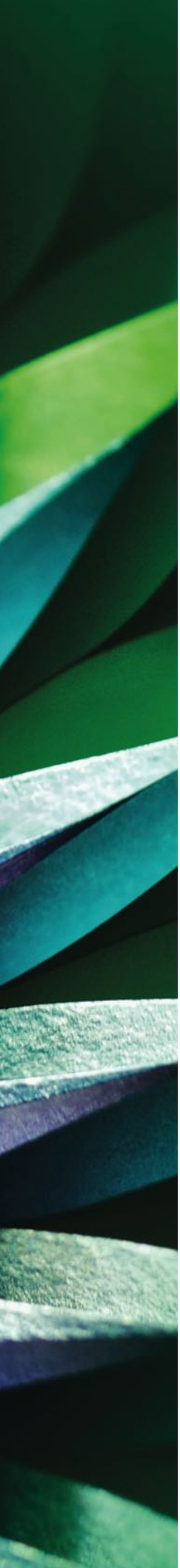

BACKGROUND PAPER

Changing Farm Size and Agricultural Productivity in Asia

Futoshi Yamauchi

DISCLAIMER

CHANGING FARM SIZE AND AGRICULTURAL PRODUCTIVITY IN ASIA[1]

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I. INTRODUCTION

When labor is abundant relative to land in the early stage of economic development, labor-intensive methods of cultivation are socially efficient. In such cultivation systems, no major indivisible inputs are used and, hence, there is no major source of scale economies. Roughly speaking, a farm of 1–2 hectares (ha) can be managed efficiently by family labor consisting of a few workers. Beyond that scale, hired labor must be employed. However, the monitoring cost of hired labor arises, which increases more than proportionally with the cultivation size. This explains why the family farm dominates in agriculture in most countries in the world. Thus, the optimum farm size in low-wage economies is bound to be small because of the limited availability of family labor and the costly substitution of capital for labor. This situation was predominant in Asia, which justifies the dominance of relatively small operational size.

In the process of the economic development in Asia, which accompanies the continuous increases in the real wage rate, the comparative advantage of the economy in most Asian countries has been shifting from agriculture to nonagricultural sectors. A part of the reason could be the predominant small farm size in this region, which requires labor-intensive cultivation. Farm size expansion, however, is difficult to realize because of the imperfection of land markets. As a result, high-income economies in East Asia, for example, Japan and the Republic of Korea (ROK), have been increasing imports of grains.

The striking feature of Asia is its historically unprecedented rapid and successful industrialization,

[1] I thank Mengying Wang for her excellent research assistance, and participants in the Asian Development Bank workshop held on 25–26 March for valuable comments.

realized outside European and North American continents, which transformed the economies, including agriculture. A large part of rural population had a chance to migrate to urban sectors that are highly able to absorb surplus labor from rural origins. As a result, the real wage rate and, therefore, the opportunity cost of family labor in agriculture also increased continuously. Labor abundance disappeared in most of the Asian agriculture. To reduce the labor cost, farmers need to substitute machines for labor. To operate machines more efficiently, farm size must be expanded. Since large machines are indivisible, scale advantages arise. Thus, larger farms become more efficient than smaller farms, and so the land must be transferred from the smallholder farmers to the larger farmers.

In the context of these emerging challenges, section II of this paper overviews historical paths taken by agriculture in the region following Hayami and Ruttan. We cover Northeast Asia (People's Republic of China [PRC], Japan, and the ROK); Southeast Asia (Cambodia, Indonesia, the Lao People's Democratic Republic [Lao PDR], Malaysia, Myanmar, the Philippines, Thailand, and Viet Nam); and South Asia (India, Pakistan, Bangladesh, Sri Lanka, and Nepal).

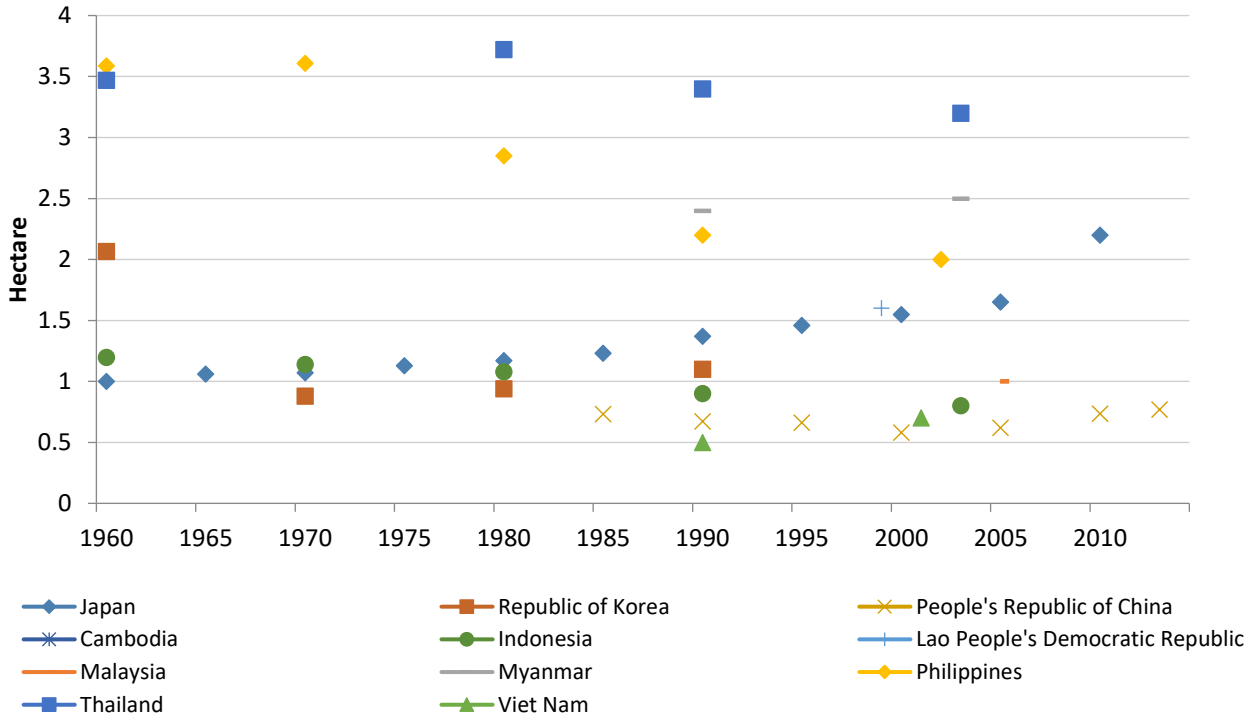
II. PRODUCTIVITY GROWTH IN AGRICULTURE

In this section, we follow Chapter 5 of Hayami and Ruttan (1985) to overview long-term changes experienced by Asian countries. Asian paths in Hayami and Ruttan (1985) are characterized by continuous efforts to increase land productivity by intensifying labor and other input use, especially through biochemical technological innovations, given that the initial condition was that the majority of farmers were small family-based cultivators, including owner and tenant farmers. Arable land per person, land-labor ratio, and the average farm size were generally small under high population density. Rapid and successful industrialization in this region has absorbed a large share of the labor force, which has resulted in a shortage of labor in agriculture. The rapidly rising real wage makes it necessary to substitute for labor. Divergence from historical paths observed in the past has been confirmed in Japan recently and is expected to happen soon in many other countries in the region.

A. Factor Endowment

Figure 1 shows changes in the average farm size in East Asia and Southeast Asia. Though the initial size differs between East Asia and Southeast Asia and many countries showed decreasing trends until 2000, Japan clearly showed an increase in the average size recently. Farm size expansion has also been taking place in the PRC since the early 2000s through land rental markets (Huang and Ding 2016). The decreasing trend in the Philippines and Thailand was especially clear after 1980.

