

On the Central Role of Small Farms in African Rural Development Strategies

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Abstract

Improving the productivity of smallholder farms in Sub-Saharan Africa offers the best chance to reduce poverty among this generation of rural poor, by building on the limited resources farming households already possess. It is also the best and shortest path to meet rising food needs. Using examples from farmers' maize and rice fields, and comparisons with Asia, this paper examines why the set

of technologies promoted to date have produced localized successes rather than transformational change. The paper explains the limitations of alternative policies that are not centered on small farms. It provides indicative examples of how resource-management technologies can supplement seed-fertilizer technologies to speed an African Green Revolution.

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1. Introduction

The goal of boosting productivity on smallholder farms is a central pillar in the rural development strategies of most African governments. There are many reasons for the broad support given to African smallholders, but two are most often cited. First, the vast natural resources in the hands of Sub-Saharan African smallholder farmers can be used more productively to feed a growing global population, a quarter of whom will live in Africa. Second, increasing agricultural incomes through improved technologies offers the shortest path to poverty reduction in rural areas, where poverty has been most persistent. In this essay, we argue that while it is the second argument that is especially compelling for policy, finding ways to boost smallholder productivity in Africa offers the best chance to achieve both objectives.

On average, smallholder farmers in Africa would earn higher incomes working in sectors other than agriculture. And in countries where agriculture productivity is highest, farms are usually larger than they are in Africa. Further, as economies develop, the share of workers in agriculture declines and a larger share of the population lives in cities. So, why should rural development strategies in Sub-Saharan Africa remain focused on smallholder farms?

The answer has to do with the slow pace of this archetypical economic transformation. For many reasons, the reallocation of labor from agriculture to other sectors is constrained and occurs over generations, even when income gaps are large and sustained. The pace of farm restructuring is slower still, so farms tend to remain small even as agriculture's share of employment declines. Consequently, policies designed to reduce poverty for this generation of rural poor must work largely within the constraints of small farms. In the case of Asia's Green Revolution, new technologies were developed and quickly adopted that did just that. What is more, productivity growth rates were sustained even though farms remained small. Ultimately, Asia's success significantly influenced Sub-Saharan African policies, where most strategies to boost productivity have three common elements: a focus on smallholders; an emphasis on staple crops, mostly maize and rice; and a reliance on improved technologies, most often based on fertilizer-responsive high-yielding seeds.

Nevertheless, while the need to drive rural development through improved smallholder productivity is clear, the task is harder in Sub-Saharan Africa than it was in Asia. Specifically, the agroclimatic and market conditions that predicate the success of new technologies is more varied in Africa than it was in Asia at the start of its Green Revolution. Consequently, the portfolio of technologies needed to launch a transformational African Green Revolution is larger and the task of identifying what work best locally is more difficult. It also means that the seed-fertilizer-focused technologies that work well in Asia, though important, are unlikely to solve all of the key constraints faced by African farmers. This, in turns, holds back sector-wide productivity growth and explains why successes to date have been local rather than sectoral. Part of the solution is to design and deploy a larger set of targeted technologies with local constraints in mind. Toward this goal, we draw on a set of farm studies originally published in Otsuka, Larson (2016) to show how resource-management based technologies can supplement conventional high-yielding seed-fertilizer technologies to improve smallholder productivity in Sub-Saharan Africa.

2. Green Revolutions as a path out of rural poverty

There are several potential pathways out of poverty for rural households, although none is easy. Family members from poor households often leave rural areas, migrating to cities or to other countries to earn incomes outside of agriculture. Still studies suggest that potential migrants are often hampered by mismatched skills and anchored by illiquid land assets and place-specific social capital that provides informal protection against a variety of otherwise uninsurable risks (Larson, Anderson and Varangis, 2004). Additionally, the benefits of moving from agriculture decline with age. Consequently, the window for sectoral migration is brief and constrained. As a result, the pace of structural transformation is exceedingly slow and takes generations to achieve (Larson and Mundlak 1997; Gardner, 2000; Butzer, Mundlak and Larson 2003). In many African countries, it is a process that is far from complete. According to the Food and Agriculture Organization (FAOSTAT, 2015), Sub-Saharan Africa's population is expected to remain primarily rural through 2033 and the absolute number of people living in rural areas will continue to climb through 2050.

Rural nonfarm income activities offer another path out of poverty and can be key to achieving food security (Otsuka and Yamano, 2006; Dethier and Effenberger, 2012). However, agriculture is often the engine that drives local non-farm income opportunities, and when it does not, proximity to urban areas is key (Dorosh and Thurlow, 2014). Conversely, a large number of remote farmers in Sub-Saharan Africa have no access to nonfarm income at all (Frelat et al., 2015). In addition, there is evidence that better off farmers also have better nonfarm opportunities, which weakens the links between nonfarm income gains and poverty reduction (Bezu, Barrett and Holden 2012; Haggblade, Hazell and Reardon 2010; Djurfeldt and Djurfeldt 2013).

In contrast, technological transformations in agriculture can occur in a single generation. During Asia's Green Revolution, new seeds and new farming practices spread quickly, especially among rice and wheat farmers (David and Otsuka, 1994; Evenson and Gollin, 2003a). As a result, rural incomes grew directly from on-farm productivity gains. Businesses catering to agriculture and farming households benefited as well, spurring growth in nonfarm employment. Rural families were able to invest in the health and education of their children, helping them to prepare for jobs in other sectors. In short, Asia's Green Revolution transformed rural economies and engendered a type of economic growth that benefited the poor (Rosegrant and Hazell, 2000; Hayami and Kikuchi, 2000; Hazell, 2009).

Furthermore, the dynamics of Asia's success are relevant globally. A wide-range of cross-country and country studies suggest that productivity gains in agriculture is a powerful catalyst for poverty reduction and economic growth (Irz, Lin, Thirtle, Lin, and Wiggins, 2001; Anriquez and López, 2007; Bravo-Ortega and Lederman, 2009; de Janvry and Sadoulet, 2010; Diao, Hazell, and Thurlow, 2010; Christiaensen, Demery and Kuhl, 2011). Conversely, past efforts to promote other sectors at the expense of agriculture slowed growth and lowered incomes instead (Mundlak, Cavallo and Domenech, 1989; Coeyman and Mundlak, 1992; Bautista and Valdés, 1993). It is worth pointing out that the results are consistent across a wide range of farm structures that include the small farms of Africa and Asia.

