, the rational but intuitive process that a subject follows to define the action to be taken, i.e., to reach a final decision starting from qualitative and quantitative information on the phenomenon, and on the basis of similar experiences that already addressed [71]. Fuzzy logic methods have been applied in the context of property valuations in several scientific works [72–75], developing an alternative and flexible approach to uncertainty [76]. In this context, Sarip and Hafez [77] have developed a theoretical formulation for selling price prediction through the implementation of a fuzzy regression model. Furthermore, Renigier-Biłozor et al. [78] have elaborated upon a decision-making algorithm based on fuzzy logic and rough set theory in order to obtain real estate values.

The limits of the fuzzy logic methods are connected to the preliminary definition of the membership function and of the operators to be used in the different steps; moreover, the computational burdens connected to the use of a lot of variables makes this method difficult to apply in cases where it is necessary to accurately describe the problem by using a large number of factors [79]. Furthermore, fuzzy logic methods are suitable to those applications in which the low definition of the problem being analysed requires an approach that is not particularly rigid ('fuzzy'), which allows us to intercept the errors connected to a model described in an insufficiently accurate way [80].

An Autoregressive Integrated Moving Average (ARIMA) model concerns a particular econometric technique which aims at investigating historical or temporal series in order to describe their main characteristics and to predict the future values of the series. This approach is useful in the situation in which limited information on the process of generating the data is available, or when there is no efficient explanatory model that links the forecast variable to other variables.

An ARIMA process constitutes an extension of the autoregressive moving average (ARMA) model; that is, a combination of an autoregressive model (AR) and a moving average model (MA). Therefore, while ARMA models are linear dynamic models that generate stationary processes and are able to represent and approximate the autocorrelation structure of any stationary process, ARIMA models use a process of data transformation in order to obtain a stationary series (a random walk). The main limitation of ARIMA models concerns the presumed linear form of the model and the exclusion of all non-linear correlation schemes [81].

ARIMA models have been used to support valuation and real estate issues [82–86], especially in the analysis of correlations among housing prices, population income and bank mortgage loans [87–90]. ARIMA models find their most effective application when there are substantial data time series, whereas the data that characterize the real estate market, even if they are referable to a specific historical moment, often do not have the characteristics of homogeneity and frequency such as to make this type of model applicable in an effective manner.

Spatial analysis aims to examine the aggregation forms of a phenomenon and their relationships in the space. The spatial unit to be studied have to be geo-referenced, i.e., specific geographic coordinates (longitude, latitude) capable of uniquely locating this unit in the space must be known. Furthermore, the spatial dimension is analyzed and interpreted from the illustrative-descriptive point of view in order to investigate the existence of a spatial dependence between what happens in a territorial unit and what occurs elsewhere in the space. The first law of geography according to which 'everything is related to anything else, but the things closest to each other are more related than the far ones' [91] is the logic behind the models, aimed at studying dynamic phenomena in the spatial dimension.

Spatial analysis methods have been implemented as a methodological approach for the study of different types of spatial problems [92–94]. The spatial analysis methods are particularly useful when a series of geo-referenced data is available: this allows us to analyse a multiplicity of problems by adding, among the different variables, the 'spatial' one. In these methods, different problems can arise related to the difficulty in determining the elementary analysis unit, to the behaviour near the boundaries, to the spatial interpolation, to the spatial autocorrelation, to the non-static space-time parameters and to the different definition scales of the parameters [95]. For these reasons, the statistical and geostatistical analysis of the database constitutes the preparatory phase for the application of spatial analysis methods.

In recent years, spatial analysis applications, implemented with GIS-based tools, have introduced new perspectives in order to investigate different economic phenomena.

Applications of GIS-based tools have been carried out by several authors in order to measure the impact of spatial attributes on real estate prices and to define a prediction model in terms of the spatial estimation of residential values [96–99]. In particular, Oud [100] highlighted the role of GIS applied to automated regression in order to assess the value of a panoramic view by considering two clusters in the residential market of the Dutch municipality of Alkmaar.

Moreover, Sesli [101] used a GIS tool to define Real Estate Evaluation Maps integrated by the Multi-Criteria Decision-Making Analysis, with reference to the Atakum neighborhood in Samsun Province (Turkey). Finally, Connor [102] demonstrated the effectiveness of using GIS technology to enhance data review, market and locational analysis, and the appraisers' market analysis abilities.

3. Outlines of Evolutionary Polynomial Regression and Geographically Weighted Regression

With reference to Automated Valuation Methods (AVMs), in this research, two different techniques were implemented for corporate property evaluation. The application of the method allows us to identify the functional relationships between the selling prices and the main influencing factors.

3.1. Evolutionary Polynomial Regression (EPR)

Evolutionary Polynomial Regression (EPR) can be considered to be a generalization of the classical regressive methods. EPR is a technique aimed at the construction of polynomial symbolic models that uses a genetic algorithm to search for the best mathematical structures that describe the phenomenon being analyzed. The methodology underlying EPR limits the set of operators used in the symbolic regression to a subset consisting of addition, multiplication, power, logarithm and exponentials. EPR is linear with respect to parameters but not linear with respect to the model structure, which is obtained through the combination of Genetic Programming and classical numerical regression [103].

If we set the dependent variable (Y) and the independent factors (X_i) to the established parameters that are useful to return the functional form that allows us to define $Y = f(X_i)$, the generic structure of the non-linear model implemented in EPR can be synthesized by the Equation (1):

$$Y = a_0 + \sum_{i=1}^{n}\left[a_i \cdot (X_1)^{(i,1)} \cdot \ldots \cdot \left(X_j\right)^{(i,j)} \cdot f\left((X_1)^{(i,j+1)} \cdot \ldots \cdot \left(X_j\right)^{(i,2j)}\right)\right] \quad (1)$$

where n is the number of additive terms, a_i represents the number of the parameters to be identified, X_i are the potential explanatory variables, (i, l), with $l = (1, \ldots, 2j)$ is the exponent of the l-th input related to the i-th term, and f is a function identified by the user among a set of possible mathematical expressions. The exponents (i, l) are also selected by the user from a range of possible real numbers.

The iterative analysis of the mathematical model, carried out through the combinations of exponents to be attributed to each of the potential inputs, is optimized by means of a population generated by a genetic algorithm, whose individuals are constituted by the set of exponents chosen by the user.

The underlying EPR algorithm does not require an a priori definition of the mathematical expression and of the variables that best represent the database, since it is the iterative process of the genetic algorithm that returns the best solution.

The accuracy of each equation elaborated by EPR is verified through its Coefficient of Determination (CoD), defined through the Equation (2):

$$CoD = 1 - \frac{N-1}{N} \cdot \frac{\sum_N (Y_{EPR} - Y)^2}{\sum_N (Y - mean(Y))^2} \tag{2}$$

where Y_{EPR} is the value of the dependent variable assessed by the EPR algorithm, Y is the detected value of the dependent variable and N is the size of the analyzed sample. The closer the CoD value is to the unit, the higher the accuracy of the expression returned by the EPR algorithm.

The genetic algorithm underlying EPR provides a multi-objective maximization function, which aims to pursue a Pareto optimization strategy. The objectives that are optimized in the model are: the statistical accuracy of the model, by satisfying appropriate performance criteria; the optimization of computational burdens by reducing the number of coefficients a_i; the reduction of the complexity of the model, through the minimization of the number of explanatory variables X_i of the final equation. Therefore, the obtained equations must combine the statistical accuracy in the explanation of the investigated phenomenon and the simplicity of interpretation of the outputs from the end user.

With reference to the applications of the EPR technique to the real estate market sector, the literature contributions are very few and recent. In particular, Tajani et al. [104] carried out a first experimentation of the EPR technique for mass appraisal, comparing it with the ANN methods and with the HP Methods. Morano et al. [105] used EPR techniques for an analysis of the functional relationships between the socio-economic factors in the Municipalities of the Puglia Region (Italy) and the selling prices. Morano et al. [106] compared EPR with the Utility Additive Model for mass appraisal related to residential properties in the Italian real estate market, in order to interpret and forecast the formation of the selling prices. Morano et al. [34] tested an evolution of EPR on three different Italian cities, which was able to generate a 'unique' functional form in order to simultaneously identify the best set of significant explanatory variables to describe the same phenomenon in the different selected study samples.

Morano et al. [107], finally, analyzed the contribution of the energy performance component to housing prices in the city of Bari (Italy).

3.2. Geographically Weighted Regression (GWR)

Spatial statistics includes a series of methods to describe and model spatial data; in several cases, it can be interpreted as an extension of what the cognitive abilities intuitively perform through a formal representation in a spatial model aimed at capturing the distribution, the trend, the processes and the relationships of the investigated phenomenon [108]. Unlike the traditional non-spatial statistical techniques, the spatial statistics methodologies use the 'spatial' concept in its mathematical meaning, i.e., through the analysis of mono or two-dimensional characteristics, and of proximity and orientation relationships [109] allowing us, for example, to define spatial clusters, excluding any anomalous values, or to identify spatial relationships among different elements. This methodology has been successfully applied in the study of the residential market of the city of Wroclaw, located in Poland, in Lower Silesia [110].

Geographically Weighted Regression (GWR) is a non-parametric weighted local regression technique, developed in statistics for curve-fitting and smoothing applications, in which regression coefficients are estimated using a spatial proximity variation model that allows the local calibration of the coefficients. The spatial coordinates of the points associated to the data are used to calculate the distance among the points: this represents the input of the kernel function that allows us to calculate the weight that represents the spatial dependence among the observations. This methodology is based on the assumption that there is a spatial correlation among the regression coefficients.

Starting from the concept underlying the regression models for the mathematical description of the GWR model, i.e., the determination of the relationship among two or more sets of variables, the most common situations involve the presence of a response variable Y and a number of input variables $x_1, x_2, \ldots, x_r$. If the regression is linear, the Equation (3) shows the respective functional form:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \cdots \beta_j x_{ji} + \cdots + \beta_r x_{ri} + e_i \tag{3}$$

where Y_i indicates the dependent variable of the i-th observation, β_j represents the constant to be associated with the independent variables x_j, and e is the random variable that returns the random error. In a generic multiple regression model, the assessment of the unknown parameters is obtained through the Least Squares technique. If the available observations are geographically referenced, it is possible that the hypothesis of homogeneity could be not verified, which happens in the case of spatial data characterized heterogeneity [111]. GWR allows us to investigate this typology of phenomena through the introduction of the geographic coordinates (u_i, v_i) assigned to each survey in the space. The representative functional structure of the linear regression becomes the Equation (4):

$$Y_i(u_i, v_i) = \beta_0(u_i, v_i) + \beta_1(u_i, v_i)x_{1i} + \cdots + \beta_r(u_i, v_i)x_{ri} + e_i \tag{4}$$

The substantial difference between GWR and a classical linear regression is that, in the GWR, a coefficient is assessed for each observation, as well as for each independent variable.

The dissemination of databases from different sources, as evidenced by the various applications developed thanks to the open data [112], represents an important preparatory resource for the increase of the transparency of the evaluation processes. When these information data are associated with a shape file, they become particularly useful, because they allow: (i) an effective map display that makes the information intelligible even to a non-expert user; (ii) the geostatistical analyses to be performed [113]; and (iii) the users to create interactive queries.

Several applications of GWR have been carried out in the scientific literature concerning property valuations [114–116]. Dziauddin et al. [117] assessed the effect of a light rail transit system (LRT) on residential property values in Greater Kuala Lumpur, Malaysia. Geographically Weighted Regression was implemented to assess the increased land value as a result of improved accessibility related to the construction of the LRT systems. Dimopoulos and Moulas [118] highlighted the importance of GWR in an ArcGIS environment to identify the critical parameters that affect property values in the Municipality of Thessaloniki (Greece), and to create a market value forecasting tool for a fairer taxation system. Cohen et al. [119] developed a new methodology for obtaining accurate and equitable property value assessments, that adds a time dimension to the Geographically Weighted Regressions (GWR) framework; this method was also applied to sales data for residential properties in 50 municipalities in Connecticut for 1994–2013 and 145 municipalities in Massachusetts for 1987–2012 to compare results over a long time period and across cities of two different states. Bujanda and Fullerton [120] implemented a GWR analysis to determine the geographic footprint and to quantify the impacts of transportation infrastructure proximity and accessibility on real property values in El Paso (Texas).

With reference to the present research, a GIS-based Territorial Information Tool called SIT Valuation was been developed. In particular, the proposed tool, on the basis of the property prices and of a series of independent variables, using the two different EPR and GWR techniques, has allowed us to define the 'price' function by which the contribution of each variable on the selling prices has been analysed. Property prices have a strong spatial component, as neighbours develop in the same historical period and according to similar building typologies. In this sense, the buildings will have homogeneous intrinsic characteristics. Moreover, the neighbouring buildings will be influenced by the same positional characteristics, such as the shops, schools or the presence of green areas. The SIT Valuation provides the database population with the independent variables (geographic, socio-economic, etc.) to define the map basis, and the introduction of qualitative information allows the identification of independent variables.

4. Application

4.1. Case Studies

The case studies considered in the research concern the city of Rome (Central Italy) and the city of Milan (Northern Italy), which are the Italian cities for which there is a more dynamic real estate market, both in terms of number of the transactions and turnover of the real estate industry. Furthermore, these two cities are the only two characterized by a high number of transactions in the corporate sector and, at the same time, a consistent public property asset to be enhanced. These elements allow the construction of a database, named DB Corporate Real Estate, which is representative of the corporate properties, as composed by a sufficiently large population even after the necessary operations aimed at excluding anomalous data. In particular, the database related to the city of Rome concerns 170 corporate properties sold in the period from 2004 to 2016, whereas the database for the city of Milan regards 188 corporate properties, for an overall market value equal to 10 billion euros, which represents approximately 25% of the total value in corporate property investments in the two considered metropolitan cities (Figure 1).

Figure 1. Corporate investments for the cities of Milan and Rome compared to the Italian context.

The choice of these two Italian cities is linked to the highest interest for corporate properties at the national level. Figure 1 shows the percentage of corporate investments from 2008 to 2016 with reference to the cities of Milan and Rome and compared to the Italian context [121]. The graph attests the most relevance for the two Italian cities in terms of a high amount of corporate investments.

In the last few years, the strong prevalence of the city of Milan to present a larger number of prime properties compared to the city of Rome should be pointed out. The international interest for the Rome and Milan markets is relevant: this confirms the significance for foreign investment related to these cities and the partial saturation of the European markets.

The city of Rome presents a consistent number of trophy properties, i.e., those buildings characterized by high architectural quality that attracts prestigious brands, and consequently high standing tenants. The trophy asset concerns a specific market segment composed of high-end range buildings with a strategic and relevant location, and excellent architectural levels and finishes [122].

The strong tourist vocation and the centralization of the governmental functions of the Italian capital are further elements that guarantee the high return of real estate investments made in Rome.

The city of Milan, on the other hand, is the Italian city with the most European style: it has always been the capital of finance and fashion; in recent years it was the location of important international events, such as Expo and the Winter Olympics, and real estate redevelopment initiatives that added further appeal to the city, i.e., the Porta Nuova project, the interventions of CityLife and Milano Innovation District (MInD) in the Expo 2015 area.

Attention has therefore focused on Rome and Milan, taking into account the interest of institutional investors and foreign professional operators. For the city of Rome, investors are looking for properties situated in prestigious and central locations, characterized by a continuity of tenants and a low vacancy rate (<10%). Conversely, for the city of Milan, investors have a higher risk appetite due to the confidence climate that characterizes this metropolitan city. This also translates into the search for peripheral properties, with a rather high market rent compared to the value, even if there is less certainty about the tenants' persistence and vacancy times. Further development of the research may address different national or international cities in order to select the most representative ones for the analysis of the corporate property markets and to apply the evaluation methods.

4.2. Variables

The construction of the database required the identification of the variables that most influence the selling price formation as a preliminary step [123].

The selling price per unit surface (Y) of the property sold in the period 2004–2016 in the cities of Rome and Milan for the corporate sector is the dependent variable.

With reference to the choice of the influencing factors for the price formulation, it should be pointed out that the selection of the explanatory variables to involve in a mass appraisal model is always somewhat arbitrary, and requires an unavoidable trade-off between bias from omitted variables and increased sampling variance associated with collinearity [124–129]. There is relative agreement, however, on what represents the major influencing factors [130,131]. Some authors have studied the main characteristics to be considered in the assessment of corporate properties [132] by identifying the fundamental classes of influencing factors [133] and outlining the importance of location and site selection factors [134].

Several studies highlighted that better 'comfort' in the workplace [135–137] increases buildings' attractiveness for occupiers and decreases the risk for investors, determining a higher occupancy rate and a premium on rents or property values. Some authors [138,139] point out the linkages between the two viewing angles from which a corporate real estate can be observed, i.e., the owner perspective, which aims at maximizing the value of the assets, and the user perspective, which aims at ensuring a suitable work environment for all operational processes [140]. Rymarzak and Sieminska [141] illustrated that the demand and supply factors affecting the general location choice of corporate real estate are linked not only to the ordinary locational, technological and market factors (accessibility in terms of transport networks, parking capacity, age and technical standard of existing space, market rents/sale prices, office building pattern and size) but also to the features that make the environment of work familiar and comfortable for the employees (e.g., the office space per employee).

Taking into account the mentioned literature, and through the support of the experience of the appraisers and real estate agents directly consulted, the independent variables considered are:

- $C\left(€/m^2\right)$: the units' average selling price provided by the Real Estate Market Observatory (OMI) of the Italian Revenue Agency, relating to the semester in which the sale occurred, the specific market micro-zone and the intended use of the property;
- $L\left(€/\left(m^2 \cdot month\right)\right)$: the units' average rent provided by the OMI, clustered as the variable C;

- $P\left(residents/m^2\right)$: the resident population per unit surface relative to the year of sale, built starting from the Italian Institute of Statistics (ISTAT) surveys, processing the data through a grid modeling that considers the subdivision of the municipal territory into grids of 90 meters on each side [142];
- $S\left(m^2\right)$: the saleable surface of the property;
- Q: the architectural quality of the property. In particular, the variable Q is a dummy set equal to '0' if there is no evident architectural quality; vice versa, it is set to '1'. The importance of identifying this variable is connected to the market appreciation for trophy buildings;
- V: the representative coefficient of the presence of public green areas (and their size) around the property. For the assessment of the influences connected to the public green areas, the parks, gardens and historic villas within two kilometers of the property were considered, and the surface extension of the green area (A_v) and the distance of the i-th property estate from the green areas $(d_{i,v})$ were simultaneously determined. The green index V_i is obtained through the sum of the ratios of the root of the areas and the distance of the property from the green area: $V_i = \sum_v \frac{\sqrt{A_v}}{d_{i,v}}$;
- M: the representative coefficient of the subways around the property [143,144]. A maximum distance of 2 km was considered, in order to limit the computational burdens. Note the distance $d_{i,j}$ of the i-th property from the j-th subway within the 2 km radius; the value of the proximity coefficient from the subway will be: $M_i = \sum_j \frac{1}{d_{i,j}}$.

In order to identify the data related to each property, i.e., the value of the dependent variable Y, the value of the independent variable S, the address and the date of sale, the databases provided by the Immobilium site (I) and by Nomisma (N) were considered.

With reference to the aims of this research, it was decided to exclude properties characterized by a saleable surface of less than 500 square meters, as they are not representative of the corporate concept, as previously defined.

In the corporate sector, the most frequent intended uses are executive and commercial, on which this research has consequently concentrated.

In the city of Rome, 59% of the total transactions for the reference period concern executive properties, with an average unit selling price (Y_{avg}) equal to 4123 €/m^2, whereas 26% is attributable to commercial ones (see Table 1). Even in the city of Milan, the executive market (71%) is the most widespread sector; the commercial one follows, with 14% and the remaining 15% divided among the other intended uses (see Table 2).

Table 1. Rome–the main data of the DB Corporate Real Estate.

Main Use	Selling Price (€)	Percentage	Number	Y_{avg} (€/m^2)	$Y_{weighted}$ (€/m^2)	Average Price (€)
Residential	-	-	-	-	-	-
Retail	1,147,546,028	26%	80	3470	2655	14,344,325
Office	2,583,870,725	59%	79	4123	3326	32,707,224
Industrial	126,000	0%	1	1465	1465	126,000
Hotel	92,250,000	2%	2	9902	9902	46,125,000
Building area	153,548,838	3%	4	2852	212	38,387,210
Others	431,552,888	10%	4	7750	6695	107,888,222
Total	**4,408,894,479**	**100%**	**170**			

An analysis of the Moran index for the DB Corporate Real Estate of the city of Rome (see Table 3) shows a high spatial autocorrelation for the variables P, L, V, Q and C, a good autocorrelation for Y, and an absence of correlation for S and M. The analysis of the Moran index relating to the DB Corporate Real Estate for the city of Milan (see Table 3) shows a high spatial autocorrelation for the variables P, C, Y and L, a good autocorrelation for Q, and an absence of correlation for S, V and M.

Table 2. Milan–the main data of the DB Corporate Real Estate.

Main Use	Selling Price (€)	Percentage	Number	Y_{avg} (€/m^2)	$Y_{weighted}$ (€/m^2)	Average Price (€)
Residential	57,961,530	1%	3	4789	4088	19,320,510
Retail	773,298,000	14%	37	16,906	1046	20,899,946
Office	3,884,179,991	71%	115	3327	2842	33,775,478
Industrial	120,255,022	2%	8	511	436	15,031,878
Hotel	148,600,000	3%	4	2267	2126	37,150,000
Building area	125,400,000	2%	3	1013	1045	41,800,000
Others	356,612,974	7%	18	3807	3874	19,811,832
Total	**5,466,307,517**	**100%**	**188**			

Table 3. Moran index for the cities of Rome and Milan.

Input	Y	C	L	P	S	Q	V	M
I Moran (Rome)	0.769	1.226	1.372	1.514	0.251	1.033	1.295	0.497
I Moran (Milan)	1.061	1.103	1.037	1.185	0.187	0.931	0.190	0.154

These results can be interpreted taking into account the construction of the database itself; in fact, for both the cities, the most autocorrelated variable is P, which reflects a logic of the continuity of the variation of the population in the space, independent from the temporal component. For the variables C and L, there is also a high spatial autocorrelation both in Rome and in Milan: the OMI of the Italian Revenue Agency has detected that there is a difference between the selling prices in the central areas and those in the peripheral areas equal approximately to 50% in the city of Rome, and to 70% in the city of Milan. This observation is consistent with the spatial distribution, and the consequent autocorrelation, of the variable Y—especially for the city of Milan—and of the variable Q—especially for the city of Rome, where the properties with the highest architectural quality are located in the central areas.

S and M are spatially heterogeneous, both for Rome and Milan. This behaviour outlines the absence of a specific spatial distribution of these variables, taking into account the relationships observed through the values associated with the properties in the database. The variable V is the only one for which the two cities present a very different Moran I, which is probably more connected to the specific location of the properties than to reasons related to the construction of the variables, or to the geography of the public green areas.

4.3. EPR Implementation

The EPR technique was applied to the database by considering the following inputs: (i) the maximum number of terms is equal to 7, that is, the number of independent variables; (ii) Y is the dependent variable in the models A and B, and ln(Y) is dependent variable in model C of Table 4; (iii) the exponents of the dependent variables are positive in the models A and C of Table 4, and negative in model B of Table 4.

Table 4. Basis assumptions for the EPR implementation.

Model Setting	Model A	Model B	Model C
Number of terms	7	7	7
Dependent Variable	Y	Y	lnY
Exponents	0; +0.5; +1; +2	0; ±0.5; ±1; ±2	0; +0.5; +1; +2

At the end of the elaborations carried out according to the three models A, B and C on the cities of Rome and Milan, the maximum CoD relative to each model was compared (Table 5): for the city of Rome, the models A and B are characterized by a CoD higher than 75%, which is higher than the statistical accuracy determined for model C; for the city of Milan, there are high performances for all the models, with a CoD of around 80%. For these reasons, model A was selected for both the cities, as it combines a good statistical performance with more simple interpretation related to the absence of negative exponents.

Table 5. CoDs of the models for the cities of Rome and Milan.

City	Model A	Model B	Model C
Rome	75.31	75.60	62.20
Milan	79.43	83.55	80.92

For the city of Rome, the Equation (5) is generated by EPR (model A):

$$\begin{aligned} Y = 46.2645PQ^2 \; & -26.3719LP^{0.5}QV^{0.5} + 65.3552C^{0.5} \\ & -0.03555(\text{Error! Bookmark not defined.})C^{0.5}Q^{0.5}V^2M^2 \\ & + + 17.3068C^{0.5}L^{0.5}Q^2V - 0.0070096CS^{0.5}Q^2V + 7.2625 \\ & \cdot 10^{-10}C^2L^{0.5}S - 2021.4151 \end{aligned} \tag{5}$$

For the city of Milan, the Equation (6) is returned by EPR (model A):

$$\begin{aligned} Y = \; & 0.28706S^{0.5}V^{0.5}M + 13.8813L^2 + 19.6459L^2Q^{0.5} - 4.4751\cdot 10^{-7}L^2P^2S^{0.5}V^2M^{0.5} + \\ & -1.4599\cdot 10^{-6}C^2S^{0.5} - 0.00010065C^2L^{0.5}Q^{0.5} + 1.5228\cdot 10^{-9}C^2L^2S^{0.5}Q^{0.5} + 697.212 \end{aligned} \tag{6}$$

In order to determine the influence of each independent variable on the formation of the selling price according to the EPR models, the function shown in the Equation (7) was determined for each independent variable:

$$Y_{EPR}(X_i) = f\left(\overline{X_1}, \ldots, X_i, \ldots, \overline{X_7}\right) \tag{7}$$

where X_i represents the independent variable in the analysis, and $\overline{X_i}$ is the average value of the other independent variables. Therefore, the contribution of each independent variable on the price formation can be expressed by the Equation (8). (Tables 6 and 7):

$$\Delta Y_{EPR}(X_i) = \left| min(Y_{EPR}(X_i)) - max(Y_{EPR}(X_i)) \right| \tag{8}$$

Table 6. Range of the estimated selling prices (Y_{EPR}) and of the explanatory variables for the city of Rome.