Figure 1: Changes in Farm Size in East Asia, 1960–2014



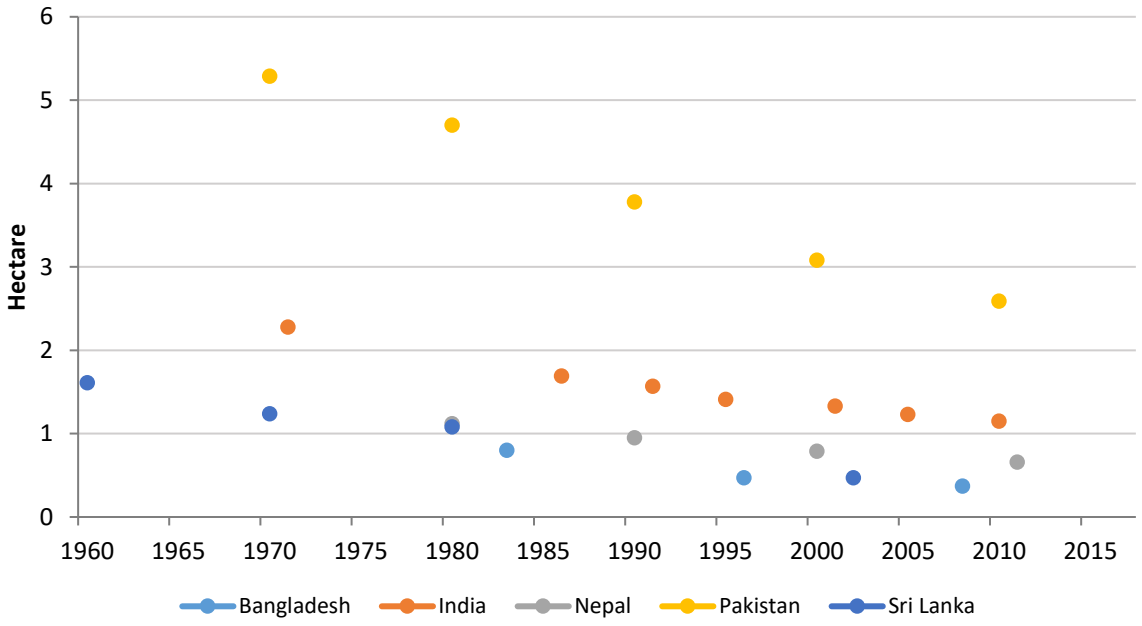
Sources: FAO. 2010. World Census of Agriculture. www.fao.org/world-census-agriculture/en/; for the People's Republic of China, J. Huang and J. Ding. 2016. Institutional Innovation and Policy Support to Facilitate Small-Scale Farming Transformation in China. *Agricultural Economics* 47: 227–237; for Japan, Ministry of Agriculture, Forestry and Fisheries, Government of Japan. Statistics. https://www.maff.go.jp/e/data/stat/index.html (accessed 7 October 2019).

Obviously, whether farm size increases in Asia is a serious issue. The average operational farm size was already small in the 1970s, ranging from 1 ha in Indonesia and Japan to 3 ha or 4 ha in the Philippines and Thailand. It has declined in subsequent periods in all these countries except in Japan and the PRC because of rapid population growth in rural areas. Farm size increased in Japan and the PRC, but it is far below the average farm size in high-income economies in Europe and North America where farms of more than 100 ha are common. If small farms continue to dominate

and become a major constraint on large-scale mechanization in high-wage Asian economies, the continent could become a gigantic importer of food grains. This has already happened in high-income economies in Asia, such as Japan and the ROK (Otsuka 2013). To address this issue, the Government of the PRC has started facilitating land consolidation through the rental market and introduced subsidies for mechanization. Therefore, the farm size in the PRC is expected to increase much faster than generally assumed.

In contrast to East Asia, South Asian countries show monotonic downward trends in farm size over time (Figure 2). A dramatic decline in farm size is seen in Pakistan. India, Nepal, Bangladesh, and Sri Lanka, which shows farm size of about 1 ha or below in recent years. We have not observed changes in the trend. At least on average, there seems to be no movement to increase farm size, which is considered to be a precondition that promotes mechanization in response to rising real wages (labor substitution). Adamopoulos and Restuccia (2014) show some recent evidence on size differences.

Figure 2: Changes in Farm Size (Hectare) in South Asia, 1960–2014

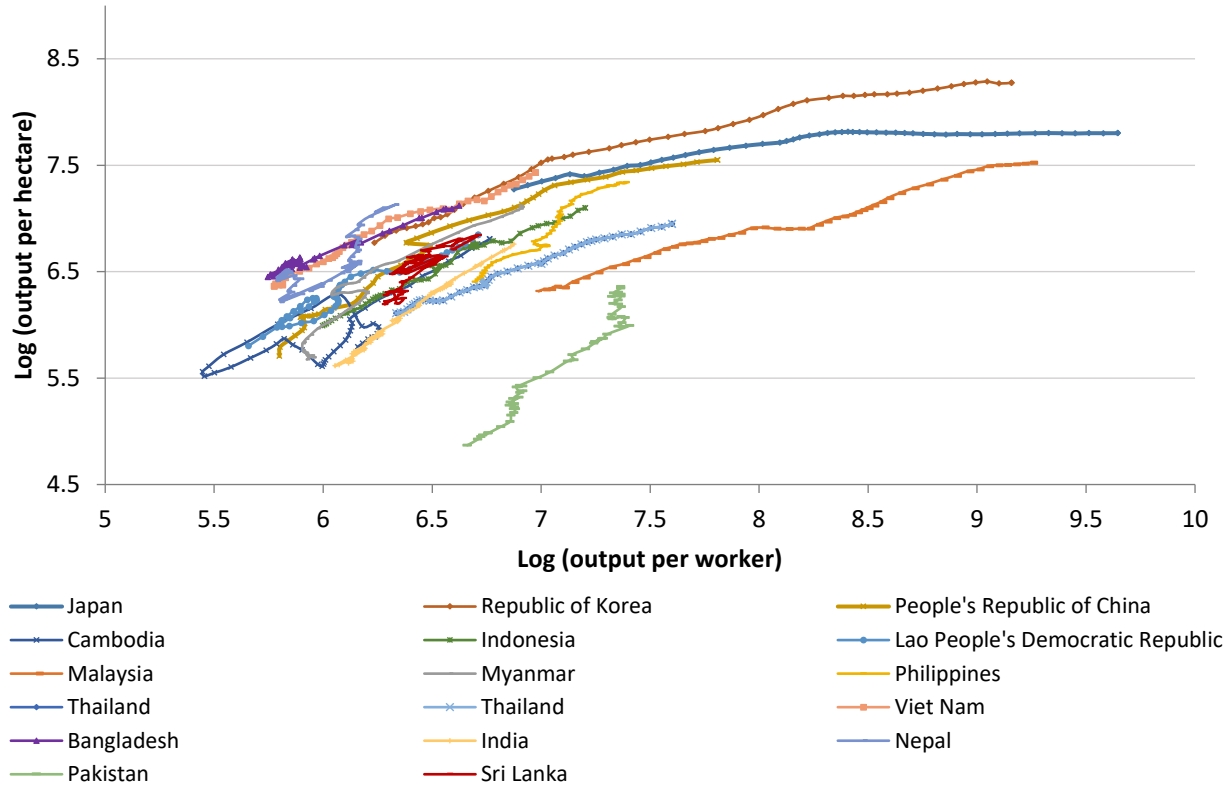


Source: FAO. 2010. World Census of Agriculture. www.fao.org/world-census-agriculture/en/.

B. Productivity Growth

This section characterizes productivity growth, both partial and total, following Hayami and Ruttan (1985). Figure 3 shows the relationship between output per worker (horizontal axis) and output per agricultural land (vertical axis), both of which are log transformed. First, overall, countries in the region followed the so-called Asian path, described in Hayami and Ruttan (1985), in which land productivity increases faster than labor productivity in the early period followed by fairly rapid growth of labor productivity, even after the mid-1980s. The clearest case is the ROK. The two economies of the ROK and Japan started almost from an identical path (initial condition), whereas development stages were different across them. Second, divergence is clearly detected in Japan away from this path; labor productivity keeps increasing while land productivity remains constant. That is, Japan is approaching the European path, described by Hayami and Ruttan (1985), which is closely related to an increase in farm size and mechanization. Third, Malaysia follows a unique path; labor productivity is clearly higher than the other countries at the same level of land productivity. Although the analysis is descriptive and not rigorous, trends observed in Figure 3 seem largely consistent with the Hayami-Ruttan induced innovation hypothesis.