3. Scale, technology adoption and global food supplies: Past lessons and future prospects

Despite many changes brought about by Asia's Green Revolution, sector productivity in Asia is still driven by what happens on small farms, and the same is true in Sub-Saharan Africa. In East Asia, South Asia and Sub-Saharan Africa, 95 percent of the farms are less than 5 hectares and these farms occupy most of the farmland in these regions (Lowder, Scoet and Singh, 2014). Additionally, historical farm census data suggest that the small scale of farming in Asia and Africa persists, even when economic growth in non-agricultural sectors is high. In fact, if there is a noticeable trend, the trend is toward smaller average farm size (Table 1).

Nonetheless, the small scale of farms in Africa need not stand in the way of technology adoption and productivity gains. The breakthroughs that launched Green Revolutions in Asia and Latin America largely centered on seeds, not machines, so the benefits were available to farms of all sizes. Nevertheless, initial adoption rates were highest on Asia's small farms. For example, Evenson (2003, p. 450) reports that by 1998, about 82 percent of the area in Asia planted to major crops used improved seeds. In Latin America, where farms are larger, adoption rates were similar for wheat, a significant export crop; however, rates were lower overall, with 62 percent of the land planted to modern varieties by 1998.

Only in Africa did the spread of the new technologies stall. By 1998, only 27 percent of farmland in Sub-Saharan Africa was planted to modern varieties. Adoption rates improved subsequently, but remained well below rates on Asia's small farms. By 2005, the adoption of new varieties were 45 percent for maize, 26 percent for rice, and 15 percent for sorghum (Binswanger and McCalla 2010; Pingali 2012).

However, gains outside Africa were sufficient to drive global food markets. During the first Green Revolution, productivity gains from improvements in crop germplasm boosted global agricultural productivity by 1 percent per year for wheat, 0.8 percent for rice and 0.7 percent for maize (Evenson and Gollin 2003a; Pingali 2012). From 1961 to 2001, world maize, rice and wheat yields grew annually at 2.1 percent, 1.9 percent and 2.3 percent, well above the 1.8 percent growth in population (FAOSTAT, 2015). In Asia, rice yields grew by 2 percent annually and maize and wheat yields grew by more than 3 percent. Productivity gains outpaced demand growth and real prices for food fell.

Since 2000, the global experience with food prices has changed. Real cereal prices, which declined at an annualized rate of 2.4 percent from 1961 to 2000, rose on average by 6.8 percent per year between 2000 and 2013; real food prices rose by 5.5 percent (World Bank Pink Sheet 2015). Additionally, the period was punctuated with sharp price spikes with harsh consequences for the poor. Food prices fell subsequently, although current and projected prices remain above 1990s levels (World Bank 2015).

Rising along with prices are concerns that food security gains will be hard to maintain going forward. The global population is expected to grow to 9 billion before leveling off in 2050; twice as many people are expected to live in Africa in 2050 as there were in 2010 (Godfray et al. 2010b). Income gains, especially in fast-growing Asia, are driving a still-incomplete nutritional transition that features a growing demand for animal protein and feed crops, which compete with food crops for land (Popkin, 1998; Delgado, Narrod., and Tiongco, 2008). Additionally, although they represent a poor choice of instruments to address climate change, biofuel mandates and subsidies have become an integral part of agricultural and energy policies, adding pressure on agricultural resources (de Gorter and Just, 2010).

There are signs that productivity growth has stagnated in many areas, falling behind the pace needed to meet future demand, and leaving fewer opportunities for future global gains (Ray et al. 2012; Ray et al. 2013). Poor management of water, fertilizer and pesticide use globally, and specifically during Asia's Green Revolution, have degraded land and water resources, and have likely played a role in declining yields (Pinstrup-Andersen and Hazell 1985; Pingali and Rosegrant 1994; Godfray et al. 2010a; Stevenson et al. 2013). Especially in Africa, inadequate fertilizer use has depleted the nutrient content of soils (Drechsel et al., 2001; Cobo, Dercon and Cadisch, 2010). Further ahead are the uncertain consequences of climate change on food production and prices (IPCC, 2014). What's more, the anticipated transition to mechanization in fast-growing countries in Asia, where wages are increasing, may have the unexpected effect of undercutting future land productivity gains (Otsuka et al., forthcoming).

Using projections of food and biofuel demand by Bruinsma (2009) and Fischer (2009), Hall and Richards (2013) calculate that grain yields on current agricultural lands would need to grow by 1.2 to 1.3 percent per year pace (depending on uncertain policy-driven biofuel demand) to keep pace with growing demand through 2050. In their study, the researchers consider known but unexploited opportunities to improve yield potentials for rice, maize and wheat, and speculate about promising new technologies, but conclude that current and expected future rates of improvement in genetic potential will be insufficient to meet future demand.

Against this background, we discuss two alternative paths to global food security especially relevant for Sub-Saharan Africa. The first is to expand production by bringing more land and water resources into agriculture. In general, the potential for bringing more natural resources into agriculture in a sustainable way is limited, especially once competing resource demands and agricultural lands lost to urbanization are accounted for. Nevertheless, many researchers conclude there is scope to bring new lands under sustainable production, especially in Sub-Saharan Africa. An alternative approach is to improve the productivity of existing farms. Worldwide, there are a number of places where there is significant potential to "close yield gaps" – that is, to reduce the difference between obtained productivity and potential productivity, as determined by using the best available genetic materials and technologies. However, some of the largest yield gaps are to be found in Sub-Saharan Africa, where most agricultural resources are managed by smallholder farmers.

4. African smallholder resources as a solution to future food needs

A number of studies suggest that staple crop yields in Africa could be improved by using better seeds, better nutrients, and by improving water management (Neumann et al., 2010; McDermott et al., 2010; Mueller et al, 2012). For example, in their global study, Mueller et al. (2012) note that some of the largest yield gaps are for African staple cereals, including rice and maize.

Alternatively, it is also possible to expand food production in Africa by planting more land to crops in places where agricultural land remains relatively abundant. Deininger et al. (2011) estimate that more than 200 million hectares in Sub-Saharan Africa could be converted to rainfed agriculture, roughly 45 percent of the total area in the world suitable for expansion. Much of the land is isolated; however, they calculate that about 95 million hectares could be accessed without a major investment in infrastructure. In the case of rice, Balasubramanian et al. (2007) estimate that, once double-cropping is taken into account,

upwards of an additional 236 million hectares of agro-climatically suitable wetlands is available in Africa. Additionally, they argue that the expansion of rice production need not compete with other food crops, since much of the low-lying wetlands suitable for rice during rainy seasons is inhospitable for other crops.