Parameter	Y_{EPR} €/m^2	C €/m^2	L €/$(m^2 \cdot month)$	P residents/m^2	S m^2	Q –	V –	M m^{-1}
Min	502	1800	9.5	0	526	0	0.00	0.00
Avg	3741	5236	26.1	69	9951	-	0.83	0.01
Max	12,677	11,300	79.3	245	110,000	1	4.00	0.03
ΔY_{EPR}	-	8546	3924	2073	9191	1472	4600	769

Table 7. Range of the estimated selling prices (Y_{EPR}) and of the explanatory variables for the city of Milan.

Parameter	Y_{EPR} €/m^2	C €/m^2	L €/$(m^2 \cdot month)$	P residents/m^2	S m^2	Q –	V –	M m^{-1}
Min	998	1550	6.5	0	574	0	0.13	0.00
Avg	4298	4013	19.2	82	9847	-	0.93	0.02
Max	15,323	7900	35.0	308	86,086	1	4.15	0.39
ΔY_{EPR}	-	21,893	26,767	6328	4478	1010	8035	8979

The analysis of the results allows interesting considerations.

For the city of Rome, the variables *S* and *C* are the most significant ones in the determination of Y_{EPR}: for both the variables, a direct linear relationship with the estimated unit selling prices was detected (graphs (a) and (c) in Figure 2 which reflects the widespread interest in the Italian capital for properties characterized by large size (>4000 sqm), and the relevant correlation and high correlation between the quotations returned by the OMI and the property prices (the correlation between *Y* and *C* is equal to 0.6). The variables *V* and *L* also have a significant contribution to the determination of Y_{EPR}; however, contrary to what is empirically expected, the functional relationship between Y_{EPR} and *V* is characterized by an inverse proportionality (graph (d) in Figure 2), as if the most distant properties from the green areas are more appreciated than those near them. This behavior can be explained by observing that the central properties, which are also those farthest from the large city parks, have a higher selling price (>5000 €/sqm) related to their location close to the city center.

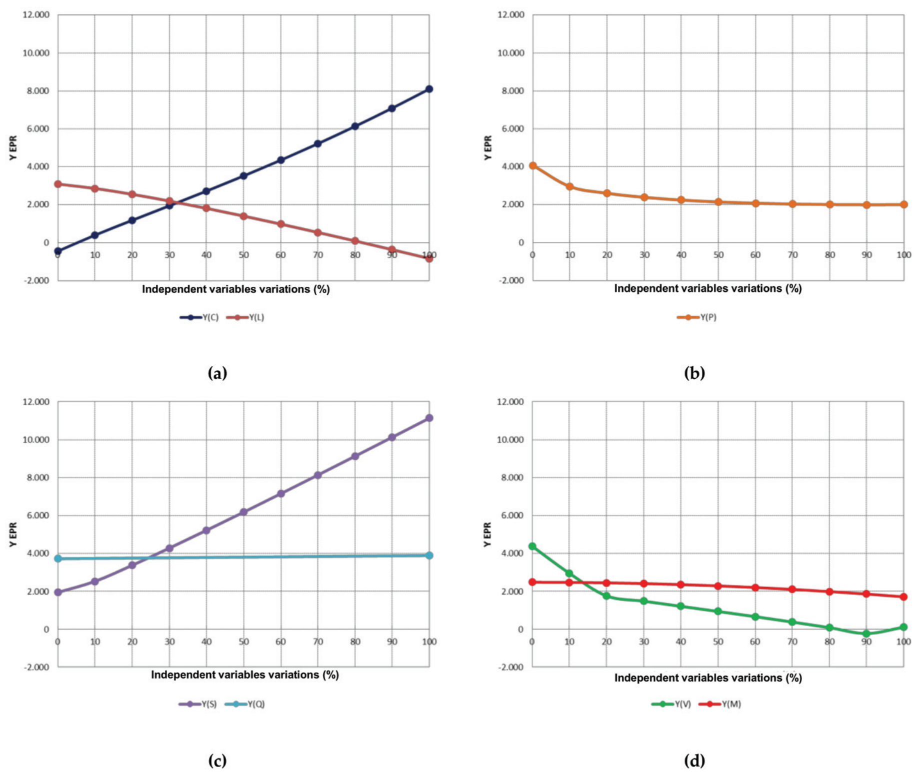


Figure 2. Functional relationships between the selling prices (Y_{EPR}) and the influencing factors selected by the EPR model for the city of Rome. (**a**) Unit average selling price and unit average rent; (**b**) Resident population per unit surface; (**c**) Saleable surface and architectural quality of the property; (**d**) Public green areas and subways.

The relationship between the market rent reported by OMI (*L*) and Y_{EPR} is also inverse (Figure 2a), which is an indication of how the market appreciation is not strictly connected with the ability of the property to generate income, or that there is little consistency in OMI data with this asset typology. The variable *P* is also characterized by a good contribution to the price formation, since a higher price (>5000 €/sqm) is detected in areas of low population density (<3000 inhabitants/sqkm) or commercial-executive vocations (Figure 2b). In the expression returned by EPR, the variables *Q* (Figure 2c) and *M* (Figure 2d) behave like two constants, resulting in little influence, although it is possible to capture a slight increase in the unit price for properties characterized by high architectural quality.

For the city of Milan, *C* and *L* are the most significant independent variables (Figure 3a) and their behavior is practically symmetrical: contrary to what was found for the city of Rome, the price formation seems to be connected more to the market rent detected by OMI, given the exponential relationship linking Y_{EPR} a *L*.

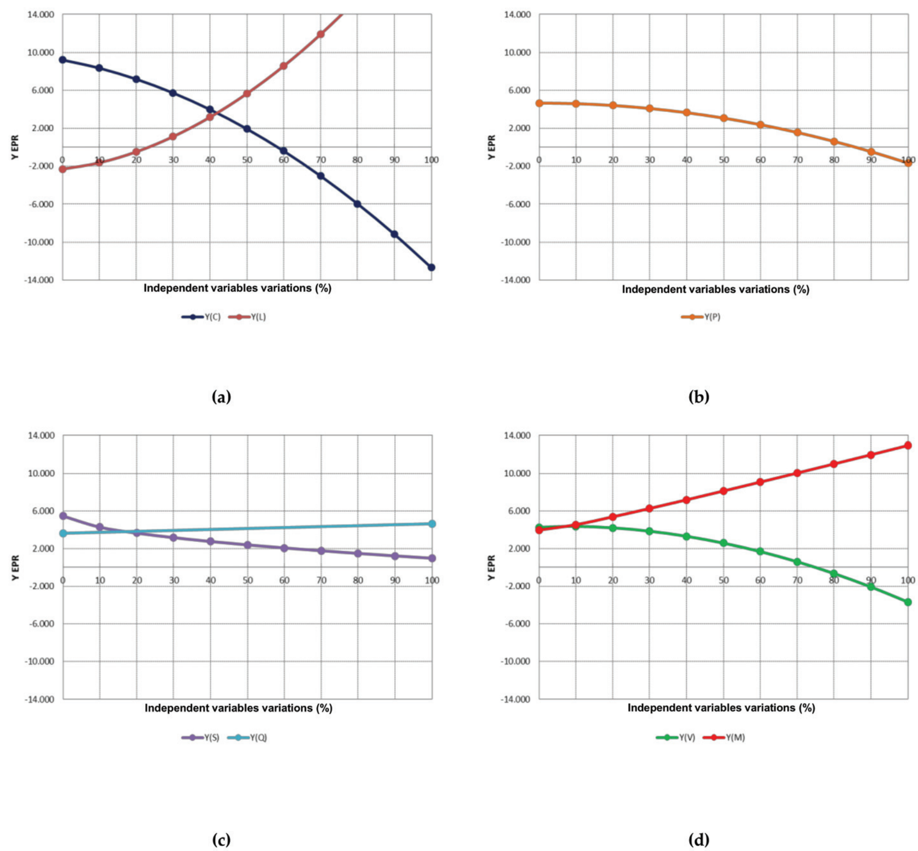


Figure 3. Functional relationships between the selling prices (Y_{EPR}) and the influencing factors selected by the EPR model for the city of Milan. (**a**) Unit average selling price and unit average rent; (**b**) Resident population per unit surface; (**c**) Saleable surface and architectural quality of the property; (**d**) Public green areas and subways.

The interpretation of what was described regarding the variables *C* and *L* could lead to the conclusion that, in the city of Rome, property price is essentially linked to its positional characteristics, as returned by the market quotations of the OMI, whereas in the city of Milan, the selling price is more connected to the rental status: this contingency describes the different attitudes with which the investors approach the real estate market in the cities of Rome and Milan. In fact, for the city of Rome, the investors are mainly interested in properties located in prestigious locations, for which a continuity of tenants and a low vacancy rate (<10%) are detected, even if they have a lower entry or initial yield (about 4.5%), whereas, for the city of Milan, the investors show a higher risk appetite, which determines the market demand of peripheral properties with a high entry yield (about 7%), even if they come with more tenant risk and a physiological vacancy (about 20%).

The variables M and V (Figure 3d) are characterized by a good contribution to the price formation: the closer the property is to a subway, the higher its value is, as was intuitively expected for the city of Milan, where the subway constitutes an effective means of public transport. The relationship between V and Y_{EPR} is inverse, probably for the same reasons previously exposed for the city of Rome. The variables P and S influence the price formation: the areas with a lower density (<5000 inhabitants/sqkm) are those for which there is a higher price (Figure 3b), and properties with smaller sizes (<2000 sqm) have a higher unit price (>7000 €/sqm) (Figure 3c), probably due to the central position or the lower unit price (<2500 €/sqm) that can be obtained for property assets with high sizes (>10,000 sqm). As for the city of Rome, the architectural quality (graph III in Figure 3) does not decisively affect the determination of Y_{EPR} for the city of Milan, even if the model detects a higher price for the properties with good architectural quality (>5000 €/sqm).

Figure 4 summarizes the contribution that each independent variable makes to the price formation in the corporate property market of the cities of Rome and Milan, according to the EPR equations: the most influential variables are indicated with the green colour; the red colour indicates the less influential variables; the yellow colour indicates those with intermediate influence between the previous ones and with the slash the variables that behave like a constant. The '+' symbol indicates the existence of a direct relationship by which the price increases as the value of the variable increases, contrary to what happens for the variables marked by the symbol '−'. The '/' symbol indicates the absence of the specific variable in the analysed model. It should be noted that the behaviour of the more strictly property variables, i.e., those related to OMI market quotations (Q and L), is diametrically opposite for the two case studies, whereas the behavior associated with the P and V variables is similar, both in the functional form and in the intensity of the related contribution, which is exactly the opposite of what was found for the variable S.

Case study	C	L	P	S	Q	V	M
Rome	+	−	−	+	+	−	/
Milan	−	+	−	−	/	−	+

Figure 4. Qualitative contributions of each explanatory variable to the price formation, according to the EPR model.

4.4. GWR Implementation

Similarly to what was described for the EPR models, for both the cities analysed, different elaborations were carried out by considering as the dependent variable Y and $ln(Y)$, and implementing the fixed and adaptive kernel model. Following the statistical analysis, which aims to determine the error between the estimated and detected unit price, the best performing models were obtained, both for the city of Rome and the city of Milan, for the model that uses the natural logarithm of the unit price as a dependent variable and the adaptive kernel model.

In the elaborations on the city of Milan, there is a multicollinearity caused by the simultaneous presence of C and L (a correlation index between C and L equal to 0.99), which prevents the elaboration of the regression. In order to overcome this problem, the variable L was excluded, even if it had a higher correlation with Y than the variable C (a correlation index between Y and C equal to 0.73, while the coefficient of correlation between Y and C is equal to 0.74), maintaining the descriptive independent variable of the quotation provided by the OMI, since the latter is more easily interpretable in the analysis of the results.

The functional form considered for the DB Corporate Real Estate concerning the city of Rome is shown in the Equation (9):

$$lnY_{GWR} = a_C C - a_L L \mp a_P P \pm a_S S + a_Q Q + a_V V \pm a_M M + k \quad (9)$$

whereas the corresponding function for the city or Milan is represented by the Equation (10):

$$lnY_{GWR} = a_C C - a_P P - a_S S + a_Q Q - a_V V + a_M M + k \tag{10}$$

The values assumed by the variables are always positive, whereas each coefficient determined through the GWR technique, taking into account its variability, could be always positive, always negative or both positive and negative. For this reason, in the previous expressions, the '∓' symbol indicates that the coefficient is almost always negative, but that it can also assume positive values; vice versa, the '±' symbol indicates that the coefficient is almost always positive, but that it can locally assume negative values.

The contribution of each independent variable to the price formation is equal to the form expressed in the Equation (11):

$$\alpha_{X_i} = \left| \frac{X_i \cdot a_{X_i}}{lnY_i - k_i} \right| \cdot \frac{1}{\sum_i X_i \cdot a_{X_i}} \tag{11}$$

where $X_i = C_i, L_i, P_i, S_i, Q_i, V_i, M_i$ is the independent variable related to the i-th property of the considered DB Corporate Real Estate. Therefore, the adimensional contribution of each variable with respect to the others was determined by the Equation (12):

$$\sum\nolimits_{X_i = C_i, L_i, P_i, S_i, Q_i, V_i, M_i} a_{X_i} = 1 \tag{12}$$

The analysis of the coefficients α_{X_i} related to the GWR techniques applied to the DB Corporate Real Estate highlighted that, for both the case studies (see Tables 8 and 9), the most significant variable is the average selling price detected by OMI (C).

Table 8. Range for the contributions of each explanatory variable for the city of Rome.

Parameter	a_C	a_L	a_P	a_S	a_Q	a_V	a_M
Min	53%	19%	0%	0%	0%	0%	0%
Avg	63%	27%	1%	1%	4%	4%	0%
Max	72%	39%	6%	22%	23%	18%	1%

Table 9. Range for the contributions of each explanatory variable for the city of Milan.

Parameter	a_C	a_P	a_S	a_Q	a_V	a_M
Min	42%	0%	0%	0%	1%	0%
Avg	72%	7%	8%	2%	9%	2%
Max	92%	36%	49%	18%	51%	26%

In the case of the city of Rome (Table 8), the average market rent (L) is characterized by a relevant contribution to the price formation, even if the coefficient a_L is negative and the coefficient a_C is positive. The variables Q and V give a positive (but not relevant) contribution to the determination of lnY_{GWR}, which is the index of the positive influence of green areas' proximity and high architectural quality on the price formation. The influence of the other variables is not significant, as for the population density (P) and the property size (S), or it is null with respect to the presence of subways around the property (M).

For the city of Milan (Table 9), C is the most significant variable, followed by P and V; the areas with a lower population density (<5000 inhabitants/sqkm) are characterized by a higher price (>7000 €/sqm) than the more populated ones; the property price grows with the increase of the distance from green areas, which can be justified by interpreting V as a proxy variable for the distance from the center. Even the variable relating to the size of the properties (S) affects, albeit marginally, the price formation, indicating how the properties characterized by smaller sizes (<2000 sqm) have a higher unit price

(>7000 €/sqm). The contribution of the architectural quality (*Q*) and the proximity to the subway (*M*) is not relevant.

By comparing the results obtained for the two GWR models (Figure 5), according to the logic already illustrated for the EPR models, and indicating with 'NA' the variables that have not been considered, it can be observed that *C* is the only variable that has the same behaviour for the two case studies.

Case study	C	L	P	S	Q	V	M
Rome	+	−	/	/	+	+	/
Milan	+	NA	−	−	/		/

Figure 5. Qualitative contributions of each explanatory variable to the price formation, according to the GWR model.

4.5. Comparison of the Results Obtained by the Implementation of the Two Techniques

The elaborations produced with the two different techniques (EPR and GWR) for the two case studies considered were compared in terms of statistical performance and the empirical reliability of the results.

In Table 10, three statistical indicators of EPR and GWR models for the cities of Rome and Milan were determined: the Maximum Absolute Percentage Error (MaxAPE), the Mean Absolute Percentage Error (MAPE) and the Root Mean Square Error (RMSE). In particular, from the comparison of the statistical indicators, it emerges that both the techniques were more effective in their application to the city of Milan, probably due to the lower spatial extension (182 sqkm for the city of Milan and 1285 sqkm for the city of Rome) and the higher concentration of corporate properties.

Table 10. Comparison between the statistical indicators of the EPR and GWR models for the cities of Rome and Milan.

Statistical Indicator	GWR Rome	EPR Rome	GWR Milan	EPR Milan
MaxAPE	17.6%	18.4%	14.1%	15.3%
MAPE	4.2%	3.6%	4.0%	4.5%
RMSE	5.5%	4.9%	5.1%	5.7%

In order to compare the discrepancy between the detected and the estimated selling prices through the EPR and GWR techniques, the residual values $\Delta_{EPR,i}$ e $\Delta_{GWR,i}$ were determined by the Equations (13) and (14):

$$\Delta_{EPR,i} = \left(\frac{Y_{EPR,i} - Y_i}{Y_i}\right) \quad (13)$$

$$\Delta_{GWR,i} = \left(\frac{Y_{GWR,i} - Y_i}{Y_i}\right) \quad (14)$$

where, in relation to the *i*-th property, $Y_{EPR,i}$ ($Y_{GWR,i}$) is the value estimated through the EPR (GWR) technique, and Y_i is the selling price detected through the DB Corporate Real Estate.

The representation of the distance between the Y curve and the Y_{GWR} e Y_{EPR} curves (Figures 6 and 7) also indicates that there is not a more clearly powerful technique than the other one. However, for both the cities of Rome and Milan, the deviation of the Y_{EPR} curve from the Y curve is less than that of the Y_{GWR} curve for the properties characterized by high unit prices; therefore, the EPR technique would be more reliable in the assessment of properties characterized by a unit price higher than 8000 €/m^2 for the city of Rome and 10,000 €/m^2 for the city of Milan.

By graphing the absolute residual values ($|\Delta_{EPR,i}|$ e $|\Delta_{GWR,i}|$) through circles whose size increases as the error between the estimated and the detected price increases, it was found that, as for the city of Rome, both the EPR model (Figure 8a) and the GWR model (Figure 8b) perform poorly in the forecast of the selling prices in the East area; vice versa, both the models, especially those returned by the GWR technique, are reliable in the central areas. In summary, in the applications of the two techniques to the DB Corporate Real Estate relating to the city of Rome, for 58% of the properties the EPR technique is better performing, whereas in the remaining 42%, the GWR technique should be preferred, confirming what was previously reported by the comparison of the statistical tests.

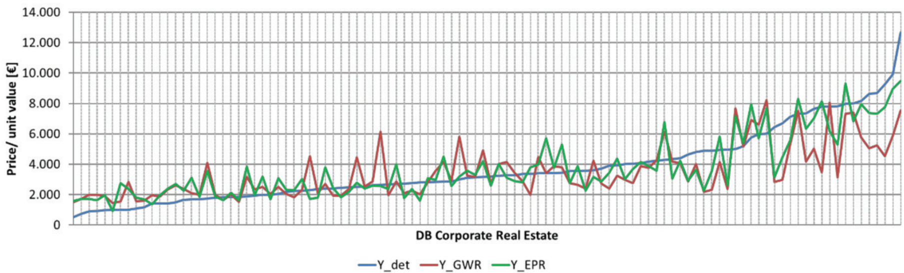


Figure 6. Comparison between the detected values and the values estimated by the GWR and EPR models for the city of Rome.

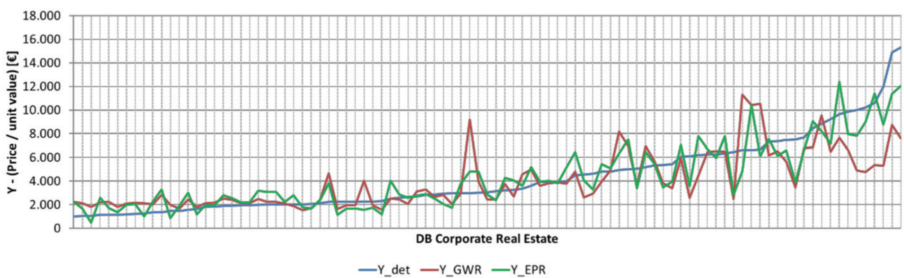


Figure 7. Comparison between the detected values and the values estimated by the GWR and EPR models for the city of Milan.

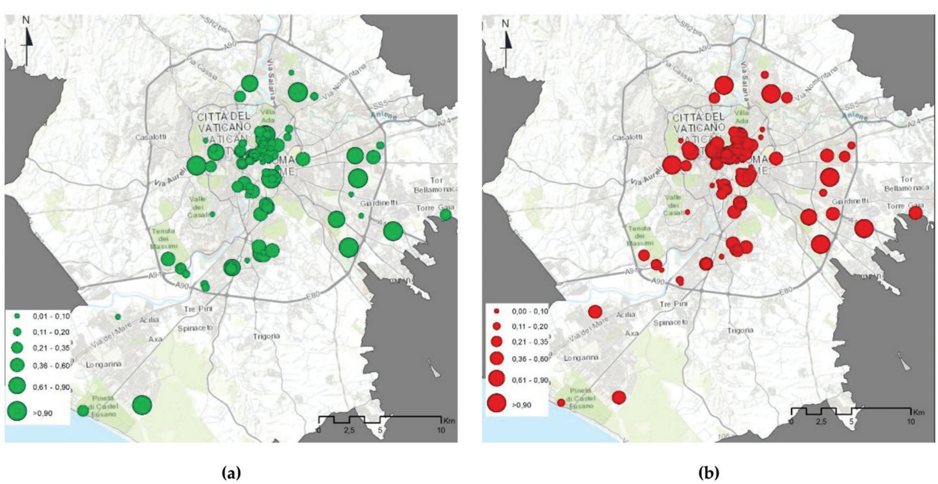
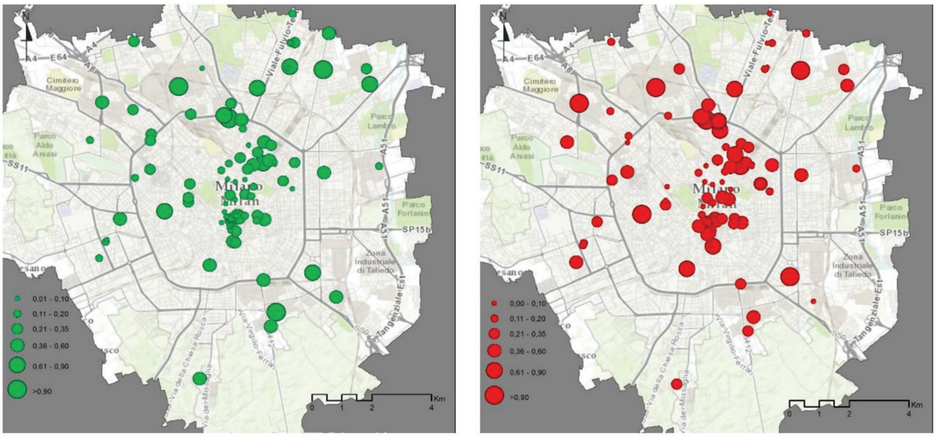


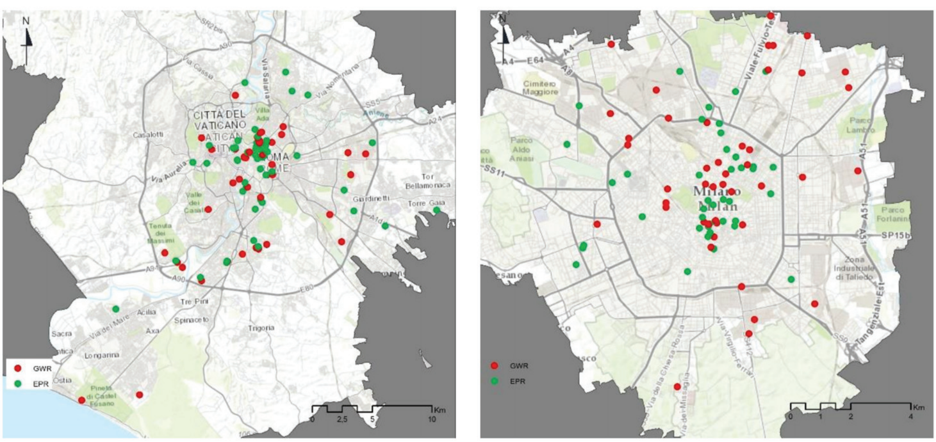
Figure 8. Models related to the city of Rome. (**a**) Absolute residual values for the EPR model; (**b**) Absolute residual values for the GWR model.