Figure 3: Output per Worker versus Output per Agricultural Land in Asia, 1961–2014



Note: Gross agricultural output in 2005 United States dollars per the number of economically active adults in agriculture is on the *x*-axis; gross agricultural output in 2005 United States dollars per total agricultural land in hectares of rainfed cropland equivalents is on the *y*- axis. They are both log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

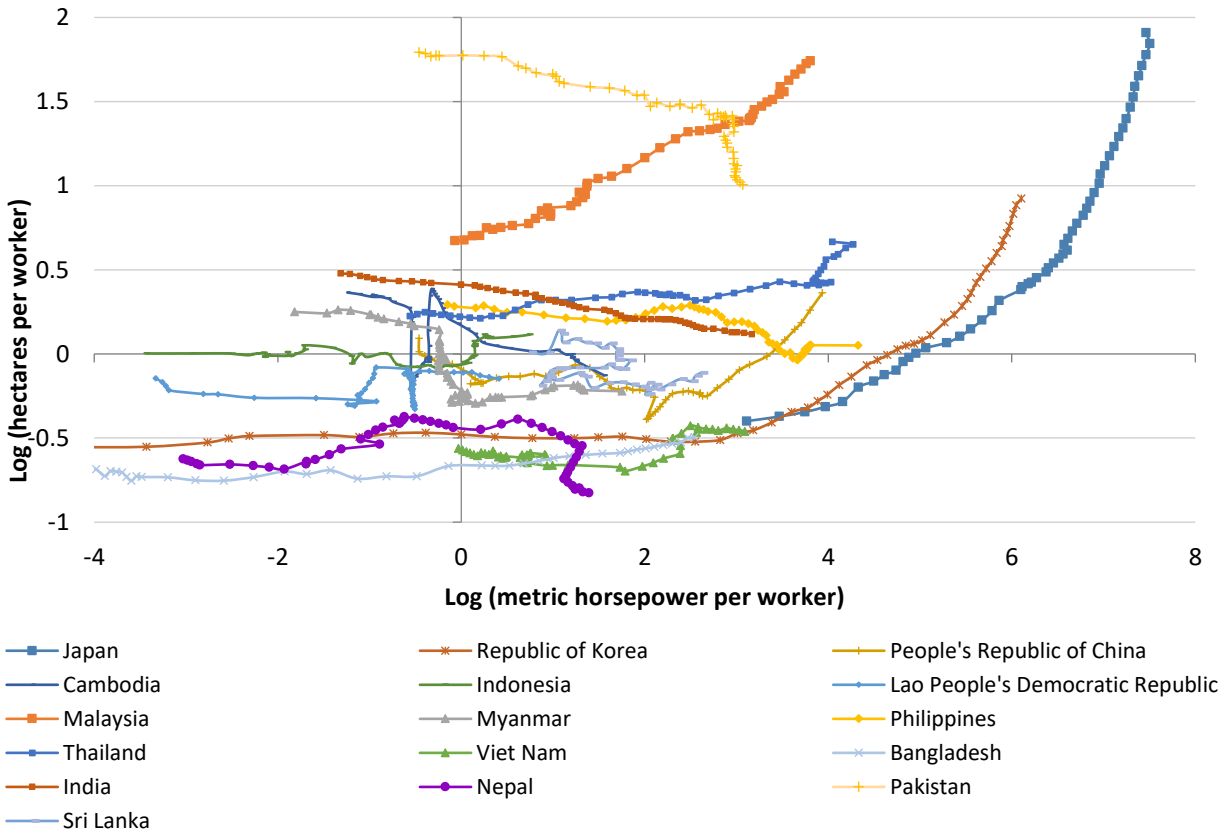
In South Asia, we did not observe fast changes in land and labor productivities as seen in the East Asia paths. They resemble some countries in Southeast Asia, such as Thailand, the Lao PDR, and Cambodia. In South Asia, there were differences in the initial point reflecting the initial endowments. The biased movement toward an increase in land productivity observed in some advanced countries in East Asia has not been observed.

Figure 4 shows the relationship between land-labor ratio (vertical axis) and machine use per worker (horizontal axis), both of which are log transformed. First, Japan, the ROK, and Viet Nam seem to follow a similar path (starting from a nearly identical land-labor ratio), though machine use in Viet Nam clearly is still at the early stage relative to Japan and the ROK. Machine use per worker in Viet Nam is comparable to that of many countries in Southeast Asia. Second, Malaysia stands alone in starting from a very high land-labor ratio and achieving high machine use per worker (almost the same level of land-labor ratio as in Japan). Third, other countries, including the

PRC, fall between the above two cases. In the PRC, an increase in machine use per worker recently seems to happen with an increase in land-labor ratio. In the Philippines, Indonesia, and Thailand, machine inputs per worker increased while land per worker has been relatively constant.

According to Figure 4, the land-labor ratio is significantly related to machine use per worker, which can be interpreted as a proxy for mechanical technology. Interesting observations are that land-labor ratio is higher in Malaysia compared with machine use per worker, and it is lower in Japan and the ROK compared with machine use per worker. These observations suggest that Japan and the ROK failed in expanding land area per worker because of the protective agricultural policies, which deter the exodus of the rural population. It seems that not only factor endowment, but also other factors affect the mechanization.

Figure 4: Land-Labor Ratio and Machine Use per Worker in Asia, 1961–2014



Note: Metric horsepower of machinery per the number of economically active adults in agriculture is on the *x*-axis; total agricultural land in hectares of rainfed cropland equivalents per the number of economically active adults in agriculture is on the *y*-axis. Both are log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

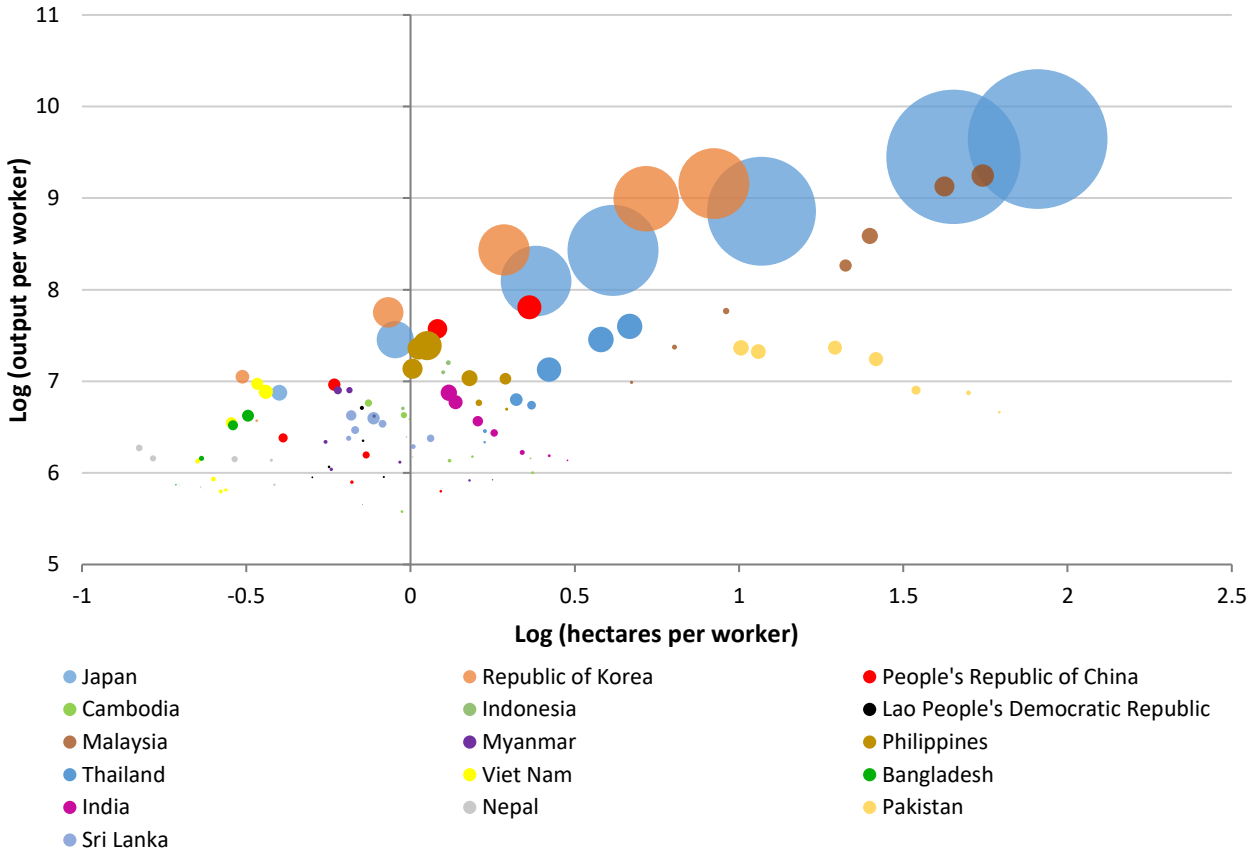
In South Asia, the land-labor ratio has not increased in the period from 1961 to 2014. In Pakistan, India, and Nepal, declines in the land-labor ratio were observed in recent years (India shows a downward trend). In contrast, machine use per worker has been increasing over time in all countries except Pakistan and Nepal in recent years.

At the stage where machine use per worker increased while land-labor ratio staying relatively constant, as seen in South Asia and many Southeast Asian countries, the process is driven by small-scale machines that do not require large operational size. However, when real wages start rising fast (though this factor was not explicitly included in Figures 4 and 5), the need to introduce large-scale machines coupled with an effort to increase operational size (farm size) becomes much stronger. Institutional innovations such as machine rental arrangements and/or machine service providers who can operate large-scale machines can be a solution for this too. Note that machine service providers can realize scale economies by contracting smallholders.

Metric horsepower of machinery faces measurement challenges. Aggregation and utilization also add more delicate technical challenges to this issue. For example, nonmonotonicity observed in Cambodia, Myanmar, and Sri Lanka could be related to these data problems.