Still, converting new lands to agriculture seems an unlikely path to expanding crop production. On average, the share of agriculture cropped in Africa stands at 22 percent, leaving large tracts of meadow and pastureland available to convert to crops with fewer up-front investments by farmers.¹ In addition, there are also important advantages to spending public resources on improving the productivity of existing farms rather than investing infrastructure or incentives to carving out new farms. For example, Deininger and Byerlee (2012) estimate that quadrupling maize production through area expansion alone would require 90 million new hectares. Alternatively, closing average maize yield gaps in Sub-Saharan Africa from 80 to 20 percent would bring about an equivalent increase on existing cropped land, leaving land and water sources to sustain natural ecosystems and the services they provide, including carbon sequestration (Satterthwaite et al., 2010; Godfray et al. 2010a, 2010b). Further, closing the yield gap by improving soil nutrient management could halt and possibly reverse the problem of declining soil fertility in Africa (Deugd, Röling, and Smaling, 1998; Place et al., 2003; Zerfu and Larson, 2010).

Even so, while there is widespread agreement that boosting productivity on current lands is the preferred approach to expanding food production, there is less agreement on how to close yield gaps, and even disagreement on the relevance of calculated yield gaps.

First, potential yields are usually based on selected genetic material combined with inputs, especially chemical fertilizer that must be purchased (Lobell et al, 2009). Tautologically, fully closing the gap means inducing farmers to take up the technologies implicit in calculating the gap. As discussed later, seed-fertilizer technologies work well for some crops in some parts of Sub-Saharan Africa. In other places, the technologies are simply not adopted. This has led some to question the relevance of conventional yield gap measures and propose alternative measures. For example, Tiftonell and Giller (2013) suggest calculating productivity potential based on ecologically intensive farming method. These methods, which depend on ecological processes to minimize external purchased inputs, can be indicative where fertilizer and other inputs are expensive relative to output value. Tiftonell and Giller (2013) note that common elements of ecological intensification, such as integrated cropping and livestock practices, are already present in many African farming systems; however, they also warn that ecological intensive systems will not suite the needs of all farmers.²

More generally, calculated yield gaps, regardless of methodology, ultimately depend on a technology choice that may or may not be relevant for place-specific livelihood strategies. For this reason, yield gaps are useful as an indicator of prevailing technology choices, relative to a practical standard, but provide less insight about how yield gaps come about or how they might be closed. In Section 7, we return to the topic and discuss practical aspects of technology choices and the role of policy.

¹ In contrast, 87 percent of agricultural land in Southeast Asia is cropped (FAOSTAT, 2015).

² Marenja and Barret (2006) make the same point, arguing that poor smallholders in western Kenya are unable to afford integrated soil fertility management techniques.

5. Alternative rural development strategies based on larger farms

The potential for agriculture to grow through expansion, together with dissatisfaction over the uneven pace of yield gains among African smallholders, has given rise to an active debate about smallholder-focused rural development strategies (Lipton, 2006; Hazell et al., 2010; Wiggins, Kirsten, and Llabi, 2010; Collier and Dercon, 2014). Critics argue that small farms forego economies of scale associated with skills, technology, finance, capital, and face dis-economies in terms of trading, marketing and storage, disadvantages that will become more pronounced as a larger share of the population moves to cities and as rural labor wages converge toward the higher levels found in other sectors (Maxwell and Slater, 2003; Collier and Dercon, 2014). Consequently, they argue, policies should rely more on larger commercial farms to generate productivity gains, while relying on accelerating growth in other sectors to reduce poverty among the rural poor.

The notion that agricultural policies should not neglect larger farms is not controversial. In particular, government efforts to protect tenure security, property rights and land markets (for rentals and sales) are expected to benefit smallholders currently, and set the stage for an emerging class of medium-sized commercial farms (Jayne, Chamberlin, and Headey, 2014). However, it seems unlikely that shifting budgetary resources away from smallholder farms to support large-farm programs will help this generation of rural poor, or boost global food supplies any time soon.

Farm census data show there are relatively few large farms in Sub-Saharan Africa, and there is little to suggest that market forces are driving widespread consolidation (Masters et al., 2013). In addition, there are good conceptual reasons to suggest a smallholder structure is well suited for most places in Sub-Saharan Africa, where land, labor, risk and credit markets are imperfect (Binswanger and Rosenzweig, 1981; Feder, 1985).

There are several reasons why Africa's farm structure is based on small farms, but most development economists see two aspects of labor markets as fundamental. The first has to do with supervision and incentives. To start, the incentives to farm diligently and to manage soil and other natural resources are greater for family members than for hired labor. In addition, reliable hired labor can be costly to find and to supervise, which lowers the value of hired labor relative to the value of family labor (Yotopoulos and Lau, 1973; Kumar, 1979). For this reason, most farms in the world are family operated – about 75 percent of all farms according to Lowder, Scoet, and Raney (forthcoming). In itself, family ownership is not tied to scale; however, when the transition of labor markets is in its early stages, labor costs are lower in agriculture than in other sectors, which tilts profitable technology choices away from mechanization and toward labor-intensive technologies. Poor access to credit reinforces this tilt since farmers can improve their farms through “sweat-equity”, for example, by leveling fields or building fences, with little or no credit. Taken together, this means that the best suited technologies are associated with small farms managed and worked primarily by household members. Therefore, the most productive farms will be small in most places in Sub-Saharan Africa. Poorly functioning land markets also work to help keep farms small, because they keep the risks and costs of renting or purchasing land unnecessarily high (Lipton, 2009; Deininger, Hilhorst, and Songwe, 2014).

In many places in Africa, input and output markets are plagued by high transport and transaction costs, which tend to raise farm-gate input prices and lowers output prices. In general, this works against high-yielding technologies that rely on purchased inputs, especially fertilizer. It also encourages the adoption of livelihood strategies built around producing some or all of the household's food, since doing so avoids the high transport and transaction costs embedded in purchased food, and discourages the adoption of alternative strategies based on commercial sales, which rely more on markets. This strategic choice comes at a cost, since families may forego planting alternative income-producing crops, and forego alternative nonfarm activities that are more profitable on average; however, the strategy can prove crucial when food prices surge.³ Nevertheless, once the decision to produce food for home consumption is taken, price and output risk can lead families on smaller farms to use more household labor and obtain higher yields than neighbors on larger farms (Srinivasan, 1972; Barrett, 1996) .