For the city of Milan, the EPR (Figure 9a) and GWR (Figure 9b) models are almost equivalent: by observing the absolute residual values, the EPR technique is more reliable for 51% of the properties, whereas for the remaining 49%, the GWR technique generates better outputs. By representing the properties in which the EPR/GWR technique is more reliable with a green/red dot, respectively, it can be seen that both in the city of Rome (Figure 10a) and in the city of Milan (Figure 10b) it is not possible to outline a spatially relevant behaviour for the two techniques.



(a) **(b)**

Figure 9. Models related to the city of Milan. (**a**) Absolute residual values for the EPR model; (**b**) Absolute residual values for the GWR model.



(a) **(b)**

Figure 10. Comparison between the two models for the cities of Rome and Milan (**a**) EPR and GWR models comparison for the city of Rome; (**b**) EPR and GWR models comparison for the city of Milan.

The qualitative comparison between the results obtained with the two techniques for the city of Rome (Figure 11), according to the symbolism previously introduced, shows a concordance of the signs and the influence for the variables C, L, Q and M. The two models agree in indicating the OMI selling price quotations as the most significant variable, unlike the market rent, and a positive contribution is given by the architectural quality of the properties; the relationship of the properties with the subways is almost irrelevant for the price formation.

Model	C	L	P	S	Q	V	M
EPR	+	−	−	+	+	−	/
GWR	+	−	/	/	+	+	/

Figure 11. Qualitative comparison between the results of the EPR and GWR models for the city of Rome.

For the city of Milan (Figure 12), as for the city Rome, the comparison between the two models allows us to identify four variables with common behaviour (P, S, Q and V); for the city of Milan, the most significant variable it is not the same according the two models, probably due to the exclusion of the variable L in the GWR model, which was necessary to solve the multicollinearity effect. The proximity to the city center (interpreted as a proxy variable of the distance from green areas), the location of the property in areas with lower population density (<5000 inhabitants/sqkm) and smaller sizes (<2000 sqm) appear to be factors that affect the price formation.

Model	C	L	P	S	Q	V	M
EPR	−	+	−	−	/	−	+
GWR	+	NA	−	−	/	−	/

Figure 12. Qualitative comparison between the results of the EPR and GWR models for the city of Milan.

The applications of the EPR and GWR techniques to the DB Corporate Real Estate for the cities of Rome and Milan allow us to outline some useful indications for the definition of the SIT Valuation.

The GWR technique has the great limitation of being scarcely usable for forecasting purposes. For each property, through the GWR technique, the coefficients and the interception that define the linear equation are determined; therefore, in the estimation phase, given a generic property for which the values of all the independent variables are known, it will be impossible to assess the property selling price without knowing the coefficients of the equation. To overcome this limitation, the spatial variation of the coefficients for the DB Corporate Real Estate could be determined, and specific areas with homogeneous coefficients for use in the estimation phase could be assumed, as defined through the cluster analysis [145]. This elaboration presupposes that the coefficients of the independent variables uniformly vary, which is scarcely likely due to the nature of the independent variables.

The EPR technique fulfils the forecasting objective, as well as the descriptive one, even if the developed functional form is rather complex and its validation requires a considerable expansion of the analyzed sample/sufficiently representative study sample. Furthermore, the results are often difficult to interpret, and the contribution of each independent variable cannot be intuitively captured. This obstacle is partially overcome through the graphic representation of the relationship between the dependent variable Y (selling prices) and the explanatory variables.

5. Conclusions

The global economic crisis triggered by the US subprime highlighted the cogency of the use of innovative valuation methodologies which are able to formulate more reliable valuations and to effectively monitor the evolution of property values.

The present research intended to fill the absence of a valuation tool as a support for determining the market value of corporate properties characterized by large sizes, non-residential intended use and the widespread interest of professional and/or institutional investors, through the integration of geographical information data and mass appraisal techniques in dealing with complex valuation issues. This goal was pursued by defining a GIS-based Territorial Information Tool (the SIT Valuation) that, based on the selling prices of corporate properties and on a series of influencing factors in the prices formation processes, uses two different techniques for the identification of the functional relationships that link the selling prices to the considered characteristics.

The SIT Valuation aims to increase the transparency in the valuation of these property assets, and at creating a support for both the Public Administration and private operators. Through the SIT

Valuation, it will therefore be possible: (i) to represent the geographical distribution of the input data, i.e., the dependent variable and the influencing factors that constitute the DB Corporate Real Estate; (ii) to display the geographical distribution of the output data, i.e., the various indicators that represent the difference between the detected and the estimated property prices; (iii) to assess the market value of a property with a moderate average percentage of error; (iv) to periodically update the market value of large property assets.

The SIT Valuation integrates the innovative aspects of the GIS environment, in terms of database construction and map visualization, and the calculation potentialities of the EPR technique, which is useful in providing expressions that can be implemented in the estimation phase. Furthermore, the proposed method contains a broader information set than many similar applications in the reference literature [146], and directly incorporates the spatial component in the database construction, not only as a correction factor.

The developed method can constitute a valid support for all public (e.g., Italian Revenue Agency) and private entities (buyers, sellers, investors, institutions, insurance companies, banks, etc.) that manage relevant property assets and which, for various reasons (periodic reviews of the balance sheets, sales, enhancement, investment, etc.), require cyclical updated values. Therefore, the method can represent an additional tool—to be integrated by the canonical evaluative procedures (market approach, income approach, cost approach)—to verify the results and to better monitor the evolution of the values of real estate portfolios, taking into account the indications of Capital Requirements Regulation (EU) No. 575/2013, art. 208 (3) (b), which states the possibility to “use statistical methods to monitor the value of the immovable property and to identify the immovable property that needs revaluation”. Moreover, the method could also be an important reference in the assessments of the market values of the properties that constitute the Real Estate Funds, which were characterized by a widespread diffusion in the last decades. Therefore, extending the input database to a greater number of cities and including ordinary properties, it would be possible to obtain an AVM as a support for credit institutions and financial operators who are interested in quickly evaluating large property assets, in order to monitor and update the properties’ market values. In fact, the advantages for the various entities consist in the possibility to identify value creation strategies through the best use of property assets; in particular, through the developed method, on the one hand, the professional valuers, who are responsible for producing highly reliable property valuations, could verify the adequacy of the assessed values, as well as determining and suggesting the most appropriate strategies of investment enhancement; on the other hand, the investors and the company managers could directly and transparently monitor the trends of the property market values and of the investment performance over time.

The main limitations of the SIT Valuation tool are linked to the limited time series available for the detected DB Corporate Real Estate: the low transparency that has always characterized the Italian real estate market has not allowed us to collect a relevant database in terms of the considered time period and, consequently, to develop an econometric model (e.g., a Vector Autoregressive model) capable of appropriately describing and interpreting the analysed property markets and forecasting the future trends in the medium–long term. This weakness of the tool could be overcome through specific agreements with the institutions and the public entities that manage large amounts of property data (e.g., the Italian Revenue Agency), in order to detect more relevant samples of transaction temporal series.

The future insights of the research may consist in the automated implementation in ArcGIS of the elaborated algorithms, in order to obtain an AVM to be especially implemented in the valuation of corporate properties. Furthermore, the method could be applied by government agencies that, in order to guarantee the fair payment of the taxes [146], can periodically update the market values of the properties according to actual and current real estate trends.

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Do Women Affect the Final Decision on the Housing Market? A Case Study

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Abstract: This article presents the results of research on the effect of the customer's gender on the tenure choice (ownership or tenancy) on the housing market. In the study, an attempt has been made to investigate whether there is a significant role of women in making decisions in this market. The survey was conducted among residents of two cities—Olsztyn (Poland) and Vilnius (Lithuania). The obtained answers were subjected to a multi-dimensional categorical and quantitative analysis. The results showed, among others, that women generally have greater decision-making autonomy in residential issues than men, with Lithuanian women doing this much more often than Polish women. However, it should be noted that the dominant decision-making model in the housing market is the model of joint decisions taken by men and women. The results of the conducted analysis broaden the existing knowledge of the functioning of the housing market and may support the implementation of the pro-social and pro-sustainable spatial development policy of the given territorial unit. The results may also contribute to more sustainable development of enterprises in the housing construction sector. This is an important issue in a climate of intense competition between "providers" of flats and the gradual introduction of the idea of competition between them and the social environment.

Keywords: customer gender; women; tenure choice; sustainable housing; housing market

1. Introduction

Sustainable housing is one of the areas of the economy that has a significant effect on the level of satisfying social needs, dynamics of economic processes and effectiveness of developmental activities. Improved housing increases the quality of life and contributes to the achievement of several sustainable development goals (SDGs), including those addressing health (SDG 3) and sustainable cities (SDG 11) [1]. The quality of housing has major implications for people's health. Housing in cities is of particular concern, with the world's urban population predicted to double by 2050 and, along with it, the demand for housing. A key pathway for providing healthy housing conditions and improving health is sustainable housing [2].

The interconnections between housing development and the economy indicate that the former plays a significant role in elevating the level of social, economic and spatial cohesion of a country [3,4]. Housing is a special type of commodity [5], because it is a spatially immobile, highly durable, highly expensive, multi-dimensionally heterogeneous and physically modifiable commodity. These characteristics shape attitudes and behaviors toward housing and, in turn, influence neighborhood characteristics, mortgage markets, national housing policies and urban growth and decline. A housing property constitutes the most expensive of all goods purchased throughout people's lives, and many citizens cannot afford their own place to live within their lifetime. The living conditions of citizens influence professional activity, qualifications and the spatial mobility of employees. Among numerous economic and sociological theories, there is unanimity concerning the extraordinary significance of the housing market in the life of an individual, society and state [6].

To ensure proper residing conditions is every person's aspiration, and this decision is among the most important ones to be made. This is because a flat or a single-family home satisfy several basic human needs, i.e., a sense of security, a sense of belonging to a place, location in the social hierarchy and diversification of investment capital. According to Renigier-Biłozor et al. [7] the need for housing takes one of the main places in the hierarchy of the importance of needs. With reference to Markov's well-known hierarchy of needs, a house or a flat not only provides the basis for the physiological necessity of shelter for all society [8] but is also a fundamental need to strive to find one's own place on earth [9], a sense of belonging [10] and a factor in the health of societies [11], and is considered as well as a main human right [12]. It is an integral and indispensable element of meeting needs virtually in every sphere of human life: in the sphere of security needs (for stability), social needs (home, meeting place), needs for recognition and respect (prestige, highlighting social position) and the need for self-realization (proof of independence). Thus, the need for a location and appropriate living conditions is most important to all people and remains relevant throughout their lives [2]. A significant proportion of households are able to satisfy their housing needs (flats or single-family houses) through ownership or tenancy [13]. The motives for buying an apartment can be varied. On the one hand, they may result from social needs (especially family needs); on the other hand, they may result from economic needs (deriving income from renting).

Research on the housing market is being conducted in Poland and Lithuania, but the authors usually analyze the preferences of young people, i.e., mainly students [14,15]. This is facilitated by the relative ease of obtaining survey data. However, there is little comprehensive research on the issue of making tenure decisions—to buy or to rent. According to Dziworska [16], this is undoubtedly a complex problem to which there is no unequivocal answer and, as scientists and practitioners, we are obliged to search for rational system solutions, as well as to improve the premises of decisions in the scope of choosing the housing tenure of satisfying their needs. However, the results of the study on the role of women in the housing market in the countries studied are not known to the authors of this article.

This situation encouraged the authors of this article to undertake more detailed research on this issue. For the purposes of the study, the following hypothesis was formulated: women have a significant role in decision-making in the housing market in Poland and Lithuania. In the paper, two legal rights for the flats are considered—ownership and tenancy—and when the term "housing market" is used, it means the market of flats (also called premises or dwellings). In Poland, the term "housing" means a premises for a permanent residence of persons—built or remodeled for residential purposes and structurally separated by fixed walls within a building, into which separate access leads from a staircase, passage, common hall or directly from a street, a courtyard or a garden, comprising one or several rooms and auxiliary spaces [17]. According to Statistics Lithuania [18], a dwelling (housing) is defined as a one-dwelling house, a part thereof, flat or other living quarters meant for a person or family to live in. The study was followed by a survey of Polish (Olsztyn) and Lithuanian (Vilnius) housing market customer attitudes. These two Baltic countries were selected because of some important common historical facts (Poland and Lithuania formed one common state and both were under the communist regime as separate countries), although there are differences in economic, political and cultural determinants typical of a particular country reflected in the behavior of customers of different genders in the housing market. The research involved respondents from Olsztyn (percentage of women 58.4) and Vilnius (percentage of women 61.9). The paper is structured as follows. After a short introduction to the research (Section 1), a theoretical basis of the conducted research is given in Section 2 together with an overview of historical and mindset-based determinants, demographic factors and women's characteristics as housing market customers. Analyses of factors such as age and the role of women in childbirth and expectations resulting from living conditions are also presented.

Section 3 presents the general characteristics of Poland and Lithuania (for the cities of Olsztyn and Vilnius) and the characteristics of the profile of real estate market customers in both countries. Section 4 presents the results of the conducted research and a discussion of the obtained results. Section 5 presents conclusions drawn throughout this work.

2. Theoretical Basis of the Research

The tenure choice (ownership or tenancy) of residence is determined by many factors: economic [19,20], social [21–23], financial [24,25] and other factors [22]. The importance of this dilemma and the ways to solve it are determined inter alia by the decision-maker's age [26,27].

Young people with insufficient funds, when faced with a choice of whether to buy ownership of a dwelling unit and pay off the mortgage, often decide upon tenancy. A study conducted by Źróbek-Różańska and Szulc [15] demonstrated that young people not only want to live in an attractive location but also desire good access to their workplace or school and a good standard of interior finishing. Most researchers evaluated the preference of first-time homebuyers [28]. Studies of that type are generally conducted by developers wishing to know the relationship between the quality of the housing and property prices [29] and the price of the flat when it is selling under forced conditions [30].

However, there are few scientific papers concerning the effect of the customer's gender on the tenure choice [31–33]. Klak and Hey [34] examined women's access to the Jamaica National Housing Trust, created to finance housing for those most in need, and identified two gender biases. Varley [35,36] emphasized the women-headed household percentage and gender and property formalization. Lambert et al. [37] analyzed women's position in the indoor spaces in which they live. To date, very few studies have evaluated the factors that determine the choice of housing market tenure and whether women have the final say in this matter. Brzezicka and Wiśniewski [38] analyzed whether women have a decisive say regarding the choice of the place of residence and make their decisions depending on their life situation: living alone, the future upbringing of their offspring and spending their old age. This partly results from nature, in which it is the female who often chooses the location for the nest, and humans are certainly an important component of this nature [39]. This phenomenon is often emphasized by real estate developers and marketing specialists.

The issue of making decisions concerning housing tenure choice will be considered in the initial part of this paper in terms of two basic factors: historical and mindset-based determinants, and demographic factors. The issue of women as housing market customers will also be discussed in more detail.

2.1. Historical and Mindset-Based Determinants

It is a commonly held belief that holding the right of ownership ensures a sense of security, life stability and mental comfort [40]. The purchase of real estate is often viewed as moving on to a new, better stage of life and a certain kind of step into adulthood [26]. Ownership, i.e., "this belongs to me", is deeply rooted in both Polish and Lithuanian mentality. In Poland, historical experiences have also had a profound impact on the different perception of these two different rights to a housing unit, i.e., ownership and tenancy. This fact was noted in an interview by sociologist Pęczak [41]. During the era of the partitions, Poland was under Prussian, Austrian and Russian rule for many centuries. An average Pole associates rent with leasing and a leaseholder is still regarded by many Poles as a person that is temporary, non-authentic and worse-off than the others. The same situation was in Lithuania. For this reason, owning a flat today is a manifestation of freeing oneself from the previous political control. Inhabitants of Central European countries who have experienced a centrally-planned economy and communism have a similar way of thinking. This is confirmed by statistical data (Figure 1). The countries with the highest percentage of people who own their flat include Romania, Lithuania, Croatia, North Macedonia and Slovakia [42]. According to data from 2019, private ownership in Lithuania reached 90.3% and in Poland it reached 83.4%.

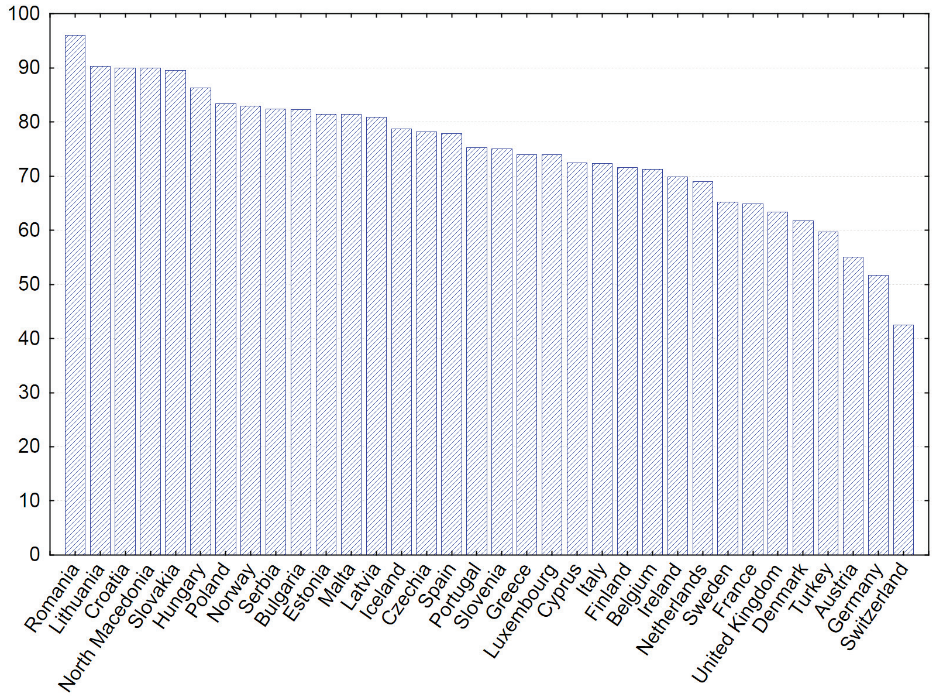

Figure 1. Share of population living in owner–occupied dwellings in the EU (%). Source: own elaboration [42].

For many people, it is also important to have ownership of a flat as a way to ensure financial security in old age [23,43]. If one assumes that today's generation of 30–40-year-olds will have pensions lower by approximately 30% than people currently aged 65–70, Poles choose the ownership of real estate as a form of preserving capital and ensuring financial security for the future. The additional advantage of owning real estate is the possibility of bequeathing it over to one's own children in the future [44]. Poles are diligent consumers and, according to statistical data, in Poland 83.5% of Poles own flats or single-family homes [17]. Because the cost of rent in Poland is still high, people who are creditworthy prefer to be the owner of a flat, as the mortgage loan installment, including the rent and additional charges related to the purchase of real estate [45], is often lower than the rental payments for a flat.

2.2. Demographic Factors

The long-term equilibrium in the housing market is significantly affected by demographic factors, especially the rate of natural increase of the population and increases in the net migration trend [46,47]. Of all demographic factors, the age structure of the society is of priority importance. It is commonly believed that owning a flat indicates a higher social status of a particular person. It is emphasized that a chief income earner's age below 45 years may indicate that he/she is a tenant of the dwelling unit, while for an age over 45 years, the probability of ownership of an occupied flat increases significantly [46]. According to Młynarska [48], the real estate market is influenced by the age at which a woman gives birth to offspring. Changes initiated in 1990 resulted in a shift of women's peak fertility from the 20–24-year age group to the 25–34-year age group. As a consequence, the median age of women giving birth increased (from the beginning of this century) from 26.1 years in 2000 to 29.9 years in 2016. During this period, the average age of giving birth to the first child increased as well (from 23.7

to 27.8 years, respectively) [17]. The data of Statistics Poland [49] show that in Poland, approximately 35% of women give birth to their first child at the age of 25–29 years; this group is closely followed by women aged 31–35 years, who account for approximately 31%. According to the data of the Lithuanian Department of Statistics, in the first year of independence of Lithuania (in 1991), the highest number of women gave birth at the age of 22. The number of women giving birth at 30–40 years old since 2005 increased about 1.5-fold. The current average maternity age (women who have given birth) in Lithuania is about 29 years [50]. The relationship between parenthood and owning a dwelling unit was reported by Foryś [51]. According to Matysiak [21], 57% of women who became pregnant with their first child live in their parents' home and 30% reside in their own flat. A tendency to change the place of residence emerged in the following years. When the child reaches the age of 2–3 years, 42% of women reside in their own flat, while for the child aged over 3 years, 47% of women reside in their own flat. It was also demonstrated that the child's age had no effect on the actual renting of a flat, and the percentage of people renting a housing unit ranged from 11% to 13%. On the other hand, the trend of moving into one's own flat is observed with an increase in family size.

According to the data of the Income and Living Conditions Survey, in 2011, most (90%) families in Lithuania with children lived in their own single-family homes or flats. However, almost 40% of families said that maintaining a house is a very heavy burden, and only 9% of families did not feel this burden. In 2011, 61% of families with children lived in flats (dwellings), 31% lived in a single-family house and 7% lived in a semi-detached house [52]. Other reasons influencing the decision as to whether to purchase or rent a flat are indicated by Forlicz [53]; these include: (a) the passage of time (the result of aging and gaining experience); (b) changing the surroundings, including physical (the location), social (health status) and cultural conditions (a new system of values, etc.); (c) the effect of imitating other people; (d) the prestige effect (Veblen's paradox); (e) the "sour grapes" effect (undervaluing the goods one is not able to acquire, and overvaluing those which are easily accessible); and (f) the emergence of new goods or information on their existence (attractively priced, with attractive utility parameters).

2.3. Women as Housing Market Customers

Since the mid-19th century, women's activity in the areas previously reserved exclusively for men has been gradually increasing. Is the situation of the real estate market similar? Are women seizing the initiative and having a decisive say in this area as well? Decision-making in investment processes based on gender has been studied in relation to the willingness to take risks [54,55], to trade on the stock exchange [56] and engage in the housing market [57]. However, it should be noted that these studies do not directly analyze the gender issue in relation to the tenure decision. No broader scientific studies of this topic are available in the Polish literature on the subject. As mentioned before, the first attempts to analyze the significance of gender and age in the decision-making process in the real estate market were made in 2018 [38]. This may be because the real estate market and free trading in rights to real estate in Poland are relatively new compared to Western European countries. After the economic transformation in the 1990s, a number of changes took place in the field of real estate management. At that time, real estate companies modeled on enterprises operating in Western European countries and the United States began to emerge. It was mainly these companies that began to assess gender impact on purchasing real estate. Even though the main purpose of their analysis was to establish the principles of effectively promoting and selling real estate, they also considered women to be significant customers in the housing market. On the other hand, no symptoms of adaptation of built apartments by construction companies to women's tastes and needs were noted. There is also no information as to whether construction companies employ, for example, architects who know the needs of women when designing buildings.

3. Case Study—General Characteristics of the Research Objects

3.1. Description of the Study Structure

A description of the structure of the study, including the specification of study stages and the methods applied to implement particular tasks, is presented in Figure 2.

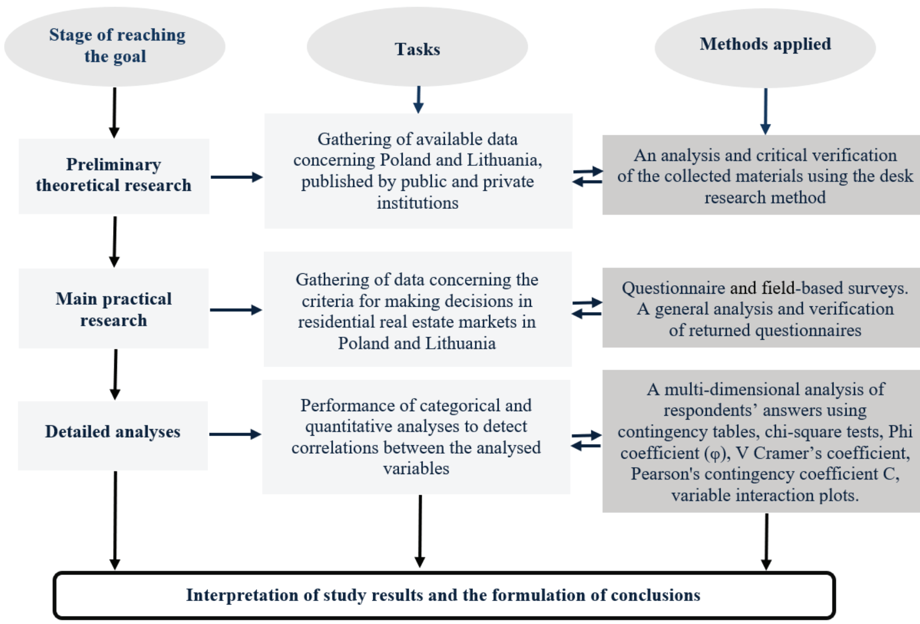

Figure 2. Diagram of the study organization.

The content of the subsequent chapters of this paper follows the above-mentioned research procedure.

3.2. Poland and Lithuania—General Data and a Short Common History

The research concerning women's importance in the housing market was conducted in Poland and Lithuania because these countries are now members of the European Union and have a common history. Figure 3 shows the location of Poland and Lithuania in Europe and the objects of the practical research (Olsztyn and Vilnius).