Figure 5 shows the relationship between labor productivity and land-labor ratio. Machine use per worker is represented by the size of circle. It is clearly shown that those countries move northeast, augmenting labor productivity, experienced an increase in land-labor ratio and machine use per worker. Significant cases are Japan and the ROK. An increase in real wages is not displayed in the diagram but the use of machines, especially an introduction of large machines, is motivated to substitute for increasingly expensive labor.

Figure 5: Labor Productivity, Land-Labor Ratio, and Machine Use per Worker



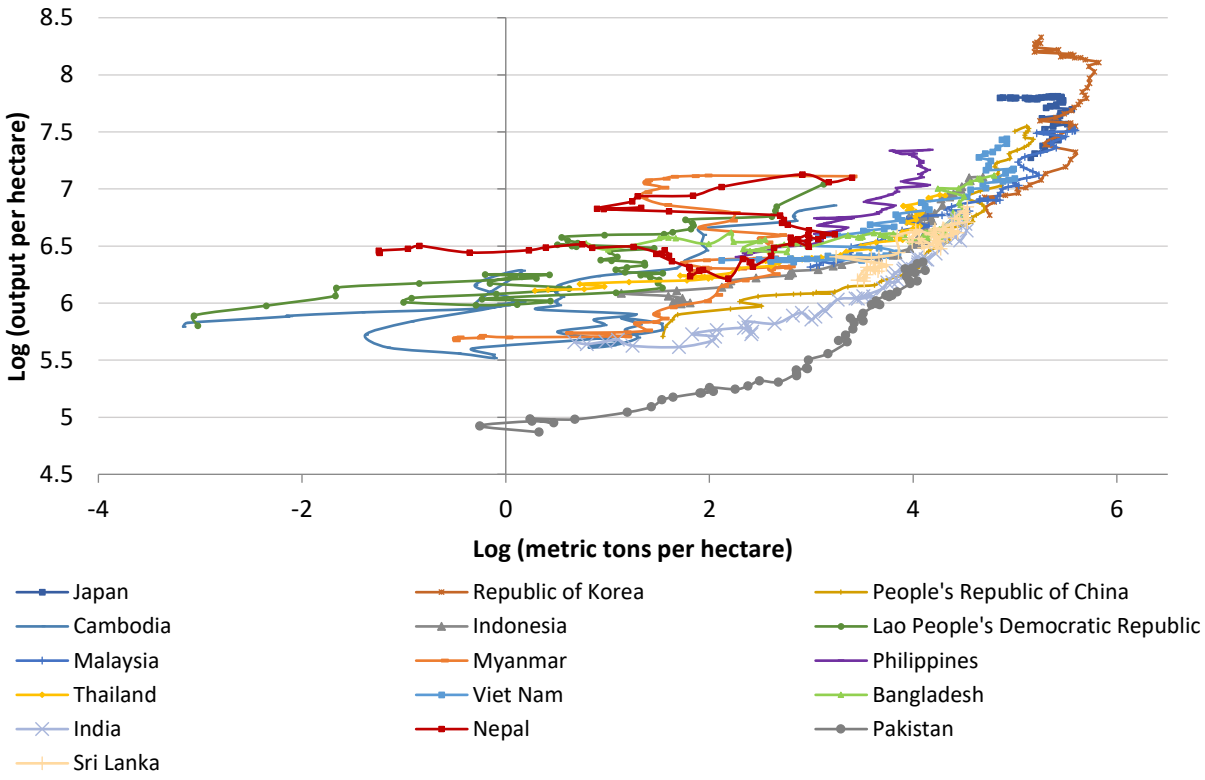
Note: Total agricultural land in hectares of rainfed cropland equivalents per the number of economically active adults in agriculture is on the x-axis; gross agricultural output in 2005 United States dollars per the number of economically active adults in agriculture is on the y-axis. Both are log transformed. Metric horsepower of machinery per the number of economically active adults in agriculture is represented by the size of circle.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

Figure 6 shows the relationship between fertilizer use per agricultural land area (horizontal axis) and output per agricultural land area (vertical axis), both of which are log transformed. According to this figure, land productivity is consistently and almost completely explained by fertilizer use per agricultural land area. Fertilizer use per agricultural land area can be interpreted as a proxy for biological-chemical technology. Strikingly similar paths across East Asian countries suggest that similar biological-chemical technologies, represented by fertilizer-using and high-yielding Green Revolution–type technologies of wheat and rice, have been developed and diffused in this region, beginning in Japan before World War II and transferred to tropical Asia primarily in the 1970s and 1980s. The elasticity of land productivity growth to fertilizer input is relatively low when fertilizer input level (per land area) is still low (below 4 log transformed), but land productivity growth appears to accelerate in response to fertilizer inputs once fertilizer use is intensified. This

observation suggests that fertilizer-using and land-saving technology is developed in the process of economic development that accompanies growing scarcity of land. In other words, consistent with the Hayami-Ruttan induced innovation hypothesis, fertilizer-using technology is developed to save an increasingly scarce factor of production, that is, land. In this context, Japan, the ROK, the PRC, Viet Nam, Indonesia, the Philippines, and Malaysia are all above the threshold. In Myanmar, Cambodia, and the Lao PDR, land productivity increased without intensification of fertilizer use, which is somewhat puzzling.[2]

Figure 6: Land Productivity and Fertilizer Input per Hectare in Asia, 1961–2014



Note: Metric tons of fertilizer per total agricultural land in hectares of rainfed cropland equivalents is on the *x*-axis; gross agricultural output (2005 United States dollars) per total agricultural land in hectares of rainfed cropland equivalents is on the *y*-axis. Both are log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

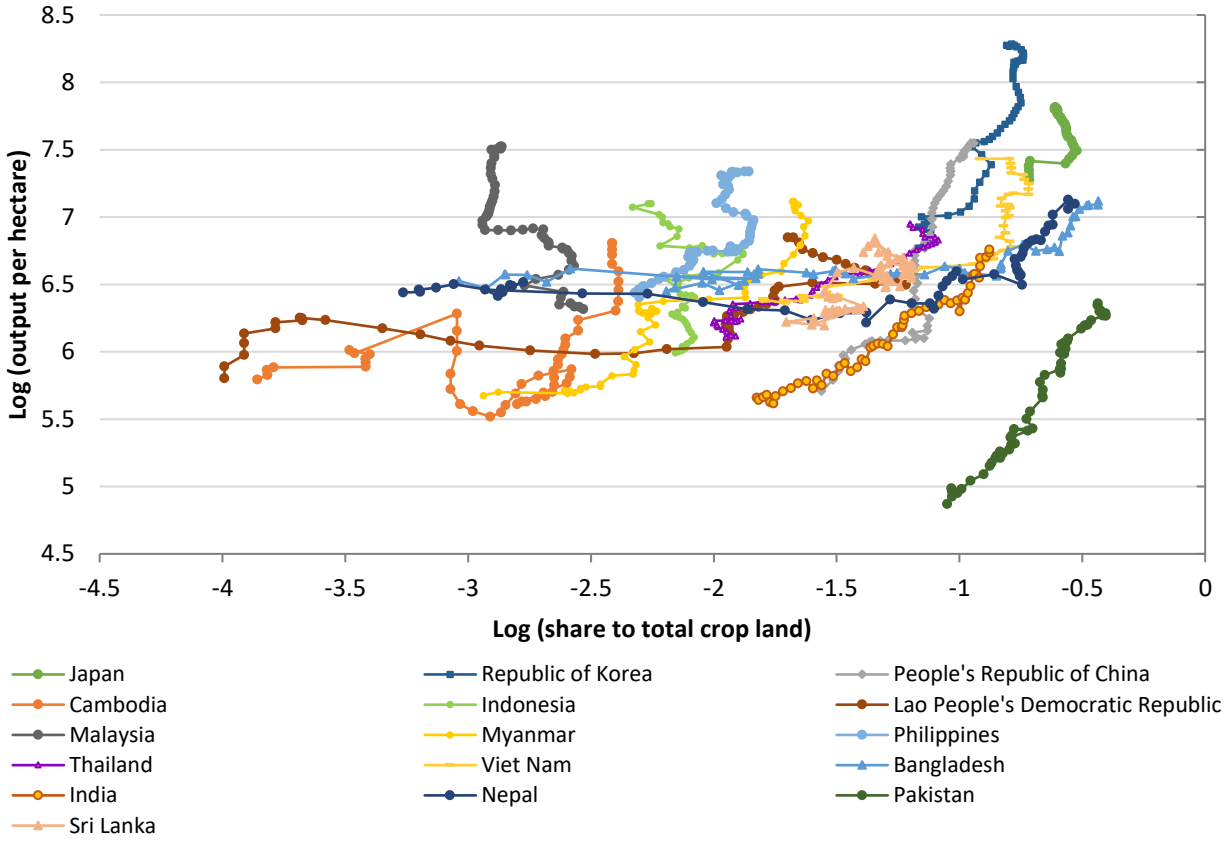
[2] Fertilizer use may need to be considered from two angles: productivity booster and soil/water polluter and greenhouse gas emitter. The overuse has become an environmental issue, and it is argued that the precise use should be encouraged to maximize the productivity as well. Since the focus of this paper is to describe actual trends in the relationship between productivity and fertilizer use, I do not discuss the optimality issue here.

