PART 1

Synthesis of the Lessons

Chapter 1

AN EVOLVING PARADIGM FOR AFRICA AND SYNTHESIS OF THE LESSONS FROM ASIA

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Abstract: Africa has experienced a paradigm shift in mechanization in the past three decades. The "new paradigm" has also given rise to new challenges and policy issues. By synthesizing the recent experiences in African and Asian countries, this chapter draws lessons from Asia and Africa under this new African paradigm. In doing so, the chapter first lays out the guiding theoretical framework used in 1987 by Pingali, Bigot, and Binswanger (PBB), based on the literature on farming systems evolution and induced technological change. The chapter then describes the "new paradigm," which builds on PBB but also integrates the additional dimension of market failures associated, on the supply side, with custom hiring services, which have become the most common mode of mechanization among smallholders in developing countries. Applying this expanded framework, the chapter then reviews the Asian experience first. It highlights how mechanization has grown in the continent, having largely avoided supply-side market failures, thanks to several factors: smaller machine sizes;[1] increased opportunities for multifunctional uses of machines; more secure land tenures that allow integration with formal credit markets; and the supportive, rather than distortive, nature of government subsidy policies. The chapter then turns to the experiences in Africa south of the Sahara ("Africa" hereafter) and highlights the emerging patterns of spatial variations in demand that are still largely consistent with the PBB framework. However, the chapter also stresses that market failures associated with custom hiring services on the supply side are substantial due to features unique to Africa, including the dominant types of large tractors, in addition to higher financial constraints on tractor ownership resulting from lack of secure land tenures and weak penetration of formal credit markets, as well as other barriers due to limited multifunctionality, lack of migratory

1 In this book, we use the term "size," in relation to tractors, to refer loosely to horsepower. Our definition of size is not based on any clear-cut engineering threshold. Rather, we focus on size aspects when we highlight the differences in typical tractor horsepower between Africa and Asia that are relatively universal, as described in the later section, and their implications for the nature of constraints and market failures that Africa is facing.

services due to insufficient infrastructure and coordination failures, and insufficient technologies complementary to mechanization. Based on country experiences in Asia and Africa, the chapter also highlights key government policies that have not always been successful, including import restrictions (or removal thereof), inefficient technology and skill promotion, and insufficient provision of public goods. Last, given the country experiences and the identified appropriate roles of governments, the chapter concludes by describing the key lessons that are important for Africa's mechanization pathway forward, including (1) understanding the emerging nature of demand, (2) actively promoting private hiring services, (3) eliminating or reducing distortions, and (4) prioritizing the mechanization technologies appropriate for African contexts.

Introduction

Agricultural transformation is imperative for growth and poverty reduction in Africa. Yet the desired progress has been elusive. The region is a net food importer despite the fact that agriculture accounts for 60 percent of employment. Main food crop yields are estimated at about half the world average, and rural poverty, hunger, and malnutrition are persistent (AfDB 2016). Recently, increased (albeit still insufficient) attention has been paid to promoting a Green Revolution–style agricultural intensification, focusing on improved seed varieties, fertilizer, and agrochemicals that increase the land productivity. In comparison, much less emphasis has been placed on addressing seasonal labor constraints and rising rural wages through mechanization to promote agricultural transformation.

Mechanization is a labor-saving technology that enables farmers to expand cultivation area and free up labor for other agricultural functions or nonfarm income generation.[2] Early efforts to promote mechanization in Africa often failed due to abundance of rural laborers within most rural farm households

2 In this book, the term "mechanization" is defined in a broad sense, including both technologies themselves and processes that involve their use. The term "tractorization" is used where the focus is specifically on tractors, and mechanization is used if the focus is generally on increased mechanical power. Mechanization can sometimes encompass tractorization if, for example, the process happens to involve a switch from draft animals to tractors. The term "farm power" is used where the focus is more on motive energy inputs in farming, which are provided through either human labor, animal work, or machinery (these all take the form of motive energy, as opposed to energy embedded in other types of inputs, such as fertilizer). The term "agricultural machinery" is used where the focus is on the physical capital items that convert energy inputs into the desired form of energy outputs. The term "agricultural implements" is used in a similar way, but specifically for machine attachments, such as plows and harrows.

Similarly, "labor-saving" is defined in a broad way, including both in economic terms (for example, saving on the cost of labor) and ergonomic terms (for example, reduced labor

that limited farmer incentives to intensify production (Pingali, Bigot, and Binswanger 1987, hereafter "PBB"). However, agricultural mechanization has gained renewed attention recently in Africa. Some indications suggest that farming systems have evolved sufficiently in many locations of Africa for farmers to demand mechanization (Mrema, Baker, and Kahan 2008; Diao, Silver, and Takeshima 2016; Binswanger-Mkhize 2017) and that increased mechanization adoption has occurred in new pockets across Africa recently (FAO 2016; Malabo Montpellier Panel 2018). Despite recent progress, however, the spread of mechanization in Africa has lagged far behind that of Asia, where mechanization has been widely adopted in most countries in recent years, including in many low-income and labor-abundant Asian countries. Moreover, research on mechanization in developing countries, and in Africa in particular, is scarce, and knowledge and insight about mechanization in Africa, in terms of both collecting statistics about it and understanding its drivers and impacts, remains limited.

Although different opinions exist in the literature for understanding factors affecting mechanization in Africa, the framework developed by PBB in 1987, based on the farming systems evolution hypothesis, which emphasizes the demand side of mechanization, remains one of the most important guiding frameworks, together with other guiding strategies, for pursuing mechanization development. In their seminal volume, *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa*, PBB argued that widespread public efforts to promote mechanization often failed because African farming systems had simply not intensified enough to generate sufficient demand for mechanization among farmers. Their theory also fits the patterns observed in Asia, where farming systems had already undergone widespread intensification and draft animal power (DAP) had been in use for a much longer period (Lawrence and Pearson 2002). Twenty years after publication of the PBB book, Pingali further asserted that "where the demand side factors are in place, agricultural intensification and the adoption of mechanical power occurs in Africa in a similar pattern to Asia and Latin America" (2007, 2787). Broadly speaking, farming systems have intensified in many places in Africa, with a shortened fallow period and an increasing share of annual crop areas among total agricultural land. However, as the rest of this chapter and the African case studies in this book show, the characteristics of demand for mechanization remain complex. Moreover, supply does not appear

requirement and reduced drudgery), both of which are becoming increasingly important motivations in Africa to address the mechanization challenge (for example, Kormawa et al. 2018).

to have responded at nearly the levels observed in Asia. As a result, the farming systems hypothesis alone has been insufficient to explain mechanization in Africa (Binswanger-Mkhize 2017). Altogether, with the intensifying farming system and growing relevance of modern mechanization technologies, there is a need for a closer understanding of not only demand but also, most important, the increasing relevance of supply-side constraints on mechanization in Africa, which we describe as a "new paradigm" for mechanization in Africa.

Mechanization could help farmers overcome the labor constraints present in agriculture, reduce drudgery in various farming operations, expand farm sizes where land is available, and permit higher levels of intensification in more labor-intensive farming activities. Although tractor plowing per se is not directly associated with yield growth, it enables key operations to be done on time, which is especially relevant for rainfed agriculture in areas with short planting windows. Evidence from Asian as well as some African countries also suggests that tractor use is associated with higher cropping intensity and use of fertilizer. Combine harvesters have also become part of mechanization practice. As shown in the case studies of Asian countries and Ethiopia, use of combine harvesters has the potential to significantly reduce postharvest losses, thus increasing outputs per unit of land. In a highly optimistic scenario, these effects of mechanization can contribute to Africa's forestalled agricultural transformation. However, for this to occur, substantial improvements in agricultural engineering research; varietal development; and market development for inputs, credit, and outputs would likely have to take place to complement mechanization. In many African countries, supply elasticity is limited partly due to technological backwardness, leading to persistently high reliance on food imports despite relatively high food prices (for example, in the case of rice, Gyimah-Brempong, Johnson, and Takeshima 2016). It is essential to understand and address these complex issues hindering mechanization development in Africa.

It has often been suggested that Africa can learn from Asian experiences of agricultural transformation, including mechanization. Asian experiences in mechanization are diverse, and distinct patterns of mechanization across Asian countries could offer many lessons to Africa. One thing that seems to be common among many Asian countries is that mechanization has often started with little direct intervention from the governments. Manufacturing of spare parts and simple tools often grew out of innovations by local entrepreneurs at the early stages of manufacturing-sector development (Diao et al. 2014). In some countries where governments did get involved, they primarily attempted to overcome market constraints for the private supply to meet

existing farmer demand, and provided key public goods to overcome market failures as well as education (Rijk 1986). As is described later in this chapter, despite the limited successes of the African government–led mechanization programs three decades ago (as diagnosed by PBB), recent efforts by a few African governments suggest that the past lesson is still relevant for today's issues. These issues include limited machine utilization rates and the insufficient provision of soil and machinery technological knowledge to the private sector, among others (Kormawa et al. 2018). The challenge to African policymakers is how to appropriately address key market failures that prevent the private sector's supply from meeting emerging demand, and how to better identify the characteristics of demand that help overcome supply bottlenecks. Later sections of the chapter describe market failures that lead to risks and uncertainty about making machine investments due to spatially and temporally variable demand in hiring markets, uncertainty about and limited opportunities for multifunctional use of machines, and insufficient machinery and oil information and knowledge that can be provided by the government as public goods (Diao et al. 2017).[3]

This book aims to update the PBB framework by integrating an additional dimension—market failures on the supply side of mechanization associated with custom hiring services, the most common mode of mechanization among smallholders in developing countries—in order to account for the recent mechanization patterns observed in Africa alongside those in Asia. By doing so, we intend not to dispute the underpinnings of PBB's hypothesis, but rather to capture the emerging challenges of mechanization, particularly those highlighted by recent experiences in Africa. An updated framework is not only important for further research but also a crucial tool for African policymakers to develop judicious approaches to supporting mechanization development.

3 PBB hypothesized that the supply-side constraints are rarely binding, and although there are many grounds to expect this hypothesis to hold in general (such as the private sector's ability to innovate mechanical technologies compared with biological technologies), testing it formally has been challenging. Further, despite the improved understanding and recognition of market failures (including those in information, risk, and finance) and of the role public-sector institutions play in sustaining private sector–led growth (Rodrick 2007; Naudé 2011), these new perspectives have not been applied sufficiently to understand how the public sector can "speed up" and "raise efficiency" of the private sector's responses to meet demand. The potential roles of the public sector to assist the private sector in such ways in the short run is important because African governments and international communities are under pressure to meet development goals that are becoming increasingly time-sensitive (for example, 2025 goals for mechanization achievements envisaged under the African Union's Agenda 2063, and 2030 goals under more general Sustainable Development Goals, among others).

This book presents evidence from 13 countries in Asia and Africa to lay the foundations for the new paradigm. These chapters largely avoid policy prescriptions, and instead aim to provide a thorough overview of where mechanization stands in each country and how it has developed to that point. They are intended as resources for policymakers, academics, and lay readers to draw upon when considering how to encourage the development of mechanization in specific contexts. This book's approach of focusing on individual countries for case studies differs from that of PBB, which focused on the African continent as one geographic region and drew collective lessons from various locations within it.

The book also contributes to the efforts in integrating mechanization into the mainstream Africa-wide agenda, including the African Union's Agenda 2063 (a strategic framework for the socioeconomic transformation of the continent over the next 50 years), the Comprehensive Africa Agriculture Development Programme (CAADP), and the Malabo Declaration. Under Agenda 2063, Aspiration #1, "To achieve a prosperous Africa based on inclusive growth and sustainable development," Goal #5 commits countries to banish the hand hoe by 2025 as part of the goal of achieving overall productivity and food security enhancement through a modern and environmentally sustainable agriculture sector (Malabo Montpellier Panel 2018). Although this is a political goal and its economic rationale remains to be investigated, it symbolizes the growing interest in mechanization within the African community. The CAADP platform, which commits African countries to spend 10 percent of national budgets on the agriculture sector to achieve a 6 percent annual growth rate in the sector, recognizes the importance of agricultural mechanization in promoting intensification (Diao, Silver, and Takeshima 2016; FAO 2016). Increasingly, agricultural mechanization has been integrated into CAADP's Pillar #4, Integrated Research, Technology Dissemination and Adoption (Malabo Montpellier Panel 2018). The Malabo Declaration further recognizes the slow pace of mechanization along the agriculture value chain and emphasizes the importance of investments into suitable, reliable, and affordable mechanization and energy supplies in order to double productivity by 2025 (Malabo Montpellier Panel 2018). In October 2018, after intensive expert consultations with a broad range of stakeholders, the African Union Commission (AUC) and Food and Agriculture Organization of the United Nations (FAO) launched the Sustainable Agricultural Mechanization in Africa (SAMA) framework, which has been integrated into CAADP and the Malabo Declaration (Kormawa et al. 2018) and recognizes that agricultural mechanization in Africa is an indispensable pillar for attaining the

Zero Hunger vision by 2025, as stated in the Malabo Declaration of 2014 (AUC 2018).

The book is written at a crucial time, and its recommendations are expected to become part of the policy dialogue and debate on how to develop and disseminate modern agricultural technologies in order to double agricultural productivity in Africa. The book emphasizes mechanization promotion as an important component of agricultural technology, together with agricultural research and development (R&D), irrigation, and so on, which requires the public sector to increase its investment while avoiding the creation of new market and trade distortions that can discourage private investment. We expect the insights of the book to be consistent with the spirit of CAADP to prioritize and coordinate investments (World Bank 2007, 24). We also expect the book to inform the implementation of SAMA, launched by the AUC and FAO in 2018 (Kormawa et al. 2018). SAMA consists of 10 elements, including (but not limited to) appropriate technologies, business models, financing mechanisms, manufacturing growth, technology development and transfer, and inclusiveness focusing on smallholders and their organizations—all of which are highly relevant for mechanization policy and promotion. Moreover, by providing concrete examples and experiences from what Asian countries have achieved, this book tries to promote South–South learning and Africa–Asia collaboration in searching for the proper pathways for African countries to adopt mechanization.