The close integration of Poland and Lithuania took place in 1569, when the so-called Union of Lublin was concluded, under which a common state emerged, named the Commonwealth of Two Nations until 1791. Further integration of Poland and Lithuania was interrupted by the partitions, as a result of which the common territories of these countries were separated and incorporated within the borders of three European powers (Austria, Prussia and Russia) until they regained independence in 1918. Unfortunately, after the end of the World War II in 1945, both countries were included into the block of socialist states dominated by the Union of Soviet Socialist Republics (USSR), with Lithuania making up one of those republics while Poland remained a dependent state. Those twists and turns in the history of both nations provided the inspiration to start comparative studies concerning the behaviors of the housing market customers in Poland and Lithuania, taking into account the role of women as an important determinant of the demand side of this market. It was expected that despite many years of historical, religious and cultural connections, important political events in the history of those countries could result in different cultural codes, which may include, for instance, a significantly different importance of women in those societies. As regards the Eastern European countries that underwent the transformation from a centrally-controlled economy to a free market economy in the 1990s, attention should be paid to the rapidly changing attitudes in post-socialist societies towards the perception of ownership rights and understanding the housing market. The introduction in the late 1990s of changes, such as ensuring freedom of economic activity and the protection of property rights and inheritance, influenced the development of the residential real estate market [58,59]. These favorable political and economic changes have an increasing impact on the possibility to choose the conditions of residence and the housing tenure.

Elderly people are burdened with the personal experience of a socialist economy, which discouraged ownership rights, including the private ownership of land, flats and houses. On the other hand, the younger part of society regards the right of ownership in the housing market as an ordinary social standard, which corresponds to the behavior of societies in Western European countries.

Figure 3. Location of Poland and Lithuania in Europe and the objects of the practical research.

As part of the preliminary research, in order to carry out comparative analyses of the preferences of flat purchasers/tenants in Poland and Lithuania, data were compiled that characterized both countries. Table 1 presents the basic information and data concerning the analyzed countries.

Table 1. General political and socio-economic data of Poland and Lithuania.

Kinds of Data	Poland (PL)	Lithuania (LT)
General location and area	Europe/312,679 sq. km	Europe/65,300 sq. km
Government	Parliamentary Republic	Unitary semi-presidential republic
Member of the European Union	From 1 May 2004	From 1 May 2004
Population	38,432,992	2,791,903
Age structure of the population		
0–14 years	15.0%	15.8%
15–64 years	68.6%	61.8%
65 years and more	16.4%	22.4%
Women as % of the population	52%	53.9%
The average size of flats	73.8 m^2 in urban areas—64.5 m^2, in rural areas—93.1m^2	68 m^2 in urban areas—62.1 m^2, in rural areas—79.9 m^2.
Gross domestic product, current prices in USD Billion Dollars	GDP 571.32	GDP 96.91
Gross domestic product per capita, current prices in USD	GDP per capita 13,811.66 USD	GDP per capita 16,680.68 USD
Unemployment rate	4.5%	6.1%

Source: authors' own research based on [49,60].

3.3. General Profile of Housing Market Customers

In order to carry out detailed research on the real estate market and to provide a proper interpretation of the results of its analysis, it is important to indicate at least one customer profile for a given market segment. For the purposes of this paper, the profile of the housing market customer in Poland and Lithuania was prepared based on information from the banking area [61]; real estate brokers [62–65] and on interviews with experts in the field of housing development and mortgage counseling (Table 2). In Poland, ten interviews were conducted with mortgage bankers, eight interviews with real estate development companies and six interviews with experts from real estate agencies. At the same time in Lithuania, ten interviews were conducted with real estate market experts and six interviews with mortgage bankers.

As results from the profile of the housing market customer, women are more involved in real estate tenure. Such an opinion was expressed by real estate brokers from both examined countries. Entering into marriage or making a decision on living together and having children is an event that significantly affects housing tenure decisions. On the other hand, according to bank data analyses, married couples receive the majority of credits, and the real estate for which they are taking this credit is primarily a housing unit. This fact in many cases justifies the decision to purchase a flat.

Research conducted by a network of real estate agencies [65] shows various preferences of real estate agency website users. Below are some of the conclusions from conducted analyses. Flats are sought mainly by young women working their way up the professional career ladder (47% of them are women aged from 26 to 35 years old). Women with an established professional position account for 21% (36–45 years of age), 13% (46–55 years of age) and 11% (over 55 years of age) of flat seekers. Women under the age of 25 account for only a few percent of the total. The female respondents' answers also show that women are interested in commercial premises and building plots to a lesser extent than men. Research conducted by the Walczak [67] shows that the final decision on the purchase of real estate is taken by women (63%).

Table 2. Profile of Polish and Lithuanian clients of the housing market.

Sources of Data	Type of Data	Polish Client	Lithuanian Client
Bank statistical analyses	Age of borrowers	Up to 35 years (57.6% share in the number of mortgage loans).	25–34 years (60% share in the number of mortgage loans).
	Aim of a mortgage	Flat purchase (66%)	Flat purchase (58%)
Direct interview—bank advisers	Gender of person signing the loan agreement	Joint ownership of statutory marriage—together. Single people—more often men; women very rarely.	Married couple—together. Single—more often men
Direct interview—real estate agents	Gender of person signing an agency contract	53% women	45% women
	Gender of person having a decisive voice in the selection of real estate	90% women	45% women
	Gender of person looking for real estate	47% women	45% women
	What right to real estate is acquired?	54% women indicated the ownership of real estate.	40% of women indicated the ownership of real estate.
	Stage of life	Young spouses make a decision together. Mature families—the wife makes the decision (men older than 40 years are more involved in work outside the home).	Young spouses make a decision together.

Source: authors' own research based on interviews with experts and Dominium [66]; SEB [64].

In Lithuania, access to such detailed data is more difficult. Online publications more often refer to the issue of investing in the market in order to earn income from real estate. People in Lithuania would be much more satisfied with their life if they earned twice as much as they currently do, and the most attractive investment is real estate property, according to the latest survey of the Bank of Lithuania [68]. Real estate market specialists say that apartments for investment in Lithuania are more often chosen by women than men. As noted by the developers of small apartment projects in the capital, most of the apartments they sell are purchased on the initiative of women, who later purchased real estate used for rent. This trend also reflects deeper differences in financial behavior between women and men. According to a survey conducted by Barclays Bank, 49% of women name real estate as the best solution for investment. According to Fidelity's survey, the US dollar investments of women in the US brought 0.4% average higher financial returns than men's investments [69].

In summary, it may be concluded that demographic and social reasons, as well as the decisions taken by women, create the image of the housing market.

3.4. The Cities Vilnius and Olsztyn as the Objects of Detailed Research

Our practical studies involved customers of two local markets in those countries—Olsztyn in Poland and Vilnius in Lithuania. Olsztyn is the capital city of the province of Warmia and Mazury, the seat of local authorities and institutions, and is a main business, educational and cultural center. Vilnius is the capital city of Lithuania, the seat of municipal authorities of the Vilnius city and the surrounding region, and a large economic, cultural and academic center. Both cities are located within a distance of 500 km of each other. In view of the history of these cities, Vilnius is also the main center of Polish culture and science in Lithuania. Table 3 presents significant data concerning those research objects.

Table 3. General description of Olsztyn and Vilnius.

Data Types	Olsztyn	Vilnius
Total number of inhabitants, including:	173,000	551,900
women	53.5%	55%
men	46.5%	45%
Households		
multi-person households	62%	64%
one-person households	38%	36%
Age structure of the population at the:		
pre-working age	17%	16%
working age	61%	67%
post-working age (retirees)	22%	17%
Gross monthly income/price of 1 m^2 of a flat	0.94	0.83
Gross monthly income/monthly rent for a 45 m^2 of a flat	2.33	3.06

Source: authors' own research based on [17,59].

All citizens of Poland and Lithuania are equal by law, regardless of their gender. Their rights are guaranteed in Poland (article 33) and in Lithuania (article 29) by the provisions of the Constitution. This also applies to holding various legal rights to real estate and the freedom of their use.

4. Results of the Research and Discussion

4.1. Characteristics of Olsztyn and Vilnius Respondents

A comparative study into the decisions taken in the residential market by households was conducted among respondents from Olsztyn (101 questionnaires) and Vilnius (84 questionnaires). In this study, a household is defined as either a one-person household, i.e., a person who makes provision for his or her own food and other essentials of living without combining with any other person to form a multi-person household; or a multi-person household, i.e., a group of two or more persons living together who make common provision for food and other essentials for living [70].

The questionnaires were drawn up in the respondents' national languages and made available from October to December 2019 on a specialized online platform. Twenty-five questions were formulated with different possibilities for providing answers, e.g., a choice of one or more suggested options or open questions. The survey questions were addressed to the target groups: public offices, private institutions and universities.

The aim was to assess the motives for the tenure decision and what were (or are) the significant reasons for changing the place of residence. The general characteristics of respondents are presented in Table 4.

Table 4. Characteristics of Polish (Olsztyn) and Lithuanian (Vilnius) respondents.

Feature	Characteristic	Olsztyn	Vilnius
Households	Multi-person household	79.2%	57.1%
	One-person household	20.8%	42.9%
Sex	Female	58.4%	61.9%
	Male	41.6%	38.1%
Age (in years)	<30	9.9%	41.7%
	31–45	65.2%	33.3%
	46–60	11%	22.6%
	61<	13.9%	2.4%
Employment	State sector	58.4%	31.0%
	Private sector	15.8%	50.0%
	Own business	14.9%	8.3%
	Unemployed	2.0%	8.3%
	Retirement	8.9%	2.4%
Place of residence	Voivodeship city	57.4%	95.2%
	County city	25.8%	3.6%
	Community	6.9%	0.0%
	Village	9.9%	1.2%
Satisfaction with the current place of residence	Definitely like	43.4%	40.5%
	Like	22.2%	19.0%
	Rather like	18.2%	9.5%
	Want to change	16.2%	31.0%

Table 4 shows that women more often than men actively participated in the study, and consequently, they accounted for approximately 60% of the total number of respondents. Over 75% of respondents in both countries were under 45 years of age. For Polish respondents, over 65% were between 31 and 45 years old, while for Lithuanian respondents the proportion amounted to slightly over 33%. The cause of this disproportion is a multi-person household (over 79% in Poland and over 57% in Lithuania). Consumer behavior is, to a large extent, determined by social relations with one's family and closest friends [71]. The study found that a one-person household (approximately 21% in Poland and approximately 43% in Lithuania) indicated different housing needs than a multi-person household.

A study of consumer behavior in the housing market should be based on answers provided by young or middle-aged people, to ensure that respondents represented the actual, and not potential, demand. High residential activity (ownership/sale/tenancy/rent) of respondents under 45 years of age results, inter alia, from:

- The willingness to confirm one's material status (the location in the social hierarchy, defined by the most valuable asset in the household, i.e., a house or a flat);
- The birth of children (the need for increasing the flat's area);

- Occupational mobility (a choice between tenancy and ownership a flat).

The elderly respondents' answers concerning the reasons for changing their place of living in the future or making a real estate tenure decision did not realistically reflect considered future decisions in the housing market. As a rule, elderly people are not interested in changing their place of residence [72]. This was also confirmed by Cocco et al. [73] and Yogo [74] concerning the purchase of residential real estate by older people and changing their place of residence [75].

As regards the older people participating in the survey (aged over 60), they only accounted for 2.4% in Lithuania and 13.9% in Poland. The presented respondents' distribution in terms of age (Table 1) is appropriate for the aim of the study. The average age of respondents (44 years in Poland, and 36 years in Lithuania) reflects the high level of professional activity (approximately 90%). An interesting fact is the Lithuanian respondents' dominant level of employment in the private sector (approximately 50%) with an almost 60% level of employment in the public sector in Poland. Almost 70% of female Polish respondents are employed in state or local government institutions, which, as a rule, is regarded as a stable and safe form of employment; 10% work in the private sector and 3% run their own business. The high rate of female respondents' employment in the public sector results from the fact that state and local administration (including state health care and education) is very expanded in Poland, and it reflects the general employment structure across Poland. On the other hand, over 58% of Lithuanian women work outside the public sector: 50% work in the private sector and over 8% run their own business. Detailed relationships between gender and the form of work activities are presented in Figure 4.

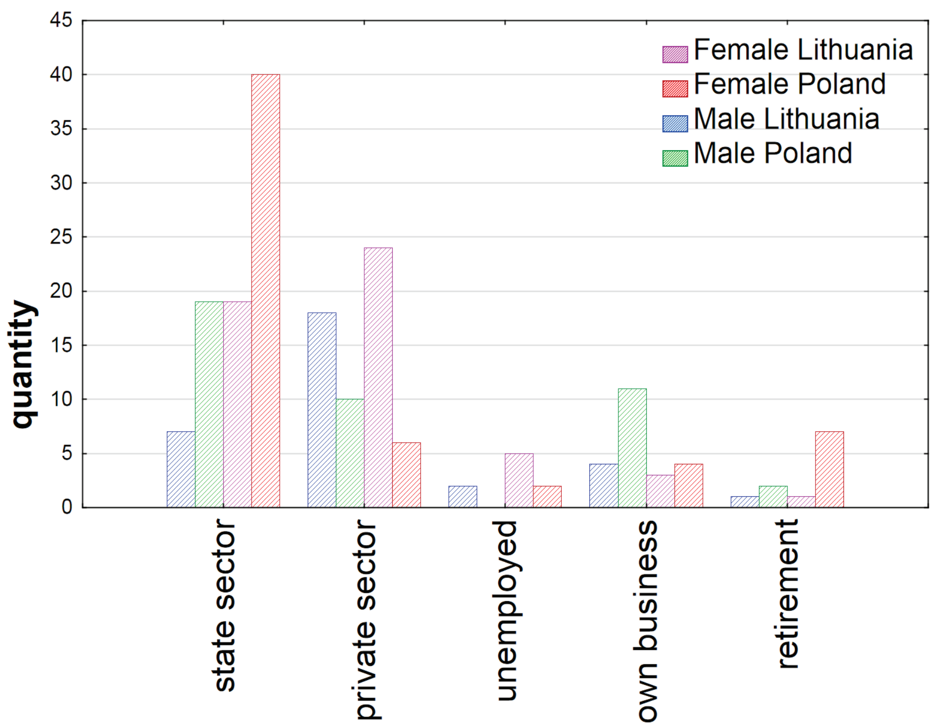

Figure 4. Multi-series bar chart of the relationship between gender and form of work activity.

As a result, 31% of respondents from Lithuania indicated a desire to change their present flat, compared to over 83% of respondents from Poland who indicated their satisfaction. Respondents from

Poland and Lithuania also provided answers to the question concerning the main reason for the intention to change their flat in the future (Figure 5).

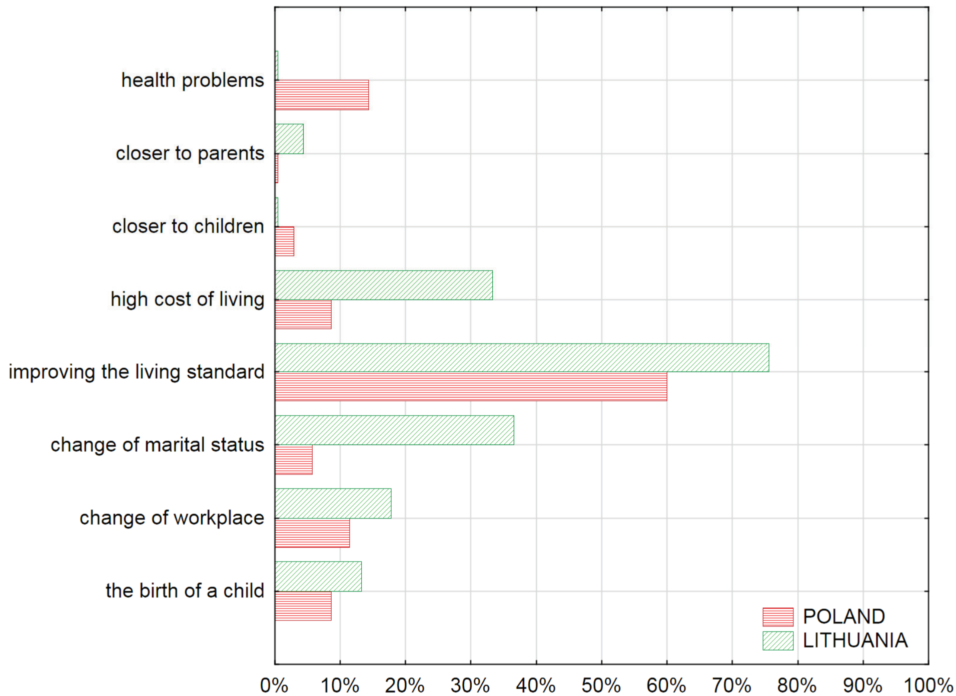

Figure 5. Reasons for the intention to change the flat.

The results based on answers provided by respondents from Poland and Lithuania (Figure 5) demonstrate that deciding to change the current place of residence is most significantly influenced by the need to improve its standard. The disproportion in marital status (Table 2) among the respondents from Poland and Lithuania is clearly noticeable in the indication of changing the marital status by Lithuanians (almost 40%) being the second most important reason for searching for a new flat. Over 30% of Lithuanian respondents indicate a high cost of living (high rent), compared to only 8% of respondents from Poland indicating this reason. However, Polish respondents indicate health problems (approximately 15%) as a significant cause of changing the place of residence.

Since a significant proportion of respondents (approximately 84% in Poland and approximately 70% in Lithuania) are satisfied with the flat they own, respondents were asked to indicate the reasons for not being interested in changing their current place of residence (Figure 6).

For most respondents from the analyzed countries (over 60%), the most important reason for not being interested in searching for a new flat was the distance to the workplace. Almost 40% of Poles and Lithuanians indicated the positive effect of proximity to health care facilities (hospitals and clinics). Financial issues were important to approximately 30% of respondents from Lithuania and 15% of respondents from Poland.

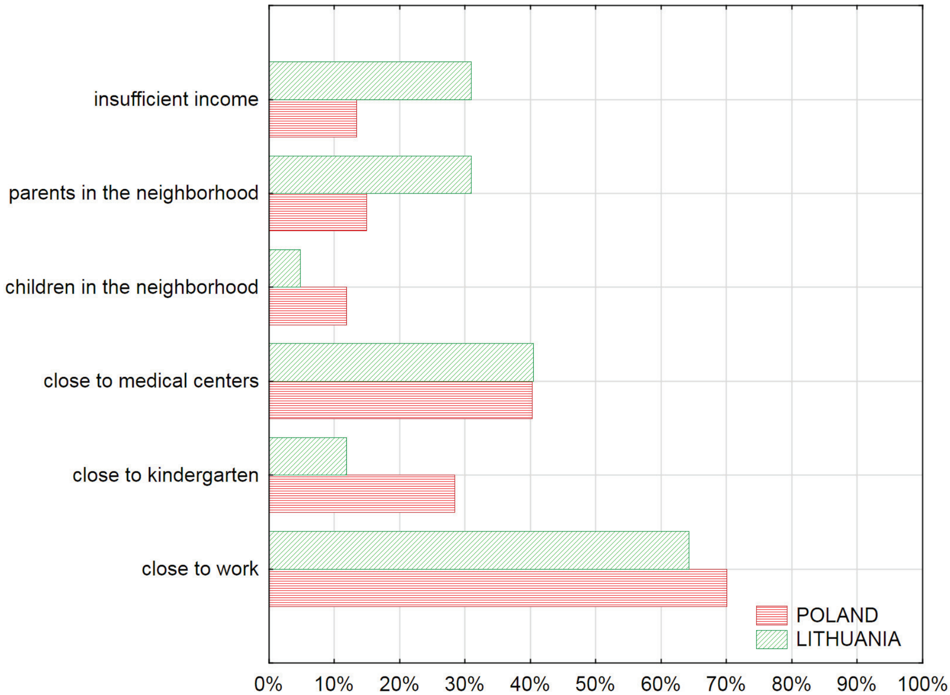

Figure 6. Reasons for not being interested in changing the flat in the future.

4.2. Examination of Gender Impact on Housing Choice Decisions

This study sought to verify the hypothesis of gender impact on decisions on the housing market. The demonstration of such a relationship using statistical measures is a significant condition for proceeding to the next stage of the study, i.e., determining gender impact on the housing market in Poland and Lithuania.

When answering a number of questions, respondents from both analyzed countries were asked to address the following issues:

- What right do they have to their currently inhabited real estate (ownership/tenancy)?
- Who has had the decisive say as regards the change of flat?
- Whether the next residential real estate will be owned or tenanted.

To this end, a multi-dimensional analysis of answers provided by all respondents included in contingency tables (crosstabs) was conducted. These tables enable the testing of the statistical significance of categorical variables and their interactions in the form of a log-linear analysis. Contingency tables [76–78] are a tool to describe categorical data involving the distribution of two or more segmentation variables. The result of the segmentation process is a matrix in which each cell indicates the number or frequency of the occurrence of analyzed attributes defined by specific variable values. Log-linear analysis [79,80] is based on the maximum likelihood estimation method and examines the independence and interactions between categorical variables. In this method, any significant deviations in the numbers observed in the analyzed population from the expected results indicate the existence of relationships between these variables. In contingency (four-fold) tables, a statistically significant relationship is verified using a chi-square independence test. In this test, the null hypothesis assumes no relationships between the analyzed variables, while the alternative hypothesis confirms the occurrence of such a relationship. On the other hand, the strength between variables can be determined by calculating the Phi coefficient (ϕ), V Cramer's coefficient or Pearson's contingency coefficient C.

Table 5 presents the basic statistics for the conducted calculations without separating respondents based on gender, as the assumed effect was the confirmation of gender significance as one of the analyzed variables.

Table 5. Main statistics for the conducted calculations in contingency tables.

No.	Relation	Statistical Measure	Chi-Square Test	df	*p*
I	Gender–current property rights (ownership/tenancy)	Pearson's Chi-square test	17.27	df = 3	$p = 0.00062$
		Pearson's Chi-square highest credibility test	17.83	df = 3	$p = 0.00048$
		Phi coefficient	0.31		
		Cramer's V factor	0.31		
		Pearson's C contingency coefficient	0.29		
II	Gender–decision -maker on the change of a flat	Pearson's Chi-square test Pearson's Chi-square highest credibility test Phi coefficient Cramer's V factor Pearson's C contingency coefficient	32.88 33.23 0.43 0.25 0.38	df = 9 df = 9	$p = 0.00014$ $p = 0.00012$
III	Gender–type of right (ownership/tenancy) when changing a flat	Pearson's Chi-square test Pearson's Chi-square highest credibility test Phi coefficient Cramer's V factor Pearson's C contingency coefficient	0.22 0.21 0.05 0.05 0.05	df = 3 df = 3	$p = 0.97469$ $p = 0.97557$

For relationships I and II (Table 5), the values of Pearson's chi-square test (17.27 and 32.88, respectively) and the maximum likelihood chi-square test (17.83 and 33.23, respectively) as well as the p-values (statistical significance at a level of $p < 0.0001$) allow the null hypothesis to be rejected and, consequently, enable the demonstration of a significant relationship between the analyzed variables. This implies that there is a statistical relationship between gender (without distinguishing its types) and the variable related to the right to the flat held. At the same time, the conducted calculations demonstrated a significant relationship between gender and the decision-maker variable, which explained who influenced the decision on changing flat (inter alia, a jointly made decision or the partner's decision). Other statistical measures, i.e., Phi coefficient (ϕ), V Cramer's coefficient or Pearson's contingency coefficient C not only enable the determination of an actual significant relationship between variables but also measure the strength of the relationship between these variables. For each of these coefficients, the closer the coefficient value is to 1 within the [0, 1] range, the stronger the analyzed relationship is (for the coefficient ϕ the [−1, 1] range). For relationships I and II, the values of the obtained coefficients were at the level of average or relatively weak relationships (0.31 and 0.25, respectively). For relationship III, all statistics confirmed the null hypothesis of no relationships between the analyzed variables ($p = 0.97$).

The confirmation of gender significance for relations I and II (Table 5) enables moving on to the next stage of the study, which involves taking into account the differences between women's and men's answers and the respondent's country of residence. Figures 7 and 8 present the plots of variable interactions between gender and the choice of a specific right to residential real estate (ownership/tenancy) as well as between gender and the decision-maker as regards changing flat.

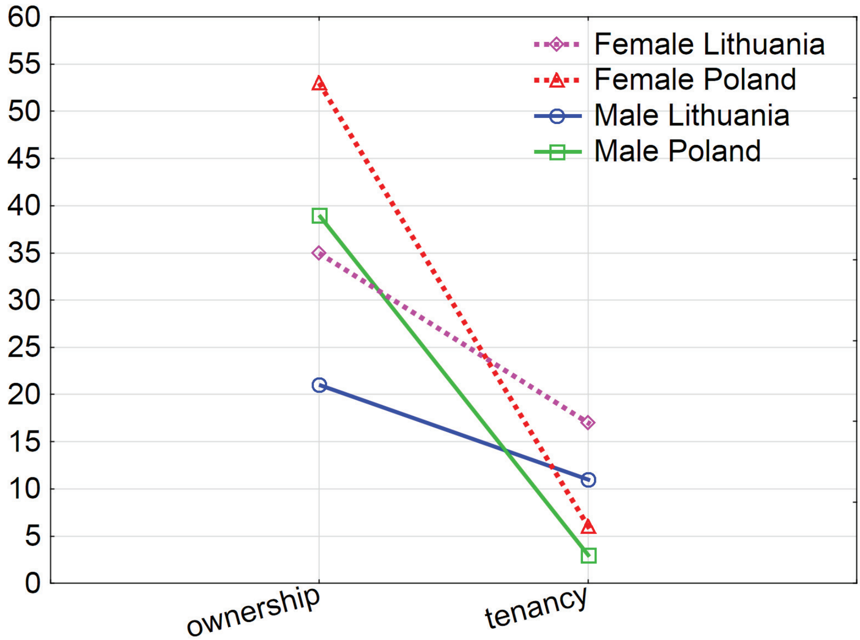

Figure 7. Interactions between gender and the current tenure of a flat.