Regardless of its conceptual underpinnings, there is considerable evidence that productivity, especially land productivity, is higher on small farms in developing countries than on larger ones. Moreover, evidence of an inverse relationship between productivity and farm size is found across a large number of farming systems of varying average scale and under a variety of agroclimatic conditions. (See the literature reviewed in Binswanger, Deininger, and Feder, 1993, Lipton, 2009; Eastwood, Lipton, and Newell, 2010.) In Sub-Saharan Africa, inverse relationships have been found in Ethiopia (Cornia, 1985; Nega et al., 2003), Kenya (Larson et al., 2014), Madagascar (Barrett, 1996), Nigeria (Cornia, 1985), Malawi (Larson et al., 2014), Rwanda (Byiringgiro and Reardon, 1996; Ali and Deininger, 2015), South Africa (van Zyl, Binswanger, and Thirtle, 1995), Tanzania (Cornia, 1985; Larson et al., 2014), Uganda (Cornia, 1985; Nkonya et al., 2004; Matsumoto and Yamano, 2013; Larson et al., 2014), and Zambia (Kimhi, 2003).⁴

Still, some researchers are skeptical of the results, and speculate that the results are statistical artifacts. One line of reasoning is that smallholder lands are more productive because farmers are less likely to sell or rent out their highest quality land. As a consequence, productivity differences may be falsely attributed to scale, since land quality usually goes unmeasured (Assuncao and Braido, 2007; Benjamin, 1995; Bhalla and Roy, 1988; Lamb, 2003). Potentially, systematic measurement errors in self-reported area and yields might also bias empirical results (Lamb, 2003). The empirical evidence addressing either criticism is thin, but a study by Barrett et al. (2010) that includes soil measurements finds no evidence of systematic bias for measured yields; Matsumoto and Yamano (2013) found inverse relationships between maize yields and plot size from estimated models that include and exclude soil carbon levels. Additionally, a recent study that incorporates self-reported and GPS-measured plot areas in Uganda concludes that measurement errors work against rather than in favor of the inverse-yield hypothesis (Carletto et al., 2013).

³ See Yamauchi and Larson (2016), references therein for a discussion about the effects of food price crises on child health.

⁴ An inverse-relationship is often found outside of Sub-Saharan Africa, where the average scale of farms is more varied. For example, inverse relationships have been found in Barbados (Cornia, 1985), Brazil (Kutcher and Scandizzo, 1981; Berry, 1984), the Indian Punjab (Sen, 1966), Malaysia (Berry, 1984); Mexico (Cornia, 1985); the Philippines (Hayami et al., 1990), the Republic of Korea (Cornia, 1985), and West Bengal (Carter, 1984).

Some critics discount the inverse-productivity findings for another reason, arguing that the empirical samples behind the studies are composed mainly of small farms (Collier and Dercon., 2014). This latter criticism is unfounded, especially when studies outside of Africa are considered. More importantly, the criticism also misses the larger point that, among the applied technologies used by a large representative class of farmers, there is no evidence that significant production economies are given up by staying small. In fact, the empirical evidence suggests the opposite: that the small-scale structure of Sub-Saharan African agriculture is an efficient way to use land and labor resources, given prevailing market conditions and constraints. For policy, this means that the full benefit of scale-neutral technology innovations, such as the development of improved seeds, can be achieved without augmenting the limited set of assets, mostly land and family labor, that smallholder farmers already possess. This is not to say that African farms should stay small, but it does offer a path for reducing poverty and building global food supplies without waiting for labor markets, capital markets, and farm structures to change.

As an alternative to smallholder-centered policies, some researchers suggest promoting larger commercial farms on new land by taking advantage of investor interest in acquiring large tracts of agricultural lands (Collier and Dercon, 2014). The strategy is risky, and even proponents urge taking a cautious and an experimental approach (Collier and Venables, 2012). This is because the history of government-managed land transfers is poor, especially in Africa (Eicher and Baker, 1982; Andrae and Beckman, 1985; Zoomers, 2010; Borras et al., 2011; Deininger and Byerlee, 2012). What's more, Arezki, Deininger, and Selod (2015) report worrisome evidence that current interest in African land deals is highest where land governance and tenure security are weak.

Given the need for caution, programs to develop new farms are unlikely to have a significant impact on food supplies anytime soon, and seem a less strategic use of resources when compared to programs designed to achieve small increases in the yields of current farmers. Further, as discussed, improving smallholder yields would likely generate greater economic growth and larger reductions in poverty than large-farm strategies, even when the effects on global food supplies are equivalent.

6. Revolution or evolution?

Many of the comparisons between Africa now and tropical Asia prior to its Green Revolution are apt. At the start of Asia's Green Revolution, agriculture was structured around small farms, yields of two the two main staple crops, rice and wheat, had been stagnant while populations grew. Food insecurity and fear of famine were widespread in Asia (Meadows et al., 1972; Drèze and Sen, 1989; Otsuka and Place, 2015). However, in Asia, new technologies, once proven, were quickly taken up with exceptional results. In contrast, progress in Africa has been characterized by a mosaic of local successes that are hard to detect in national or regional numbers (Reij and Smaling, 2008; Otsuka and Larson, 2013). In turn, this has fed disappointment among donors with policies meant to improve smallholder productivity, and has promoted a view that the smallholder policy narrative has been oversold (Dercon, 2013).

However, there are key differences that make an African Green Revolution harder to achieve. First is the greater diversity of important staple-crop systems that are the foundation of African diets. This point is illustrated in the top panel of Figure 1, which shows the share of calories originating in the two major grains for Sub-Saharan Africa, rice and maize, in 2010 and also the share of calories originating in wheat

and rice for South and Southeast Asia, at the start of Asia's Green Revolution. In 1965, more than 46 percent of the calories available in every country of South and Southeast Asia came from rice or wheat; in populous Thailand, Vietnam, and Bangladesh, the shares exceeded 65 percent. Consequently, technological innovations in wheat and rice, once adopted, had the potential for large system-wide impacts on productivity, incomes and nutrition.

In contrast, the agro-climatic conditions that support major food systems in Africa are more varied and this is reflected in African diets. In 2010, only food systems in Malawi, Zambia, Lesotho and Madagascar depended mostly on maize and rice. Consequently, the successful adoption of a single high-yielding crop technology – for example, high-yielding lowland rice – can be very important for some communities without generating system-wide impacts. Said differently, the number of successful crop innovations must be greater in Africa to generate a continental Green Revolution.

In addition, the foundation for Asia's early success was a large stock of improved germplasm from temperate zones: wheat varieties from North America, Europe and Japan, and rice cultivars derived from Taiwanese and Japanese semi-dwarfs (Evenson and Gollin 2003b). In contrast, international breeding programs for sorghum, millet, barley, lentils, potatoes and cassava, crops that are important in Sub-Saharan Africa, did not begin until the 1970s, and rice programs for Africa did not start until the 1980s. This meant a slow start to Africa's Green Revolution. Additionally, African governments have invested significantly less in agricultural research than developing countries in Asia, leading to a greater technological divide (Pardey et al. 2006).