In Pakistan, India, and Sri Lanka, an increase in fertilizer use and that of land productivity are clearly positively correlated (Figure 6). This relationship is very clear, especially in Pakistan and India. Only recently, Bangladesh shows an upward trend in land productivity. The pattern observed in Nepal needs to be reconciled carefully, especially at the time when the trend of fertilizer use was reversed.

Interestingly, the five countries in South Asia showed a strong convergence in land productivity and fertilizer input intensity (Appendix). Nepal had a large decline in fertilizer input per land at some point, but seems to show a converging process to the other countries in recent years. Figure 6 shows that the position of five countries in South Asia perfectly fit the East Asia paths after their intra-regional convergence.

Figure 7 shows the relationship between land productivity and the share of irrigated land in cropland. There are cases in which land productivity increased not directly related to irrigation. Those cases are found in the level of irrigation share smaller than 20% (about -2 in the x-axis). However, we can generally confirm a positive relationship between land productivity and irrigation share above 20%: Japan, the ROK, the PRC, Viet Nam, India, Nepal, Bangladesh, and Pakistan. It is noticeable that Pakistan clearly shows a positive relationship, but the level of land productivity is relatively low (in contrast to labor productivity).

Figure 7: Irrigation and Land Productivity in Asia, 1961–2014



Note: The share of irrigated land in total cropland is on the x-axis; gross agricultural output (2005 United States dollars) per total agricultural land in hectares of rainfed cropland equivalents is on the y-axis. Both are log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

In sum, countries in the region followed the so-called Asian path, described in Hayami and Ruttan (1985), that is, land productivity increasing faster than labor productivity in the early period, but Japan seems to divert from the path by rapidly increasing labor productivity, approaching the European path, which is closely related to an increase in both farm size and mechanization in recent years. Many countries in Southeast Asia had favorable land endowments in the initial conditions, but more recently both land-labor ratio and machine use per worker increased together in these countries following the cases of Japan and the ROK because of significant labor shortage common in the region. South Asia is comparable to some countries in Southeast Asia. Both land and labor productivities are increasing in a parallel way, not exhibiting a sign of an increase biased to augmenting labor productivity.

III. URBANIZATION, INDUSTRIALIZATION, AND LABOR SHORTAGE IN AGRICULTURE

Asian economies are going through rapid economic transformation. The fastest and most successful industrialization experienced in this region inevitably accompanied rapid urbanization and created scarcity of labor in rural areas, and therefore increased real rural wages. In rural areas, nonagricultural sectors also developed, which absorbed labor from agriculture. As a result, the opportunity cost of farming has dramatically increased in the region. Income growth has contributed to large poverty reduction (though the head counts of the poor are large in this region because of its large population size) and transformation of food demands.

Declining shares of agriculture in gross domestic product (GDP) and employment occurred very rapidly in Asia. Rural labor was absorbed by nonagricultural sectors largely located in urban areas and newly created local cities and towns. Successful industrialization not only led to the large-scale transformation of the agricultural section through a reduction in its contribution to GDP and employment (which also resulted in a substantial reduction in poverty level), but also created serious labor shortage and thus a rapid increase in real wages.

The table shows the shares of urban population in Asia. When the countries are grouped by percentage of urban population, there are three groups in the region. The first group consists of high-income countries, that is, Japan, the ROK, and Malaysia, in which more than 70% of the population was urban by 2018. The second group, the PRC, Indonesia, the Philippines, and Thailand, had 45%–60% of the population in urban areas in 2018. The last group consists of low-income countries, that is, Viet Nam, Myanmar, the Lao PDR, and Cambodia, where the share of urban population was about or below 30% in 2018. Since the share of urban population is correlated with the share of employment in agriculture, the table likely indicates that these countries went through a declining share of population engaged in agriculture with the development of economies.

South Asia shows two groups in terms of urbanization: Bangladesh, India, and Pakistan reaching the level between 30% and 40%, and Nepal and Sri Lanka remaining below 20%. Interestingly the second group is lower than Cambodia, while the first group resembles the Lao PDR, Viet Nam, and Myanmar in Southeast Asia.

Share of Urban Population (%) in Asia, 1960–2018

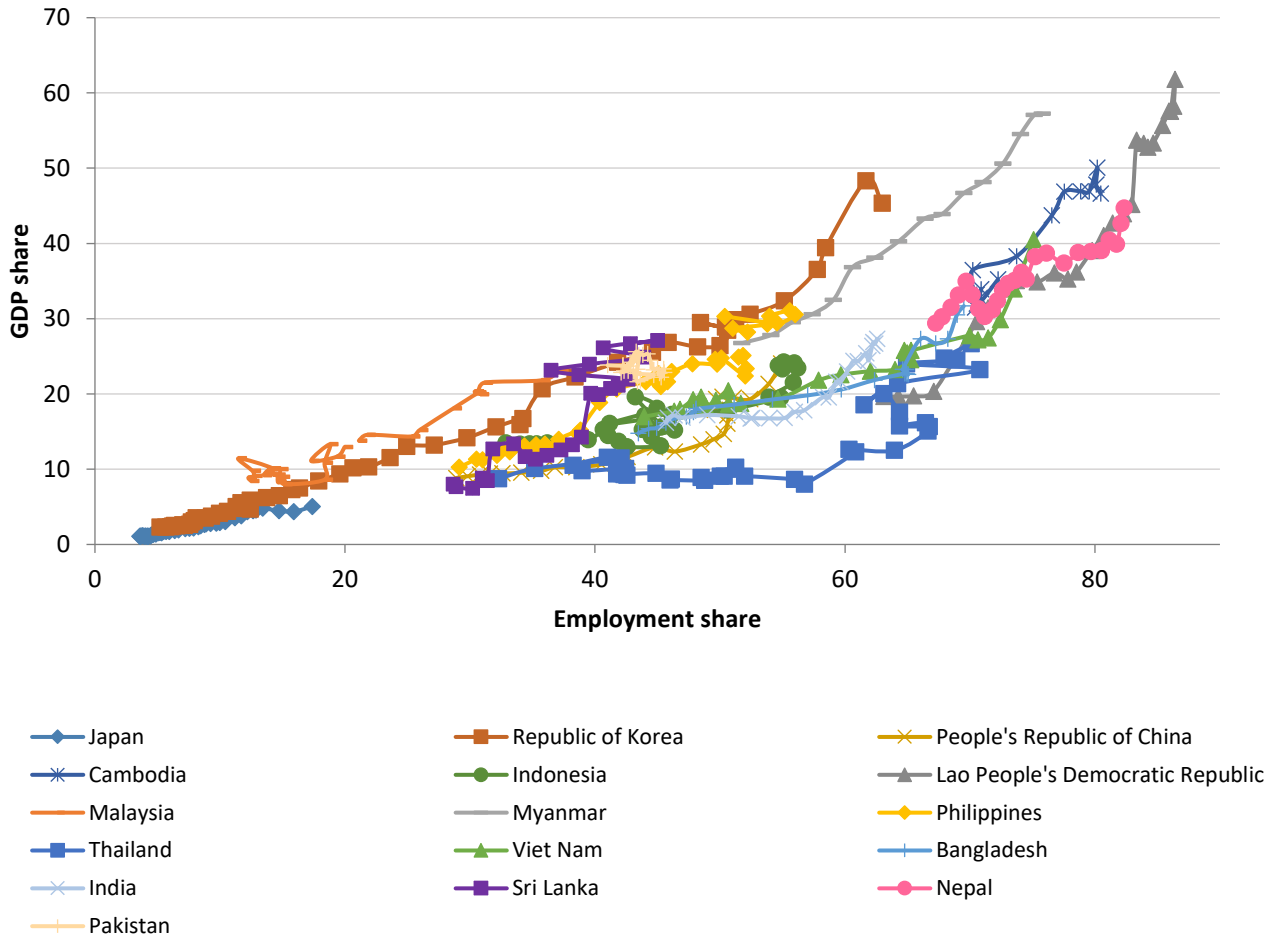
Country	1960	1970	1980	1990	2000	2010	2018
Japan	63.3	71.9	76.2	77.3	78.6	90.5	91.7
Korea, Republic of	27.7	40.7	56.7	73.8	79.6	81.9	81.5
China, People's Republic of	19.5	17.4	19.4	26.4	36.2	50.0	59.2
Cambodia	10.3	16.0	9.9	15.5	18.6	19.8	23.4
Indonesia	14.6	17.1	22.1	30.6	42.0	49.9	55.3
Lao People's Democratic Republic	7.9	9.6	12.4	15.4	22.0	33.1	35.0
Malaysia	26.6	33.5	42.0	49.8	62.0	70.9	76.0
Myanmar	19.2	22.8	24.0	24.6	27.0	31.4	30.6
Philippines	30.3	33.0	37.5	48.6	48.0	45.3	46.9
Thailand	19.7	20.9	26.8	29.4	31.4	44.1	49.9
Viet Nam	14.7	18.3	19.2	20.3	24.4	30.4	35.9
Bangladesh	5.1	7.6	14.9	19.8	23.6	30.5	36.6
India	17.9	19.8	23.1	25.5	27.7	30.9	34.0
Nepal	3.5	4.0	6.1	8.9	13.4	16.8	19.7
Pakistan	22.1	24.8	28.1	30.6	33.0	35.0	36.7
Sri Lanka	16.4	17.6	18.6	18.5	18.4	18.2	18.5

Source: World Bank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed 19 September 2019).