This book is edited mostly from economists' perspectives, although chapters are written by a mixture of agricultural economists and agricultural engineers. The book is intended for a range of stakeholders. For policymakers at higher levels, the book will be useful for any ministry of agriculture that oversees direct policies on agricultural engineering and the governance of agrifood systems that encompass the farm sector as well as upstream and downstream sectors (such as machine industries and agricultural machinery service providers on the one hand, and rural transportation of harvests on the other). However, our interpretations of PBB (and updating thereof) that highlight the roles of a broad set of economywide factors, including macroeconomic factors, provide useful insights to other policymaking institutions, such as ministries of finance, trade and industry, or education, into how their policies can have profound effects on agricultural mechanization, and further offer a useful common base of knowledge on which they may coordinate their policies toward unified development strategies. The descriptions in this book, which distinguish the modern sector and the more traditional small businesses involved with mechanization, also provide better understanding

for policymakers at an operational level and establish more realistic expectations of the impact of their programs and interventions; in this way, this book can serve as a reference for them to better communicate these expectations to stakeholders. Furthermore, the book offers useful historical perspectives to the newer and younger generation of policymakers, who are increasingly assuming political positions in Africa. This book also offers detailed descriptions of mechanization adoption at the subregional level and of the structure of the existing mechanization market sector. These can be useful for the private sector and specific industries that are interested in assessing the potential market opportunities of mechanization in Africa. The book also serves as an important document that communicates economic perspectives on agricultural mechanization in comprehensive and holistic ways to the agricultural engineering research community. Last, the book can be useful for researchers and students in the agricultural economics research community who are interested in learning about and conducting empirical research on economic issues surrounding agricultural mechanization.

The remainder of this chapter is structured as follows. First, we describe the analytical scope of the book. We then develop our updated theoretical framework for mechanization. This updated framework integrates PBB's hypothesis, centered around the theory of farming systems development by Boserup (1965) and the induced innovation theory of Hayami and Ruttan (1970, 1985), and expands it to account for common market failures in agricultural machinery investment and mechanized service provision. We then describe the selection of case study countries and their linkages with the framework. Next, we apply this framework to help explain the divergence between mechanization trends in Asia and those in Africa. We then pay attention to the role of government policies in shaping mechanization, before concluding with some recommendations that provide context for the remainder of the book.

Analytical Scope of the Book

This book primarily focuses on tractors—both four-wheel tractors (4WTs) and power tillers, also known as walk-behind tractors—though some chapters also cover combine harvesters, another example of a motive, power-intensive mechanization technology, mainly because highly specialized hiring service providers have emerged in some countries, which allow smallholders to get access to the services of combine harvesters. We acknowledge that agricultural mechanization is not just tractor use and that it involves the use of many other types of equipment. Although future studies need to investigate these broader

categories of mechanization to provide a more holistic view of agricultural mechanization in Africa, many other types of commonly used agricultural machinery in Africa are less associated with the development of the hiring service markets that have eased smallholders' access to mechanization, one reason why we did not cover them in this book.

There are several other reasons that justify this book's focus on tractors and the important role they play in agricultural mechanization. First, tractors have historically been considered one of the major mechanical innovations in agriculture that can replace animal and human power for the toughest part of farming operations—land preparation. Replacing animal and human power with a tractor makes it possible for farm size to expand and for more and more land to be brought under cultivation. Moreover, tractors as a substitution for animal and human power make it much easier to command more power per worker and significantly raise labor productivity in agriculture (Hayami and Ruttan 1970). Hayami and Ruttan (1970) went as far as to consider the tractor the single most important mechanical innovation. In an extreme case like that of the United States, tractors alone have historically raised gross domestic product by significant margins (Steckel and White 2012).

Second, partly related to the first point, the adoption of tractors generally means a considerable leap from human or animal power because of the great difference in horsepower, and thus is likely to have significant effects in reducing drudgery associated with manual farm work and in enhancing welfare, as well as a modernizing effect on the agricultural sector. Third, among major farming operations, the use of tractors for land preparation often precedes significant mechanization of other operations. Land preparation is the most energy-demanding farming operation in rainfed agriculture (Lal 2004; Baudron et al. 2015), and primary tillage is one of the first operations to be mechanized when a new source of mobile power becomes available (Binswanger 1986).

Fourth and finally, tractors are unique in various dimensions and face distinct challenges not encountered by other machines. For example, because threshing is less time-bound than some other operations, the rental market for threshing machines developed in the United States in the 19th century and in Asia in the 20th, with fewer timeliness constraints than was the case for tractors (Binswanger and Donovan 1987, 15). Multifunctionality of tractors, intensively exploited in Asia, also makes tractors unique because tools for other operations, such as planters, weeders, sprayers, and carts for transportation, are often attached to tractors when the latter are introduced. Also, tractors have served as an important source of power to run stationary equipment such as irrigation pumps and threshers (Diao, Silver, and Takeshima 2016),

especially before the widespread adoption of cheaper machines such as diesel pumps (IRRI 1983) or the emergence of modern substitutes such as solar pumps. Because tractors are relatively unique, with few substitutes (compared with other types of equipment), information is relatively more available across countries about tractors than about other farm implements. Focusing on tractors therefore provides us one way to see more clearly the gaps between Asia and Africa. Furthermore, for many African countries, tractors may be one of the most important binding constraints on the current stage of mechanization, especially where intermediate technologies such as animal traction have spread relatively widely.

Although agricultural mechanization encompasses not only crop production but also fishery and livestock production, the focus of this book is mechanization for crop production. This is not only because crop production accounts for the most significant part of agriculture in both Africa and Asia, but also because mechanization of crop production often represents the first stage of mechanization development. The share of crop production remains greater than 75 percent of the gross production value of agriculture in Africa, and 70 percent in Asia (FAO 2019a). The share of rural households engaged in crop production is also high and dominant in both Africa and Asia. Focusing primarily on crop production therefore still captures the important aspects of agricultural mechanization at both continents' current stage of agricultural development.

In fact, focusing on tractors as the core of crop-related mechanization can implicitly cover some power-intensive activities associated with fishery and livestock production, such as on-farm production of fodder (from maize and so on), transportation of fodders or water, and transportation of animals for slaughtering or sales. However, due to data availability on the use of machinery in livestock raising, we cannot do any empirical analysis explicitly on livestock mechanization in this book. Similarly, as with crop production, more control-intensive activities, such as identification, medication, vaccination, evisceration, and processing and packaging, may be mechanized only after the mechanization of power-intensive activities has been widely adopted. Such adoption represents a more advanced stage of mechanization and is not covered by this book, although mechanization in these areas is likely to be increasingly important in the future in both Asia and Africa.

Last, the book focuses primarily on production and does not directly address issues associated with postharvest and storage activities, or with processing and marketing along the value chain of agriculture (Breuer, Brenneis, and Fortenbacher 2015), except where we touch on the multifunctionality of

tractors (for example, their use for transport). We make this choice because most mobile operations, which constitute one type of power-intensive operation, occur at the production stage, whereas most operations in postharvest stages are stationary (PBB). The mechanization of mobile operations typically faces a different set of constraints than that of stationary operations. For example, activities such as milling, grinding, pounding, pressing, crushing, and threshing typically do not face the timeliness problems associated with plowing, and so efficient rental markets are relatively easily established (PBB; Binswanger and Donovan 1987). Similarly, these service providers often provide other postharvest services. For example, in Ghana, many rice mills provide drying and storage services (Takeshima, Agandin, and Kolavalli 2017). As long as there are still challenges associated with the mechanization of these activities, treating them together with mechanization for mobile operations, such as that provided by tractors, may be difficult in a single book. At the same time, mechanization of some activities, such as packaging and grading, may be adopted at later stages when demand for high-value processed foods rises substantially, at which point mechanization of power-intensive activities would have sufficiently spread. Nevertheless, as is shown in this chapter, some of the recommendations in the book may also apply to postproduction stages, and therefore our book provides a useful framework that can be adopted for analyses of postharvest mechanization issues in the future.

A Theoretical Framework for the Evolving Paradigm

Demand for mechanization depends on the level of agricultural intensification, land–labor ratios, labor costs, and the development of a hiring market. We first summarize the theoretical framework around these components and describe how our framework builds on elements of the conventional framework, before examining how it explains trends in Asia and Africa.

Farming Systems Evolution

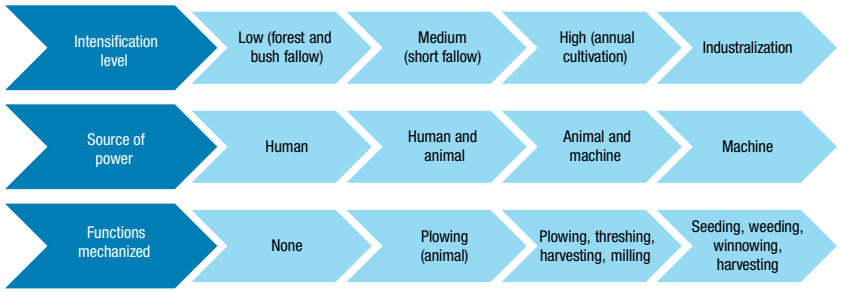
One of the elements of the conventional framework is Boserup's theory of endogenous farming systems evolution, established in her seminal work, *The Conditions of Agricultural Growth* (1965). PBB's hypothesis can be seen as an extension of this theory. Boserup argued that the evolution of farming systems is an interactive, endogenous process driven by increasing population pressure and rising demand for agricultural products through market development. Farmers respond to this process by shortening fallow periods and intensifying

production by adopting modern inputs, such as improved seeds, fertilizers, and agrochemicals, to increase land productivity (Boserup 1965). The hypothesis was further developed in Ruthenberg's 1971 book, *Farming Systems in the Tropics*, which saw its third edition published in 1980. Ruthenberg specified that when farming systems move from long fallows to short fallows (at most two years of fallow per year of cultivation) or annual cultivation, plowing—whether with animals or tractors—becomes necessary to limit weed growth as well as to bring nutrients to the surface of the soil (Ruthenburg 1980). Before this stage, stumps and other field obstacles make plowing more challenging, especially where the use of appropriate plows (such as disc plows) is not profitable (PBB). However, once this stage is reached, the grasses that emerge between seasons cannot be removed by burning. Consequently, labor requirements become too high for manual hoeing alone (Boserup 1965; Ruthenburg 1980). The crux of PBB's hypothesis focused on emphasizing that demand for plowing is insufficient if viewed from the evolution stage of such a farming system in significant parts of Africa, and that this principle had largely constrained adoption of mechanization until recently.

PBB further hypothesized that mechanization is a sequential process adopted at different stages of agricultural intensification, with a shift from human muscle to animal power to machinery. The most power-intensive operations, such as plowing and threshing, are mechanized before harvesting is mechanized. Figure 1.1 illustrates these sequences according to intensification level, power source, and functions mechanized. In PBB's view, in the areas where animal traction is feasible, bypassing it to move directly from hand hoes to tractors is not cost-effective due to the costs of destumping fields and forgoing the benefits of animal by-products. They demonstrate that although trypanosomiasis is a major constraint to developing draft animals, it becomes less of a problem as population density increases and more forests are converted to crop fields. This book's online Appendix 1D discusses in greater detail how the patterns in Figure 1.1 have, in fact, been widely observed in Asia and elsewhere.

PBB's fundamental explanation of the low adoption of mechanization in Africa focused on African small farmers, for whom farming systems had not evolved sufficiently for them to demand plowing using tractors. However, some African countries did have more tractors than many Asian countries prior to the 1960s, because of their colonial history and related farmland distribution in which large-scale farming was carried out mostly by white settlers who had a long history of mechanization (Acemoglu, Johnson, and Robinson 2002). Excluding such large-scale farms that still existed after independence,

FIGURE 1.1 Overview of sequential adoption of mechanization according to Pingali, Bigot, and Binswanger (1987)



Source: Adapted from Pingali, Bigot, and Binswanger (1987).

the smaller African farmers continued to follow farming systems characterized by long- to medium-fallow stages, and their agricultural products faced relatively inelastic demand due to low population density, lack of urbanization, and poor market access. Thus, there was limited market demand for mechanization among the majority of African farmers, and mechanized services were predominantly provided by the public tractor hiring scheme. In the few systems in which mechanization was concentrated, PBB found it to be highly correlated with intensification levels and to have developed with limited government intervention.

Induced Technological Change

Equally important for understanding mechanization is Hayami and Ruttan's induced technological innovation theory (1970, 1985). The simple intuition behind this theory is that the public and private sectors are driven to develop and adopt technologies that can help to overcome constraints caused by the scarcity of factor endowments—land or labor. Under this theory, in addition to technology innovation, institutional innovations, which include agricultural R&D as well as changes in property rights, tenancy, and labor arrangements, are expected to respond similarly to agricultural endowments. The induced innovation theory explains why mechanization, a labor-saving technology, was adopted much earlier in land-abundant North and South American countries than elsewhere; it also explains why Japan and some other land-constrained Asian countries first adopted land-saving technologies such as high-yielding varieties and intensive use of fertilizer, before machine power replaced animal power.

The intensification process described by PBB requires greater labor input in the beginning, in response to a growing labor endowment resulting from the growing population density. At the later stage, the industrial sector's pull of labor out of agriculture and emigrants' remittances to rural areas cause a labor shortage in agriculture and a rising rural wage rate, which lead to more modern mechanization development, as has been experienced in the United States, Japan, and more recently, other Asian countries (Hayami and Ruttan 1970; Binswanger-Mkhize 2017). This outline shows the importance of an overall economic transformation process for agricultural mechanization. Importantly, however, the mechanization process also varies across countries and regions. For example, many African countries have already experienced rapid urbanization and a growing service sector that leads to labor movement out of the agricultural sector, but their domestic food production responds to such transformation less through agricultural intensification than through other means. That is, despite the fact that urbanization leads to growth in domestic demand for food, that demand is increasingly met by imports. Understanding the full mechanisms underpinning the relationship between overall economic transformation and agricultural mechanization, including why some Asian countries have seen greater mechanization compared with some in Africa as a response to structural transformation, is therefore important.

For mechanical technologies, market incentives have generally been considered more effective than biological technology in inducing innovation, including in countries such as the United States (Hayami and Ruttan 1985). Unlike the farming systems theory, the induced innovation theory explicitly considers public institutions as part of the technology development and adoption process, recognizing that technological change is unlikely to originate solely and automatically from the evolution of farming systems, and instead is likely also to require institutional innovations within both the public and private sectors.