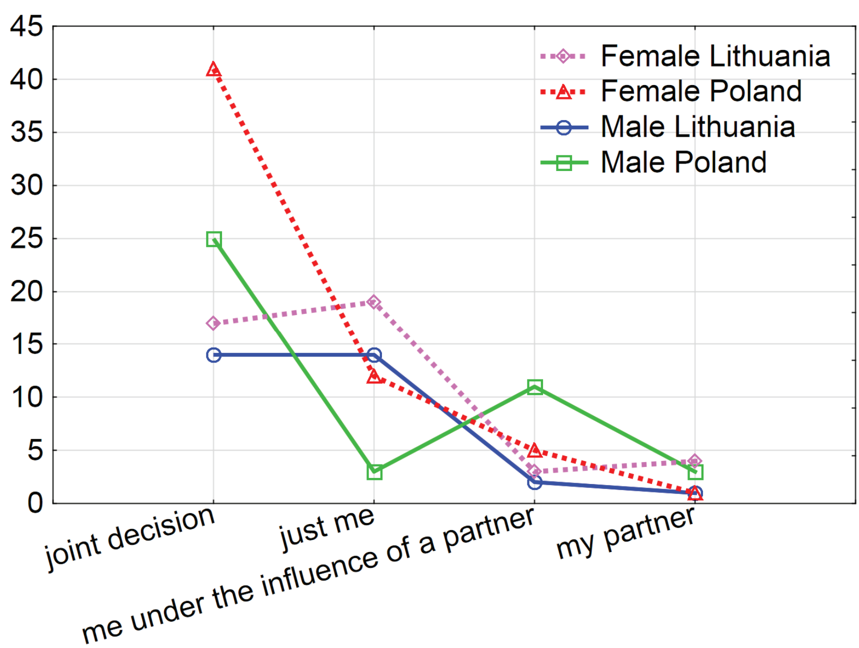

Figure 8. Interactions between gender and decision to change a flat.

Figure 7 shows the relationship between gender and the previously selected (currently owned) type of right to premises. Respondents from Poland prefer, to a small extent, tenancy as the right of possession of a flat, while respondents from Lithuania regard tenancy as an alternative to holding the right of ownership of a flat. Generally, however, in both countries, irrespective of gender, the dominant form of possession of real estate is ownership. The interaction analysis presented in Figure 8 shows that on the housing market, decisions on the intention to change housing are mostly taken jointly (by women and men) in the surveyed households. This may be due to a sense of responsibility for the family one already has or for the future offspring, where an important issue is the sense of residential security offered by the right of ownership of a flat. Only an insignificantly small group of men indicated making an independent decision, which particularly applies to respondents from Poland. The high number of respondents' answers stating that they made a decision while influenced by the partner indicates that Polish men, as a rule, await proposals from their partners. Women generally exhibit greater decision-making autonomy in this regard than men, with Lithuanian women independently make such decisions significantly more often than female respondents from Poland.

The respondents who decided to change their flat also indicated the importance of the following factors on their decisions: the birth of a child, change of workplace, change of marital status and the desire to improve the living standard (Figure 9).

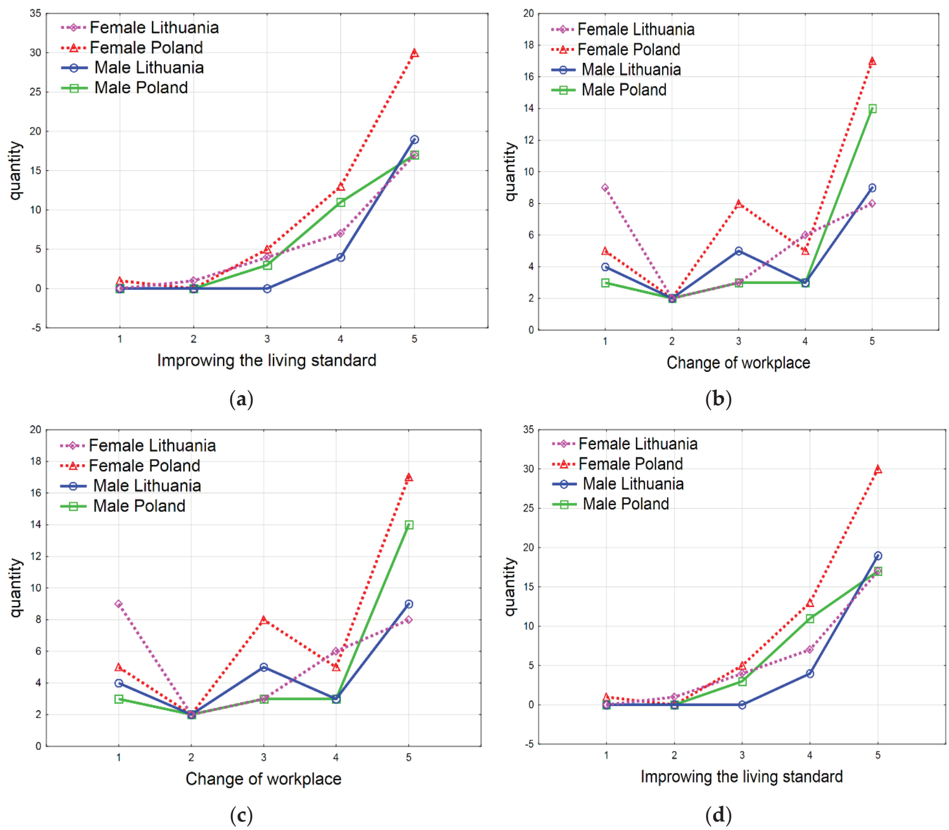

Figure 9. Factors determining the change of a flat according to the respondents: (**a**) the birth of a child; (**b**) change of workplace; (**c**) change of marital status; (**d**) improving the living standard.

The birth of a child (Figure 9a) is an important reason for changing the flat for most householders from Poland and Lithuania. The study adopted a 5-point Likert Scale of factor significance (including unimportant, slightly important, moderately important, important and very important).

Approximately 65% of Polish female respondents indicated the highest level in the applied scale (very important) compared to such an indication made by only 45% of Lithuanian women who, at the same time, regarded (approximately 30%) the birth of a child as an unimportant factor in changing the place of residence. The division of the adopted scale into 2 groups:

- The birth of a child: significant (scale—very important, important, moderately important);
- The birth of a child: not important (scale—slightly important, unimportant);

enables the determination of the general tendency in the behavior of men and women from both countries. Approximately 95% of women and men from Poland regard the birth of a child as a significant factor in changing the flat, which indicates a high similarity between both genders in this regard. A large disproportion is observed in Lithuania, as 83% of men and only 66% of women regard this factor as important. Based on the example of another variable interaction plot (Figure 9b), the high proportionality of respondent answers can be indicated more within the nationality than the sex difference. Polish respondents, both women and men, mostly considered a change of workplace as the most significant reason for changing a flat. This probably results from the low acceptance of tenancy by Polish society as a form of possession of residential premises for the period of workplace change. What is interesting is the fact that this feature is of low importance for a significant part of Lithuanian women. The dominant role of women in making decisions in the housing market can be confirmed by the results of analyses presented in Figure 9c, examining the effect of the marital status change on housing needs. Almost 70% of women from Poland indicated that a change of marital status has the most significant effect on the decision concerning the present place of residence. Therefore, the conclusion can be drawn that, after getting married, women strive towards common living in a new flat and are the more active side when making decisions in this matter (which is confirmed by the results of variable interaction plots in Figure 9a and the customer profile in Table 4. At the same time, women and men from Lithuania had very similar opinions in this matter. As regards the significance of improving the housing standard as a reason for changing the flat (Figure 9d), only 2% of women from Poland and 3% of women from Lithuania did not regard this factor to be important. Almost 100% of men from Lithuania (scale—very important, important) indicated the standard of living as an important element of decision-making in the housing market.

5. Remarks and Conclusions

The main purpose of the research was to investigate whether women have a significant role in decision-making in the housing market. After an analysis of existing theoretical views on the role of women in the housing market, a survey was conducted among respondents from Poland and Lithuania. The obtained responses were subjected to a multi-dimensional categorical and quantitative analysis. The analysis results, conducted using chi-square tests and the p-value, confirmed the occurrence of a significant statistical correlation between gender and the form of real estate acquisition (purchase or rent) and between gender and making a decision on changing a flat. The other statistical measures, i.e., Phi coefficient (ϕ), V Cramer's coefficient and Pearson's contingency coefficient C confirmed the occurrence of an average or relatively weak correlation between the analyzed relations.

The vast majority of Vilnius (Lithuanian) respondents (approximately 83%) live in multi-family blocks of flats and approximately 58% of Olsztyn (Polish) respondents live in a single-family house. Due to this fact, respondents from Lithuania are much more willing to change their current place of residence. The results based on answers provided by respondents from Poland and Lithuania demonstrated that the most important reasons for the willingness to change the current place of residence was the need to improve the standard of living, a change in marital status and the high cost of tenanted flats (high rents) in Lithuania. Due to insufficient funds, approximately 30% of households from Lithuania and 15% of households from Poland were not considering changing their flat.

It should be stressed that field research did confirm the predominance of a willingness to have ownership right of a flat over tenancy. Such preferences are quite clearly emphasized in the literature. Respondents from Poland prefer, only to a small extent, tenancy as the right of possession of flat, while respondents from Lithuania regard tenancy as an alternative to holding ownership of a flat. Women generally exhibit greater decision-making autonomy as regards housing issues than men, with Lithuanian women doing this much more often than female respondents from Poland. These results confirm the noticeable advantageous role of women in the housing market. It should be noted, however, that this role is not decidedly dominant. This is because the analysis of interactions showed that, in this market, joint decision-making (by women and men) prevails in changing flats in both considered objects. At the same time, this means that common cultural elements and a similar mentality shaped by historical conditions have a significant impact on the perception of real estate and decision-making in the real estate market.

This conclusion can be treated as a cognitive value of the conducted research. Although the number of respondents' answers was not very large, the results of the correlations could be useful for many entities, because they were additionally supplemented and confronted with the other existing sources of information and obtained at the time from interviews with experts from the local housing markets. An identification of factors affecting the choice of the tenure of flats by women and men can be used for more insightful and accurate decision-making in the field of housing policy and sustainable development. One of its instruments may be the identification of the priority tasks that need to be undertaken to create a more "fitting to needs" housing policy.

The results of the conducted analysis broaden the knowledge concerning the functioning of the housing market and may support the implementation of the pro-social and pro-sustainable spatial development policy of the given territorial unit. They may also contribute to a more sustainable development of the enterprises in the housing construction sector. This is an important issue in a situation of strong competition between "providers" of flats and the introduction of the idea of competition between them and the social environment. Due to the fact that clients of the housing market more and more often make their choice depending on the trust and position of the developer, some developers are joining programs run by public relations agencies. In these activities, they perceive the possibility of increasing a potential client's interest in their offer [81]. They also cooperate with consulting companies offering assistance in the planning process, investment implementation, consultancy and detailed analyses of local markets. These activities are part of the general term "sustainable construction", which is commonly understood as the design, construction and operation of building structures with a view to reducing their harmful effects on the natural environment while ensuring comfort and a high quality of life for their users [82,83]. Kalinowska-Sołtys [82] points out, among others, that in order for an architect to create a well-functioning, durable building, the cooperation of many participants of the investment process that are aware of a common goal is needed. This goal should be design solutions that will bring the largest ecological, economic and social benefits for planned investments. However, cooperation between construction companies and future buyers of dwellings is still not noticeable when taking into account their gender. This may be because the cooperation of enterprises in building their innovation potential in a manner more broadly suited to various social groups and their tastes is a relatively new form of cooperation in the studied countries [84].

Therefore, the answer to the question asked in the title of the article is affirmative. In addition, it was confirmed that women generally exhibit greater decision-making autonomy in final decisions regarding housing as a place to live for their family. In order to examine the extent of this advantage, more households should be included in further studies. The topics discussed in the article may become an inspiration for further research on the role of women in sustainable development, not only of the housing market, but also of the commercial real estate market.

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Varying Effects of Urban Tree Canopies on Residential Property Values across Neighborhoods

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Abstract: As more land area than ever is covered with impermeable surfaces causing problems in the environment, urban trees are effective not only in mitigating environmental problems in the built environment and reducing buildings' energy use, but also in increasing social and economic benefits. However, the benefits urban trees provide are not evenly distributed but rather disproportionately distributed in high-income neighborhoods. The purpose of this study is to estimate the varying effects of urban trees based on a variety of factors that have influence on tree canopy coverage, including land constraints, new developments, financial capacity to maintain trees, and neighborhood characteristics. Using a unique dataset that includes 24,203 single-family residential sales from 2007 to 2015 merged with Urban Tree Canopy (UTC), this study utilizes spatial models to empirically evaluate the impact of UTC on residential property values in the housing market. Multi-Level Mixed (MLM) models are used to capture the varying effects of tree cover, based on land constraints, new development, financial capacity, and neighborhood characteristics. The findings show the effect of trees is positive and varies across neighborhoods, and implication of the results to best achieve specific desired outcomes in tree-related policies and urban development are apparent.

Keywords: urban tree canopy (UTC); hedonic price model; two-stage spatial model; multi-level mixed model; varying effect

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1. Introduction

Demand for real estate developments of residential, commercial and other uses has led to urbanization and urban sprawl, resulting in significant impacts on environmental degradation. Due to land constrains for development in the built environment, most of the new developments are likely concentrated at urban fringes. According to Alig et al. [1], the increase in developed land has come from the conversion of adjacent forestland. As more land is covered with impermeable surfaces, such as streets, sidewalks, driveways, and building rooftops, the incidence and severity of serious environmental problems, such as urban heat islands, storm-water runoff, and flooding are increased [2].

Trees are effective in mitigating the environmental problems in the built environment and reducing buildings' energy use [3]. Trees can also provide attractive scenery as well as an acoustic screen between traffic noise and residential areas [4]. Trees also beautify neighborhoods and enhance residents' well-being [5], as well as increase economic opportunities through increasing sales in retail and commercial business by providing a favorable impression to shoppers, water savings and green jobs [6]. However, according to Schwarz et al. [7], maintaining tree cover creates potential costs and burdens, including the price of water supply in a changing climate, socio-demographic preferences and characteristics, and fiscal capacity to maintain tree cover. As a result, the benefits of tree canopies are unevenly distributed and disproportionally concentrated in high-income neighborhoods [7]. Ethnic/racial minorities and lower-income neighborhoods who have been traditionally marginalized lack the resources or capacity to overcome a scarcity of environmental benefits.

Motivated by the work of Schwarz et al. [7], this study attempts to examine the varying effects of tree cover of individual dwellings in the urban area on the residential property value across neighborhoods. Measuring these advantages of tree cover is challenging since many factors should be considered, such as residents' demographic characteristics costs incurred. The spatial distribution of land for development and for green space should be determined by residential choice [8] and, therefore, whether land is conserved or developed could be justified based on the economic value of tree canopies on house prices [9]. Of particular interest to this study are the varying effects of tree coverage across neighborhoods, based on a variety of factors affecting the size and proportion of tree canopy coverage, including land constraints, new developments, financial capacity to maintain trees, and neighborhood characteristics. Using a data set of 24,203 single-family residential sales from 2007 to 2015 in Des Moines, Iowa, two analytical approaches are used: a spatial model to control for spatial autocorrelation and a Multi-Level Mixed model (MLM) to estimate the varying effects of tree canopies based on the aforementioned factors.

The findings from this study indicate that there is a positive effect of tree coverage on housing prices, on average, which is consistent with previous research [10]. Moreover, the findings confirm the varying effects of tree canopies across the neighborhoods. The positive effect of tree canopies was found for homes with large lots, particularly in high-income neighborhoods, while tree canopies have a negative effect on the house value in low income neighborhoods, implying that the varying effects of tree canopies across neighborhoods mainly result from different financial abilities to maintain trees (Schwarz et al. 2015) [7]. Since the varying effects of an Urban Tree Canopy (UTC) may result in uneven distribution of tree canopies and disproportional concentration in particular neighborhoods, examining price variability between neighborhoods and measuring the varying effects of UTC play a vital role in policy decisions. Implication of the results to best achieve specific desired outcomes in tree-related policies and urban development are apparent.

This study extends the literature in two ways. First, this study estimates the varying effects of the tree canopies on the residential property using an advanced technical approach. These results suggest that the housing price differentials due to the tree canopy variation may be an additional characteristic to be included in the hedonic price model framework. The multi-level model allows for spatial heterogeneity in estimating tree-related housing price differentials in each neighborhood. Second, the findings of the varying effects of tree canopy coverages also shed light on how to implement the tree-related program to best achieve specific desired planning and urban development outcomes. The remainder of the paper is organized as follows: Section 2 provides a review of existing literature. Section 3 discusses the data and presents the empirical strategy, Section 4 presents the findings, and Section 5 concludes.

2. Related Literature

This section starts with the definition of tree canopies, then discusses methodologies for measuring tree canopy coverages, and finally describes the studies that estimate the benefits of trees on house prices. Previous literature has found that trees are positively correlated with residential property values. However, only a few studies have examined the varying effects of tree coverage (see Greene et al. [11]).

An Urban Tree Canopy, or UTC, is defined either as the size (or percentage) of the tree canopy relative to the total land area [12], or simply as the number of trees [13,14]. A field survey [14] and photographs [13] have been used to count the number of trees and gather extensive information, such as tree species, tree sizes, and environmental and landscape attributes. For instance, Anderson and Cordell [13] counted the number of trees, noting species and size, by looking at manually recorded written descriptions of properties from a Multi Listing Service (MLS) and black and white photographs. They found a positive correlation between the number of trees and housing prices. In particular, intermediate and large trees increased housing prices by $2750 on average. François et al. [14] collected extensive information on environmental and landscape attributes from a combination of CAD (Computer Aided Design), GIS (Geographic Information System) and field surveys. They found that, in general, an additional 1% of tree cover increases housing prices by 0.2%, and what they termed the "scarcity premium" differs depending on demographics, housing types, types of vegetation, and visibility.

Recent studies have begun to use aerial photos and high-resolution remotely-sensed imagery of land cover and impervious surfaces to determine tree canopy [10], since previous methods are effective only for small geographical areas. Sander et al. [10] examined the effect of trees in the Ramsey and Dakota Counties in the Minneapolis Metro area including 39 cities and 14 townships that consist of a mix of urban, suburban, and rural areas. They used the National Land Cover Database (NLCD), which leverages remotely-sensed imagery, to identify tree coverage, and found that a 10% increase in tree cover within 100 m raised the average home price by 0.48% ($1371) and within 205 m, the sale price increased by 0.29% ($836). Aerial photos have been used to identify not only tree coverage but also green covers. Conway et al. [15] defined green cover to include space that has a tree canopy, parkway, lawn, landscaped area, sports field, or cemetery, and determined the amount of cover acreage at each buffer distance of each house. They confirmed the significant positive impact of immediate neighborhood green space and found that increasing green space by 1% within 200 to 300 feet of a property increases the property value by 0.07% in Los Angeles, CA, USA.

The benefits attributed to urban tree canopies, including aesthetics, storm water runoff reduction, carbon dioxide reduction, and air quality improvement are challenging to measure in the monetary values and to translate into economic terms [13]. To estimate the value of public trees, such as city trees and street trees, Maco and McPherson [16] conduct a benefit-to-cost analysis of investing in city trees in Davis, California, and found the benefits to outweigh the costs, at a ratio of 3.8 to 1. However, the benefits associated with tress in individual dwellings, including beautification, shade, privacy, noise abatement, wind reduction, and soil protection, depend on buyer willingness to pay for tree canopies in housing prices. The majority of studies on examining the effect of trees found that the willingness to pay for trees is positively correlated with housing prices.

To measure the willingness to pay, among models used, the hedonic model estimated with Ordinary Least Squares (OLS) is the most frequently used statistical tool for analyzing the impact of a UTC on nearby property values and rental rates. In general, the environmental benefits associated with urban forests, including cleaning and improving air quality [17–19], are positively correlated with housing prices, while air pollution has a negative impact [20]. Laverne and Winson-Geideman [21], for instance, examined various attributes of landscape, including visual screening, noise attenuation, shade to parking areas, shade to buildings, recreational enhancement, space definition, and aesthetics on office rental rates. Among these attributes, good aesthetics and good building shade increased rental rates by about 7%, while others had no or negative effect. However, Cho et al. [22] addressed the limitations of the hedonic price model: "hedonic models estimated by OLS cannot be complete without consideration of the spatial configuration of green open spaces within a neighborhood" [22] (p. 415). In addition, Cho et al. [22] argued that the value of open space is sensitive to lot size, and the value of lot size increases as the distance to open space increases, which implies that site-specific land use management is needed because of spatial variation in amenity values. In order to control for spatial effects, more recent studies have started to use advanced statistical methods, such as spatial models [15,22,23], geographically weighted regression models [24], and multi-level hedonic models [25]. A variety of land covers, such as irrigated grass, non-irrigated grass or bare soil, and tree canopy, were examined using the Cliff–Ord model with fixed effects and a geographically weighted model in [24].

To investigate the causal effect of tree planting on housing prices, Wachter and Wong [26] used a difference-in-difference model to examine two tree planting programs; the Philadelphia Horticulture Society (PHS) program focused on low-income neighborhoods and the individual-based Fairmount Park Commission program. They found a significant housing price premium due to an individual local resident tree planting program. The house price differential for parcels sold within 1000 feet of tree planting was between 7% and 11%, of which 2% was attributed to the intrinsic value of trees, another 2% to omitted variable bias, and the remainder to a signaling effect. This signaling effect has high economic significance and is related to the degree of coercion among neighbors and details of the housing condition. The study was very limited, as 1151 tree plantings impacted 0.14% of sales (measured within 100 ft) and 2.15% of sales (measured within 1000 ft) were used.

That being said, the distribution of urban tree cover is uneven and inequitable, in that tree cover is highly associated with income. Schwarz et al. [7] examined the relationship between UTC and demographics, including race/ethnicity and household income, in seven cities across the US: Baltimore, MD; Los Angeles, CA; New York, NY; Philadelphia, PA; Raleigh, NC; Sacramento, CA; and Washington, DC. They found that the effect of tree cover varies across the cities as well as neighborhoods with income, a factor positively and significantly correlated with UTC across all cities examined. They concluded that UTC is disproportionately distributed in high-income neighborhoods because some traditionally disadvantaged and marginalized neighborhoods have a lack of resources or capacity to overcome a scarcity of environmental benefits. UTC could be viewed as a disamenty because it entails increased water demand, maintenance costs, allergies, and perceived safety concerns. Therefore, public investment and tree-related plans take the fact that trees indeed grow on money as concluded by Schwarz et al. [7] into consideration.

In summary, this study extends and contributes to the existing literature by estimating the varying effects of private tree coverage on house sales price. To do so, I use advanced methods—spatial and MLM models. It is also noteworthy that tree canopy coverages are defined as not only a percentage of tree coverage for each residential lot but also as the size of tree canopies in an immediate neighborhood. Neighborhood trees would reflect unobserved neighborhood characteristics. As Wachter and Wong [26] note, tree planting is viewed as a proxy of neighborhood social capital and signaling effects include details of the house condition or the degree of coercion among neighbors.

3. Data and Study Area

The city of Des Moines, located in Polk County, is the capital and largest city in Iowa. The city houses several headquarters of insurance and financial service firms. According to the 2014 US Census, 78% of the total population is white, followed by African American (11%) and Asians (5%). The median household income is $81,239, which is slightly higher than the state and US averages ($67,621 and $74,596, respectively). The city of Des Moines is a typical mid-sized city, with a total of population that has grown from 203,433 in 2010 to 216,853 in 2018. The city of Des Moines provides an ideal setting to test the varying effects of urban trees across neighborhoods with old and new housing stocks as well as different levels of intensification.

Although the city has had steady population increases overall, many of the inner-city neighborhoods have lost population as middle-class households moved to the suburbs. This has resulted in a surplus supply of housing and a house price decline in the inner city. Based on a study to understand the challenges facing the city's declining neighborhoods and identify techniques for stabilizing and strengthening them, Des Moines encouraged residents to form voluntary neighborhood associations based on geographical proximity. There are 54 neighborhood associations in the city that are generally homogenous in terms of socio-economic status, construction year, and residential property values. In addition, neighborhood tree programs are implemented through a planning process; therefore, the neighborhoods' participation and their involvement in tree planting and maintenance are critical for the programs' success [27]. On the other hand, the city has continuously attempted to annex neighboring municipalities and the city boundary has stretched toward the south and east of the city in order to accommodate an increasing population. The city has been experiencing substantial sprawl to meet development demand for residential, commercial, and other real estate uses.