In Figure 8, we examine the relationship between shares of GDP and employment in agriculture from 1961 to 2013. Both shares tended to simultaneously decrease over time, though there are variations across countries. The ROK showed the largest changes in both GDP and employment shares. Starting from low levels of GDP and employment shares, the paths of Japan and Malaysia also overlap that of the ROK. A similar path is followed by the Philippines, Indonesia, the PRC and Viet Nam. In contrast, Thailand showed a unique pattern, in which the share of GDP decreased first while that of employment stayed relatively constant. This indicates that the share of nonfarm income of agricultural households increased. Subsequently, the employment share started decreasing, which brought Thailand back to a situation comparable to the Philippines and Indonesia.

South Asia does not significantly deviate from the patterns observed in East Asia. Except Pakistan and early years of Sri Lanka, South Asian countries seem to closely trace the trajectory exhibited by the Lao PDR and Viet Nam in Southeast Asia.

Figure 8: Gross Domestic Product Share and Employment Share of Agriculture (%) in Asia, 1961–2015



GDP = gross domestic product.

Note: GDP share is on the *y*-axis; employment share is on the *x*-axis. The database includes 2015 because the recent data include forestry and fishery together with agriculture for value-added percent of GDP.

Source: World Bank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed 19 September 2019).

Outflow of labor from agriculture also involves intergenerational issues. In some countries, such as the ROK, the PRC, and Japan, farmers cannot find successors to take over their farming, which exacerbates the labor shortage problem but promotes farm size expansion in the long run. In this regard, it is also important to note that the migration of labor to urban sectors often leave women or grandchildren/grandparents in rural areas, which also exacerbate the need to substitute for missing labor by machines.

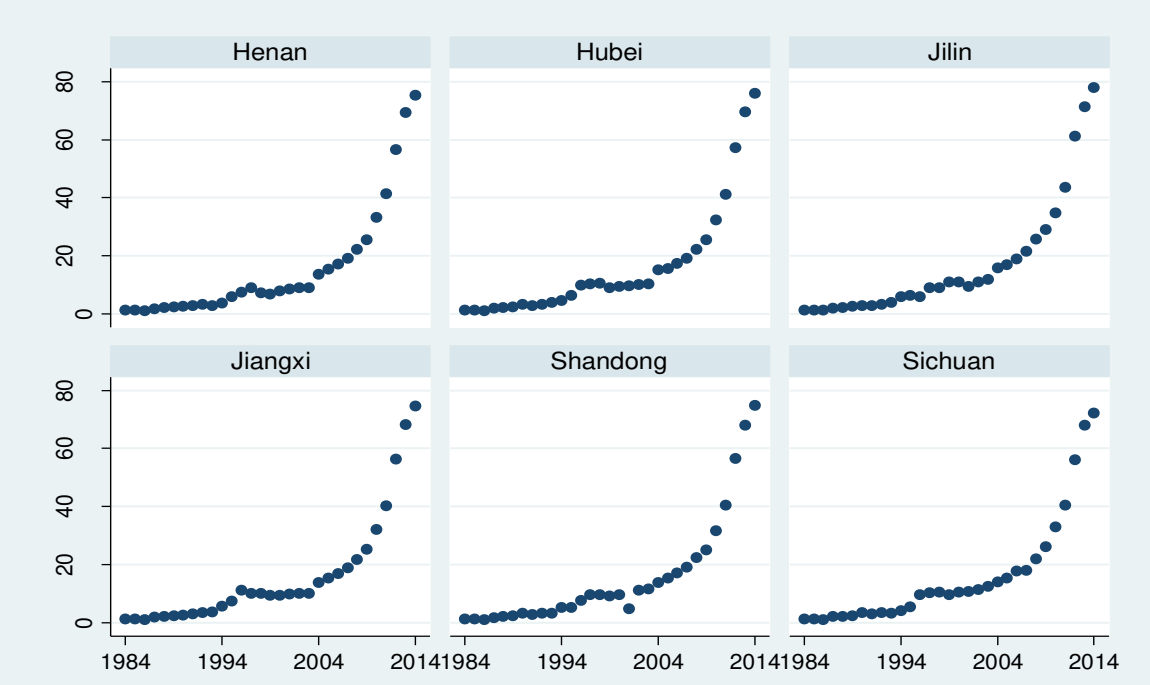
Successful industrialization not only led to the large-scale transformation of the agricultural section through a reduction in its contribution to GDP and employment (which also resulted in a

substantial reduction in poverty level), but also created serious labor shortage and thus a rapid increase in real wages. As reported in Wiggins and Keats (2014, especially Figure 11), rural wages in the region have been increasing fast recently.

In this context, whether or not the Lewis turning point has been passed is an interesting empirical issue. It is known that Japan and the ROK passed the Lewis turning point around 1960 and 1975, respectively (Minami 1968; and Bai 1982). More recently, Thailand, the PRC, and Indonesia appeared to have passed the turning point (Zhang, Yang, and Wang 2011). Viet Nam seems to be approaching the turning point relatively quickly.

Figure 9 shows changes in rural real wage in six provinces in the PRC: Hebei, Hubei, Jilin, Jiangxi, Shandong, and Sichuan (Wang, Yamauchi, and Huang 2016). Strikingly, an acceleration of rising real wages after 2000 seems to be common in most provinces. How to tackle labor shortage (and rising real wages) is an emerging issue after 2000, which is consistent with the turning point reported for the PRC (Zhang, Yang, and Wang 2011).

Figure 9: Real Agricultural Wage in Selected Provinces in the People's Republic of China, 1984–2014

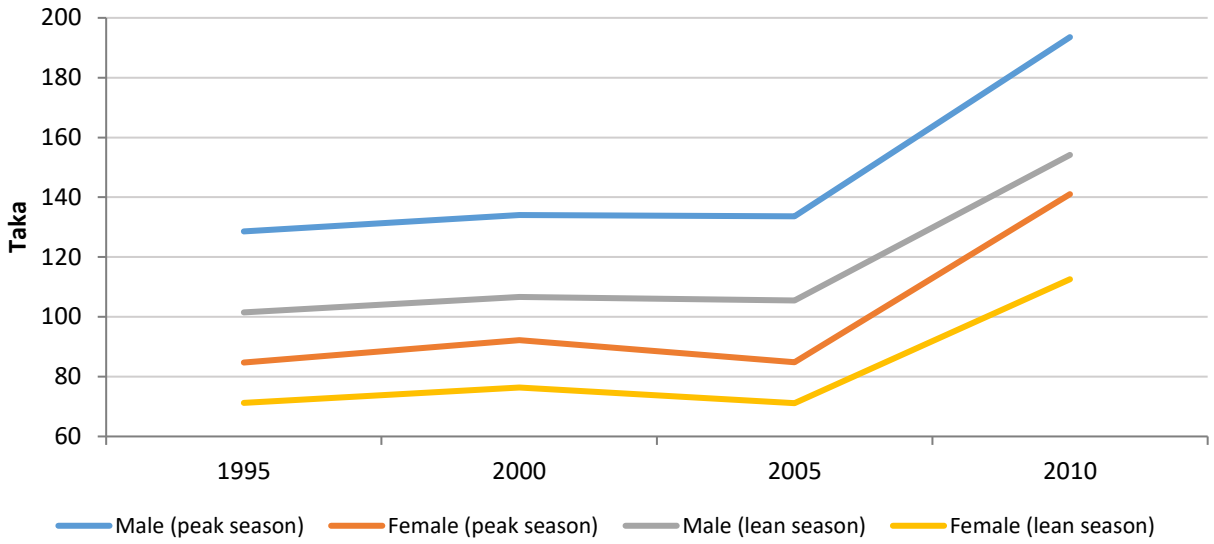


Source: X. Wang, F. Yamauchi, and J. Huang. 2016. Rising Wages, Mechanization and the Substitution between Capital and Labor: Evidence from Small Scale Farm System in China. *Agricultural Economics* 47: 309–317.