DISTINCTION BETWEEN PBB FRAMEWORK AND INDUCED INNOVATION THEORY

Micro-elements of the PBB framework are consistent with induced innovation theory, yet there are important distinctions between the two. For example, conventional induced innovation theory does not explain explicitly why mechanization (or innovation toward mechanization) did not emerge in Africa before the farming system evolution, when land was more abundant than labor.

Induced innovation theory, such as that described by Hayami and Ruttan (1970, 1985), is largely founded on the existence of a highly intensified

farming system, such as that of the United States and Japan. Whereas the premise of the theory is that relative land abundance induces innovation in land-complementary technologies, authors such as Hayami and Ruttan (1970, 1985) have shown that this pattern holds in already highly intensified farming systems. The theory does not imply that mechanization could emerge wherever land is abundant, regardless of farming system. At the preintensification stage, the traditional land-complementary strategy for farming is shifting cultivation and fallowing, rather than developing mechanical technologies. Mechanical technologies, which are labor-saving and land-complementary, require sufficient market demand for agricultural outputs, which comes from increased population density and urbanization, as described in PBB.

To understand mechanization in Africa in the early days, it is important to integrate induced innovation theory with the PBB framework because induced innovation alone cannot explain when and why mechanization occurred or did not occur in Africa, even though many countries in the continent are relatively more land abundant than Asia. To explain the evolution of the land-complementarity of mechanical technologies, induced innovation theory has to rely on the PBB framework, which draws on the farming systems evolution hypothesis.

Both induced innovation theory and the farming systems evolution hypothesis relate to the broader demand-side drivers of technological change, and the PBB framework focuses specifically on the demand-side factors applicable to mechanization. We now turn to supply-side factors, which are less prominently considered as binding factors in PBB's framework.

The Supply Side of Mechanization: Hiring Markets and Market Failures

One of the important components of our updated framework does not trace back to any particular strand of literature; instead, it focuses on the supply-side issue of mechanization, addressing market failures relating to agricultural machinery investment and mechanization custom hiring services—the most common mode of mechanization among smallholders in developing countries. In developing countries dominated by smallholders with limited wealth, most farmers are unlikely to be able to afford a tractor or other large machinery. Hiring in services often becomes the only way for many farmers to access mechanization. At the same time, farm sizes are often not large enough for tractor owners to fully utilize their machinery. Thus, hiring out services becomes necessary for owners to be able to recoup their investments. In this mechanized service market, private owner-operators are almost invariably the

most efficient way of supplying hiring services. First, private owner-operators have incentives for maximizing tractor utilization, which may not be the case for government hiring schemes. Second, on-farm benefits of tractor ownership ensure that owners can conduct plowing and other field operations on time for their own land. Third, farmer owner-operators have low risk associated with machine damage caused by irresponsible behaviors of some hired operators.

The ability of the supply of hiring services to meet the growing demand for mechanization among small- and medium-scale farmers depends on the many factors affecting the decision of a few would-be buyers to invest in a tractor. For investment in a tractor to be viable, the revenues from hiring out services plus the timeliness benefits from using a tractor on one's own fields, less the costs of fuel, maintenance, repairs and spare parts, payment to operators (when they are hired), machinery depreciation, and loan interest payments, must be enough to offset the investment over the course of the tractor's useful life (Houssou, Diao, and Kolavalli 2014). The opportunities for hiring out services are therefore key to maximizing utilization rates in a way that ensures profitable ownership of a tractor or combine harvester. Although tractors can theoretically operate for 800–1,200 hours per year, short plowing periods determined by rainfall and temperature conditions can reduce this capacity to 300 hours per year (Hunt 1983; Culpin 1988).

In addition to the length of the plowing season, achieving a break-even rate for the investment depends on many economic and technical factors that affect the development of the hiring market. First, without sufficient demand among farmers for mechanization services in their home areas, ownership of a tractor is unlikely to be profitable for a medium- or even large-scale farmer. On the other hand, farmers' demand for hiring services depends not only on farming system evolution and the relative scarcity of labor at the national level, but also on whether the expected benefit of mechanization services outweighs the service charges, a payoff that requires a high enough productivity level. The market price of hiring services, in turn, depends on the competitiveness of service markets with enough service providers and, further, the providers' operating costs. If agricultural returns are low due to low productivity, then demand for paid services may be low. Given that returns on investment in tractors are determined by the utilization rate, low or uncertain demand in the local hiring market negatively affects the decision of a would-be buyer to invest in a tractor, particularly when long-distance mobility in service provision is limited.

Second, the utilization rate of a tractor—and hence opportunities for profitable tractor ownership in rainfed systems—greatly depends on the length

of the planting window, which may be as short as 30 days in semi-arid areas (Mrema, Kienzle, and Mpagalile 2018). This makes it extremely difficult in such contexts to reach a break-even point in investment and magnifies the cost of a tractor breakdown or other delay. Therefore, opportunities for providing multifunctional hiring services with a tractor, beyond plowing, can be vital. This may be achieved by using the tractor for water pumping, maize shelling, or processing of other crops, or for other functions such as transport, although certain stationary power applications such as pumping may be less relevant in areas where general motorized pumps or solar pumps are emerging as alternatives. Opportunities for multifunctional tractor use depend on farmers' demand for additional hiring services, which may be low in the places where an irrigation system is beyond reach for most farmers or where small-scale irrigation technologies are underdeveloped. Farmers in these areas may not have adopted a practice, such as harrowing or multiple plowing, that requires tractor use multiple times in land preparation. Migratory service provision in plowing increases utilization by allowing tractor owners to use their machines for a longer period of the year by exploiting geographical variation in seasons. However, these opportunities may not currently exist in many African countries. Migratory services rely on better road infrastructure, which depends on public investment. Migratory services are also subject to coordination failures, and it is unlikely for individual tractor owners to gauge the service demand and connect with customers in locations beyond their home areas. These issues can be particularly serious in Africa, more so than in Asia, because road infrastructure is poorer and service market networks are underdeveloped at an early stage of mechanization in Africa. Transporting tractors over long distances can be prohibitively costly where physical infrastructure is poor. Alternatively, identifying medium-scale commercial farmers and encouraging their growth in a way that raises returns on machinery can also stimulate the growth of potential suppliers of custom hiring services (Mpanduji 2000; Agyei-Holmes 2014).

Even within a locality, significant obstacles hinder the efficient utilization of tractors, especially where plots are small and fragmented. In an area with small farm sizes, especially if the timing of production among small farmers is not uniform, traveling between plots, as well as turning and other maneuvers in a small plot, increases time and fuel consumption. Again, this can be especially serious in Africa, where the dominant types of tractors are larger and the road infrastructure is poorer than in Asia. These obstacles all cut into the margins of tractor operation. One way to offset this disadvantage of scale in farm size is for small farmers to coordinate planting and to jointly hire a

tractor for plowing their fields at once, but this would require coordination efforts beyond tractor owners' capacity. Moreover, there is a steep learning curve for both the technical and business aspects of tractor ownership and operation in hiring markets, which implies additional risks for tractor investment. The complex soil and field conditions across small farms require experience, which takes time for owners or hired operators to acquire. Otherwise, stumps and other obstacles hidden in unfamiliar fields can easily damage tractors.

Apart from these risks, traditional land tenure systems can not only limit the consolidation of farmland but also prevent the land from being used as collateral, making credit for tractor purchases unavailable to many would-be buyers who are farmers. This is especially prevalent in countries with particularly weak land tenure security. Thus, the lump-sum investment required becomes unfeasible for many potential owners. Even where credit is available, interest rates are often too high to be attractive for would-be buyers.

The availability of appropriate technology is also imperative for hiring-market development. All of the potential market failures described above are exacerbated when tractor sizes are large. Larger, higher-horsepower tractors are generally more expensive, require higher utilization rates for breakeven, and possess higher barriers to entry than smaller models. Thus, larger tractor size exposes owners to greater hiring-market risk because any major delay or coordination failure has greater consequences in terms of recouping the higher investment cost. Thus, it is important to strike a balance between a tractor powerful enough to effectively plow local soils and one small and cheap enough to be owned and operated cost-efficiently in areas where those smaller tractors would be in fact more suitable. However, in Africa, with hiring markets in the early stages, the tractors available are manufactured for and previously owned in other countries. With limited knowledge of the suitability of different tractors for different within-country soil conditions, achieving the balance between size and efficiency of tractors is beyond the capacity of individual owners or the private sector. These challenges are more severe in Africa, where soil conditions and other production environments are generally more diverse than in Asia (World Bank 2007), yet the public information to address them is limited. The evidence is still insufficient as to what the optimal size of tractors is in Africa, although small tractors, including two-wheel tractors, have been promoted in Africa from time to time over the course of several centuries. Continuous research is needed to shed more light on this issue and provide information to policymakers and stakeholders about the size of tractors.

Familiarity with animal traction can facilitate the adoption of tractors beyond the sequential nature of farming systems evolution, because in this case tractors are adopted simply to substitute for animal traction. Although the transition from animal traction to tractors requires learning a new technology, in the places where farmers go straight from hand hoes to tractors, they must learn not only the new technology but also new land preparation practices. In a society with established animal traction, formal or informal hiring markets already exist for draft animal services. Moving from a tradition of hiring animals for land preparation to hiring tractors for plowing is therefore a much faster process, in terms of both new technology adoption and tractor hiring market development. Having used animal traction also helps new tractor owner-operators shorten their learning period for service provision. Of course, the potential of draft animals must also be evaluated against the risks of owning the animals, such as disease and competition with the growing demand for livestock products. Where feasible, leapfrogging draft animal technology should remain as one of the options (Kormawa et al. 2018). However, as is described in this book, animal power often preceded the growth of mechanical power in developing countries in the 20th century and has spread considerably in parts of Africa in the last few decades, suggesting that lessons from these experiences can be applied to other parts of Africa in the future.

To summarize, we integrate induced technological innovation theory and market failure challenges in the development of markets for hiring services with PBB's farming systems hypothesis to better explain contemporary mechanization trends under the new paradigm. PBB focused on the relative efficiency of the private sector compared with the public sector in overcoming some of the aforementioned challenges associated with hiring-service operations. In contrast, we emphasize that the private sector continues to face the remaining challenges, and the public sector must still play an active role in mitigating these challenges, not through direct interventions in hiring-service schemes, but instead through other measures. Demand is still a necessary precondition for adoption. Demand depends not only on farming systems but also on the availability of labor relative to land in the context of broader economic transformation. The development of mechanization hiring markets is constrained by many factors that can slow down the spontaneous supply response of mechanization services. Our framework recognizes that certain market failures associated with investment risk and hiring market development are significant, with some form of public support required to overcome them. One key difference from PBB is that we highlight more

the complex nature of the demand for mechanization of specific activities, such as land preparation. Whereas PBB illustrated the nature of demand in a broader scheme, including its sequential nature, they focused relatively less on, for example, its variations across farm households or at the intensive margins (for example, the number of times each plot is plowed). The key will be understanding the extent and determinants of such variation.

Case Study Countries in the Book

The validity of the theoretical framework presented in the previous section is assessed drawing on collective evidence from a set of countries. Key aspects of this framework are further investigated through focused empirical analyses from a subset of countries.

Theoretical Framework and Country Chapters

Countries covered in this book are selected based on various criteria. First, we focus on countries in which substantial research has been done by the International Food Policy Research Institute and other CGIAR centers so that we can make the best use of existing research results. In addition, Asian countries are selected to represent diversity in mechanization experiences with different levels of economic development and manufacturing capacity, and various mechanization-sector development patterns. Selected Asian countries have also developed various mechanization supply models (for example, Bangladesh, China, and India, as highlighted in Diao et al. 2014). Although some Asian countries are not included due to the unavailability of substantial research with relatively detailed empirical assessments, the information that is available for excluded Asian countries (for example, in FAO and CSAM 2014) is generally consistent with the key patterns described in this book. Although China and India are much larger than other Asian countries included, their lessons can potentially be useful for subregional approaches within Africa, which have been promoted in recent years (Kormawa et al. 2018).

African countries are selected from East Africa (Ethiopia, Kenya, and Tanzania) and West Africa (Ghana and Nigeria). Four of these countries are among the largest countries in Africa in terms of economically active population in agriculture, and they together (plus Ghana) account for 40 percent of all of the economically active population in Africa's agriculture sector and more than 30 percent of Africa's arable land, including the nation of South Africa and some northern African countries (USDA ERS 2018; GGDC

2019). South Africa and some countries in northern Africa (such as Egypt) are much more advanced in mechanization than other areas due to domination of either large-scale commercial farms (in the case of South Africa) or irrigated agriculture (in the case of Egypt). Therefore, they are excluded from this book, which focuses, in the case of African countries, on smallholders and rainfed agriculture. For similar reasons, Latin America is not covered by the book.

Although a general framework is provided in the previous section, many chapters of the book adopt different approaches to addressing this framework. Table 1.1 summarizes how the case study countries covered in this book are collectively linked to each key aspect of the theoretical framework described in the previous section.

In addition, an online appendix, Appendix 1C, that provides a brief review of other African countries' experiences, particularly Francophone countries and Lusophone countries, as well as experiences of some Latin American countries, is included as a supplement to the book. As is described in the overview in Appendix 1C, although the experiences in the countries have been by no means identical, they do have much in common with those of the countries explicitly covered in this book.

Empirical Framework and Approaches

The empirical approach also differs across chapters also because of the available primary data. Table 1.2 summarizes the types of data covered in each chapter's empirical analysis. Note that Table 1.2 omits five country chapters (Chapters 4, Sri Lanka; 5, Thailand; 8, Myanmar; 11, Ghana; and 14, Tanzania), which include no quantitative empirical analyses due to the unavailability of data.