Another significant difference has to do with land availability. The lower panel of Figure 1 shows the portion of agricultural land planted to annual or permanent crops; the remaining portion is devoted to meadows and pastureland. In the places where Asia's Green Revolution found early success, like Pakistan, India and Thailand, more than 85 percent of available agricultural land was already cropped, leaving little room to expand by converting pastureland. In Asia, the technologies that proved successful were fertilizer-responsive, high-yielding varieties of rice and wheat that greatly improved land productivity. Because household landholdings were small as well, the seed-fertilizer technologies solved a constraint faced by many farming households as well as a primary constraint for the sector (Johnston and Cownie, 1969).

Land availability is more varied in Sub-Saharan Africa. In places like Mozambique and Liberia, large tracts of pastureland are available for conversion. But more than 74 percent of the land is already cropped in Burundi, Rwanda and Cameroon. Consequently, technologies that boost land productivity are more relevant in some places than others. In addition, differences in transportation and transaction costs are often greater in more sparsely populated land-abundant countries. This affects technology choices as well, since remote households farming where input prices are higher and output prices lower will find fertilizer-intensive technologies less attractive (Larson and Gurara, 2013). This point is brought home by considerable empirical evidence that farmers' preferences for varieties reflect more than potential yields (Adesina and Baidu-Forson, 1995; de Groote et al., 2002; Lunduka, Fisher, and Snapp, 2012).

The diversity of conditions and its implications for the suitability of any single technology also complicates the design and implementation of programs meant to disseminate developed technologies. In

Asia, national campaigns to improve smallholder productivity could be built around a single crop with a standard knowledge base and lessons gained from similar growing conditions in one country could be adopted in the next. In Africa, regional campaigns with multiple technologies and varying knowledge bases are needed to deliver the same impact.

Broadly, the great diversity of circumstances that condition smallholder technology choices in Africa means that the unfolding of Africa's Green Revolution has been slower than Asia's. It has also meant that successes to date have been dispersed and the accumulate effects of success harder to discern. Even so, there are signs that the gap in cereal yields is beginning to close in some places. Figure 2 shows annualized growth rates in yields for two periods: 1961 to 2000, the 20th Century Green Revolution years 1961-2000 and the more recent years, 2000 to 2013. During the first period, growth in Asian cereal yield outpaced those in Sub-Saharan Africa by a wide margin. Since then, Asian yield growth rates have slowed somewhat, as have average world rates. However, growth rates in Sub-Saharan Africa have accelerated. The figure shows considerable regional differences for both periods, with the largest yield gains occurring in Southern Africa. Keeping in mind that yield improvements in Asia have been sustained for six decades, it is clear that the yield gap between Asia and Sub-Saharan Africa remains large. However, the recent differential growth rates of crop yields do suggest that the gap between Asia and parts of Africa have begun to close.

7. Lessons from farmers' fields

In this section, we focus on elements of maize and rice productivity in SSA that illustrate why the task of developing and disseminating appropriate smallholder technologies is complex in SSA, and provide some examples of technologies that have succeeded. The detailed studies are reported in Otsuka and Larson (2016).

7.1 Maize

Recent empirical studies suggest that the adoption of technologies built on high-yielding fertilizer-responsive modern varieties (MVs) significantly increases crop revenue and household income (Bezu et al., 2014; Mathenge et al., 2014; Khonje et al., 2015), reduces poverty (Khonje et al., 2015; Mathenge et al., 2014; Zeng et al., 2015) and improves food security (Bezu et al., 2014; Khonje et al., 2015; Smale et al., 2015). Nevertheless, regional adoption rates of MV maize differ significantly, and in many places, most farmers use traditional maize technologies. For example, Smale et al. (2013) report the following MV adoption rates for 2006-2007: 33 percent of maize area in Eastern Africa; 52 percent in Southern Africa, excluding South Africa; and 60 percent in West and Central Africa. Drawing on data from 2001-2006, Kostandini et al. (2013) also report considerable differences in MV adoption rates among countries, ranging from 5 percent in Angola to more than 70 percent in Kenya and Zambia.

As in Asia, the full benefits of the maize technologies developed for Africa are only achieved with high-levels of soil nutrients, which in practice means using chemical fertilizers (Morris et al., 2007). And there is ample evidence that the MV technologies, once adopted and used in combination with fertilizer, perform as expected. For example, estimated marginal response rates of maize to fertilizer ranged from 12 kg maize per kg. of nitrogen application in Zambia (Xu et al., 2009) to 25 kg. in Kenya (Matsumoto and

Yamano, 2013). In addition, studies suggest that adopting seed-fertilizer maize technologies is profitable in: Western, Eastern and Southern Africa (Morris et al. 2007); Kenya (Sheahan et al., 2013; Matsumoto and Yamano, 2013); Uganda (Matsumoto and Yamano, 2013); and Zambia (Xu et al., 2009). Still, the share of farmers that apply fertilizer to their maize plots varies widely. For example, Shehan et al. (2013) reports use rates of 76 percent in Kenya in 2010; Matsumoto and Yamano (2013) report use rates of 74 percent in Central and Western Kenya in 2004 and 2007. In neighboring Uganda, Larson et al. (2016) found that 6 percent of maize farmers used fertilizer in 2009-2010; Matsumoto and Yamano (2013) report a 3 percent share.

As discussed, boosting the adoption of MV technologies is often the key proximate objective of rural development strategies, so the question of why adoption rates are often low among African maize farmers has received considerable attention. Recently, much of the discussion has focused on use rates of chemical fertilizer, which are low when compared to recommended levels and in comparison to typical practices on Asia's small farms. In the case of maize, there is often evidence that MV technologies are welfare-improving, so much of the recent debate has focused not on the technology promoted, but on information gaps, market failings and "non-fully rational behavior" (Larson et al., 2016; Duflo, Kremer, Robinson, 2008). Generally, policy advocates agree on the need for governments to invest in infrastructure and public goods, which lower information and cost barriers to technology and markets, but there is less agreement on whether additional interventions are needed.