A dataset using parcel-level sales data and UTC was constructed. The housing sales data were obtained from the Polk County Assessor's Office, and include detailed information on sale price and sale date, as well as structural characteristics, such as the size of the living area, the size of land, bedrooms, bathrooms, construction year, condition of the structure, and presence and type of garage. The initial data contained 40,566 observations from 2007 to 2015, of which 24,203 single-family residential sales were included for the final dataset after removing sales with missing information, sales with a price below $10,000 and non-single family home sales. Since the tree coverage data were collected in 2007 using high-resolution aerial imagery, homes constructed after that date were removed from the dataset. The tree coverage data might not be accurate for new construction, since trees may have been added or removed during the construction process. The average tree coverage was 34.88% and the average housing price was $105,593 during the study period. The detailed variables' definitions and their descriptive statistics are presented in Table 1.

Table 1. Descriptive statistics.

Variable	Variable Definition	Mean	Std. Dev.	Min	Max
price	Sale price	$105,593	$75,229	$10,000	$1,264,000
ln_hp	Log of sale prices	11.348	0.697	9.210	14.050
w_hp	Lagged log of sale price	11.316	0.402	8.573	13.041
%_tree	Percentage of tree cover	34.641	20.715	0	100.00
sz_tree	Size of tree cover	3671.36	4364.38	0	80,575.7
age	Property age	71.177	28.432	0	164
con_bnormal	Dummy for Below normal condition	0.075	0.263	0	1
con_poor	Dummy for poor or very poor	0.029	0.167	0	1
con_normal	Dummy for normal	0.313	0.464	0	1
con_good	Dummy for very good or excellent	0.174	0.379	0	1
con_anormal	Dummy for Above normal condition	0.410	0.492	0	1
ln_land	Log of land size	9.082	0.437	7.507	11.512
ln_living	Log of living space	7.030	0.357	5.808	9.098
far	Floor to Area ratio	16.352	20.638	0.890	3028.051
bedrooms	Number of bedrooms	2.665	0.831	0	8
bathrooms	Number of bathrooms	1.277	0.534	0	7
fireplaces	Number of fireplaces	0.310	0.535	0	5
fin_bsmt	Finished basement (sqft)	128.622	248.285	0	3100
foreclosure	Dummy for foreclosed homes	0.259	0.438	0	1
golfcourse	Dummy for golf course	0.006	0.075	0	1
park	Dummy for park	0.067	0.249	0	1
openspace	Dummy for open space	0.021	0.143	0	1
cemetery	Dummy for cemetery	0.010	0.101	0	1
water	Dummy for Water	0.009	0.093	0	1
major_road	Dummy for major road	0.204	0.403	0	1
rail	Dummy for Railroad	0.018	0.134	0	1
crime	Number of crime incidents	9.575	8.111	0	46
med_income	Median household income	$51,361	$17,689	$14,808	$163,500
ln_income	Log of median income	10.788	0.348	9.603	12.005
p_white	Percentage of white population	0.809	0.167	0.089	1

Note: summary statistics are reported based on 24,203 single-family housing sales from 2007 to 2015 in Des Moines, Iowa. %_tree is the percentage of tree canopy coverage to its own lot, while sz_tree represents the size of the closet tree cover.

The address information in the sales transaction dataset enables researchers to geocode each sale and to identify the census block-group and neighborhood. Information on neighborhood characteristics including the percentage of white population and household median income were obtained from the US 2010 Census at the census block-group level. Crime rates were obtained from the Areavibes website, which contains a detailed overview of all crimes in Des Moines as reported by the local enforcement agency. Using a standard geographic information system (GIS), location-specific variables were created, including the percentage of tree canopy coverage per parcel and the size of the tree coverage in immediate neighborhoods. I drew 500 feet buffers around major roads and railroads, which are expected to exert a negative effect on residential property values due to the noise nuisance. Lastly, buffers were drawn along the rivers to identify sales within 500 feet. Mixed effects due to both amenities (accessibility and view) and disamenities (noise and traffic) were expected in areas near water. Parks, open spaces, golf courses, and cemeteries were used to control for undeveloped or uncovered land, as shown in Figure 1.

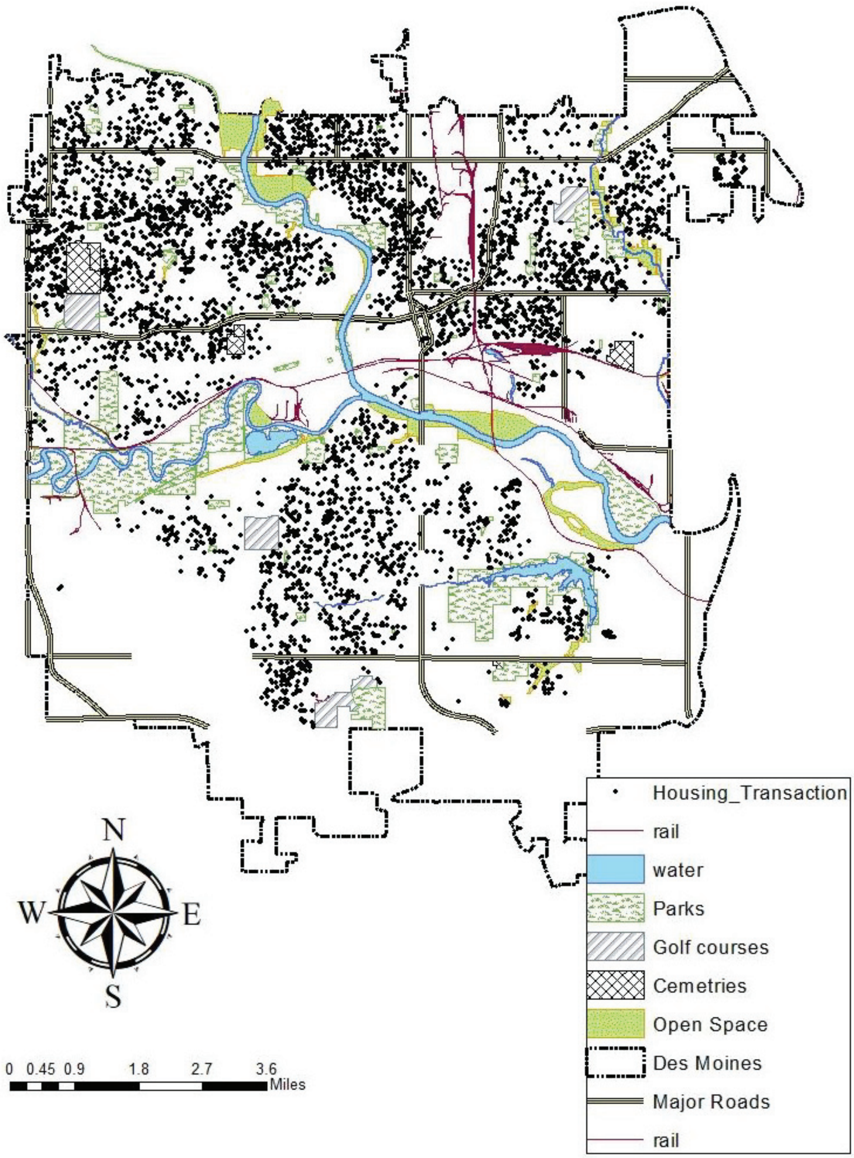

Figure 1. Undeveloped or uncovered land in the city of Des Moines.

A UTC shape file was obtained from the Spatial Analysis Laboratory (SAL) of the Rubenstein School of the Environment and Natural Resources at the University of Vermont. The SAL measures the coverage of trees based on the 2007 high-resolution aerial imagery and light detection and ranging (LiDAR) data in Des Moines. This project was funded by the USDA (US Department of Agriculture) for UTC assessment protocols to the city of Des Moines. However, the UTC information includes the size of tree coverage but does not provide detailed information on tree species or heights. According to the report [28], 12,466 acres of the city of Des Moines are covered by a tree canopy, accounting for 26% of the total area. The highest percentage of UTC was found on land designated as residential, government, and schools. In addition, the report compares the existing UTC in Des Moines with other cities that have completed similar UTC assessments. The coverage of tree canopy in Des Moines is similar to that of much bigger cities, such as New York, NY (23%) and Boston, MA (29%), but much smaller than comparable-sized cities, such as Greenbelt, MD (62%) and Baltimore County, MD (49%).

At the neighborhood level, tree coverage varies based on several factors, including land constraints, new development, financial capacity, and neighborhood characteristics. The lot size of the land and the age of the structure are used as the proxy variables representing the land constraint, and new development as time constraints for tree growth. I expected the values of tree canopies will increase as the size of land and the age of the structure increase. Anecdotal evidence suggests that trees are more of a burden than a benefit in particularly marginalized neighborhoods with a lack of resources for tree care. The low-income neighborhoods may not be able to afford to plant and maintain trees because trees require regular watering and trimming, and are vulnerable to various diseases. Since income at the individual household level is not available, I used the neighborhood median income as a proxy to represent neighborhood financial capacity to maintain trees, and expected the value of trees will increase as the neighborhood income increases. Lastly, I constructed neighborhood characteristic variables using the combination of the average age of the properties and the average neighborhood income. I categorized neighborhoods into five groups: "old and poor", "old and affluent", "new and poor", "new and affluent" and "mid and med" as a reference. For simplicity, I constructed discrete variables for these factors by partitioning the continuous variables into five categories based on percentiles As seen in Table 2, the %_tree significantly varies across the percentiles of the size of the land, the age of the structure, neighborhood income, and neighborhood characteristics.

Table 2. Tree canopy coverage by land size, age, neighborhood income, and neighborhood type categories.

	(1)	(2)	(3)	(4)	(5)
Land(sqft)	1820–6600	6602–7295	7296–8450	8452–11,440	11,450+
%_Tree	32.30%	33.11%	32.53%	34.81%	40.55%
size_tree	1914	2304	2552	3388	8250
Average age	0–51 years old	52–62 years old	63–85 years old	86–97 years old	98+
%_Tree	30.62%	35.49%	37.88%	34.68%	34.49%
size_tree	3783	3954	4011	3296	3276
Income($)	$14,808–36,313	$36,699–47,273	$47,500–53,947	$54,219–63,859	$64,393–1,635,000
%_Tree	33.38%	31.83%	35.62%	35.87%	36.57%
sz_tree	2901	2934	3783	3983	4782
Neighborhood	New and poor	New and affluent	Reference	Old and poor	Old and affluent
%_Tree	32.89%	34.54%	35.35%	33.96%	36.38%
size_tree	3554	4758	3733	2644	3212

Note: the numbers represent the average value for each group. Each group is broken down into five categories by quantiles. (1) represents the lowest quartiles, while (5) represents the highest quartiles.

The old and affluent neighborhoods in Des Moines have higher tree coverage in their lots than the rest of the city. For example, tree coverage ranges from 65% in Westwood to 3% in some newly developed neighborhoods at the city boundary such as Hillsboro. An example of an older neighborhood with low coverage is East Village at 8%, which has a low median income and a location close to downtown. The tree canopy has higher coverage in "old and affluent" (36.38%) and "old and poor" (33.96%) compared to "new and affluent" (34.54%) and "new and poor" (32.89%). One of the potential explanations of low tree coverages in the "old and poor" neighborhoods might be that residents cannot afford to plant trees or to properly maintain them. Newly developed areas generally have lower tree canopy coverage than the old neighborhoods, which may be because construction sites are often cleared of trees to facilitate construction and reduce costs. Replacement trees that may have been planted would still be small and immature in new neighborhoods.

4. Model

To test the hypotheses that the effect of tree cover will vary across neighborhoods with different physical property characteristics and socio-economic characteristics, two approaches were used: a spatial model to control for spatial autocorrelation and a Multi-Level Mixed model (MLM) to estimate the varying effects of tree canopies. As noted earlier, Cho et al. [23] argued that the value of open space is sensitive to lot size, and the value of lot size increases as distance to open space increases, indicating spatial variation in land use. The spatial model is used to resolve such problems as well as unobservable factors, and potential biased coefficients estimated from the traditional hedonic price model because house prices are spatially correlated with neighboring home sales prices that cause a spatial autocorrelation problem. Nevertheless, the spatial model is limited to test the hypothesis that the effect of tree cover varies across neighborhoods. The varying effects of tree coverage on house prices cannot be measured in a single hedonic price model, and each market needs its own model to estimate the varying effects. However, the coefficients estimated from different equations cannot be directly compared due to different sampling distributions. A Multi-Level Mixed model (MLM) including fixed and random effects allows accounting for the varying effects of trees across the neighborhoods.

4.1. Spatial Model

To detect spatial dependence and spatial heterogeneity, the Lagrange Multiplier (LM) tests were used after the OLS model. The LM tests for spatial lag and spatial error and robust lag and robust error. A Portmanteau test for serial correlation was used to determine which model is appropriate [29]. The results suggested the use of a spatial autoregressive lag and error model (SARAR (1,1)) to deal with the spatial autocorrelation and heteroskedastic disturbances. The spatial model will serve as a baseline model and will aid in understanding an average effect of tree coverages on sale prices across the city. I estimated the effect of tree canopies on the residential property value in the traditional hedonic framework. The home sale price is a function of physical and neighborhood characteristics, location, and the size of tree canopies. The model is specified as follows:

$$\begin{gathered} \ln{(P)_{ij}} = \beta_0 + \rho_1 W ln(P)_{ij} + \ X\beta_2 \ + \beta_3 \%_{\text{tree}ij} + z + q + e_{ij} \\ e_{ij} = \lambda_1 W e_{ij} + v_{ij} \\ where\ E(v_{ij} \middle| X,\ W,) = 0\ \ Var(v_{ij} \middle| X,\ W) = E(v_{ij} v'_{ij}) = \Omega = \sigma^2 I \end{gathered} \tag{1}$$

where $\ln{(P)_{ij}}$ is a vector of the log of sales price of each home home (*i*) in neighborhood (*j*) and X is a vector of physical structural and neighborhood characteristics. e_{ij}, the vector of regression error term, is assumed to be normally distributed with mean 0, and v_{ij} is a vector of innovations.

The physical structural variables include the age, lot size, the number of bathrooms, the number of bedrooms, fireplace, size of finished basement, categorical variables of property conditions (poor, below poor, normal, good, and above good), and foreclosure status. Floor and Area Ratio (FAR), which is the ratio of the building square footage to the size of land, is used to control for density and is expected to be negative. The neighborhood variables include the percentage of white population and the log of household median income at the block group level. z is the year fixed effect and q is the quarter fixed effect, all of which are the time-fixed effects to control for the unexpected effect and seasonal effect. βs and ρ_1 are vectors of regression coefficients to be estimated.

The variable %_tree, which is the percentage of tree canopy coverage, is the key variable of interest for this analysis. As noted earlier, two measures of the variable %_tree—percentage of tree canopy to the lot size and the log of the tree canopy size—are used. The former reflects the relative size of the tree canopies, while the latter reflects the absolute size of the tree canopies. The coefficient β_3 reflects the marginal willingness to pay for additional percentage of trees and is expected to be positive. W is a spatial weight matrix created based on the k-nearest distance between each pair of spatial units, *i* and *j*. That is, *W* is as follows;

$$W_{ij} = \begin{cases} 1, & j \in N_k(i) \\ 0, & otherwise \end{cases} \quad (2)$$

where d_{ij} is a set of distances between each pair of spatial units *i* and *j*, $d_{ij(1)} \leq d_{ij(2)} \leq \cdots \leq d_{ij(n-1)}$ and $N_k(i) = \{j(1),\ j(2),\ \ldots..,\ j(k)\}$ that contains the k closest units to *i*.

Generalized Method of Moments (GMM) estimates are used in a Generalized Spatial Two-Stage Least Squares Estimator (GS2SLS) for the spatial lag model. Bivand and Piras [30] explain the steps of estimation for the spatial lag model. First, the initial estimator of γ is obtained using the regression residuals. The sample moment γ and residual obtained from the first step are transformed into a generalized spatial two-stage least squares model. In the second step, the variance–covariance matrix of the sample moment vector is estimated based on the residuals from the generalized least squares model. The advantages of this method are that the computation is simple for large samples, and more consistent parameters are generated and compared to the maximum likelihood method [31,32]. These spatial models will portray overall housing market conditions in Des Moines and provide the average impact of tree canopies on the residential property value across the city after controlling for spatial effects.

4.2. Multi-Level Model

As noted earlier, it can be argued that the effect of urban tree coverage will differ between densely constructed inner city neighborhoods with less space for trees and suburban neighborhoods with large lots. In addition, newly developed areas may have formerly had agricultural uses, which implies fewer trees. This is particularly true for grassland areas such as Des Moines, IA. Trees removed during the construction process can be replanted, but it takes years to fully grow and replace old and large trees. The MLM model, which allows coefficients to vary, is able to estimate tree-related sales differentials and measure spatial variation in the effect of UTCs.

$$\begin{gathered} \varphi_0 = \gamma_{00} + u_{0j}\beta_3 = \gamma_{10} + u_{1j} \\ \text{where } \begin{pmatrix} u_{0j} \\ u_{1j} \end{pmatrix} \sim \mathrm{N}(0,\ \Psi) \qquad \Psi = \begin{bmatrix} \sigma_{u0}^2 & \sigma_{u11} \\ \sigma_{u01} & \sigma_{u1}^2 \end{bmatrix} \end{gathered} \quad (3)$$

To incorporate random effects into the model, the model is rewritten and combines Equations (1) and (3) as:

$$\begin{gathered} \ln(P)_{ij} = (\gamma_{00} + u_{0j}) + \rho_1 Wln(P)_{ij} + X\delta_2 + (\gamma_{10} + u_{1j})\%\_\text{tree}_{\ ij} + z + q + \epsilon_{ij} \\ ar(\epsilon_{ij}) = \sigma_\varepsilon^2 : var(u_{1j}) = \sigma_v^2 \\ v(\epsilon_{ij}, u_{1j}) = 0 \end{gathered} \quad (4)$$

The effect of the tree canopy is decomposed into a fixed effect (γ_{10}) and random effect (u_{1j}). The fixed effect (γ_{10}) is the grand mean that is constant across the neighborhoods, while the random effect (u_{1j}) is a deviation from the mean that captures the varying coefficients and different effect of tree coverage for each neighborhood. If there are no varying effects of trees on house prices, u_{1j} equals zero.

5. Model Results

5.1. Spatial Model Results

The results of the LM test suggest that a SARAR (1,1) (the first order spatial autoregressive and disturbances) model is appropriate to control for both spatial autocorrelation and heteroskedastic disturbances. Table 3 reports the results of the five spatial models: (1) the base; and the interactions between (2) %_tree and log of land; (3) %_tree and age; (4) %_tree and log of income; and (5) %_tree and age together with log of income. The OLS model results are presented in the Appendix A.

The magnitudes and signs for each variable used in the models were consistent with the expectation. For the physical characteristics, log of the land size, log of living area size, number of bathrooms, and number of bedrooms were positively correlated with house prices, all of which were statistically significant. In particular, the log of living space had a substantial positive effect on house prices with a high t-value. Five categories of the condition variables (good, above normal, normal, below normal, and poor) were used to control for the physical condition of the housing structure. Using the "normal" condition as a reference category, the physical condition variables had positive signs for better quality and negative signs for poorer conditions, all of which were statistically significant with very high t-values and low p-values ($p < 0.001$). As in most hedonic studies, sales price decreases with age, which is also statistically significant. To control for the density of the development, the variable Floor Area Ratio (FAR) was added in the model and indicated a negative effect on housing prices.

The median income and the percentage of white population at the block-group level were positively correlated with house prices as expected, while the crime rate and foreclosure were negatively correlated with property values. The year and quarter time-fixed effects were also included in the model to control for any unexpected events during the study period. Proximities to rail tracks and major roads exerted negative effects, while proximity to a golf course was positively correlated with housing prices.

Of particular interest in this study is the effect of tree canopy cover (%_tree) on the property values. The effects of %_tree were mixed across the models with and without the interactive variables, implying that %_tree is associated with these factors. More specifically, the base model result indicated that %_tree is positive but is not statistically significant in Model (1). The coefficient of %_tree was 0.006, which can be interpreted as the implicit price of tree cover that can be used to recover marginal willingness to pay. Hence, an additional 1% of tree canopy coverage increases house prices by 0.006% ($633.56 at the average housing price of $105,593), holding all else equal. The interaction variables between %_tree and all the variables including the log of land, age, and the log of income were positive, implying that the effects increase as land size, age, and income increase, all of which are statistically significant.

Table 3. Generalized spatial model results.

Variable	(1)		(2)		(3)		(4)		(5)	
	Estimate	Z-Value	Estimate	z-Value	Estimate	z-Value	Estimate	z-Value	Estimate	z-Value
con_	3.909	(25.44) ***	4.143	(21.38) ***	3.950	(25.58) ***	4.600	(21.64) ***	4.787	(22.36) ***
%_tree	0.0002	(1.34)	−0.005	(−1.96)	−0.001	(−2.71) **	−0.018	(−4.51) ***	−0.023	(−5.67) ***
%_tree*ln_land			0.001	(2.02) *						
%_tree*ln_age					0.00001	(3.14) **			0.00002	(4.34) ***
%_tree*ln_income							0.002	(4.59) ***	0.002	(5.47) ***
age	−0.006	(−16.55) ***	−0.006	(−16.75) ***	−0.006	(−16.82) ***	−0.006	(−17.05) ***	−0.007	(−17.62) ***
age2	−0.000002	(−0.71)	−0.000002	(−0.6)	−0.000003	(−1.13)	−0.000001	(−0.29)	−0.000002	(−0.8)
fin_bsmt	0.0002	(15.72) ***	0.0002	(15.61) ***	0.0002	(15.94) ***	0.0002	(15.71) ***	0.0002	(16.04) ***
bedrooms	0.025	(6.17) ***	0.025	(6.2) ***	0.025	(6.14) ***	0.025	(6.2) ***	0.025	(6.17) ***
bathrooms	0.035	(5.76) ***	0.034	(5.66) ***	0.034	(5.65) ***	0.034	(5.66) ***	0.033	(5.49) ***
fireplaces	0.107	(19.64) ***	0.106	(19.57) ***	0.106	(19.42) ***	0.107	(19.62) ***	0.105	(19.34) ***
ln_living	0.657	(54.65) ***	0.657	(54.6) ***	0.657	(54.67) ***	0.656	(54.52) ***	0.656	(54.54) ***
ln_land	0.095	(12.86) ***	0.070	(4.83) ***	0.095	(12.91) ***	0.093	(12.57) ***	0.093	(12.59) ***
far	−0.0001	(−2.26) *	−0.0001	(−2.17) *	−0.0001	(−2.37) *	−0.0001	(−2.27) *	−0.0001	(−2.43) *
con_bnormal	−0.311	(−23.55) ***	−0.311	(−23.55) ***	−0.310	(−23.5) ***	−0.311	(−23.55) ***	−0.310	(−23.48) ***
con_poor	−0.685	(−31.12) ***	−0.685	(−31.13) ***	−0.686	(−31.15) ***	−0.684	(−31.12) ***	−0.685	(−31.16) ***
con_good	0.332	(44.63) ***	0.332	(44.6) ***	0.333	(44.7) ***	0.331	(44.51) ***	0.332	(44.59) ***
con_anormal	0.180	(29.02) ***	0.180	(29.02) ***	0.181	(29.1) ***	0.180	(28.96) ***	0.181	(29.09) ***
major_road	−0.020	(−3.16) **	−0.021	(−3.19) **	−0.020	(−3.04) **	−0.021	(−3.29) **	−0.020	(−3.15) **
water	−0.021	(−0.82)	−0.022	(−0.83)	−0.024	(−0.93)	−0.018	(−0.69)	−0.022	(−0.82)
golfcourse	0.035	(1.29)	0.035	(1.30)	0.033	(1.24)	0.032	(1.18)	0.029	(1.09)
park	−0.020	(−2.03) *	−0.021	(−2.04) *	−0.020	(−2.02) *	−0.021	(−2.13) *	−0.022	(−2.14) *
openspace	−0.018	(−1.01)	−0.018	(−1.01)	−0.019	(−1.1)	−0.018	(−1)	−0.020	(−1.12)
cemetery	0.007	(0.25)	0.007	(0.25)	0.007	(0.24)	0.005	(0.18)	0.005	(0.16)
rail	−0.038	(−1.83).	−0.039	(−1.91).	−0.036	(−1.75).	−0.043	(−2.08) *	−0.041	(−2.01) *
foreclosure	−0.456	(−69.54) ***	−0.456	(−69.57) ***	−0.456	(−69.55) ***	−0.456	(−69.55) ***	−0.456	(−69.57) ***
p_white	0.339	(17.52) ***	0.338	(17.49) ***	0.339	(17.52) ***	0.338	(17.44) ***	0.337	(17.43) ***
crime	−0.003	(−8.57) ***	−0.003	(−8.63) ***	−0.003	(−8.63) ***	−0.003	(−8.84) ***	−0.003	(−8.97) ***
ln_income	0.182	(19.33) ***	0.182	(19.34) ***	0.180	(19.05) ***	0.121	(7.58) ***	0.107	(6.65) ***
λ	0.013	(1.52)	0.013	(1.51)	0.013	(1.52)	0.013	(1.57)	0.013	(1.57)
ρ	0.125	(8.51) ***	0.125	(8.54) ***	0.125	(8.52) ***	0.124	(8.48) ***	0.124	(8.48) ***
year*quarter fixed	Yes		Yes		Yes		Yes		Yes	
obs	24,203		24,203		24,203		24,203		24,203	
Wald Chi	126.43		126.92		126.36		126.32		126.22	

Note: this table includes the five models: (1) base; and interaction between (2) % tree and log of land; (3) % tree and age; (4) % tree and log of income; and (5) % tree and age together with log of income. ***, **, and * indicate statistical significance at the 0.1%, 1%, and 5% levels of the confidence intervals, respectively. The z-values are in parentheses. The sample size consists of 24,513 single-family residential sales in the city of Des Moines from 2007 to 2015. % tree and tree size of immediate neighborhoods are measure in square feet and logged.