The Viet Nam, Bangladesh, Kenya, and Nigeria chapters focus on the determinants of mechanization adoption. The China chapter focuses on the importance of machine rental, assessing the effect of machine rental on agricultural production using a structural production function. Similarly, the Nepal chapter focuses on the effects of machine rental on production technology characteristics and provides further insights into the effects on returns to scale. The India, Nepal, and Nigeria chapters focus on detailed aspects of the associations between tractor adoption and agricultural input uses (land, labor, draft animals, and other inputs such as chemical fertilizer or irrigation). The Bangladesh, Nepal, and Nigeria chapters assess the associations between tractor adoption and off-farm labor supply or incomes. The Nepal and Nigeria chapters also assess the associations between tractor adoption and agricultural

TABLE 1.1 Key aspects of theoretical framework covered in country chapters

	Chapter												
	2	3	4	5	6	7	8	9	10	11	12	13	14
Key aspect of the theoretical framework	China	India	Sri Lanka	Thailand	Viet Nam	Bangladesh	Myanmar	Nepal	Ethiopia	Ghana	Kenya	Nigeria	Tanzania
Farming systems evolution													
Farming systems intensification									x	x	x	x	x
Sequential nature of mechanization	x	x	x	x			x		x	x	x		
Induced technological change													
Land endowments and mechanization	x	x	x	x	x	x	x	x	x	x	x	x	x
Labor scarcity due to economic transformation	x	x		x	x		x	x	x	x		x	
Actual impacts of mechanization	x	x				x		x	x			x	x
Supply-side issues: Market failures													
Risk and uncertainty in economics of service provision	x	x			x	x	x	x	x	x		x	x
Insufficient knowledge of machinery, operations, repairs, mechanization		x	x	x				x	x	x	x	x	
Supply-side issues: Complementary efforts by the government (or shortage thereof)													
Public goods and complementary technologies	x	x	x	x	x	x		x		x		x	
Research and development on mechanization		x	x	x	x					x		x	x
Financial sector reform (for example, land tenure reform)		x					x		x				x
Coordinating roles (or shortage thereof)	x				x		x			x			
Supply-side issues: Government failures (or absence thereof)													
Subsidies (fairness or distorting nature of)	x	x		x	x			x		x		x	
Excessive import restrictions (or absence thereof)		x	x			x	x	x	x	x	x	x	x
Arbitrary selection of service providers					x					x		x	
Excessive regulations (or absence thereof)						x	x	x					

Source: Authors.

incomes or revenues. The Ethiopia chapter provides a more detailed assessment of the effects on wheat yields of using tractors and harvester-threshers. Finally, regarding the types of machines used, the chapters on Bangladesh, Nepal, Kenya, and Nigeria focus specifically on tractors, the India and Ethiopia chapters consider tractors and harvester-threshers, and the China, Viet Nam, and Kenya chapters consider agricultural machinery in general.

TABLE 1.2 Focus of empirical analyses in selected chapters

	Chapter							
	2	3	6	7	9	10	12	13
Focus area in mechanization	China	India	Viet Nam	Bangladesh	Nepal	Ethiopia	Kenya	Nigeria
Adoption			x	x			x	x
Impact on production, farm resource use								
Production function	x				x			
Farm size/area		x			x			x
Yield		x			x	x		
Labor use		x			x			x
Animal use		x						x
Other inputs use—fertilizer		x			x			x
Impact on incomes								
Income—agriculture					x			x
Income—overall, other					x			
Off-farm labor supply, income				x	x			x
Analysis by crops/farming operations	x	x				x		
Types of mechanization technologies								
Tractor		x		x	x	x	x	x
Combine thresher		x				x		
Machinery in general	x		x				x	

Source: Authors.

These empirical analyses fill the gap in the mechanization literature and build on early studies (for example, Jayasuriya, Te, and Herdt 1986) by providing updated evidence while taking into account the changes in technological and socioeconomic conditions and the farming systems evolution that have occurred within the last few decades. Further, some empirical analyses offer evidence based on more rigorous estimation methods that address issues such as endogeneity of mechanization adoption decisions, which were not always adequately addressed in earlier studies.

VARIATIONS IN EMPIRICAL SPECIFICATIONS ACROSS CHAPTERS

Different empirical specifications and approaches are used for different chapters, based on data availability and data quality. First, there are differences with regard to the definitions of "mechanization". For some countries,

information was available only for "machines," whereas more specific information on "tractors" was available for other countries. Generally, we provided more results in the latter case (for example, for India, Nepal, and Nigeria).

Second, in the African country chapters, quantitative analyses are limited due to generally low mechanization adoption levels at the national level. The exceptions are Ethiopia and Nigeria, both of which have either detailed nationally representative samples or detailed information on machine use. In contrast, although Tanzania also has Living Standards Measurement Study–type data, the adoption rate of tractors captured in the survey is very low. Similarly, for Ghana, data such as those from the Ghana Living Standards Survey provide information only on "equipment" rather than "tractors," terms that are often exchangeable in the country. Quantitative analyses are also not conducted for three Asian countries (Sri Lanka, Thailand, and Myanmar) due to lack of data. These countries are nonetheless included, given the rich qualitative evidence.

Specifications are selected to best fit the available data and adapted to the differences in data quality that exist across countries. Where data quality is considered less than satisfactory, we often use techniques such as propensity score–based models, rather than linear regression models. Linear models try to answer more questions (producing coefficients for each variable) given the number of variables, whereas approaches such as propensity score–based models that focus on one variable (here, the number of tractor/machine adoptions) may be more suitable in cases with poorer data quality (Heckman and Vytlacil 2007). Production functions are estimated only in the China and Nepal chapters. Insights on production functions are important and relevant for mechanization (especially to assess properties such as returns to scale), but estimations require both strong instrumental variables and good data quality. The China data are considered to have especially good quality. Similarly, data from the lowland area of Nepal are considered suitable because, despite the homogeneity of the agroclimatic environment, prices can vary considerably depending on the distance to the Indian border and thus serve as good instrumental variables.

Analyses by crop or farming activity are limited to the cases in which information is available and there is a sufficient sample size for a particular crop or farming activity. Only China, India, and Ethiopia (wheat) meet these criteria.

Last, where applicable, data in Asian chapters are selected with a particular focus on drawing lessons for Africa. For example, the analyses in the India chapter rely on datasets from semi-arid tropical regions that largely practice

rainfed farming, comparable to the majority of agricultural production environments in Africa, so that the findings can be more relevant to African countries.

Reviewing Country Experiences through the Updated Framework

Armed with this updated framework, we examine the development patterns of agricultural mechanization in eight Asian and five African countries. The objective is to provide a detailed, clear, and consistent summary of mechanization in each country. Unlike some books that have a uniform conceptual framework for all chapters, this book, rather, takes the approach of synthesizing common messages from each country study and using them as concrete, illustrative examples that help update the PBB framework. We do our best to provide each chapter with a similar structure, enabling easy comparisons across countries. Each chapter first reviews the history of mechanization in the country. The chapters then analyze the demand for mechanization at the system and household levels, paying attention to differential farming systems, land–labor ratios, farm size distribution, and labor market dynamics, among other elements. This leads to an assessment of the extent to which the demand for mechanization has emerged, and its spatial patterns. The next section of each chapter then turns to a supply-side analysis for machines—in terms of import, subsidy, and promotion policies—by looking, where relevant, at manufacturing, and more important, at service provision through hiring markets. Attention is again paid to spatial variation within countries. Each chapter analyzes how mechanization has factored into broader agricultural transformation in the country, through its effects on farm size, land productivity (through complementarities with yield-enhancing technological inputs and reduction in postharvest losses), and agricultural employment.

We first review some of the trends from Asia and Africa, which further demonstrate the need for our updated framework as described above to explain the slower adoption of mechanization in Africa, despite emerging demand. Whereas lack of demand was an appropriate diagnosis for low levels of mechanization in Africa before the 1980s, in many parts of African countries this no longer appears to be the case. The farming systems have changed and the pressure on agricultural labor has increased. In the parts of African countries where we do observe increasing adoption of mechanization, the supply has not fully met emerging demand due to the market failures described above; elsewhere in the continent, demand for mechanization has not grown

significantly. Meanwhile, in Asia, the shift from draft animals to tractors and the adoption of other agricultural mechanization after the Green Revolution seem to be mainly driven by agricultural intensification, industrialization, and overall structural transformation. Tractor hiring markets have developed over time to respond to emergent demand in a wide range of Asian countries, with relatively few obstacles, first in the favorable regions in response to agricultural intensification (at a relatively early stage), and later at greater scale in response to structural transformation (at a later stage). Therefore, PBB's hypothesis needs to be augmented to fully account for the divergence between mechanization in Asia and in Africa. Our updated framework, described above, tries to explain this divergence by identifying obstacles that are relatively more unique in Africa's developing mechanization hiring markets, while also highlighting the role of government policies.

Asia

In general, mechanization has been widespread in Asia, given relatively conducive conditions. In all eight Asian countries covered in this book, intensified farming systems have long been established and the tradition of animal plowing and use of some small and simple agricultural machinery can be traced back hundreds of years, and at times even longer.[4] In a few Asian countries, such as Sri Lanka, the adoption of tractors had reached significant levels by as early as the 1970s (see respective chapters). The key issue in Asia is not the adoption of plowing as part of the farming practice but the substitution of tractors and power tillers for animal draft power and the adoption of engine-powered machinery such as combine harvesters or threshers for harvesting or postharvest processing. Thus, the induced technological innovation theory is much more relevant than the theory of farming system evolution for explaining the sequences of mechanization in Asia.

Rapid mechanization in developing countries of Asia largely came as part of broader economic transformation processes. Although the Green Revolution of the 1970s further intensified agricultural production and created demand for irrigation-related mechanization, the replacement of animal traction with tractors for plowing and the development of mechanization for planting, weeding, harvesting, and postharvest operations came later and was

4 Various information for other Asian countries not included in this book (for example, Bhutan, Cambodia, Indonesia, Laos, Pakistan, the Philippines) has been provided in other studies, including FAO and CSAM (2014). Many of those countries' experiences are similar in one way or another to experiences in the eight Asian countries covered in this book.

mainly a response to rising labor costs. The Asian country case studies indicate that mechanization truly began to accelerate when the pace of industrialization started to accelerate, and when the development of labor-intensive manufacturing and the rural nonfarm economy put upward pressure on wage rates, albeit at different times in different countries (Zhang, Yang, and Wang 2011; Wei, Xie, and Zhang 2017). However, distinct patterns between countries still exist in terms of when mechanization was adopted on various types of farms.

TYPICAL CASES

In China, India, Thailand, and Viet Nam, mechanization has followed a fairly predictable path. For India and Thailand, farmers with small and relatively larger-scale farm sizes have coexisted for decades, while in China and Viet Nam the distribution of farm sizes became more diversified in the years following their economic reforms. Whereas larger farmers had traditionally used tractors for land preparation long before the shift from animal draft to tractor power among smallholders, the pattern of the spread of mechanization among smallholders seems to be similar among these four countries. In each of these countries, increased returns on farm power use in general, which were led by the overall agricultural intensification process, industrialization and economic growth, and the subsequent urbanization that pulled labor out of agriculture, all created demand for mechanization because of rising labor costs that induced labor-saving technological change. Smaller 4WTs or power tillers with lower horsepower have dominated mechanization in land preparation, while small to medium-size combine harvesters have been widely adopted, even among smallholders. As detailed in their chapters, these countries have all developed various extents of capacity to manufacture a broad variety of different sizes of equipment, much of it affordably priced, to meet demand from farmers with different farm sizes. Government subsidies have been used to support both manufacturers and farmers, but these subsidies were rarely targeted to specific groups of farmers. Still, machinery is typically concentrated among a small number of farmers, with the majority accessing services through the hiring market. Although not covered in this book, tractor rental markets have been relatively efficient in some other Asian countries such as the Philippines (Takahashi and Otsuka 2009). Whereas markets for plowing services are typically local, harvesting services commonly involve migration across the country to reach farmers in different agroecological zones. These patterns have also been consistent with experiences at the early stage of mechanization in countries such as the United States (Olmstead and Rhode 2001).

ATYPICAL CASES

Agriculture in Bangladesh, Nepal, and Sri Lanka is dominated by small-scale farmers—even by the Asian standard (FAO 2019b)—with relatively abundant rural labor, especially the former two countries. The average small size of farms would intuitively make them seem less suitable for exploiting scale economy advantages through engine-powered mechanization as a substitute for animal traction. However, land preparation in both Bangladesh and Sri Lanka is highly mechanized through power tillers. For example, 89 percent of farm households in Bangladesh had adopted tractors or power tillers for land preparation by 2008, 80 percent of whom had less than 1 ha of farmland. However, only about 4 percent of farm households owned the machinery, highlighting the wide adoption and robustness of the hiring market. Most of this development occurred over a short period after the late 1980s, following the removal of import restrictions on Chinese power tillers when a typhoon decimated the draft animal population (Mandal 2017). An estimated 80 percent of tillage is also mechanized in Sri Lanka, again mostly through power tillers (Biggs and Justice 2017), and farmers in most districts also use combine harvesters. Although Nepal, a country with mountainous and hilly terrain, is the least mechanized among the eight Asian countries studied in this book, and indirect evidence suggests significant market failures in its tractor hiring markets, tractor adoption in Nepal has been growing rapidly since the 1990s. This is particularly evident in the Terai plains, and mini-tillers have also started spreading in the hilly/mountainous regions in the most recent decade (Nepal chapter). Finally, Myanmar has been undergoing an extremely rapid transition in mechanization, with growth in the adoption of 4WTs and power tillers for plowing, as well as combine harvesters, accelerating following major economic reforms in 2012. Between 2006 and 2016, the share of farm households in Ayeyarwady and Yangon regions using mechanized land preparation rose from 36 to 97 percent, and the share using mechanized harvesting rose from 5 to 57 percent (Myanmar chapter).

COMMON FACTORS

Although the need to overcome labor constraints may have driven the substantial progress in mechanization in all eight Asian countries, physical and market conditions seem to have provided few impediments to the development of mechanization-hiring markets, which emerged organically as the dominant form of service provision to smaller farmers in these countries.

Government subsidies and public goods played a key role in mechanization development in most Asian countries. As will be discussed in the section on government policy, these interventions mostly played a supportive role in facilitating the development of machinery and implements to support farmers' needs, increasing access to machinery, and overcoming coordination failures. In other words, they supported the private sector's supply response to rising demand, rather than attempting to create demand or directly intervene in the supply of mechanization.