7.1.1 Appropriate technology but inadequate promotional programs

One area of debate is whether the market reforms eliminating grain and fertilizer parastatals, which accelerated in the 1990s, stunted the adoption of high-yielding varieties (Akiyama et al., 2003; Crawford et al., 2003; Jayne et al., 2003; Morris et al. 2007). A related debate concerns the importance of subsidies on fertilizer, irrigation, power, and credit, and supported output prices in the early stages of Asia's Green Revolution (Timmer 1997; Johnson, Hazell and Gulati, 2003). Some conclude that markets have failed in Africa and call for greater state intervention (Moseley, Carney, and Becker 2010; Poulton, Kydd, and Dorward, 2006; Winter-Nelson and Temu, 2005).

Still, in the case of maize, there have been several aggressive state-sponsored campaigns reminiscent of the early programs in Asia, and more recently national programs built around subsidized inputs (Jayne and Rashid, 2013). Perhaps the effort most comparable to the Asian programs was the Global 2000 Campaign, promoted by Norman Borlaug, who had been awarded a Nobel Prize for his work on Asia's Green Revolution, former US President Jimmy Carter, and Japanese billionaire philanthropist Ryoichi Sasakawa. The regional program, begun in Ghana in 1986, was designed to promote the hands-on transfer of MV maize technology by offering a selected package of seeds, fertilizer and extension services to a small cadre of farmers (Brinkley 1996). In Ghana, maize yields tripled on early demonstration plots, and by 1989 nearly 80,000 farmers had adopted the recommended MV technology. Nevertheless, Tripp (1993) argues that many of the promoted technologies were not consistently the best in all regions of Ghana, and were often marginally profitable under ideal conditions. When poor weather inevitably arrived, many farmers were unable to repay loans, and soon many of the farmers who had adopted the

technology abandoned it. A 1990 survey found that only 29 percent of the farmers who first used fertilizer under the program kept using it (Tripp, 1993, p. 2012).

Similar programs were launched for maize in Ethiopia, Ghana, Kenya, Malawi, Mozambique, Sudan, Zambia, and Zimbabwe (Smale, 1994; Brinkley, 1996; Howard et al., 2003; Smale and Jayne, 2011). Some programs showed early success before reaching an adoption plateau; however, often adoption gains were reversed and new technologies abandoned. Frequently, adoption depended heavily on controlled prices or subsidies that proved too expensive to maintain. Similarly, researchers are finding that several recently launched campaigns to promote MV technologies with subsidies are proving expensive with marginal benefits at best (Ricker-Gilbert et al., 2013; Jayne and Rashid, 2013).

7.1.2 Heterogeneous conditions and technologies

An alternative explanation is that the circumstances that affect the profitability of a given technology are heterogeneous, so it is unlikely that all farmers will decide to use the same technology. In this sense, the choice of technology is endogenous (Mundlak, 1988; Mundlak, Butzer and Larson, 2012). Differences in natural endowments, for example soil fertility or water availability, affect fertilizer response rates, yields, and therefore the profitability of a given technology (Larson and Leon, 2006; Marenja and Barrett, 2009; Jayne and Rashid, 2013). Variable weather adds to the risk of a technology, even if the technology is profitable on average (Larson et al., 2016). Spatial differences in transport and transaction costs affect relative profitability (Xu et al. 2009). In the specific case of maize, Suri (2011) concludes that in Kenya, the differences in the costs and benefits of using maize hybrids explain the differences in choices made by adopters and non-adopters of MV technologies. In short, the market prices and relevant shadow prices farmers face differ, which generates variation in pursued livelihood strategies and employed technologies.

Practical differences in technology preferences is illustrated by Table 2, which shows that input use intensities such as chemical fertilizer and manure application per hectare, the share of intercropped fields, and the percentage of adoption of hybrid seeds are all substantially higher in Kenya than Uganda, which led to the higher maize yields and higher crop income in Kenya than Uganda. Nevertheless, in the case of Uganda, the use of low-input-low-yield technologies are consistent with weather-related yield risks (Larson et al., 2016).

7.1.3 The Integrated Maize Farming System

While research and extension programs often focus on high-yielding seed-fertilizer technologies, another avenue is to adopt integrated soil fertility management systems, which use both organic and inorganic fertilizers. For example, in India, Kajisa and Palanichamy (2013) found that application of organic fertilizer directly increased productivity of upland cereals and also raised the efficacy of chemical fertilizers in low fertility soils. Evidence from Malawi and Kenya shows that intercropping or rotating maize with nitrogen-fixing legumes is another possible way to restore soil nutrients (Snapp et al., 2010; Ojiem et al., 2014).

A more complex integrated maize technology, which seems to work well in populous areas that are also free from sleeping sickness, is examined by Muraoka et al. (2016) and Otsuka and Yamano (2005). In the highlands of Kenya, farmers who adopt this system grow forage crops such as Napier grass and

feed it to genetically-improved stall-fed cows, from which they produce manure. They apply the manure along with chemical fertilizers to fields planted with hybrid maize varieties and often intercropped with nitrogen-fixing legumes. This integrated maize-livestock farming system is more labor-intensive and land-saving than the traditional farming system, in which livestock is grazed without much interaction with crop farming.

It is worth noting that this highly complex farming system is indigenous and represents a novel combination of technologies that has not been researched as a system so that the best combination of inputs and the optimum timing of their application is unknown.

7.2 Rice

A series of empirical studies of rice farming were conducted based on household data collected in Mozambique, Tanzania, Uganda, Ghana, and Senegal published in Otsuka and Larson (2016). As the studies reveal, rice is a promising crop in Africa and one well suited to technologies currently used in Asia (Otsuka and Larson, 2013; Estudillo and Otsuka, 2013; and Nakano et al., 2013).

In the Senegal River Valley, paddy yields average 4.5 tons per hectare, highest among the five countries studied. Rice farmers in the Senegal River Valley have access to an irrigation facility with ample supply of water, adopt Asian-type semi-dwarf modern varieties, apply chemical fertilizers amply, and practice improved management such as bunding, leveling, and straight-row planting (Sakurai, 2016). Yields are comparable with yields observed in Asia's irrigated areas in the late 1980s (David and Otsuka, 1994). Irrigated yields in Tanzania were lower, averaging 3.7 tons per hectare, partly because of lower quality irrigation facilities and partly because of the incomplete adoption of improved management practices (Nakano et al., 2016). Irrigated yields in Mozambique ranged between 1.6 to 2.0 tons per hectare, well below the average of 2.2 tons in SSA (FAOSTAT, 2015). This lower yield can be attributed to low-quality irrigation facilities, inadequate chemical fertilizer application, the use of old varieties, and the low adoption of improved management practices (Kajisa, 2016). Thus, it is clear that irrigation alone is not sufficient to achieve high rice yields.