5.2. Multi-Level Model Results

Panels A and B of Table 4 report the fixed and random model results, respectively. The results of Panel A are similar to those of the spatial models in terms of magnitudes and signs. In particular, Panel B includes the range of the percentiles and the random coefficients estimated by the multi-level models that reveal the varying effects of tree canopies across houses with different land constraints, new construction, neighborhood median incomes, and neighborhood characteristics. As noted earlier, the lot size was used as a proxy for land constraints. The average lot size in Des Moines is 9894 square feet. As expected, the random coefficients for the tree canopy varied based on the land size. The negative effect was found for houses with small lots, and the sign turned positive for those with lots larger than about 6600 square feet. The positive effect increased as the lot size increased. Homes with large lot sizes benefited more from trees, holding others constant.

Table 4. Mixed model results.

Panel A: Fixed Model Results								
Variables	(1) Land Constraints		(2) New Development		(3) Neighborhood Income		(4) Neighborhood Characteristics	
	Estimate	z–Value	Estimate	z–Value	Estimate	z–Value	Estimate	z–Value
_cons	3.110	(19.20) ***	2.581	(16.53) ***	5.079	(47.49) ***	3.210	(20.92) ***
%_tree	0.0002	(0.60)	−0.0002	(−0.46)	0.0001	(0.14)	0.0001	(0.37)
age	−0.007	(−17.39) ***	NA		−0.006	(−16.80) ***	−0.007	(−18.09) ***
age2	0.000001	(0.51)	NA		−0.000001	(−0.49)	0.000002	(0.83)
fin_bsmt	0.0002	(14.08) ***	0.0002	(13.3) ***	0.0002	(14.59) ***	0.0002	(14.54) ***
bedrooms	0.023	(6.36) ***	0.022	(6.05) ***	0.025	(7.00) ***	0.024	(6.61) ***
bathrooms	0.039	(6.46) ***	0.057	(9.67) ***	0.034	(5.77) ***	0.038	(6.32) ***
fireplaces	0.104	(18.4) ***	0.095	(16.43) ***	0.099	(17.37) ***	0.100	(17.60) ***
ln_living	0.648	(59.27) ***	0.662	(59.80) ***	0.640	(58.31) ***	0.648	(58.92) ***
ln_land	0.105	(8.83) ***	0.091	(13.86) ***	0.095	(14.62) ***	0.098	(14.55) ***
far	0.000	(−0.68)	0.000	(−1.14)	0.000	(−0.94)	0.000	(−1.37)
con_bnormal	−0.306	(−30.6) ***	−0.335	(−33.36) ***	−0.303	(−30.34) ***	−0.304	(−30.39) ***
con_poor	−0.673	(−44.87) ***	−0.711	(−46.95) ***	−0.675	(−45.01) ***	−0.671	(−44.74) ***
con_good	0.327	(43.06) ***	0.292	(38.74) ***	0.330	(43.47) ***	0.333	(43.85) ***
con_anormal	0.176	(29.12) ***	0.145	(24.56) ***	0.180	(29.83) ***	0.181	(29.92) ***
major_road	−0.020	(−3.32) **	−0.023	(−3.74) ***	−0.018	(−2.92) **	−0.023	(−3.75) ***
water	−0.013	(−0.47)	−0.004	(−0.15)	−0.037	(−1.39)	−0.014	(−0.52)
golfcourse	0.041	(1.28)	0.022	(0.68)	0.054	(1.68) *	0.029	(0.92)
park	−0.016	(−1.59)	−0.015	(−1.47)	−0.022	(−2.26) **	−0.022	(−2.20) **
openspace	−0.015	(−0.88)	−0.004	(−0.23)	−0.022	(−1.28)	−0.014	(−0.81)
cemetery	0.026	(1.08)	0.007	(0.30)	0.001	(0.06)	0.010	(0.41)
rail	−0.041	(−2.30) **	−0.050	(−2.73) **	−0.041	(−2.27) **	−0.036	(−2.00) **
foreclosure	−0.452	(−80.21) ***	−0.455	(−79.53) ***	−0.450	(−79.83) ***	−0.452	(−80.11) ***
p_white	0.320	(18.55) ***	0.300	(17.21) ***	−0.003	(−7.40) ***	0.331	(19.16) ***
crime	−0.003	(−9.03) ***	−0.003	(−8.54) ***	0.345	(19.86) ***	−0.003	(−8.44) ***
ln_income	0.171	(19.83) ***	0.181	(20.73) ***	NA		0.168	(14.87) ***
w_hp	0.093	(15.32) ***	0.093	(15.19) ***	0.093	(15.31) ***	0.094	(15.55) ***
year*quarter fixed	Yes		Yes		Yes		Yes	
Obs.	24,203		24,203		24,203		24,203	
Log likelihood	−10,396.486		−10,725.457		−10,378.507		−10,392.023	
Panel B: Random Model Results								

Table 4. *Cont.*

Category	(1) Land Constraints		(2) New Development		(3) Neighborhood Income		(4) Neighborhoods	
	Range (sqft)	**Estimate**	**Range (year)**	**Estimate**	**Range ($)**	**Estimate**	**Range ($)**	**Estimate**
(1)	1820–6600	−0.00068	0–51	−0.0012	1480–36,313	−0.0003	reference	0.00038
(2)	6602–7295	0.00008	52–62	−0.0007	36,699–47,273	−0.0007	new and poor	−0.00050
(3)	7296–8450	−0.00007	63–85	0.0002	47,500–53,947	−0.0001	new and affluence	0.00036
(4)	8452–11,440	0.00088	86–97	0.0003	54,219–63,859	−0.0001	old and poor	−0.00003
(5)	11,450+	0.00069	98+	0.0006	63,860+	0.0015	old and affluence	0.00020
LR test (χ^2)	158.4		3341.04		611.94		167.33	

Note: panels A and B report the respective fixed and random model results using the 24,203 single-family residential sales in the city of Des Moines from 2007 to 2015. ***, **, and * indicate statistical significance at the 0.1%, 1%, and 5% levels of the confidence intervals, respectively.

Similarly, the relationship between the effect of tree canopies on house price and house age was positive. The random model results indicate that there is a negative effect for homes aged 62 years and under, but the signs turned positive for homes aged over 63 years old. As expected, the neighborhood income, which reflects the financial capacity to maintain trees, was also an important factor in determining the size of the tree canopy effect. The tree canopy effect was negative on housing prices in the neighborhoods with income lower than $63,859; then it became positive for those with an income of more than $63,860. The discount for %_tree decreased as income increased.

The effect of tree canopies was also positively correlated with housing prices in the "old and affluent" and "new and affluent" neighborhoods, and negatively correlated in both the "old and poor" and "new and poor" neighborhoods. Counterintuitively, the effect of tree canopies had a positive effect in the "new and affluent" neighborhood, and the magnitude was larger than that of the "old and affluent" group. The results indicate that "new and affluent" neighborhoods with high housing prices of around $137,880 located in the south and north sides of the city have minimal tree canopies (ranging from 3% to 30%), but these neighborhood are more willing to pay a premium for an additional percentage of tree canopy coverage than the other neighborhoods. These model results support the argument of Schwarz et al. [7] that tree coverages are highly correlated with income, since maintaining tree canopy cover is challenging for low-income neighborhoods, in particularly some cities in California with arid weather. These results strongly imply that financial resources may play a critical role in determining tree canopy coverages at the neighborhood level and are the most influential factor for the positive effect of trees on housing prices.

6. Conclusions and Discussions

This study examined the value of tree coverages on single-family residential property sales prices and house price differentials associated with the tree canopy coverages in the city of Des Moines, Iowa. Using 24,513 sales data from 2007 to 2015, the spatial model results indicate that tree canopy coverages are positively correlated with and capitalized into the residential property values. The results are consistent with and confirm previous findings.

The results of the multi-level model support the varying effects of tree coverages and indicate that residents' willingness to pay for trees differs across the neighborhoods based on land constraints, new development, financial resources, and neighborhood characteristics. The model results also support the argument that tree coverages would be burdens in especially marginalized neighborhoods and imply that it may be due to financial capacity to plant and maintain them, while the positive effect of trees is found for homes with large lots in old, new, and high-income neighborhoods. High-income neighborhoods are more willing to pay for the benefits trees provide, including privacy, accentuated views and so forth, than low-income neighborhoods. The varying effects of trees on house prices across the neighborhoods have important policy implications for city planners when deciding how to implement tree-related policies, and for real estate developers to determine where and how to develop a project.

As noted, if the negative effect of UTCs on sales prices in low-income neighborhoods is the result of a lack of financial resources to overcome a scarcity of environmental benefits, then planting trees in these neighborhoods may not be a good approach. Due to the costs incurred, it would not be affordable for low-income households to plant and maintain trees in their backyards. Tree planting programs should take into account different neighborhoods' circumstances and be tailored to meet their unique needs. Planting street trees and creating green space (e.g., urban community gardens) would be potential alternative approaches to mitigating the concern of an inequitable distribution of benefits. As Donovan and Butry [33] found, one additional street tree creates positive effects and increases house prices by about 3%. Although the positive effect of street trees such as view would be confined to only those homes that are directly in front of street trees, overall, there are some neighborhood benefits.

In new development areas, stronger tree protection and planting programs should be implemented to maintain a certain degree of tree canopies. Most newly developed residential areas at the urban fringes of the city of Des Moines have minimal tree canopies. As most new developments have included mostly young trees, it will take many years for full canopies to develop. Many cities provide ordinances and standards for protection and preservation of trees and shrubs in new developments. Often based on a property's size; ordinances specify minimum planting requirements to ensure that the city will have aesthetically pleasing developments and enhanced green space, making it a better place to live.

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Appendix A

Table A1. OLS (Ordinary Least Squares) Regression model results.

	(1) Estimate	(1) t–Value	(2) Estimate	(2) t–Value	(3) Estimate	(3) t–Value	(4) Estimate	(4) t–Value	(5) Estimate	(5) t–Value
_cons	4.034 ***	(35.04)	4.263 ***	(28.77)	4.083 ***	(35.33)	4.733 ***	(26.26)	4.919 ***	(26.59)
%_tree	0.0002	(1.35)	−0.005 *	(−2.38)	−0.001 *	(−2.30)	−0.018 ***	(−4.99)	−0.023 ***	(−6.03)
%_tree*ln_land	NA		0.001 *	(2.45)	NA		NA		NA	
%_tree*age	NA		NA		0.000 **	(3.14)	NA		0.000 ***	(4.43)
%_tree*ln_income	NA		NA		NA		0.002 ***	(5.04)	0.002 ***	(5.85)
age	−0.006 ***	(−16.71)	−0.006 ***	(−16.85)	−0.007 ***	(−43.47)	−0.006 ***	(−17.18)	−0.007 ***	(−17.74)
age2	−0.000	(−0.80)	−0.000	(−0.69)	NA		−0.000	(−0.36)	−0.000	(−0.91)
fin_bsmt	0.000 ***	(14.39)	0.000 ***	(14.32)	0.000 ***	(14.79)	0.000 ***	(14.35)	0.000 ***	(14.63)
bedrooms	0.025 ***	(6.78)	0.025 ***	(6.81)	0.025 ***	(6.74)	0.025 ***	(6.81)	0.025 ***	(6.76)
bathrooms	0.035 ***	(5.80)	0.034 ***	(5.69)	0.033 ***	(5.54)	0.034 ***	(5.70)	0.033 ***	(5.52)
fireplaces	0.106 ***	(18.53)	0.106 ***	(18.46)	0.106 ***	(18.51)	0.106 ***	(18.52)	0.104 ***	(18.27)
ln_living	0.659 ***	(59.83)	0.658 ***	(59.77)	0.657 ***	(60.44)	0.658 ***	(59.71)	0.658 ***	(59.74)
ln_land	0.095 ***	(14.54)	0.071 ***	(5.99)	0.096 ***	(14.69)	0.093 ***	(14.21)	0.093 ***	(14.24)
far	−0.000	(−1.13)	−0.000	(−1.17)	−0.000	(−1.16)	−0.000	(−1.15)	−0.000	(−1.14)
con_1	−0.310 ***	(−30.72)	−0.310 ***	(−30.72)	−0.309 ***	(−30.66)	−0.310 ***	(−30.73)	−0.310 ***	(−30.68)
con_2	−0.684 ***	(−45.16)	−0.683 ***	(−45.14)	−0.684 ***	(−45.18)	−0.683 ***	(−45.12)	−0.683 ***	(−45.17)
con_4	0.333 ***	(43.39)	0.332 ***	(43.30)	0.335 ***	(44.24)	0.332 ***	(43.25)	0.332 ***	(43.32)
con_5	0.180 ***	(29.58)	0.180 ***	(29.59)	0.183 ***	(30.82)	0.180 ***	(29.52)	0.181 ***	(29.68)
major_road	−0.022 ***	(−3.52)	−0.022 ***	(−3.55)	−0.021 ***	(−3.36)	−0.022 ***	(−3.65)	−0.021***	(−3.50)
water	−0.023	(−0.87)	−0.024	(−0.88)	−0.028	(−1.03)	−0.020	(−0.75)	−0.023	(−0.87)
golfcourse	0.033	(1.01)	0.033	(1.02)	0.032	(0.99)	0.030	(0.92)	0.027	(0.84)
park	−0.021 *	(−2.12)	−0.021 *	(−2.13)	−0.021 *	(−2.13)	−0.022 *	(−2.23)	−0.022 *	(−2.24)
openspace	−0.019	(−1.14)	−0.019	(−1.13)	−0.021	(−1.26)	−0.019	(−1.12)	−0.021	(−1.24)
cemetery	0.002	(0.09)	0.002	(0.10)	0.002	(0.07)	0.001	(0.02)	−0.000	(−0.01)
rail	−0.041 *	(−2.26)	−0.042 *	(−2.34)	−0.039 *	(−2.17)	−0.046 *	(−2.54)	−0.045 *	(−2.46)
foreclosure	−0.456 ***	(−80.14)	−0.456 ***	(−80.16)	−0.456 ***	(−80.15)	−0.456 ***	(−80.18)	−0.456 ***	(−80.21)
p_white	0.338 ***	(19.42)	0.337 ***	(19.37)	0.341 ***	(19.79)	0.337 ***	(19.35)	0.336 ***	(19.34)
crime	−0.003 ***	(−8.81)	−0.003 ***	(−8.87)	−0.003 ***	(−9.10)	−0.003 ***	(−9.07)	−0.003 ***	(−9.21)
ln_income	0.183 ***	(21.03)	0.183 ***	(21.02)	0.182 ***	(20.98)	0.122 ***	(8.14)	0.107 ***	(7.03)
year and quarter dummy	Yes		Yes		Yes		Yes		Yes	
Adj.R-sq	0.7096		0.7097		0.7097		0.7099		0.7101	

Note: ***, **, and * indicate statistical significance at the 0.1%, 1%, and 5% levels of the confidence intervals, respectively. The t-values are in parentheses. The sample size is 24,513 single-family residential sales in the city of Des Moines from 2007 to 2015. %_tree and tree size of immediate neighborhoods are measure in square feet and logged.

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An Integrated Methodological Analysis for the Highest Best Use of Big Data-Based Real Estate Development

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Abstract: This study investigates the integration of methods for real estate development planning and feasibility studies in the changing business environments of emerging big-data. It examines high-rise mixed-use development projects for the highest best use by combining fuzzy theory; thus, it identifies a big data-based innovative decision-making method for systemizing the various factors expected to influence real estate development. In this context, the study creates new evaluation fields and factors by integrating both conventional and big-data based high-rise mixed-use projects. The weight of each value was calibrated by relative significance and fuzzy measure using the Analytic Hierarchy Process (AHP) method. A measuring technique that applies analysis methodology to the evaluation areas was developed for more objective and clearer evaluation, and its application in the field was proposed. Evaluators can systematically assess the concerned evaluation areas during development project planning by examining the process. The findings also provided implications for the evaluation system's operation by reflecting the variability of specific conditions of the varying projects in real estate and urban and land use planning.

Keywords: big data; decision-making; feasibility study; fuzzy theory; high-rise building; mixed-use development

1. Introduction

With advances in information and communications technology (ICT), the amount of data being disseminated is growing exponentially; as a result, big data technology has become one of the most innovative, garnering much attention among other recent information technologies [1]. Accordingly, firms are interested in introducing big data systems to analyze and use various types of data and create new businesses [2]. In response to this change, real estate developers who oversee the planning of development projects are making efforts to create and implement a data-based decision-making system in their primary areas of real estate development planning and feasibility studies [3]. In particular, high-rise building mixed-use development projects, which are one of the most recognizable types of sustainable real estate development, are the ultimate method of development; they encompass all situations, including policy legislation, business entities' planning, and the modification of consumer patterns to implement a compact city, one of the future urban strategies [4].

Throughout history, humans have sought to construct increasingly higher buildings. Since urban population has escalated with intensive land use development in cities, high-rise building construction has been a driving force to change skylines of cities and boost real estate development. South Korean high-rise building construction began in the 1980s with the 63 Building and the Convention and

Exhibition Center (COEX). Since the 2000s, South Korean cities have witnessed a growing number of high-rise buildings for mixed use development due to the market and technological proficiency boom. In particular, super high-rise tower developments boomed because of various financing projects, until the global financial crisis occurred in 2008. However, such developments resulted in negative perceptions of high-rise buildings, as monotonous tower groups spoil the urban skylines and lead to serious traffic congestion in project areas. Such perceptions of high-rise buildings have mostly been examined through personal interviews of building and neighborhood residents, and from research on high-rise buildings.

This study investigated the integrated methods of conducting feasibility studies for the highest best use of high-rise mixed-use building development in the emerging big-data era. We identified a big data-based innovative evaluation method for systemizing various factors that are expected to influence real estate and urban land use planning projects. Moreover, the study used big data to distinguish those factors preferred by business entities planning to implement high-rise building mixed-use development projects, and by consumers who look at such projects, to determine evaluation items. By doing so, the study aims to suggest a system for evaluating high-rise building mixed-use development projects, and to develop a decision-making method that can evaluate these projects more objectively and clearly by combining fuzzy theory with big data-based customized evaluation. Ultimately, this study aims to increase methodological utility for the feasibility study of high-rise building mixed-use development projects in the future amid rapidly changing business environments. Moreover, the research methods used in this study involve categorizing the influence factors expected in high-rise building mixed-use development projects by unit, conducting analysis with the Analytic Hierarchy Process (AHP) technique to set priorities based on the factors in each hierarchy, and applying fuzzy theory to compensate for relativity [5], thus proposing a more objective and systematic computation method. Figure 1 illustrates the analysis process of this study.

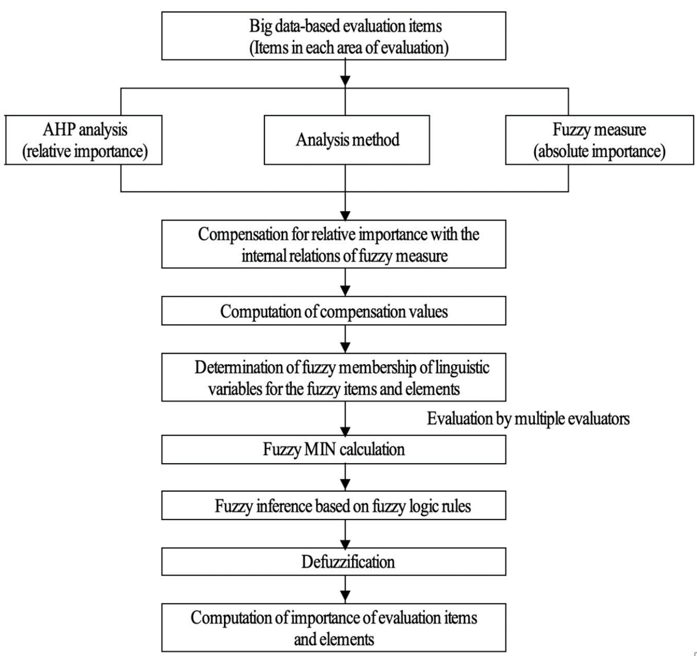

Figure 1. Flow of research.

2. Literature Review

2.1. Definition and Elements of Big Data

"Big data" refers to data that are bigger and more diverse than those in the past in terms of quantity, data generation cycle (i.e., produced in real time), and format (including not only numerical but also non-structured data such as texts), which are difficult to collect, store, search, and analyze using traditional methods [6]. The term big data is changing to include tools, platforms, and analytic methods for systematization and refers to the information technology that extracts valuable information by using and analyzing large volumes of data and predicting changes based on generated knowledge [7]. It creates new values that cannot be obtained from conventional approaches. In general, the size of big data differentiates it from other traditional data in terms of its volume, velocity, and variety (see Table 1) [8].

Table 1. The role of big data in future society.

Characteristics of Future Society	Role of Big Data
Uncertainty	- Analyze patterns and predict the future based on social phenomena and data in physical reality. - Simulate scenarios for various possibilities. - Provide insights that consider multi-faceted situations. - Respond flexibly to changing situations in multiple scenarios.
Risk	- Identify risk signals or signs by analyzing patterns in environmental, social, and monitored information. - Recognize and analyze issues ahead of time and support swift decision-making and real-time responses. - Enhance the reputation of a firm or country and reduce wasted elements.
Smart	- Recognize the situation by analyzing data on a large scale and providing artificial intelligence services. - Expand the provision of personalized and intelligent services. - Support the optimal choice through social analysis, evaluation, and credit and reputation analysis. - Ensure product competitiveness by analyzing changing trends.
Convergence	- Create new values through combination with other areas. - Ensure security and minimize trial and error through data analysis in the convergence area for causality and correlations. - Create a new convergent market by using massive amounts of data.

Source: Swain, Prasad, and Senapati, 2017, p.7 [8].

2.2. Characteristics and Forms of Big Data

A characteristic of big data known as Volume, Velocity, Variety (3V) can add value or complexity to the data depending on the researcher (see Table 2) [9]. In other words, big data is composed of, not only a database management system (DBMS), but also real-time data, such as social data. Big data contains a huge amount of information beyond the existing data units, including various types of unstructured data such as photographs and moving pictures, and the speed with which data is generated and flows is accelerating data processing [10]. Additionally, big data is not standardized, a fact that intensifies the complexity of data management and processing and requires the development of new techniques [11]. The fundamental purpose of big data is to identify flows and patterns hidden in vast amounts of data that exist in the technical, social, and economic environments.

Table 2. Components of big data.

Division	Contents
Volume	• Advancement of technology and the informatization of all fields leads to the exponential increase of digital data every year (Zeta byte era)
Variety	• Rapid growth of data types (log records, social, location, realistic data, etc.) • Acceptance of the diversity of informal data
Complexity	• Unstructured data, differences in data storage methods, redundancy issues, etc. • Increase of management targets by expanding data types and using outsourced data • Intensification of data management and processing complexity requiring new techniques
Velocity	• Increased real-time information such as the Internet of Things, sensors, and streaming information • Creation of real-time data and increase of distribution speed • Use of large data processing and valuable current information • Importance of data processing and analysis speed
Value	• Existing limitations overcome and new insights sought • Value extracted from a variety of data at low cost

Source: Manekar and Pradeepini, 2016, p. 9 [9].

One of the biggest differences between big data and general data analysis is that big data utilizes semi-structured or unstructured data in real time. The data generated in the information age can take various forms—such as documents, images, videos, and maps—in either analog or digital format [12]. Big data can be classified into fixed, irregular, and semi-fixed data according to the degree of shaping. The main sources of these informal data are smart devices, social network services, and the Internet of Things (IoT). In particular, informal conversation data centered on communication, which contains personal meaning among users, is increasing exponentially. In Korea, the amount of non-standardized data is more than three times greater than formal data [13]. Additionally, as smart technology and mobile use have continued to spread, social data has become a typical form of unstructured data, which is generated by the voluntary participation of users through the Social Network System and helps users understand the world [14]. These social data can be utilized by governments and corporations as a means of two-way communication to create a moment of empathy with customers in real time.

In fact, the social data collected through the Social Network System represents emotional information based on empathy, which is meaningful and highly relevant data [15].

2.3. Development of High-Rise Mixed-Use Buildings

The Council on Tall Buildings and Urban Habitat (CTBUH) defines high-rise buildings not according to their height or number of stories but rather by the direct effects they have on building design, use, and city planning. As the construction environments and impacts of such buildings are considerably different from those of common buildings, high-rise development projects have been highly scrutinized by society and particularly by neighborhood communities in project areas.

There are many different opinions about when and where the first high-rise buildings were built, but they are usually considered to have originated in American cities. Particularly, major cities in the United States have been developed with matrixes of high-rise towers through the real estate development boom, which has significantly influenced the local economies of modern cities. Additionally, the matrix network deeply impacted the social and cultural values for integrating urban infrastructure [16]. In addition, high-rise mixed-use buildings were further constructed using high-performance materials and advanced construction technologies, including elevators. Better building security and safety systems for disaster prevention further supported the development.