Small and relatively low-cost tractors, power tillers, and harvesters, typically manufactured domestically or imported from China, India, Thailand, or other nearby Asian countries, are among the agricultural machinery most commonly adopted in Asia. Power tillers are dominant throughout Bangladesh, Sri Lanka, and Myanmar, and are common in rice-producing areas elsewhere. More important, the smaller size of tractors in Asia is not only due to the common presence of power tillers. Even where larger 4WTs have been adopted, they rarely exceed 50 hp. With rising rural incomes, the cost of machines has been low enough that some small- and medium-scale farmers could afford to buy them and become service providers in the hiring market. Moreover, though subsidized credit was widely available in a few countries, farmers could also use their land as collateral to acquire machines. Recent land reforms appear to have been one of the major catalysts of the spread of smaller tractors and combine harvesters in Myanmar in the past few years (Myanmar chapter). The role of land tenure security in Myanmar might have been particularly strong because of rising demand for mechanization, which stands in contrast to its role in some African countries, such as Kenya, where a relatively sophisticated land tenure system played a limited role due to slower farming system intensification and slower growth of mechanization demand.

In irrigated cereal systems, climate conditions have led farmers to plant their crops simultaneously, which helps overcome the scale issues associated with mechanization services on small farms. In addition to irrigation's overall role in intensification, long-established irrigation systems and the rapid spread of shallow-water irrigation have presented opportunities for multifunctional tractor use, such as powering water pumps with tractor engines, particularly at early stages of mechanization, before the arrival of cheaper diesel pumps. Using tractors for carting agricultural and nonagricultural goods has also been common in rural Asia. In larger countries, climate patterns and infrastructure have enabled migratory service provision, increasing opportunities for greater utilization of agricultural machinery.

Africa

CONTINENTAL AND COUNTRY TRENDS

After cases of Asian mechanization development, the focus of the book turns to Africa. The five African countries covered also differ significantly in their patterns of mechanization, but most of them are relatively mechanized compared with the rest of low-income African countries. In many other countries, mechanization levels are often too low or data are too scarce to justify the inclusion of detailed descriptions. However, the online Appendix 1C of this book provides a brief overview of the experiences in Francophone and Lusophone countries to supplement this chapter. Analysis of the available data from the country chapters and elsewhere shows that there has been a resurgence in mechanization, but with significant variations across countries. According to a study published by the FAO and AUC (Kormawa et al. 2018, Figure 2), the share of farm areas primarily prepared by tractors in the whole of Africa was possibly around 10–20 percent in 2005. Though there might have been some growth in tractor adoption since then, that growth has been slow in some major countries, including Nigeria (Nigeria chapter), which has the largest amount of arable land in Africa. It is therefore expected that tractor use in Africa is still far behind the levels seen in Asia.

All five African countries covered in this book contain regions that have experienced significant mechanization adoption, despite slow mechanization growth at the national level. Of these countries, demand seems to be most widespread in Ghana, where many medium-scale farmers have acquired tractors and one-third of agricultural households now use some form of mechanization (Ghana chapter). However, demand for mechanization is concentrated in the northern savannah zones (including Upper West region, where the adoption rate is 88.5 percent). Because tractor use is not feasible in most of the forest zones, the adoption rates range from 2 to 10 percent in the forest zones. However, tractor operators often receive requests for plowing from more farmers than they can serve, indicating that supply has not kept up with demand. Likewise, although the value of agricultural machinery imports into Ethiopia increased sevenfold between 2005/2006 and 2013/2014, it did so from a very low base, and still less than 1 percent of agricultural plots in 2013/2014 were plowed by tractor. The rapid adoption of tractors and combine harvesters appears to have been generally concentrated in wheat-barley systems in the southeast of the country, which has bimodal rainfall and where terrains are relatively flat and larger farmers and smallholders are intermingled (Ethiopia chapter). Tanzania seems to exhibit generally similar patterns

of mechanization growth; the tractor population nearly doubled from 2005 to 2015, plowing about 14 percent of cultivated land nationwide, but 64 percent of tractors were located in six contiguous regions that are relatively dry and land-abundant, with good market access. Power tillers tend to be generally concentrated in grain-surplus areas of the southern highlands, particularly in rice cultivation areas. In Kenya, tractor ownership remains generally low, at 2 percent of farm households in 2012 (Kenya chapter), although it appears higher in the tropical highlands and in the coastal lowlands. In Nigeria, the area plowed by tractors declined to 7 percent in 2012 (Nigeria chapter), and it appears fairly concentrated in input-intensive systems in remote areas with high wages, for rice in the south and a variety of cereals in the north.

The nature of demand is complex as well, because adoption appears to be relatively extensive but not intensive. Although it is not discussed in all the chapters, we see little evidence of the intensive use of tractors and draft animals. Rather, adoption tends to be at the extensive margin, with tractors being used for only a single plowing. Observations from Ghana and Ethiopia suggest that there appear to be many cases in which tractors are generally not used for multiple plowings, unless there is a tradition of using animal draft for a second plowing (Ghana and Ethiopia chapters). This issue could relate to the learning curve and behavioral factors associated with technology adoption, or it may simply reflect low perceived returns from multiple plowings. Nevertheless, the effects of lower demand for multifunctional use, which is discussed below as a market failure because it constrains profitable ownership of tractors, are an important component of demand itself.

We now turn to the separate components of our framework, to explain these divergent patterns between Africa and Asia.

Components of the Framework

DEMAND-SIDE FACTORS

A key demand-side factor in Africa today is that overall demand for mechanization has risen, and thus it has become important to dig deeper and better understand its complexity. Farming systems in Africa have intensified significantly over the past 30 years, albeit at varying speeds and with different patterns. Population density and market access have induced the shift to permanent cropping, even in sparsely populated areas such as the savannah zones of West Africa (Binswanger-Mkhize and Savastano 2014). At the same time, despite the increased farming intensity, the level of agricultural development has remained unclear. For example, much of Africa has not experienced

any type of Asian-style Green Revolution at a large scale (Diao, Headey, and Johnson 2008; Woodhouse 2009; Nin-Pratt and McBride 2014). Adoption rates of improved seeds, fertilizers, pesticides, and other inputs remain relatively low, and opportunities for irrigation development are quite limited and underexploited (You et al. 2011). Increased agricultural production has primarily come from land expansion, and crop yield growth has been extremely modest. Compared with the eight Asian cases in this book, it appears that at least at a national level, the five African countries in the book still have not reached the overall level of agricultural intensification that already existed in Asia a few decades ago when its mechanization started growing.

There is also much spatial variation in the availability of land among African countries. The majority of Africa's virgin land suitable for cultivation is in remote regions of a handful of countries, while in most systems farms are declining in size and fragmenting as rural populations grow (Chamberlin, Jayne, and Headey 2014). Virgin land in northern Ghana is still available; most surveyed tractor owners who acquired farmland recently were able to get access to such land, and some were given land freely by relatives or community chiefs (Chapoto et al. 2014). In contrast, land is scarce in much of Kenya and Ethiopia, where farm sizes have been declining. Though a general rise in population density and intensification of farming systems are preconditions for mechanization demand growth, land remains scarce if much of the population remains in the agricultural sector, which can depress land expansion, one of the motivations for investments in tractors. This is especially true if land markets are weak.

On the other hand, the low adoption of yield-enhancing technologies may mean agriculture is simply not profitable enough to justify the cost associated with mechanization adoption. This may be particularly the case in Nigeria, where the stagnant agricultural sector described in the country chapter limits incentives to invest in a tractor.

Africa also has many more systems than does Asia in which tree crops and root crops, which can be less conducive to plowing, are dominant (Diao, Silver, and Takeshima 2016; Mrema, Kienzle, and Mpagalile 2018). This partly explains the very low adoption of tractors in forest zones such as southern Ghana and Nigeria, where roots and cereals are often planted among cocoa and other tree crops.

Spatial variation in the demand for general labor-saving technology in African agriculture is also closely related to the patterns of economic growth. Although parts of Africa have undergone substantial economic growth and structural change over the past three decades (McMillan, Rodrik, and

Verduzco-Gallo 2014; Rodrik 2016; Diao, McMillan, and Rodrik 2017), Africa's recent growth trajectory is much different from the one Asia went through at similar stages of development. In Asia, rising agricultural productivity essentially drove the process of structural transformation, industrialization, and urban growth (Johnston and Mellor 1961). There, the agricultural productivity growth, coupled with Engel's law, had also caused declining employment in the agricultural sector (Timmer 1988) and raised farm wages, partly by stimulating the growth of the industrial sector through backward and forward linkages, which absorbed workers away from the agricultural sector (Haggblade, Hazell, and Reardon 2007). In contrast, urbanization in Africa has been driven by neither a substantial increase in agricultural productivity nor industrialization. Rather, urbanization has been driven by the growth of consumption in cities dominated by nontradable services, which are often driven by natural resource revenues (Gollin, Jedwab, and Vollrath 2016). There has been substantial growth in the rural nonfarm economy, linked to growing urban demand (Diao, Silver, and Takeshima 2016), suggesting that similar effects of service-led nonagricultural growth may occur in rural areas. Such trends, where they take place, may accelerate the rise of rural wages more so than the typical model of industrialization-led structural transformation. In parts of Africa, the demand for mechanization is likely to have been raised substantially by rising food demand that has increased not only food imports but also purchases from the domestic farm sector (AGRA 2019), as well as by labor productivity growth (Diao, Hazell, et al. 2019; Diao, Kweka, and McMillan 2019) and land productivity–enhancing intensification (Christiaensen 2017; Otsuka 2019). However, in other parts of Africa, rising food prices and food imports have not necessarily induced sufficient agricultural productivity growth, and effects on demand for mechanization have been limited. These somewhat unique conditions in Africa today can complicate the nature of the demand for mechanization and magnify market uncertainty, risks, and other market failures, as discussed in the later section.

Where economic growth and urbanization have progressed, the overall trend has been a pronounced shift of labor out of agriculture, involving migration to urban areas and diversification of households into farming and nonfarm income generation, with youth exiting agriculture much more rapidly. Such economic transformation could further raise demand for mechanization in the near future (Diao, Silver, and Takeshima 2016). Shifting food demand to higher-value and more labor-intensive crops, associated with urbanization, can also exert upward pressure on agricultural labor demand (Tschirley et al. 2015; Binswanger-Mkhize 2017). In Ghana, increased demand for maize as

both food and fodder crop has entailed a higher concentration of labor costs in land preparation, relative to other costs (Ngeleza et al. 2011). In a growing number of African countries, labor constraints are becoming more binding and inducing further demand for mechanization. For example, in Ghana, land is abundant, yet over 50 percent of the population now lives in urban areas. Farmland per agricultural worker has been rising over the past several decades and the sizes of small, medium, and large farms have all been growing (Diao et al. 2014). In contrast, countries like Kenya are still largely rural and dense in regions with high agricultural potential. Farm size per worker has declined as rural population growth remains high. Whereas some areas have shifted to high-value horticulture production, the harvested areas under vegetables and fruits have remained at about 6 percent of the total harvested area in the country (FAO 2018).

Another contrast exists between Ethiopia and Nigeria—in Ethiopia, rapidly rising rural wages and the rising cost of keeping livestock have been inducing the substitution of tractors for animal draft power even on small wheat-barley farms. However, low real wages in northern Nigeria and the relative availability of grazing lands have contributed to growth in animal traction alongside stagnation in tractor plowing (Nigeria chapter).

Considering the diverse patterns of farming system evolution and factor endowments in African agriculture, there is likely to be much spatial heterogeneity in the demand for mechanization. It is clear that in some areas, farming systems and labor scarcity have induced significant demand for tractors and, in some cases, combine harvesters. However, the viability of animal traction appears limited to areas with favorable conditions for keeping livestock, low wages, and available grazing land. In areas where demand for tractors has not developed and animal traction is not feasible, attempts to create demand may remain ill-advised. Therefore, we now turn our attention to market failures hindering the supply response in places where demand for mechanization has emerged, which justifies public-sector mechanization-related interventions.

SUPPLY-SIDE FACTORS

As described above, under the new paradigm with greater overall demand for mechanization, an updated framework that more closely analyzes supply-side factors than does the PBB framework is needed. Factors that are unique to mechanization and factors that are relatively unique to Africa both exacerbate the market failures on the supply side. These market failures show why supply is unlikely to respond fully and spontaneously to emergent demand for mechanization.

Tractor size

Tractor sizes are often much larger in Africa than in Asian developing countries. According to World Bank (2014) studies of seven countries, the average horsepower of 4WTs is more than 100 hp in Ethiopia and Kenya; between 60 and 85 hp in Ghana, Mozambique, Nigeria, and Zambia; and between 40 and 60 hp in Burkina Faso. This stands in contrast to Asia, where power tillers for rice cultivation dominate in countries with small landholdings, and among 4WTs, medium-size tractors dominate, with a range of 30–50 hp.

Farmers in Africa frequently cite heavy soils as a reason for preferring large tractors. Although direct evidence is scarce, assessments based on soil data from FAO and others (2012) suggest that a greater share of the agricultural area in Africa may have relatively high constraints in terms of soil workability. Table 1.3 suggests that in Asia, when weighted by the size of the agricultural area in each country, 74 percent of soil may have either no constraints or only slight constraints, whereas this ratio drops to 58 percent in Africa. However, these ratios may vary considerably across subregions; for example, the share of soils with workability constraints is considerably higher in South Asia, compared with East or Southeast Asia (Table 1.3). Similarly, soil conditions in rural Africa are highly heterogeneous even within a locality (Turner 2016), and soil knowledge may still be very limited due to weak capacity for soil research and soil mapping across different agroecological zones within a country. This implies that for some areas, soil conditions may not require tractors as large as those typically used. Moreover, interviews with farmers in both Ethiopia and Ghana show that they often prefer deep plowing, which uses a large disc plow that requires a more powerful tractor, even when it is not ideal for their soil conditions (Diao, Silver, and Takeshima 2017). More important, African farmers might have been more exposed to large and high-horsepower tractors than to smaller types due to the government's introduction and continued promotion of secondhand tractors. As a result, it could be that tractor owners, operators, and mechanics have become experienced only with these large tractor models, and perhaps the supply chain for both tractors and spare parts has developed only for the few popular brands of large tractors. This market failure could persist because this path dependence may not be easily overcome in the short run.