Njeru et al. (2016) observed paddy yields as high as 5 tons per hectare in the Mwea irrigation scheme in Kenya, where improved management practices were widely adopted, even though high-quality but low-yielding basmati varieties are grown. In some areas of the Mwea irrigation scheme, where varieties developed by IRRI were grown, yields of 8 tons per hectare were obtained. It is thus possible to achieve high yields in irrigated areas in Africa if improved varieties and chemical fertilizer are combined with improved management practices.

Still, achieving a sweeping revolution in rice will require improvements in rainfed rice yields, since 85 percent of lowland paddy field in SSA is rainfed (Balasubramanian et al., 2007). Rainfed yields ranged from 0.8-1.0 ton per hectare in Mozambique, 2.0 tons in Ghana, and 2.3-2.5 tons per hectare in Uganda. The higher average yields in Uganda are close to the average yield in rainfed areas in Asia in the late 1980s (David and Otsuka, 1994). It is important to note that management training programs were not implemented in Mozambique, but were in rainfed areas in Uganda and Ghana.

In rainfed areas in northern Ghana, yields averaged a mere 1.5 tons per hectare without any improved management practices, but reached 2.6 tons per hectare with the adoption of all recommended management practices, including use of improved seeds, chemical fertilizer, bunding, leveling, and straight-row dibbling. Similarly, management training is found to be effective in rainfed areas in Uganda. It is noteworthy that substantial yield gains have been achieved even in rainfed areas in SSA without accompanying major market reforms or new investments in roads or irrigation systems.

In Table 3, we turn to a broader measure of productivity and examine the effects of improved management practices on profitability, defined as the value of production per hectare minus paid-out cost and imputed costs of owned resources evaluated at the market prices. Because imputing the value of family labor is error-prone, the table also includes income per hectare, which is defined as the value of production minus paid-out cost per hectare. In Tanzania, both income and profit per hectare were significantly higher in irrigated areas compared to rainfed areas. In rainfed areas in Ghana, both income and profit per hectare were significantly higher for full adopters of improved seeds, fertilizer, bunding, leveling, and dibbling than for non-adopters. In Uganda, income per hectare was significantly higher for management training participants. The study also found that training participants adopted improved seeds, chemical fertilizer, and improved management practices more often than the non-participants.

Considerable differences in income and profit between training participants and non-participants and between full adopters and non-adopters suggest that it is profitable to adopt a seed-fertilizer-management (SFM) rice technology in Sub-Saharan Africa. Supporting evidence is provided by the ongoing study on the adoption of intensive rice cultivation system in rainfed areas in Kilombero Valley in Tanzania by Nakano et al. (2015), who also found significantly higher yields and profit per hectare associated SFM technologies.

8. Concluding remarks

Most rural development strategies in Sub-Saharan Africa focus on improving the productivity of smallholder farms. The approach has clear advantages, since it leverages resources already in place in rural communities – primarily land, family labor, farming knowledge and social capital – while the slow-paced dynamics of economic transformation and farm restructuring play out. Importantly, improving smallholder productivity speeds up economic growth and complements programs that prepare rural workers for jobs in other sectors.

With the possible exception of mechanization, technologies that improve overall small-farm productivity usually help farmers achieve higher yields. In general, yield gaps are high in Sub-Saharan Africa and even a partial narrowing could have a significant impact on local and global food supplies. A careful and transparent approach to promoting new commercial farms, carved out from under-utilized land resources, can help improve food supplies over time, but with fewer benefits for economic growth or poverty reduction, and with greater stress on Africa's natural resources and ecologies.

A key instrument in the pursuit of improving smallholder productivity is the development and dissemination of new technologies. In the case of Asia's Green Revolution, a small set of technologies had a transformational impact on rural communities and food systems that were land-constrained and structured largely around wheat and rice. In Sub-Saharan Africa, agroclimatic and market conditions are

more diverse, as are food systems. Consequently, a larger set of place-specific technologies are needed to prompt an African Green Revolution. This raises the cost of developing and testing new technologies and the cost of disseminating technologies that meet farmers' needs.

Lessons from the fields of maize and rice farmers in Sub-Saharan Africa illustrate these points. In the case of low-land rice, the seed-fertilizer technologies that transformed many Asian food systems work well in well-managed irrigation systems and generate similar yields. But the technologies are not enough to materially change the lives of most rice producers, since most of the rice produced in Sub-Saharan Africa is rainfed. Nevertheless, research suggests that, in many communities, rainfed rice yields can be improved by focusing not only on seeds and fertilizer, but on improved agronomic practices.

In the case of maize, differences in risk, markets, and growing conditions help explain dramatic differences among farmers about using fertilizer and high-yielding seeds. Heterogeneity also helps explain why technology promotion programs based on a single technology packet, which proved transformational in Asia, have seen limited success in Africa. However, as the example of highland maize farmers in Kenya illustrates, indigenous hybrid systems based on improved genetic material and improved resource management can supplement traditional seed-fertilizer technologies.

Taken together, all of this suggests that a strategy of boosting smallholder productivity is a sound one, especially when combined with policies that help families prepare for jobs outside of agriculture. However, the task of building out, cataloging, and disseminating the full set of technologies needed for transformational change represents a challenge to African governments and the development community. Still, there is evidence of local success and some indication that yield gaps have closed in recent years. Pursuing additional paths, built on resource-management technologies and indigenous innovations, can speed Africa's Green Evolution.

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Table 1: Average farm size from census data

	Decades				
	1960	1970	1980	1990	2000
India	2.70	2.30	2.00	1.60	1.30
Indonesia	1.20	1.10	1.10	0.90	0.80
Bangladesh	1.40		1.30		0.30
China			0.56	0.43	0.40
Cote d'Ivoire		5.00			3.90
Ethiopia		7.30	4.20	6.20	
Kenya	11.70	4.10	2.50		
Philippines	3.60	3.60	2.90	2.20	2.00
Pakistan	3.50	5.30	4.70	3.80	3.10
Senegal	3.60				4.30
Tanzania		1.30		2.80	2.40
Thailand	3.47		3.70	3.60	
Uganda	3.30			2.20	
Vietnam				0.50	0.70

Source: Fan and Chan-Kang (2005), Lowder, Skoet and Singh (2014)

Table 2: Maize technology adoption in Kenya and Uganda

	Kenya		Uganda
	2004	2012	2009/2010
Maize yield (tons/ha)	1.8	2.1	1.2
Crop income (KSh/ha)	37,869	46,786	--
Chemical fertilizer use (kg/ha)	49	47	0.3
Manure use (kg/ha)	971	1,578	22
Share of intercropped fields (%)	76	72	45
Adoption of hybrid maize (%)	50	78	30