Zhang et al. (2014) analyzed real rural wages in Bangladesh. Figure 10 shows male and female real wages in both peak and lean seasons in 1995–2010. It is clear from this that real wages for

both male and female in both seasons started rising after 2005. Because of relative shortage of labor in the labor market driven by successful expansions of nonagricultural sectors, the upward trend of real wages is expected to continue in recent years after 2010.

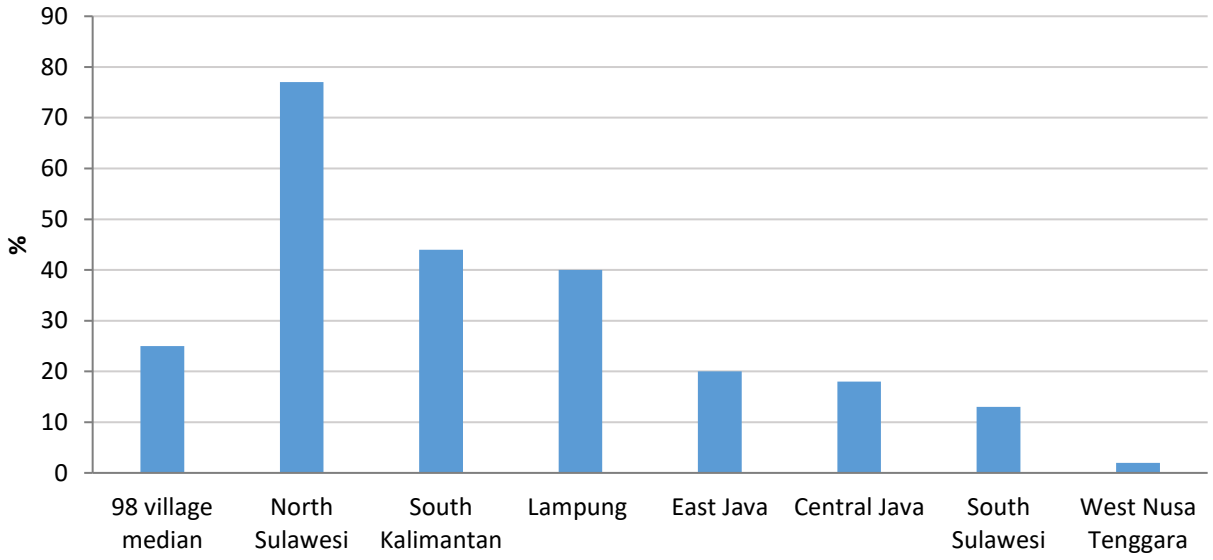
Figure 10: Real Agricultural Daily Wages in Bangladesh



Source: X. Zhang, S. Rashid, K. Ahmad, and A. Ahmed, 2014, Escalation of real wages in Bangladesh: Is it the beginning of structural transformation. *World Development*, (table 1, panel B).

Figure 11 shows percentage change of rural real wage in Indonesia over the period of 2007–2010 calculated from the panel household surveys conducted in 98 villages in 7 provinces over 5 macro regions. The sample was designed to represent the major agro-climatic zones in Indonesia. The median change in the 98 villages is 25% over 3 years. The rate of change is comparable to that reported in Bangladesh (Figure 10).

Figure 11: Change in Rural Real Wage in Indonesia, 2007–2010



Source: Author's estimates.

IV. TECHNOLOGICAL AND INSTITUTIONAL INNOVATIONS

A. Innovations and Agricultural Transformation in Asia

The majority of farmers in Asia are smallholders. Given rising real wages in rural areas, the conventional view that small farms are more productive is currently challenged. Labor-intensive production methods are not an optimal choice anymore in large parts of Asia. However, transition to more capital-intensive methods using machines requires a realization of scale economies, and a critical constraint is relatively small farm size in the region. The current land markets are unable to help progressive farmers to consolidate land. I discuss technological and institutional innovations under such circumstances in this region. They include activation of land rental markets, land consolidation, and mechanization in different forms including the emergence of machine service providers, which together introduce more labor-saving production methods. The emergence of the advantage of large-scale farming is discussed here.

Although small farms in Asia achieved higher land productivity than their larger counterparts in the past, they are facing more and more challenges as structural transformation has been occurring in most developing countries in Asia. In these countries, the rapid growth of the nonfarm sector has created more lucrative employment opportunities, which has resulted in a higher real wage in both farm and nonfarm sectors. Coupled with technological advances in manufacturing industries,

the price ratio of labor to machine use is increasing, which renders the substitution of labor by machine profitable. The rapidly growing machine rental markets in the PRC and Viet Nam represent a response to such trends in recent decades (see, for example, Liu et al. 2020; and Zhang et al. 2011). As farming systems gradually change from labor-intensive to capital-intensive systems, the advantage of small farms relying on family labor is declining, while large farms' advantages are enhanced by farm machinery.

Recently, we also observed an evolution of machine service providers as an institutional response to reduce the user cost of machine use. For example, in the PRC (Yang et al. 2013), small farms can contract with the provider to use machine services, rather than renting or purchasing machines, in order to save on labor costs. By contracting with a large number of small farms, the provider can enjoy scale economies, provided that the transaction cost of machine service provision is sufficiently low. If it is high, small farms cannot save labor as much as large farms.

It is still also possible that farmland consolidation can be facilitated by market transactions as well as institutional arrangements. Historically, consolidation was largely achieved through market transactions in many countries of the Organisation for Economic Co-operation and Development. Previously, in the PRC, land transactions were seriously constrained by the insecurity in farmers' individual land rights, but farmland rental arrangements have been facilitated recently through both more secure land contract rights and online services provided by county and township governments in every province in the PRC. In some areas, land banks are also established to facilitate borrowing and lending (renting in and renting out) of farmland. In this way, farm size expansion is taking place in the PRC (Huang and Ding 2016).

In sum, when the real wage rate is low, the optimum farm size is small and the inverse correlation between farm size and productivity tends to emerge. When the wage rate increases, mechanization will take place to save labor. Since machines and land are complementary and machines are indivisible to some extent, the optimum farm size tends to increase. If farm size adjustments take place smoothly through market transactions and institutional arrangements, efficient large farms emerge. In practice, however, land markets may not function smoothly, so a positive relationship can arise between farm size and productivity in high-wage economies.

B. Recent Evidence from Several Countries in Asia

I examine the validity of our arguments by drawing on recent empirical evidence available from East Asian countries (Otsuka, Liu, and Yamauchi 2016). They include case studies in Indonesia (Yamauchi 2016), Viet Nam (Liu et al. 2020), the PRC (Wang, Yamauchi, and Huang 2016; Wang, Yamauchi, Otsuka, and Huang 2016; and Wang, Yamauchi, Huang, and Roselle 2020), and India (Foster and Rosenzweig 2011, 2017; and Deininger et al. 2018). These recent studies explicitly look at the impact of rising real wages on land and machine service transactions and the dynamically changing disadvantage of small farms or the emerging advantage of large farms. This is a major departure from the earlier literature that assessed factors that were considered to explain the inverse relationship between farm size and productivity observed in cross-sectional data.[3]

Indonesia is an interesting case for the purpose of our study because of the coexistence of small farms in Java and relatively large farms in the outer islands. Yamauchi (2016) examines the dynamically changing patterns of land use, capital investments, and real wages by using farm household panel data from seven provinces collected in 2007 and 2010. His regression analyses show that an increase in real agricultural wages induced the substitution of labor by machines, either through machine rentals or machine service providers, notably among relatively large farmers. The total amount of payments for hired-in machines or services or both has increased significantly in response to rising real agricultural wages, especially among relatively large farms. They tend to increase the scale of operation by renting in more land when real agricultural wages increase. Further, the effect of an increase in farm size on crop productivity per hectare becomes positive among relatively large farms. Thus, the Indonesian case study clearly supports our hypothesis that the efficiency of large farms increases with rising real agricultural wage rates.