Prices of tractors are highly correlated with their sizes; larger tractors, the purchase of which is usually self-financed in Africa, require greater financial investments, have higher break-even utilization rates, and have lower maneuverability on small farms. Farmers might be willing to adopt smaller tractors to some degree. In recent focus group discussions, Ghanaian farmers expressed

TABLE 1.3 Share (percentage) of agricultural area with different levels of soil workability constraints

Area	No or slight constraints	Moderate constraints	Severe constraints	Very severe constraints
East/South Asia	74	12	7	7
SSA	58	22	12	8
East Asia	84	8	4	4
Southeast Asia	70	24	5	2
South Asia	50	15	16	19
East Africa	59	20	12	9
Middle Africa	73	11	10	6
West Africa	49	31	14	7
Southern Africa	56	20	13	11

Source: Authors' calculations based on FAO et al. (2012) and FAO (2018).
Note: SSA = Africa south of the Sahara. The figures are based on the assumption that distribution of soil workability is equal between agricultural land and other land. Therefore, these figures need to be interpreted with caution.

willingness to purchase 45–55 hp tractors if they were 20 percent cheaper than the 65–70 hp tractors that are the most commonly used. However, they would not consider a tractor of less than 40 hp at any price, because they believe such a tractor to be too weak to plow heavy soils (Diao et al. 2018). Nevertheless, other than the power tillers used in irrigated areas, few such tractors are imported into Ghana.

More still must be known about why farmers prefer large tractors and under what conditions they would adopt smaller machines. With scarce knowledge of soil conditions, it is difficult to determine the optimal level of horsepower required for different soil conditions in different areas. Without such knowledge and information on different plowing methods, farmers are unlikely to change their preferences and adopt smaller machines. It is also difficult for manufacturers in tractor-exporting countries to design new equipment suitable for the local conditions in Africa.

Barriers to tractor ownership

Even where significant demand for plowing does exist, the number of medium- to large-scale farmers who are capable of purchasing tractors may still be suppressed because of the indivisibility of such investments, and this can limit the supply in hiring markets (Houssou et al. 2015; Takeshima 2015). In Africa, such constraints can be exacerbated by the aforementioned large tractor sizes. Put differently, though the number of medium- to large-scale farmers investing in tractors and providing hiring services has been growing in

Africa, the pace of this growth could have been even faster if market failures had been mitigated.

Even though tractors acquired through private channels tend to be more of the secondhand type in Africa, the cost of these tractors is still quite high, especially when compared with the tractors that were adopted by Asian farmers at the early stages of mechanization. In addition, although tractors can be imported secondhand, plows and other implements have to be imported new, and these implements for large tractors are also more expensive than those for smaller tractors.

Historically, both private and government credit was important in the adoption of mechanization in some Asian countries. Whereas the up-front cost for a tractor in Africa is significantly higher than in Asia, there is little use of credit for tractor purchases in Africa. For example, only 2 percent of surveyed tractor owners in northern Ghana used any formal credit to purchase tractors, and 87 percent were completely self-financing (Chapoto et al. 2014). This stands in contrast to India, where up to 95 percent of tractor sales are made on credit. This likely relates to the reluctance of African private banks to lend to farmers, which is associated with the poor performance and low repayment of agriculture-related loans. African countries can potentially learn from experiences in India, including its relative success in directing a significant fraction of credit to the agricultural sector. It is, however, important to note that Indian success might have been endogenous; that is to say, it might have been enabled by rising overall demand for mechanization and the resultant growing density of potential would-be buyers of tractors, which reduced transaction costs per unit of credit provided and lowered interest rates. Another key factor seems to be the difficulty of registering land as collateral, as well as general concerns about the viability of the commercial value of agricultural products. In contrast, Myanmar allowed farmers to use land use right certificates as collateral for loans from private banks after its land reform. Credit thereby played a huge role in the rapid adoption of mechanization technology in Myanmar. Importantly, as was discussed above, the potential role of stronger land tenure is conditional on the presence of significant demand, and thus may be less relevant for parts of Africa where demand is still insufficient due to the low level of farming system intensification. However, where the farming system has sufficiently intensified, the role of land tenure may be significant.

Tanzania has been trying to resolve such financing issues by establishing an agriculture window at the Tanzania Investment Bank, as well as establishing the Tanzania Agricultural Development Bank in 2014, although the

extent to which farmers have been able to take advantage of these services needs to be formally evaluated in more rigorous studies. Leasing schemes for machinery in Africa are underdeveloped (Ströh de Martinez, Feddersen, and Speicher 2016), and joint liability schemes, often implemented through cooperatives, have been riddled with collective action problems; the performance of loan guarantee schemes in this context is also mixed (Zander, Miller, and Mhlanga 2013). One promising case is a contract farming scheme in Zambia that facilitates access to credit for tractor purchases to its emergent farmers, who are guaranteed to have other nearby members of the outgrower scheme as customers for plowing services (Ströh de Martinez, Feddersen, and Speicher 2016). Such schemes can potentially help address both the credit and uncertainty constraints in the equipment hiring market.

Coordination and information failures

Small farmers with fragmented plots are common in both Asia and Africa. But the lack of coordination among farmers seems to be a bigger issue for agricultural machinery hiring in Africa than in Asia. Consolidating demand within the locality to attract service providers seems harder in Africa than in Asia, due to greater heterogeneity even within the relatively small geographical area, including soil types and cropping systems (World Bank 2007; Turner 2016). Most agricultural areas in Asia have grain-dominant crop systems, with a relatively homogeneous crop calendar within a locality, in which planting or harvesting occur at similar times. Generally higher adoption rates of relatively more homogeneous improved seed varieties in Asia may also be a contributing factor for such homogeneity in farming operations. On the other hand, when cropping systems are diverse within the locality, such as in the root crop–dominant systems or the root, legume, and maize mixed cropping systems found in many African countries, nearby farmers may not necessarily plant and harvest their crops following a similar calendar. The dominance of rainfed agriculture in Africa, with relatively long planting windows in some tropical conditions, causes farmers in the same community to plant at different times. As a result, operators of tractors or combine harvesters are reluctant to provide hiring services to small farmers in a community when their fields are not ready for plowing together (see Ghana chapter), because dispersed plots consume more time and fuel. These constraints can be binding at early stages of mechanization growth, although they can be partly overcome as the overall demand for mechanization rises to a sufficiently high level.

The challenges due to heterogeneity in land preparation timing within a locality should be distinguished from such heterogeneity at a regional level.

As is discussed elsewhere, the latter can help with increasing utilization rates of machines for service providers because demand is more spread out within a year. However, similar heterogeneity within a locality poses constraints rather than opportunities because economies of scale in the hiring service become compromised.

Moreover, farming system intensification and the use of animal traction is relatively new and has a short history in much of Africa. This limits the existing knowledge and skills in plowing that are easily transferable to tractor ownership. Historically, animal traction has been constrained by trypanosomiasis in many African countries (Alsan 2015), although some of this disease has been eradicated through the expansion of human settlement recently. Although crop–livestock integration had progressed to the point that knowledge on animal traction and appropriate animal rearing has been accumulated (McIntire, Bourzat, and Pingali 1992), livestock is still owned by pastoralists in other parts of Africa and crop–livestock integration has started only recently there (Ehui and Polson 1993; Mrema, Kienzle, and Mpagalile 2018). Of the countries covered in this book, Ethiopia, drier areas of Kenya, northern Nigeria, some regions of Tanzania, and Sahelian Francophone countries have had some history of animal traction, but this is only relatively recent for most countries. In Africa, only Ethiopia and Mali have a long history of widespread plowing and animal traction (Mrema, Kienzle, and Mpagalile 2018). Therefore, though animal traction is not always a precondition for eventual tractor adoption, the limited spread of animal traction in many areas suggests significant knowledge constraints for mechanized plowing service provision, which can also constrain efficient tractor use.

Observations of new tractor owners and operators in Ghana show that many still lack basic knowledge, not only of the machines, but also of plowing practices and soil characteristics (Diao et al. 2018). In contrast, the authors' own field visits and conversations with farmers in Ethiopia indicate that farmers who had experience with animal traction were able to avoid such challenges when moving from draft animals to tractors. In such areas, farmers combine animal traction and tractor plowing. Plowing before the first rain, when the soil is too hard for animal traction, is done with tractors, and then second and third plowing and harrowing are done with animal traction. In areas of Ghana without animal traction, multiple plowing is rarely practiced (Diao et al. 2018). Without a tradition of animal traction, the technical and business learning curves may be much steeper and limit the efficiency of service providers in a hiring market. More broadly, the evidence on the role of

plowing intensity on productivity and overall profitability is limited in Africa, and such evidence likely has to be generated by public-sector R&D.

Taking advantage of information and communication technology could also present an opportunity for the private sector to help farmers overcome hiring market coordination failures, as has been the case in India (see chapter). Some companies in Ghana (Diao et al. 2018), Nigeria, and Kenya (Ströh de Martinez, Feddersen, and Speicher 2016) have developed relatively new platforms that make tractor hiring services more easily accessible through SMS and mobile apps. Uber-type hiring modalities such as Hello Tractor are also potentially promising in the long run. However, more evidence is needed to evaluate their impact on efficiency, long-term viability, and outcomes for farmers.

Opportunities for migratory service provision

Whereas migratory service provision has become common for combine harvesters in China, Myanmar, and Thailand, few tractor owners engage in migratory service provision in Africa. In Ghana and Nigeria, the few migratory tractor owners tend to be clustered in a small number of areas. In addition to the challenges described earlier within local hiring markets in Africa, migratory service provision can face the additional challenges of market information asymmetry, lack of customer networks, and other coordination failures. These challenges may be more constraining at the early stage of hiring market growth, when potential customers are still few and sparsely located. Asia overcame these challenges over time, and now Africa will face these challenges. Furthermore, because tractors need to be loaded on trucks to be transported around the country, rural road networks and trucking services need to be sufficiently developed for this to be viable. Such infrastructure and institutional capacity are much less common in Africa than they are in Asia. Without established client networks and well-developed trucking service logistics systems, migratory service providers risk not being able to find customers in unfamiliar areas. This coordination failure often requires a third party to intervene, as county governments have done in China. However, not all local governments in Africa have this capacity. In such cases, there may be opportunities for private information and communication technology platforms to provide the necessary coordination. For parts of Africa, including eastern and southern Africa, Kormawa and colleagues (2018) advocated a more regional approach, encouraging migratory services that extend beyond country borders to take advantage of greater variability in peak demand season and enhance the utilization rate of machines. In such a setting, the

aforementioned public-sector role in coordination, including cross-country coordination, is likely to be even more critical.

Types and uses of machinery

The selection, in both size and function, of machinery available to African farmers also tends to be limited. Farmers purchasing tractors in Africa frequently opt for cheaper secondhand imports. The average age of tractors in most countries is quite high and, in some cases, exceeds the useful life of a tractor (Diao, Silver, and Takeshima 2016). However, evidence from Ghana suggests that these tractors perform as well as, if not better than, new tractors (Houssou, Diao, and Kolavalli 2014). Because secondhand imports tend to be of several common brands, markets for spare parts and maintenance services develop much more robustly for these tractors than for the new tractor brands often imported by governments. This makes secondhand tractors more attractive investments. In contrast, new tractors that are mostly acquired by large commercial farms or imported under government programs are widely reported to be less efficient than secondhand tractors acquired by farmers through their own means, often because of the lack of maintenance services and spare parts supply. This difference makes it hard to compare the performance of used and new tractors. It could be that if smaller, cheaper machinery were available, then owners acquiring it through private channels would use it more efficiently, particularly as tractor fleets continue to age.

Opportunities for multifunctional use of tractors also appear limited in Africa compared with Asia, with some exceptions, such as tractor-powered maize shellers that have become common in Ghana and elsewhere. Although multiple plowing and harrowing is commonly practiced in Asia, including the rainfed area in Bangladesh (Aboagye et al. 2016), and in small parts of Africa to improve overall soil quality given the rainfall patterns (for example, Temesgen et al. 2008), this practice is still rare among most African farmers, limiting the demand at the intensive margins by individual farmers. Additionally, irrigation potential is much lower in Africa than in Asia, limiting opportunities for tractor-powered irrigation. Whereas tractors are used in carting harvested produce in Africa, they are less commonly used for other transport purposes than in Asia. There is also increasing competition from three-wheel motorcycles that are cheaper, more comfortable, and faster than tractors for passenger transportation. Though the three-wheel motorcycles certainly offer important alternatives for rural mechanization, the point here is the changing nature of the multifunctionality potential of tractors.

There is a need for more in-depth examination of whether and how such multifunctionality can be exploited to enhance utilization from tractor owners' perspective.

Whereas tractor assembly plants in a few African countries have been operated to varying degrees of success, the manufacturing of agricultural machinery has not taken off in Africa on a large scale. In Asia, even in smaller countries without domestic tractor manufacturing such as Bangladesh, Myanmar, Nepal, and Sri Lanka, manufacturers in nearby countries have been able to develop and distribute machinery suitable for local conditions, and most implements other than plows and harrows are often made locally now. In Africa, although such cross-border diffusion of technology should be possible, market failures persist due to various factors. The distance between global manufacturers in emerging countries and Africa, in addition to relatively low aggregate demand continentwide, may still lead to significant transaction costs for the private sector to transfer knowledge and innovate mechanization technology appropriate for Africa.

Implications of the Empirical Analyses

Importantly, empirical analyses conducted in several chapters of this book support the discussions so far. As described above, the focus areas of empirical analyses covered by selected chapters in this book (Table 1.2) largely fall into three categories: (1) adoption of mechanization, (2) impacts of mechanization (associations between mechanization adoption and various production characteristics such as the production function, productivity, and the use of other inputs), and (3) impacts on income (associations between mechanization adoption and farm/household incomes). Evidence on (1) generally suggests that both conventional demand-side factors (highlighted in PBB) and various supply-side factors are important determinants of mechanization adoption. Furthermore, the importance of agroclimatic conditions, including soil types, for adoption (as shown in the Bangladesh and Nigeria chapters) is linked to the provision of public goods such as better knowledge of spatial distributions of agroclimatic conditions (for example, soil maps).