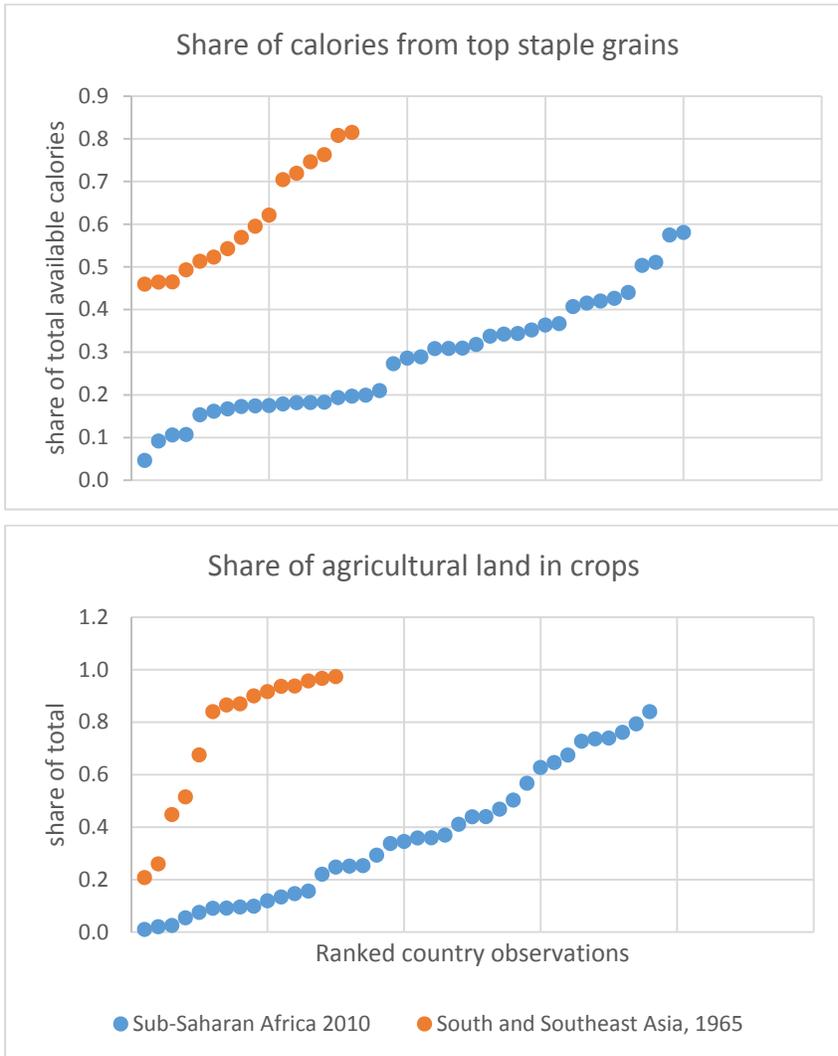
Source: Larson et al. (2016), Muraoka et al. (2016). Crop income is defined as crop production minus all paid costs associated with crop production.

Table 3: Income and profit of rice cultivation, by status of training and technology adoption

	Income per ha	Labor cost per ha	Profit per ha
Tanzania			
Irrigated area	1,011	421	590
Rainfed area	453	300	153
Uganda (rainfed)			
Training participants	1,327	--	--
Non-participants	905	--	--
Ghana (rainfed)			
Full adopters	374	114	260
Non-adopters	228	169	59

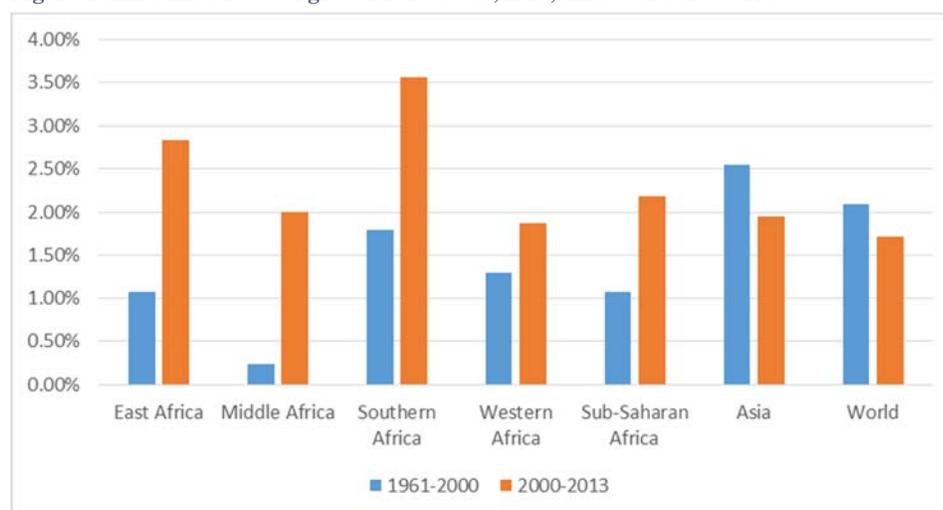
Sources: Kijima (2016), deGraft-Johnson et al. (2015), Nakano et al. (2016), and Otsuka and Larson (2016). Note: income and profit are measured in \$US. Income is defined as the value of production minus paid-out costs. Profit is defined as income minus imputed costs of owned resources, including family labor.

Figure 1: Starting points for East and Southeast Asia and Sub-Saharan Africa



Source: FAOSTAT (2015) and authors calculations. For Sub-Saharan Africa, reported calories originate in rice and maize. For South and Southeast Asia, the reported calories originate in rice and wheat.

Figure 2 Annualized rates of growth for cereals, Asia, Africa and the world



Source: FAOSTAT (2015) and authors calculations. Note: Eastern Africa includes: Burundi, Comoros, Djibouti, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Eritrea, Zimbabwe, Réunion, Rwanda, Somalia, United Republic of Tanzania, Uganda, Ethiopia, and Zambia. Middle Africa includes: Angola, Cameroon, Central African Republic, Chad, Congo, Gabon, Sao Tome and Principe, and the Democratic Republic of the Congo. Southern Africa includes Botswana, Lesotho, Namibia, South Africa, and Swaziland. Western Africa includes: Cabo Verde, Benin, Gambia, Ghana, Guinea, Côte d'Ivoire, Liberia, Mali, Mauritania, Niger, Nigeria, Guinea-Bissau, Senegal, Sierra Leone, Togo, and Burkina Faso