High-rise building mixed-use development projects have had positive effects on urban land use and sustainable development. This development highlights the intensity of land use, and thus, leads to sustainable city spaces in a compact city. This is considered to minimize land use by avoiding horizontal urban expansion, and comprehensively underlines vertical urbanism with intensive land use for environmental and economic sustainability. This concept allows more people to walk, with improved pedestrian environments, because high-rise development of an area encourages the inclusion of more open spaces for public use by limiting the building-to-land ratio in downtown districts. Thus, this can expand a sense of openness in cities [17].

According to a literature review, the perceptions of high-rise mixed-use building development were investigated through interviews of building designers and residents, and can be summarized based on the following factors: Height, shape, profit, location, sustainability, evacuation, density, structure for safety, and usability [18]. In addition, the following planning components for increasing publicity can be found in these elements: Site location, green landscape, neighborhood context, secure infrastructure, connectivity to amenities, street environment, and safety from disasters [19]. Several studies have investigated the influences of high-rise building projects in terms of economic, cultural, technological, and building institutional aspects on the society, and argued that investors and developers should significantly regard their projects as both private and public assets in a city [20], because skyscrapers play a crucial role to integrate with the city center of dynamic life and culture [21]. A previous study examined the locations of super high-rise buildings globally and found that Chinese major cities have the largest number of towers, followed by the United States, United Arab Emirates, and South Korea [22]. A study of Manhattan's high-rise buildings, constructed within the last century, reported increased significance of building code establishment to control costs and benefits in the market conditions, rather than other economic factors such as building height, block number, and housing price [23].

3. Research Methods

For further investigation of the effects of high-rise mixed-use building development, this study collected information from stakeholders such as investors, developers, and end-users of the projects. The data collection procedure focused on a list of influential factors for the project effects that were seriously considered by stakeholders. Thereafter, the qualitative factors were quantitively customized for more practical and feasible evaluation and reasonable decision making.

3.1. Composition of Expected Effects of High-Rise Mixed-Use Development Projects

The evaluation fields and factors in higher categories are necessary for systemical organization to measure the qualitative and quantitative effects of high-rise mixed-use building development projects. Therefore, in this study, the evaluation elements from previous studies in the major categories were reorganized in Table 3.

Table 3. Evaluation factors of influence factors in high-rise building mixed-use development projects based on big data with information and communications technology (ICT).

Categories	Evaluation Fields	Evaluation Factors
Economy and industry	National economy	Increased tourist revenues
		Expanded size of national economy
		Increased cash flow
	Local economy	Formation of business districts
		Influx of tourists
		Recirculation according to increased tax revenues
	Industrial effects	Impact on the construction industry
		Linkage effects with other industries and mobile resources
		Increased global competitiveness of the construction industry
	Information and communications technology	Convenience of living environment
		Ease of use ability of residents
		Infrastructure compatibility based on big data analysis
Society and culture	Society and cities	Recognition of landmarks
		Effects of urban redevelopment
	Cultural ripple effects	Brand positioning of national, social, and corporate leaders
		Cultural products and Korean Wave effects
Technology and environment	Environment	Urban environment
		Traffic environment
		Pedestrian environment
		Environment protection in the outskirts
	Architectural institutions and standards	Introduction of advanced architectural institutions
		Advancement of standards
		Export of standards
	Costs	Environment costs
		Traffic costs
		Infrastructure costs
	Architectural technological level	Design technology
		Engineering technology
		Construction technology
	Land usage	Efficiency of land usage
		Complexity of land usage
		Diversity of land usage
Reputation	Awareness	Awareness of nation
		Awareness of area
		Awareness of investors, including owners
		Awareness of design offices and construction companies
	National sentiment	People's interest
		Pride
		Local economy

Table 3 outlines the evaluation system, which consists of four categories (Economy and Industry, Society and Culture, Technology and Environment, and Reputation). First, the Economy and Industry category comprises three evaluation fields: National Economy, Local Economy, Industrial Effects, and Information and Communications Technology, which consists mainly of national and local economies and industrial effects. The Society and Culture category considers socio-cultural effects in two evaluation fields: Society and Cities, and Cultural Ripple Effects. The Technology and Environment category comprises five evaluation fields, concerning the national image and perception of people in connection with the development of high-rise mixed-use projects, in the following fields: Environment, Architectural Institutions and Standards, Costs, Architectural Technological Level and Land Usage, and Reputation.

3.2. Quantification Procedure of Evaluation Fields

As shown in Table 3, each evaluation factor should be reset by the integrated methods for the qualitative and quantitative effects. In particular, establishing evaluation items involves a process that identifies the innovative method of big data analytics. The following analysis flowchart of the feasibility study of evaluation items in high-rise building mixed-use development projects ultimately precedes business decision-making. In this study, the measurement of expected effects from fuzzy theory were systemically arranged [24] based on the following process: (1) Calculating the significance of each evaluation field, (2) compiling the influence results, and (3) prioritizing the evaluation fields and factors.

Figure 2 shows the methods for analyzing the evaluation factors. As most cases generated qualitive evaluation elements for investigation, it is necessary to quantify these qualitive outputs for measuring the influence of evaluation factors in high-rise mixed-use building development projects. Therefore, this study selected the evaluation items by categorizing them, calculated the fuzzy effect and the influence from the fuzzy measurement and Analytic Hierarchy Process, and applied the Choquet fuzzy integral.

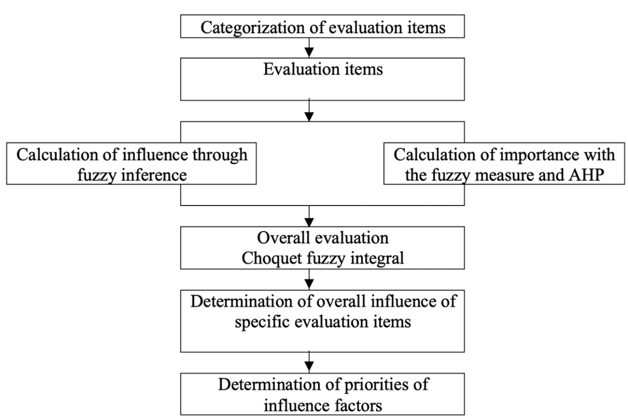

Figure 2. Analysis flowchart for the feasibility study of evaluation items in high-rise mixed-use building development projects.

3.3. Calculation of Influence on Evaluation Fields

In this study, fuzzy inference was used to measure the influence factors of each category of the projects based on the fuzzy set theory. This indicates an ambiguity level for the measurement of each evaluation factor [25]. The process is shown in Figure 3. In addition, this process selects the importance of items to suggest the optimal feasibility study method for business decision-making, which ultimately can be understood as a process to develop a user interface business decision-making platform in the future. This study uses fuzzy inference to discover the significance levels of the evaluation items. The significance levels of the evaluation items are identified with a linguistic variable through the fuzzy set theory that can describe ambiguity in the evaluation and verification processes. The quantified value is then identified after de-fuzzying the fuzzy inference based on the patterns of fuzzy logic [26]. Table 4 shows the linguistic variables for indicating the degree of verification of evaluation items.

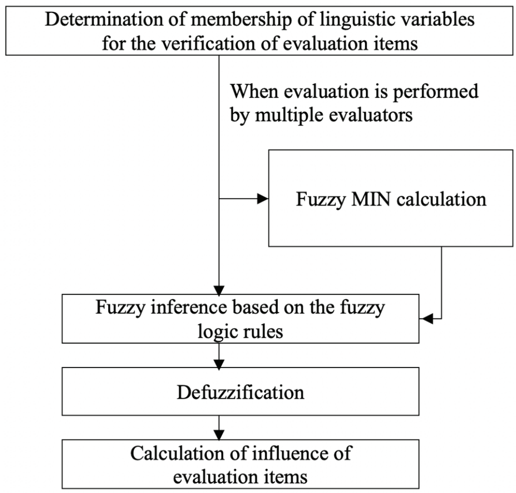

Figure 3. Analysis flowchart for the feasibility study of evaluation items in high-rise building mixed-use development projects.

Table 4. Linguistic variables to show the degree of verification of evaluation items.

Linguistic Variable		
Very low	VL	0.1
Low	L	0.3
Medium	M	0.5
High	H	0.7
Very high	VH	0.9

When the items have a low degree of verification, or are not verified in the evaluation areas, their need should be lowered for calculating the influence on the evaluation areas. In the present study, a higher degree of verification of evaluation subjects led to greater importance in the fuzzy sets (see Table 5).

Table 5. Linguistic variables to show the importance of evaluation items.

Linguistic Variable		
Very Low Contraction Value	VL	0.1
Low	L	0.4
Medium	M	0.6
High	H	0.8
Very good	VG	0.9

If there are two or more experts to assess the degree of verification of items in the evaluation areas, the means of their evaluation results will be based on a MIN calculation.

Evaluation of items and element verification by evaluation area

= MIN (evaluation results of Expert A, evaluation results of Expert B, . . .)

= Evaluation results of Expert A ∧ evaluation results of Expert B ∧ . . .

Based on evaluating the degree of verification of items in the evaluation areas, the study calculated the influence distribution for each evaluation result through fuzzy inference with the If-Then rule [27]. Then, triangular fuzzy sets functioned as forming membership to the linguistic variable showing the significance of each item, and these were measured by the center of area method, which is a defuzzification procedure, as following in Equation (1).

$$x_0 = \frac{\sum_{i=0}^{n} \mu_s(x_i) \cdot x_i}{\sum_{i=0}^{n} \mu_s(x_i)} \tag{1}$$

Fuzzy integration is used to make ambiguous decisions that require the absolute importance of the endpoints. The fuzzy scale is a contribution to the higher endpoints of an individual endpoint and is not reliable. On the other hand, the importance obtained from the comparative comparison of evaluation items is relatively high in reliability. For this reason, Equation (1) was used. In the present study, the final importance was calculated by considering the redundancy, which is the relative relationship between the evaluation items obtained from the fuzzy scale, in the relative importance using AHP.

3.4. Calculation of Total Influence of Evaluation Items

The overall significance level of each factor was measured by the Choquet fuzzy integration method, as shown at Equation (2). This can indicate the λ- fuzzy values representing the significance levels between conflicted evaluation factors.

$$g(\{x_1, x_2\}) = g(x_1) + g(x_2) + \lambda g(x_1) g(x_2) \tag{2}$$

$$g(\{x_1, x_2\}) = g_1 + g_2 + \lambda g_1 g_2 \tag{3}$$

This study set up an area of the urban outskirts to measure overall significance levels of the evaluation factors from high-rise building development projects. Each category was arranged into urban condition, traffic condition, pedestrian condition, and environmental protection. Fuzzy inferences resulted in the influence of each factor, such as 0.300, 0.574, 0.404, and 0.300, respectively, and their importance was 0.508, 0.621, 0.501, and 0.425, respectively. Table 6 shows the importance levels of evaluation factors, which were regarded simultaneously.

Table 6. Importance when evaluation items are considered simultaneously.

Set	Importance	Set	Importance
$\emptyset$	0	$\{x_2,\ x_3\}$	0.834
$\{x_1\}$	0.508	$\{x_2,\ x_4\}$	0.801
$\{x_2\}$	0.621	$\{x_3,\ x_4\}$	0.729
$\{x_3\}$	0.501	$\{x_1, x_2,\ x_3\}$	0.949
$\{x_4\}$	0.425	$\{x_1, x_2,\ x_4\}$	0.932
$\{x_1,\ x_2\}$	0.837	$\{x_1, x_3,\ x_{34}\}$	0.893
$\{x_1,\ x_3\}$	0.773	$\{x_2, x_3,\ x_4\}$	0.930
$\{x_1,\ x_4\}$	0.733	$\{x_1, x_2,\ x_3,\ x_4\}$	1.000

The Choquet fuzzy integral was applied based on (4). There was the total influence level of the environment, 0.407, in the evaluation areas. The results were as follows:

$$\begin{aligned} \int_X h(x)^\circ g(\cdot) &= h(x_1) g(\{x_1, x_2, x_3, x_4\}) + [h(x_1) - h(x_2)] g(\{x_2, x_3, x_4\}) \\ &+ [h(x_4) - h(x_2)] g(\{x_3, x_4\}) + [h(x_3) - h(x_4)] g(x_3) \\ &= 0.3 \times 1.000 + (0.574 - 0.3) \times 0.93 + (0.3 - 0.574) \times 0.279 \\ &+ (0.404 - 0.3) \times 0.501 \cong 0.407 \end{aligned} \tag{4}$$

3.5. Data Collection and Analysis Settings

By utilizing the influence factors of high-rise building mixed-use development projects, this study examined real estate development firms, construction companies, financial firms, trust companies, real estate investment trusts and fund-related firms, and credit rating companies for 15 days from April 5 to 19, 2019. Based on the judgmental and non-probability sampling methods, 200 experts were selected from these professional fields for their individual interview responses. Table 7 provides the attributes of the interviewees, including their professional fields and career duration. Of the total respondents, 73.5% were directly related to real estate development, and 79% had worked for over five years in their real estate development careers.

Table 7. Characteristics of the data set.

Interviewee Characteristics		Interviewee Numbers	Ratio
Company Fields	Real Estate Development Company	56	28.0%
	Construction Company	46	23.0%
	Financial Company	45	22.5%
	Real Estate Investment Trusts and Fund-related Company	39	19.5%
	Credit Rating Company	14	7.0%
Total		200	100%
Career Duration	Less than 3 years	10	5.0%
	3 years to 5 years	32	16.0%
	5 years to 10 years	67	33.5%
	More than 10 years	91	45.5%
Total		200	100%

A questionnaire was distributed, which consisted of items concerning relative importance based on AHP and absolute importance based on fuzzy measure, in the evaluation areas of the qualitative indicators. The relative importance scale of AHP had an interval of two, as in, 1, 3, 5, and 7 (see Table 8) [19].

Table 8. AHP scale.

Scale	Definition	Explanation
1	The same	The two items have the same contribution to the goal.
3	A little bit important	One item is a little bit more important than the other.
5	Important	One item is more important than the other.
7	Very important	One item is very important compared with the other.

The present study also considered the effects of individual lower evaluation elements on the upper evaluation items based on absolute importance via fuzzy measure (see Table 9).

Calculating the importance of items by evaluation area is a critical operation in analyzing evaluation areas. Especially in subjective evaluations, it is almost impossible to calculate importance in clear expressions. In such a case, the experiences and knowledge of experts play significant roles. The present study employed the AHP technique, known for its excellent testing power for subjective evaluations. The absolute importance of items in the evaluation areas is also needed for the fuzzy integral to make subjective decisions, which was why the concept of fuzzy measure was used in the present study. This process is shown in Figure 4. The final comprehensive value is calculated from

Figure 4, and the major point in this process is to measure the relative weight according to the AHP method by the project evaluator, and to deduce objective evaluation results by complementing the absolute weight through fuzzy measurements.

Table 9. Fuzzy measure.

Measure	Definition	Evaluation Index
6	Very important	0.90
5	Important	0.75
4	A little bit important	0.60
3	Average	0.45
2	Less important	0.30
1	Not important	0.15
0	Never important	0

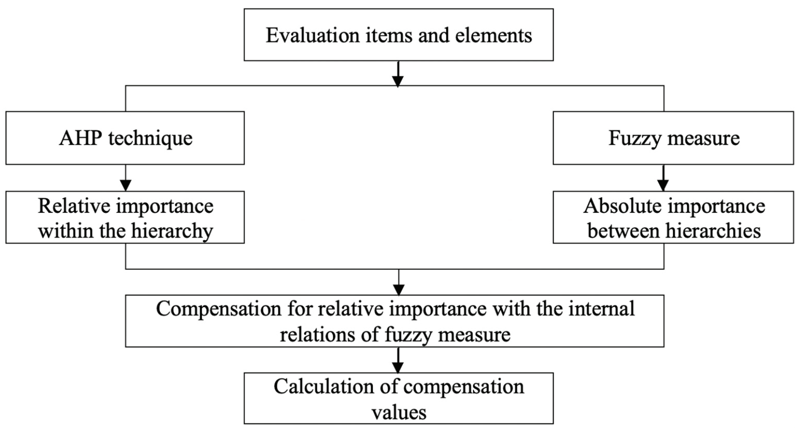

Figure 4. Calculation process of compensation values.

4. Findings and Discussions

4.1. Calculation of Influence with the Fuzzy Integral

This study calculated the importance of items by evaluation area using the Choquet fuzzy integral. When evaluating a subject across many different items, the fuzzy integral uses fuzzy measure for the evaluation value of each item. The range is broad—from 0.1 to 1.0—obtained through fuzzy inference based on the center of area method. Table 10 shows the influence of corresponding values for the unnecessariness of items in the evaluation areas.

Table 10. Influence of unnecessariness.

Evaluation Index	0.1	0.2	0.3	0.4	0.5
Unnecessariness	0.950	0.833	0.762	0.700	0.606
Evaluation index	0.6	0.7	0.8	0.9	1.0
Unnecessariness	0.574	0.404	0.300	0.196	0.100

In the Choquet fuzzy integral, a change in the evaluation value of an evaluation item will always lead to the consideration of influences on other evaluation items. There is, thus, no abrupt change to the evaluation results. Since the Choquet fuzzy integral reflects the influence of evaluation values sequentially, errors to a couple of evaluation items will not immediately influence the entire evaluation.

They will result in a gradual reduction of effects in their interactions with the evaluation values of other evaluation items. This is able to alleviate the extreme effects of examination results with strong subjective tendency, and secure some degree of objectivity.

4.2. Utilization of Evaluation by Innovative Methods for Big Data Analytics: Suggested Decision-Making Method through User Interface Big Data Analytics

Based on the calculation values of items in the evaluation areas, total influences were obtained due to the varying importance of items among the evaluation areas (see Table 11). In addition, evaluators varied in subjectivity and scale among high-rise building mixed-use development projects. Considering that evaluation results vary according to project uniqueness, there is a need for methodological alternatives that will put these results to universal use.

Table 11. Example of an evaluation method based on influence by evaluation area.

Evaluation Areas	Influence	Evaluation Areas	Influence	Evaluation Results	Evaluation Indices	Unnecessariness
Society and cities	0.587	Recognition of landmarks	0.544	VG	0.900	0.196
		Effects of urban redevelopment	0.458	H	0.800	0.300
Cultural ripple effects	0.413	Brand positioning of nation, society, and corporate leaders	0.549	H	0.800	0.300
		Cultural products and Korean Wave effects	0.440	M	0.600	0.574

This study estimated the influence of the evaluation area by using the fuzzy integral and identified the implications for each item. The evaluator in the above project was able to carry out a tailored evaluation that could overcome the limitations of generality for qualitative indicators in each area. When the evaluator of a particular evaluation area selects “Very important” on the “Recognition of landmarks” item in the evaluation area of “Society and cities,” based on influence by unnecessariness, the total influence will be 0.544, assuming evaluation index and unnecessariness values of 0.9 and 0.196, respectively. This process can mitigate the fierce interests of subjects involved in a development project and help to apply a scientific technique to quantify qualitative indices objectively. Therefore, this study established an evaluation system that can enhance the methodological utility of the feasibility study of high-rise building mixed-use development projects in the future, amid rapidly changing business environments, through an innovative and quantified decision-making method that combines big data and fuzzy theory.

4.3. Effectiveness Validation and Appreciation

Table 12 shows the evaluation using the study’s methodology conducted by an evaluator in charge of the project who works for the Korea Land and Housing Corporation (LH), a public organization in Korea. The evaluation results calculated the unnecessariness using fuzzy reasoning, and suggested the influence of the evaluation fields. The evaluation fields were simplified by limiting them to Environment, Architectural technological level, and Awareness. The results were suggested in the following order: Environment (0.787), Awareness (0.322), and Architectural technological level (0.178). This order considered the weight of the items according to the areas in the evaluation categorization system of future projects by measuring the language variables according to each evaluation item. In this evaluation field, Environment has a high influence, indicating the importance of considering factors from the Environment evaluation fields for this project; thus, these should be the major factors considered during future evaluations of the project. Within Environment, the pedestrian environment was the factor with the highest evaluation (0.544), Design technology was highest among Architectural technological level (0.549), and Awareness of design offices and construction companies was highest among Awareness (0.568). The results showed that custom-made evaluations are possible.

Table 12. Effects of the evaluation areas by the evaluator.

Evaluation Fields	Influence	Evaluation Results	Evaluation Index	UNNECESSARINESS	Evaluation Factors	Influence	Evaluation Results	Evaluation Index	Unnecessariness
Environment	0.787	VG	0.900	0.196	Urban environment	0.442	VG H M L	0.900 0.800 0.600 0.400	0.196 0.300 0.574 0.700
		H	0.800	0.300	Traffic environment	0.458	VG H M	0.900 0.800 0.600	0.196 0.300 0.574
		M	0.600	0.574	Pedestrian environment	0.544	VG H M	0.900 0.800 0.600	0.196 0.300 0.574
		L	0.400	0.700	Environment protection in the outskirts	0.417	VG H M L	0.900 0.800 0.600 0.400	0.196 0.300 0.574 0.700
Architectural technological level	0.178	H	0.800	0.300	Design technology	0.549	VG H M L	0.900 0.800 0.600 0.400	0.196 0.300 0.574 0.700
		M	0.600	0.574	Engineering technology	0.440	VG H M	0.900 0.800 0.600	0.196 0.300 0.574
		M	0.600	0.574	Construction technology	0.370	VG H M	0.900 0.800 0.600	0.196 0.300 0.574
Awareness	0.322	VG	0.900	0.196	Awareness of nation	0.508	VG H M L	0.900 0.800 0.600 0.400	0.196 0.300 0.574 0.700
		VG	0.900	0.196	Awareness of area	0.381	VG H M	0.900 0.800 0.600	0.196 0.300 0.574
		VL	0.100	0.950	Awareness of investors, including owners	0.386	VG H M	0.900 0.800 0.600	0.196 0.300 0.574
		H	0.800	0.300	Awareness of design offices and construction companies	0.568	VG H M L	0.900 0.800 0.600 0.400	0.196 0.300 0.574 0.700

4.4. Suggestions and Tasks on the Evaluation Method

This study suggested a method to evaluate the factors and characteristics of the detailed evaluation areas of a particular project that can be applied onsite. An appropriate project evaluation is the most important aspect to ensure that the project runs smoothly from start to finish. In particular, the evaluator must sufficiently consider the individual nature and particularities of the project before conducting the evaluation. These evaluators can select the final items and factors for the evaluation areas by assessing them under consideration of the unnecessariness and importance suggested in this study. Therefore, the evaluator can evaluate project appropriateness by putting together an evaluation method according to the purpose of the project. However, to continuously use the evaluation method suggested in this study, the following issues should be taken into account.

The evaluation areas should be continuously monitored to increase the effectiveness of this evaluation method. The major problem in terms of applying the evaluation method is that the evaluation areas cannot be set according to either the project type and characteristics or the economic environment. In other words, evaluation areas that may be appropriate at a certain point in time may later lose their effectiveness. Therefore, to consider the variability, processes should be established to improve the evaluation areas, and periodic inspections conducted to improve the considered factors on the foundation that influences the evaluation standards. A user-friendly program should also be developed to allow evaluators easy use of the study model. In addition, the evaluation factors generated by this fuzzy-AHP technique can be integrated with a multiple criteria decision analysis (MCDA). As practical projects in the field will be faced with many conflicting factors, MCDA can help simplify the multiple different criteria by discerning the relative significance for better judgment.

5. Conclusions

This study focused on a decision-making method in the feasibility study of real estate development planning, amid the rapidly changing business environments faced by real estate development firms. At a time when big data are used across all industries due to advances in ICT, this study was conducted through a convergent process that established an evaluation method based on big data for high-rise building mixed-use development projects, and combined it with fuzzy theory. In particular, this study focused on the process of quantitatively converting qualitative data using scientific analytical methods by organizing the evaluation factors to complement the limitations of subjective evaluations of existing studies. Based on the problem that the existing evaluation analysis makes it difficult to exclude subjectivity in the qualitative process, this study proposed a methodology for minimizing the subjectivity of the evaluator and proposed an alternative that can be applied to actual projects. In addition, we proposed an evaluation method that is practically applicable in projects by the If-Then rule for evaluating the degree of verification of each evaluation field. In this regard, the evaluator can calculate the degree of influence by indicating the degree of verification for each evaluation factor in language variables. Thus, the evaluator can objectively quantify uncertain or ambiguous subjective measures. The present study focused on the application of evaluation methods to compensate for qualitative project evaluation using a classification system for influence factors expected in future projects when considering the old high-rise building mixed-use development projects; thus, it lacks specific measures for evaluation methods that will be easily applicable in the field and will reflect user convenience. In particular, more evaluations and tests are needed regarding the usefulness of the model. In addition, there was a problem with lower statistical consistency according to questionnaire structural differences due to the characteristics of AHP and fuzzy theory, despite the improved application of evaluation methods, which calls for further research. Authors should discuss the results and how they can be interpreted considering the previous studies and working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted. In particular, as the Fuzzy-AHP technique, which works on specific projects, collects more evaluation factors, these can be categorized based on certain patterns by certain projects in big data sets for homogeneity and heterogeneity. This mechanism can be consolidated by patterning the evaluation system and risk management through big data analysis for the highest best use of real estate development.

One of the study's limitations is its use of non-universal evaluation criteria. As this study produced evaluation factors based on a specific typology, such as the high-rise mixed-use building development project, the findings of the evaluation methods may not be applicable to generic development type projects. Further research should adjust the evaluation methods to include specifications and evaluation conditions of other types of real estate development and land use planning.

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