Evidence on (2) suggests that mechanization is generally associated with more intensive production systems, including greater land cultivation intensity as well as use of yield-enhancing inputs such as irrigation or fertilizer. Quite often, mechanization adoption is associated with greater overall labor use, because the effect of intensification outweighs the substitution effects between machinery and labor. These sets of evidence are linked to various policy recommendations, including public goods such as the development

of complementary technologies—for example, high-yielding varieties. Furthermore, effects on returns to scale (see the Nepal chapter) suggests that scale effects typically associated with machines are also present, pointing to the importance of developing more efficient land markets that facilitate the exploitation of such scale effects in the medium term.

Evidence on (3) suggests that mechanization often has positive income effects on smallholders. Significant effects of mechanization evidenced by both (1) and (2) have been largely realized through custom hiring services of machines provided by individual machinery owners, suggesting that private custom hiring services are efficient given the currently prevailing knowledge constraints and existing market distortions. These sets of evidence are linked to the importance of further focusing on the efficient promotion of custom hiring services with reduced market distortions, as discussed in this section and the next. Moreover, overall, these sets of evidence suggest that mechanization can be promoted (in an appropriate way) to support smallholders in Africa, and it is also important for achieving inclusive agricultural transformation.

The Role of Government Policy

Comparing mechanization development in Africa and Asia underscores the many preconditions for the supply of mechanization to meet emerging demand. Although PBB accurately diagnosed the inappropriateness of government schemes to promote mechanization in Africa when demand had not emerged, recent trends do not suggest that supply will spontaneously respond adequately when demand does emerge. Even in Asia, which faced relatively fewer obstacles in supply responses to mechanization than Africa, governments played a critical role in creating an enabling environment and providing public goods in many countries. Although this demonstrates the importance of supportive government policies, recent policies and interventions in Africa have not fared much better than those discussed by PBB. Therefore, such efforts must be judicious and aim to resolve key market failures without distorting private supply channels.

In Asia, governments generally have limited direct interventions to the provision of subsidies and subsidized credit for machinery, and in most cases, such as in India, China, and Thailand, governments have minimized the distortive nature of subsidies by keeping them open to a wide range of equipment and implements and to all who met a transparent set of qualifications (Singh 2006; Diao et al. 2014).

Rather than emphasizing direct interventions, many governments in Asia focused their efforts on R&D, whether through developing machinery and implements as a mandate for agricultural engineering institutes or through performing other types of agricultural R&D such as the development of new seed varieties that make the use of mechanization more efficient. In both Nepal and Nigeria, the adoption of mechanization by smallholders has been positively associated with the availability of improved varieties suitable for their production environment (Takeshima 2017; Takeshima and Liu 2018). As agricultural machinery manufacturers have benefited from the government subsidy policy, subsidies, in turn, have created incentives for manufacturers to develop more varieties of machinery suitable for local conditions, to stimulate demand among farmers. Training and extension in some countries provided by both the public and private sectors helped familiarize farmers with different types of machinery, creating more demand for mechanization. Because of this, government policies that include a subsidy rarely limit the types of machines that farmers adopt or who can become the beneficiaries of the policies, which relatively efficiently avoids distortion in the markets, both for imports and for hiring services, as well as rent-seeking behaviors.

In cases in which early restrictive government policies were in place, mechanization rapidly accelerated when liberalization removed these restrictions. For example, after the liberalization of the Vietnamese economy in the late 1980s, mechanization levels skyrocketed in the following decade. The rapid spread of mechanization in Bangladesh is also generally attributed to the lifting of import restrictions on cheap Chinese engines used to power shallow tube wells and on Chinese-made power tillers (Biggs and Justice 2017; Mandal 2017), although other factors, such as the disaster-triggered decimation of many draft animals, general interest in tractors, and the authoritarian regime at that time, might have also indirectly affected the process. Although the government originally restricted cheaper Chinese engines and power tillers because they were perceived to be of inferior quality to Japanese models, farmers overwhelmingly opted for the "cheap but good enough" Chinese models when liberalization lifted the restrictions (Biggs and Justice 2017). Most recently, the liberalization of the banking system in Myanmar and the country's 2011 land reforms unleashed nascent demand for mechanization that led a majority of farmers in surveyed regions to adopt mechanization for land preparation and 40 percent to do so for harvesting. All of this machinery, which was predominantly low-cost Chinese equipment, was imported from other Asian countries by the private sector.

Import Policies

Given that tractors and combine harvesters are not manufactured in Africa, the availability of various options for the importation of machinery is critical. As the Asian cases demonstrate, mechanization typically succeeds in the absence of restrictions and tariffs on machinery. These policies are often put in place to ensure that only high-quality equipment reaches farmers and to protect domestic manufacturing industries where they exist. However, they may limit the uptake of mechanization at key early stages. This is relevant for countries such as Ethiopia, where an enterprise must prove it is an agribusiness enterprise in order to qualify to obtain foreign exchange for importation; both of these policies make the importation process more cumbersome.

Currently, few African countries have import duties on agricultural machinery, but many still have taxes on imported spare parts. Given limited potential to manufacture many of these spare parts in most African countries, there is little justification for such taxes, which can impede the market for spare parts. The import tariff on agricultural machinery parts can affect not only the tractor owner's service provision but also the farmers who hire tractor services. Removing obstacles to dealers' building up of their stocks is very important. Import procedures for machinery also cause delays; in Ethiopia, importing tractors requires an investment license, and machinery must be cleared and purchased within six months for import duties to be waived (World Bank 2012). Although the actual implementation of tax policies, including differentiation between agricultural purposes and others, faces its own challenges, there will likely be a need to consider adjusting tax rates and to better balance tax revenues with improved spare parts availability in the country.

Promotion Policies

The distortionary effects of premature government promotion of mechanization from the colonial period up to the 1980s are well documented by PBB and others. As they note, government efforts to manufacture, distribute, and hire out tractors were unsuccessful attempts to induce intensification where demand conditions were not sufficient.

Whereas governments' direct involvement in mechanization service provision decreased during the 1990s, some different types of government involvement have picked up in recent years. However, not all of this involvement has been judicious. For example, at least 11 African countries have had government-run or subsidized tractor hiring services this century (Diao,

Silver, and Takeshima 2016). Such services not only face inherently higher barriers to profitability than those operated by the private sector (including farmers) due to operating costs and the lack of own-farm benefits, but may also crowd out potential private service providers, especially when service charges are below market rates.

Recent attempts by governments to subsidize private hiring schemes have been met with a similar set of challenges. For example, initial iterations of Ghana's Agricultural Mechanization Services Enterprise Center (AMSEC) program and Nigeria's Agricultural Equipment Hiring Enterprise program provided nonfarm enterprises with subsidized loans to purchase tractors for hiring-out services. However, such programs appear to suffer from the same cost disadvantages and misaligned incentives that purely public programs did. In Ghana, there is no evidence that AMSEC programs reduce service charges for plowing, enable farmers to plow greater areas and adopt more modern inputs, or encourage them to acquire similar tractors through a demonstration effect (Benin 2013). Many of the entrepreneurs who obtained government-imported machinery using AMSEC loans have defaulted because their operations were not profitable (Diao et al. 2014; Houssou, Diao, and Kolavalli 2014). Though formal evaluation of these programs in rigorous studies is needed to shed more light, the potential efficiency consequence of selective targeting of beneficiaries in these programs, among others, remains relevant.

As suggested above, the market failures in African mechanization call for looking for second-best solutions through public sector engagement, particularly in the early stages of mechanization development. Countries can learn from past mistakes and avoid creating government failures in their attempts to replace failed markets in the mechanization process. One example of such learning is discussed in the Ghana chapter, which describes the way the AMSEC program was refined through reducing the barriers to qualify for the subsidy program, widening the selection of machinery available, and introducing a training program for operators under a new concessional loan facility. Though such a program is unlikely to be a panacea for Ghana's mechanization issues, the effort to refine this subsidy program is quite encouraging.

Although government failures have been less pronounced in Asian countries, they have not been free from them, either. Although not included in the set of studied countries in this book, in Pakistan, unexpected changes in the interest rates of government loans to farmers for tractor purchases, as well as uncertainty about tariffs and other pricing policies, reportedly have constituted a significant source of demand uncertainty in the tractor manufacturing industry, leading to efficiency losses (Andrabi, Ghatak, and Khwaja 2006).

Government failures like the creation of such uncertainty should be avoided as much as possible in African countries as well.

Public Goods Policies

One area of government support that played a key role in Asian mechanization and is unlikely to have distortionary effects is the provision of public goods. In Asia, this has consisted of government support to R&D institutions, which develop and adapt wide varieties of locally appropriate machinery, often in collaboration with domestic private sectors, as has been the case in India (Singh 2006; Diao et al. 2014), Sri Lanka, and Thailand (see chapters), as well as in international organizations (Thailand chapter).

R&D elsewhere in agriculture has also been important for mechanization. For example, as was mentioned earlier, improvements in rice varieties appear to have stimulated demand for tractor plowing in Nepal, Viet Nam, and Thailand (see chapters). This occurs both through technical improvements that make mechanization feasible—such as improved varieties that respond better to more intensive tillage, are suitable for mechanical reaping, or permit more frequent cropping—as well as through yield increases that promote further intensification. Investment in broader agricultural R&D, including the continuous development and commercialization of a newer generation of improved seed varieties, has been limited in most African countries compared with Asia (Beintema and Stads 2017), which can further limit opportunities for intensification and thus mechanization. R&D on agronomy is also relevant even for the rainfed one-crop systems that dominate Africa. For example, the transfer of intensive land preparation to the rainfed rice system in Ghana has raised the returns on mechanization (deGraft-Johnson et al. 2014).

Coordination, which was briefly touched upon earlier, is also an intangible public good that governments could provide to overcome market failures in certain cases. Although the private sector also plays a role in providing efficient coordination at the local level, such coordination at a more regional level or coordination combined with public goods, such as information and infrastructure, tend to be undersupplied by the private sector alone. Yang and others (2013); Zhang, Yang, and Reardon (2017); and the China chapter describe local governments' involvement in enabling combine harvester owners to link with customers in remote provinces, transport their machines, and distribute free harvesting information. Moreover, when the number of migratory service providers rose, the local government devolved its role from directly escorting combine operators to helping them to form groups. This is not to say that such a model would be easily adoptable in Africa; certainly, demand for combine

harvesting is scarce except in a few cereal systems. However, local governments could learn from this case as an example of providing commonsense, demand-driven services to help meet demand by overcoming previous market failures. This could be especially relevant given the pervasiveness of hiring market failures in Africa compared with Asia. Lack of coordination at the rural community level among smallholders in farming will be an increasingly significant barrier for mechanization as more farming activities are mechanized. Local governments can adopt a problem-solving approach, helping farmers overcome collective action problems where they arise. Farm-based organizations, cooperatives, and other types of collective actions are encouraged and promoted by African countries' governments. Encouraging such organizations to own tractors is shown in the literature to be less efficient than encouraging individual ownership, due to the moral hazard issue and other failures in collective actions. Instead, such organizations can be considered as institutional mechanisms for promoting local coordination in crop planting and harvesting. This will possibly help small farmers access hiring services.

There have also been mechanization R&D success stories in Africa, such as the ASI thresher in Senegal, as well as some cases such as Tinkabi and Kabanyolo tractors. Tanzania has a government institution dedicated to designing and modifying equipment for local use, although it is unclear how successful its designs have been. Nevertheless, most countries lack institutions with the mandate and capability for such functions. However, the development and introduction of more appropriate types of equipment depend heavily on knowledge that is largely missing, such as knowledge of specific localized soil conditions. Investments in soil mapping not only could help in adapting machinery to local conditions and determining optimal tractor sizes, but also could help countries move from a blanket promotion of fertilizer to integrated soil fertility strategies. Similarly, increased R&D on ergonomics, or more broadly the R&D on demand for drudgery reduction, among other topics, is likely to be important for Africa from a welfare enhancement perspective (Kahan, Bymolt, and Zaal 2018).

Public investments for raising smallholder productivity remain important also given the patterns of farmland investments in Africa. The concerns regarding growing commercial farmland investments after the global food price hike (for example, Byerlee and Deininger 2013) have been partly tempered as domestic, rather than foreign, actors have become major investors (Jayne et al. 2016), and these medium-size farmers have become important providers of mechanization services to neighboring smallholders (Diao, Silver,

and Takeshima 2016). At the same time, the system that has evolved has been the coexistence of medium-scale farmers and smallholders, rather than a more rapid takeover by larger-scale farmers, and such coexistence has been partly facilitated by the custom hiring market for mechanization services. To the extent that exogenously raising smallholder productivity raises the returns from more intensive land preparation and thus raises demand for custom hiring of mechanization services, public investments to raise smallholder productivity are likely to complement private investments in machinery by medium-size farmers in Africa (Byerlee and Deininger 2013).

Institutional Development and Capacity Enhancement Policies

As discussed earlier in this chapter, both market failures and government failures can affect mechanization development, and the public sector (national government, regional and international organizations, and so on) plays important roles in mitigating the market failures. In Asia, the national governments and national agricultural research institutes often played important roles in monitoring the status of agricultural mechanization in countries, through means including a tractor census or collection of other data describing the status of various aspects of mechanization-sector development. Asia also had a greater number of advanced educational institutions in agriculture, including state agricultural universities, which had been established as early as the 1950s and 1960s, often more than three decades prior to such development in Africa, and which contributed to the generation of new agricultural knowledge tailored to local conditions (Lele and Goldsmith 1989; FARA 2014). Professional bodies of agricultural engineers, agricultural economists, or commercial farmers had also long been established in Asian countries, often dating back to the 1940s and the 1950s, and can play important roles in policy advocacy for agricultural mechanization. Capacity of similar bodies is relatively weak in Africa and needs to be strengthened, through means including greater regional concentration and enhanced analytical capacity to generate required evidence on mechanization-sector issues with methodological rigor (Lantin 2013; FARA 2014).

At the same time, the rich set of information generated by the national organizations has been extensively exchanged at the forums offered by international and regional organizations. These organizations have included the Regional Network for Agricultural Machinery (established in 1974 with support of the United Nations Development Programme, FAO, and the United Nations Industrial Development Organization), the United Nations Asian

and Pacific Centre for Agricultural Engineering and Machinery (a regional institution of the United Nations Economic and Social Commission for Asia and the Pacific, which became the Centre for Sustainable Agricultural Mechanization in 2004), and the Asian Productivity Organization. The CGIAR system, including centers such as the International Rice Research Institute and the International Crops Research Institute for the Semi-Arid Tropics, also contributed not only to conducting R&D on machine designs and performance but also to knowledge transfer across countries (outcomes of which were documented extensively in reports such as IRRI 1978, 1983, 1986). Sufficient capacity of the national organizations to gather, process, and sometimes analyze relevant mechanization information in the countries has complemented investments in international/regional organizations. Substantial national-level information on the mechanization sector and other information on the agricultural sector is also likely to have enabled regional and institutional organizations to effectively assist each country in formulating sound agricultural mechanization strategies.

Importantly, these institutional efforts in Asia have also been complemented by significant private-sector R&D and innovation. Scholars have argued that mechanical research, compared with biological research such as plant breeding, has been driven significantly more by the private sector than the public sector (Evenson and Binswanger 1978, 201). This is because the mechanization research is generally less tied to basic science and instead relies significantly on long-established physical and metallurgical principles that do not vary much across geographic regions. As a result, the private sector in each country is given much scope to conduct applied research using those long-established principles (Evenson and Binswanger 1978, 201). The process of such adaptive research has been documented from early on in India, where significant exposures to foreign mechanical technologies through importation stimulated later manufacturing of indigenous tractors that are more suitable for Indian conditions (Morehouse 1980; Ito 1986; IRRI 1983; Bell, Dawe, and Douthwaite 1998). An older history of power tiller manufacturing is also documented in Japan (Francks 1996). Such active innovations in the private sector in Asia are likely to have complemented the regional institutions as well, by providing more knowledge and relevant information about the technologies that can be transferred across countries. The efforts to strengthen similar institutions that can effectively support mechanization in Africa will require substantially mobilizing the potential of private-sector innovations, including those that originate from traditional small businesses.

Africa's Path Forward: Lessons from Asia and the Past

The evolution of farming systems in Africa over the past 30 years and deepening labor constraints suggest that there is a rising demand for agricultural mechanization across a wide geographical area, which has not been sufficiently met by mechanization supply. This stands in stark contrast to Asia, where in many countries even the smallest farms have been rapidly mechanized. This raises the question of whether such a rapid transformation is possible in Africa, and if so, how it can be achieved.

PBB's hypothesis that supply-side constraints are less binding than those from the demand side may hold in the long run, but evidence on this has been weak or, rather, absent, particularly for effects in the short to medium run. Even in some late-adopting countries such as Nepal, indirect evidence suggests that lack of access to custom hiring services may still be a significantly binding constraint, particularly in lowland Nepal, where 4WTs are more common and indivisibility of technologies is still relevant (Nepal chapter). These experiences suggest that in locations where 4WTs are more suitable and common, the overall spread of tractor use requires market development to support a substantial increase in tractor population as well as efficiency improvements in the custom hiring service market. It appears that mechanization growth in Africa is likely to be constrained in the near future at least partly due to the supply-side market failures—and in some cases, policies that exacerbate rather than ameliorate such failures—discussed above. Significantly greater efforts are needed to overcome these market failures while judiciously avoiding the distortionary effects of past interventions. Importantly, as in Asia, mechanization needs in Africa are not uniform and there is no unique solution that can apply to all contexts. These needs will differ not only between countries but among agricultural systems within countries as well. Appropriate solutions will require focusing not only on the needs of farmers in different systems but also on the constraints faced by a group of farmers who are potential suppliers of mechanization. Their acquisition, operation, and hiring out of agricultural machinery services must be facilitated. Therefore, the aim of this book is to provide policymakers and researchers with more detailed accounts of mechanization development in Asian and African countries, and to identify where cross-country learning is relevant and where country-specific solutions must be developed. Nevertheless, the following recommendations can be considered across different contexts.

Demand Must Be Closely Assessed

First, PBB's predictions have largely held regarding the growth of demand for mechanization in the past three decades. As also described in Appendix 1D, PBB hypothesized that whether tractors can be more profitable than animal traction varies on a case-by-case basis, even if farming systems have reached sufficient intensification levels and animal traction or tractors have become more relevant technologies (PBB's hypothesis 10). Similarly, PBB hypothesized that in relatively land-scarce endowments, including many African countries, advancement in biological technologies may drive the adoption of mechanical technologies (PBB's hypothesis 14). Experiences described in many Asian chapters (for example, Bangladesh, India, Nepal, Thailand, Viet Nam) suggest consistent indirect evidence that substantial public R&D in biological technologies, as well as other infrastructure such as roads and irrigation to the extent that they contribute indirectly to biological technologies, preceded and contributed to enhancing demand for mechanization in land-scarce, smallholder-dominated environments and, particularly, raised mechanization demand at the intensive margins. Where such investments have been made, experiences suggest that mechanization can be used not only for crops like rice and wheat, but also for crops like sugarcane and maize, as well as root crops, such as cassava (for example, Thailand), even though the mechanization potential for these crops in Africa has been questioned. Whereas rising farm wages are observed across various pockets of African countries, public R&D and infrastructure investments have remained relatively insufficient. This might have made the demand for mechanization volatile and risky from hiring service providers' perspectives, even though overall demand is rising. Further efforts are needed to investigate whether and where it is beneficial to enhance public investments in technologies that are complementary to mechanization technologies.

Market-Led Hiring Services Must Be Prioritized

As described above, private hiring services are almost invariably the most efficient method of supplying mechanization services for smaller farms. Hiring markets enable *relatively* larger-scale (often called "medium-scale") farmers to profitably invest in machines, and smaller farmers to access services. The viability of mechanization service provision depends on the ability of owners to make a substantial lump-sum investment in a machine and achieve efficient utilization rates. Experiences in Africa, including Ghana and Nigeria, suggest that service providers selected by governments have often faced challenges in reaching the break-even level of utilization rates, incurred losses overall

(including the machine depreciation costs), and been unable to reach an economically sustainable level, while service providers not targeted by the government have been more efficient and achieved utilization rates above break-even points (Ghana and Nigeria chapters). Efforts to make ownership and service provision more viable could focus on widening the selection of available machinery, addressing coordination failures that pose barriers between hiring service providers and consumers, and promoting access to agricultural finance. However, the specifics of such efforts will depend on highly localized factors, and none of these potential solutions are likely to be universally applicable.

Highlighting the market-led hiring services remains important for African countries because many African governments feel pressure to intervene more directly in the selection of beneficiaries for their support programs, including programs that promote hiring-service businesses (for example, Ghana and Nigeria chapters). Targeted subsidies to selected beneficiaries, who are not always selected transparently, can waste public funds by providing machines to owners who do not use them efficiently or could afford them without the subsidy. The experience described in the Viet Nam chapter attests to this phenomenon as well; the significant involvement of government in tractor hiring services intensified during the 1980s through collectivization, but it did not lead to significant tractor use growth, in contrast to the growth in tractor use under the more liberalized system of subsequent decades.

The public sector's role becomes rather important in coordinating functions, as is showcased in the China chapter, such as linking service providers and customers, providing free harvest information, linking with other service providers (such as mobile companies), and waiving of highway tolls, which can potentially induce the emergence of more hiring service providers in competitive ways. Similarly, the role of the development of an enabling environment has been highlighted in the chapter on Myanmar, where improvements in access to financial services following post-2011 reforms led to a surge of machine investments. As the demand for mechanization rose, the strengthening of the land tenure system through issuance of transferable land use rights that can be used as loan collateral, together with partial relaxation of restrictions on the banking sector, is likely to have removed significant constraints on the supply side.

Eliminate Distortions

On the other hand, programs that arbitrarily select beneficiaries, limit technology choices, and do not provide incentives for machines to be properly

utilized and maintained are likely to exacerbate existing market failures and encourage rent-seeking behaviors. For the most part, duties on imported machinery have been removed, but it is still important also to exempt spare parts where possible. If subsidies are pursued, they should be wide-ranging and aimed to increase rather than limit exposure to new brands, types of machinery, and implements. As was mentioned earlier, in some Asian countries where subsidies have been provided, subsidy levels have been relatively low and instead been extended to cover a wide range of machines in terms of brands and sizes, among other factors (for example, China and India chapters). Asian countries have also promoted the importation of a broad range of machines at the early stage of mechanization growth, often with fewer trade restrictions. This helped expose the local population to a variety of machines and provided ideas later on for local manufacturing of machines (for example, India and Sri Lanka chapters) or spare parts and attachments (for example, Bangladesh chapter). It also led to a significant inflow of cheaper, "good enough" machines, such as power tillers from manufacturers in neighboring countries (for example, Myanmar chapter). At an early stage, tractor use grew even where regulatory policies were weak in terms of machine quality controls, and appropriate regulatory policies become more relevant to the sector once adoption reached a sufficient scale (for example, Nepal chapter). In contrast, government importation of tractors through concessional loans in Africa in recent years has required equipment to be imported from the donor country and resulted in a limited range of brands, for which supply chains of spare parts and repairs were not developed; these actions risked crowding out private supply channels and led to importing tractors for which supply channels were difficult to develop (Diao et al. 2014; Diao, Silver, and Takeshima 2016). The experiences in countries like Bangladesh and Nepal suggest that African countries can also first focus on liberalizing machine imports to allow the inflow of various types of tractors and machines, and then start investing in regulatory capacity once the adoption reaches certain levels.

Sometimes, focusing the government's intervention on specific brands has the potential to reduce the unit price of tractors due to economies of scale, especially when combined with regional approaches that overcome the small market sizes in certain African countries. Such efforts should, however, still be based on an understanding of the demand in the market for a different set of brands based on a range of factors, including not only the suitability for different soils, but also existing operational and maintenance/repair knowledge, spare parts availability, and so on. For cases in which such analytical capacity of the government is limited, the government's interventions in

brand selection may need to be seriously questioned against more market-led machine importation.

As mentioned above, mechanization services provided by the private sector, including traditional small business–type service providers, have consistently been more efficient than those provided or subsidized by the government (PBB; Kienzle, Ashburner, and Sims 2013; Diao et al. 2014; Houssou, Diao, and Kolavalli 2014; Diao, Silver, and Takeshima 2016). The experiences described in the Thailand chapter also suggest that the government has often been more effective by keeping private small businesses active, rather than solely through direct intervention focusing on the more modern sector. Providing subsidies to individual farmers to purchase tractors may therefore be more efficient than aiming to promote so-called professional service provision enterprises. When subsidies are in place, care should be taken to widen the range of machinery available to farmers and not crowd out private suppliers. For example, the frequent changes in brands and models imported under different concessional loan arrangements can disrupt the current private supply chains for machines and spare parts, and create uncertainty for private dealers.

We also recognize that efficient, traditional small businesses are important in the processing sectors, although the book does not directly address postharvest operations. For example, some African countries have tried to promote large-scale modern processing facilities, without recognizing that traditional small business–type processors were expected to be more efficient given local constraints such as unreliable paddy supplies—as in the case of rice milling in Nigeria (Gyimah-Brempong, Johnson, and Takeshima 2016). Such attempts to promote large-scale facilities were made despite the fact that the milling sector in Asia has continued to rely on efficiency improvements of small-scale mills (for example, Bangladesh; Reardon et al. 2012).

Identify Appropriate Technology

Ensuring that appropriate technology can reach farmers and service providers is likely to involve a blend of direct imports of some technologies and their local adaptation. Whereas evidence has been accumulating regarding the agronomic effects of different tillage methods in Africa, the overall evidence was rather mixed in early years (for example, Lal 1993) and has been generally scarce (for example, Sithole, Magwaza, and Mafongoya 2016). Economic studies of different tillage methods, including those comparing different types of tractors, seem scarcer. More research is required to understand whether the tractors used in most African countries are larger than necessary, and

whether deep plowing by big disc plows is more prevalent than needed, despite its higher cost and possibly damaging effect on soil. While it may take time to change farmers' perceptions of mechanization technology, governments can nevertheless influence the adoption of appropriate technology through demonstration, experiments, and other incentive-promoting interventions for new, more efficient types of machinery and mechanization practices. Agricultural machinery is often sensitive to local conditions, and for many new machines that are less popular in Africa now, such as planters and small harvesters, adaptation to local conditions will be necessary. With proper policy and public funding support, local R&D institutions can play an important role in adapting imported models to local conditions, developing new designs, educating engineers, and offering extension programs, often in collaboration with the private sector, as is documented in some Asian chapters (for example, the Thailand chapter). The capacity of local artisans to fabricate various implements, such as maize shellers, exists in many countries, but their capacity to fabricate more advanced implements, such as plows or harrows, may need time to develop. Small artisans and manufacturers in low-income Asian countries like Bangladesh and Myanmar have played an important role in local adaptation of many implements, including those that are imported. With proper policies from the government, including financial and technical support, small local manufacturers can play a role equally as important in Africa as the one they played in Asia. Finally, the development of complementary technologies, such as irrigation and rural infrastructure, can also be important for mechanization development.

Although past policy failures show the types of interventions that are unlikely to succeed, relatively little is known about how government interventions can effectively complement the private sector in Africa. To develop an effective government policy to support mechanization, it is important to both identify market failures in mechanization and recognize the risk that inappropriate government interventions may create market distortions that disincentivize the private sector's role in developing mechanization supply chains. As described above and in the country chapters, there have also been cases in which private entrepreneurs and farmer-investors have emerged as relatively efficient mechanization service providers. Gathering more information about these cases, many of which occurred among the traditional small businesses; understanding their business models; and sharing their knowledge is likely to remain an important domain of the government. A deeper understanding of the suitability of different sizes and types of machines under different conditions, of the progression of hiring market dynamics, of better practices

in mechanization—especially for the promotion of other intensified farming technologies—and of alternatives for overcoming credit constraints are much needed. Given that solutions are likely to be highly localized, effective public-sector support requires not only accounting for different climatic conditions and factor endowments, but also broader economic transformation pathways that effect agricultural transformation, frequent exchanges of experimental knowledge, and mutual learning among African countries.

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