The case of Viet Nam resembles that of Indonesia. Liu et al. (2020) use data from 1992 and 1998 Viet Nam Living Standards Surveys and from four rounds of Viet Nam Household Living Standards Survey data between 2002 and 2008. This makes it possible to investigate machine use

[3] The existing empirical tests on the inverse relationship are grouped into several types. The first type investigates whether the advantage of small farms can be attributed to imperfect factor markets, particularly the labor market. The emerging reality that real wages are rising rapidly in East Asia is related to this. The second type inquires whether unobserved factors, such as soil quality, can explain the inverse relationship if such factors are unevenly distributed between small and large farms (Benjamin 1995). The third is concerned with the effect of measurement errors of farm size on the inverse correlation between farm size and productivity (Lamb 2003).

and the farm size–productivity relationship from the 1990s to the 2000s. Descriptive analysis suggests that tractor rental has become more common: in 2008 more than 60% of farms rented-in machines, whereas less than 20% did so in 1992. Rapid increase in tractor use would be associated with an increase in the relative advantage of large farms. Consistent with such an expectation, large farmers are more likely to use agricultural machines, pointing to the scale economies arising from machine use. Interestingly, machine use was not responsive to the real agricultural wage in 1992 or 1998 but became significantly responsive in 2006–2008, suggesting the emergence of a clear substitution relationship between machine and labor in recent years when the wage rate has become high. Such differences may be attributed to the development of machine rental markets over time. The estimation results of the paddy yield regression demonstrate that the inverse relationship between farm size and land productivity has significantly lessened: when farm size doubled, the expected paddy yield is estimated to have decreased by 15.6% in the 1990s but only by 6.1% in the late 2000s. Thus, the inverse relationship is lessened but not reversed. Yet, another interesting finding is that the inverse relationship may be reversed in areas where farm size is larger and the wage rate is higher. This indicates that a positive relationship has emerged between farm size and productivity in advanced areas where the wage rate is higher. This result is also consistent with the observation of Estudillo and Otsuka (2016) that the average farm size among their sample households increased from 1.0 ha in 1996 to 1.4 ha in 2009 in the Mekong Delta region.

The economy of the PRC has been rapidly growing over the last three and one-half decades, and the wage rate has been rising sharply, particularly since 2003 (Zhang, Yang, and Wang 2011). Correspondingly, the use of riding tractors and combine harvesters is increasing (Yang et al. 2013). Yet the average farm size remained at 0.6 ha in 2010, increasing only by 0.05 ha per year since 2000, even though land rental markets have become increasingly active (Kimura et al. 2011; and Huang, Wang, and Qui 2012). More recently, Huang and Ding (2016) pointed out that farm size in the PRC is somewhat underestimated.

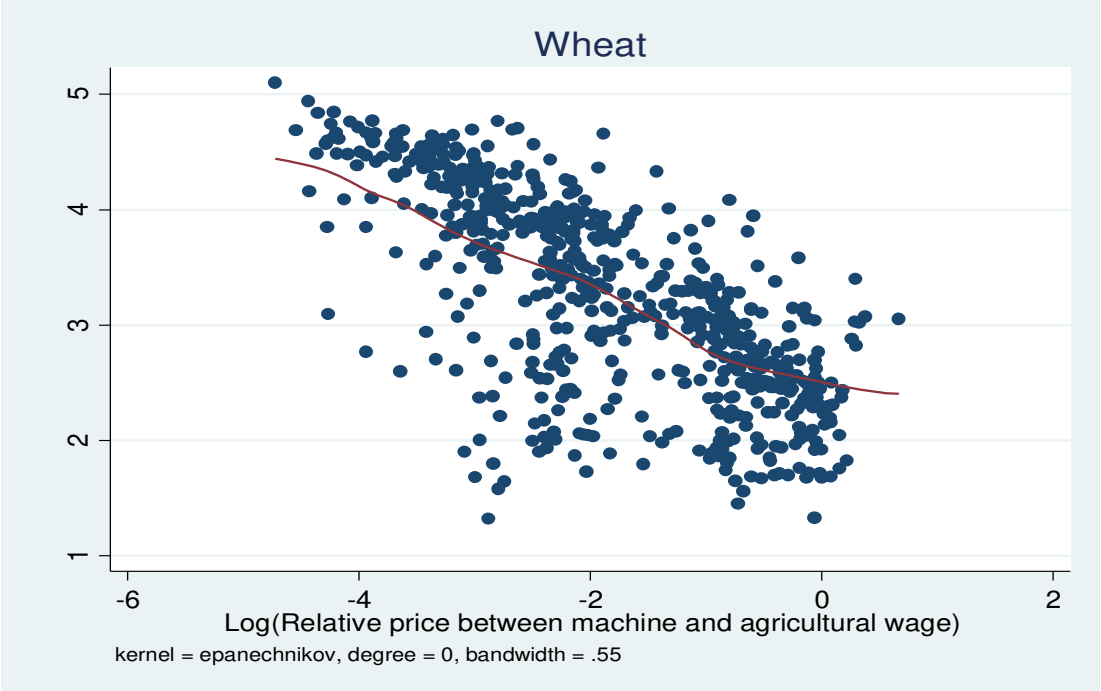
Using farm household panel data from the PRC, collected in six provinces in 2000 and 2008, Wang, Yamauchi, Otsuka, and Huang (2016) analyze the dynamic changes in land rental transactions, machine investments, and the use of machine services. Their study looks at the effects of nonagricultural and agricultural wage growth, changes in the migration rate, and the proportion of nonagricultural income, all of which are estimated at the village level, on changes in self-

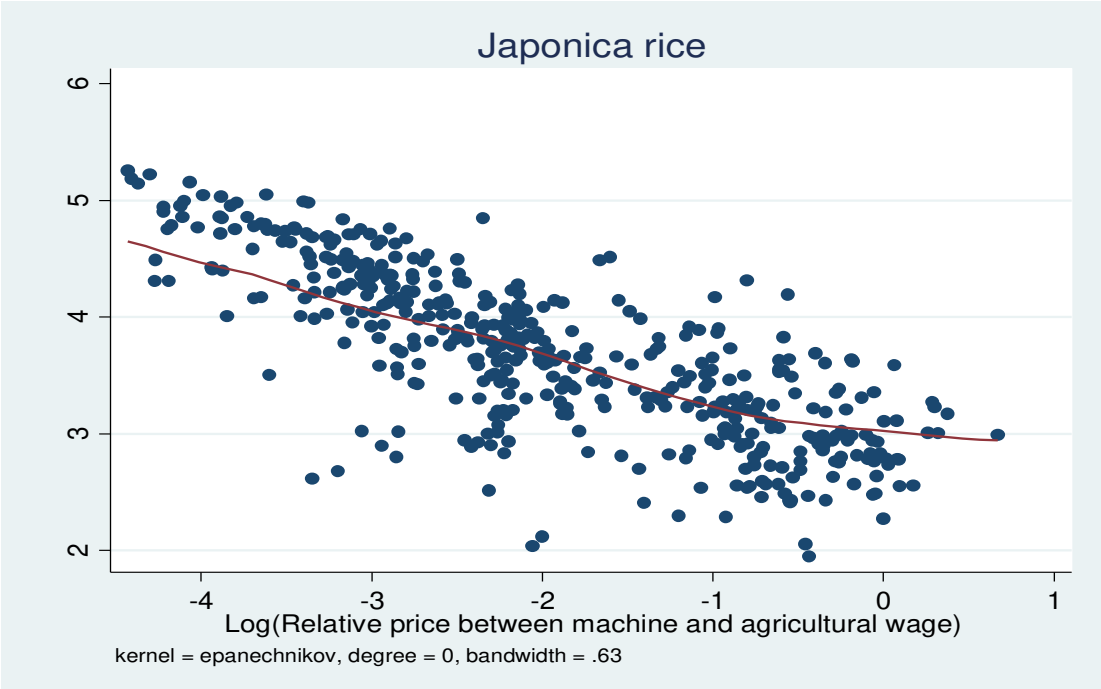
cultivated farm size, rented-in land areas, machine services used, and machine investments. The regression results show that increases in nonagricultural wages, the proportion of nonagricultural income, and the migration rate lead to the expansion of the operational farm size. Consistently, the demand for machine services also increased along with increases in agricultural wages and migration rates. This effect is larger for relatively large farms.

As in the case of the Indonesia study, the regression results of crop income equations support the hypothesis of complementarities between rented-in land and machine services demanded, especially among relatively large landholders in the PRC. In other words, the possibility of renting in land and the availability of machine service providers led to expansion of farm size to take advantage of scale economies.

Wang, Yamauchi, and Huang (2016) used province-level crop-wise panel data in the PRC to investigate the substitutability between agricultural labor and machine service. They support the conjecture that machines are increasingly used to substitute for labor under the circumstances where the real wage has been rapidly increasing. Figure 12 shows the relationship between machine use per hectare (expenses) and the relative wage of labor to machine cost in wheat and (japonica) rice production. In the production of both crops, an increase in agricultural wage relative to machine cost led to intensive machine use (measured by expenses on mechanical operations).

Figure 12: Expenses on Mechanical Operations in the People's Republic of China, 1984–2014





Source: X. Wang, F. Yamauchi, and J. Huang. 2016. Rising Wages, Mechanization and the Substitution between Capital and Labor: Evidence from Small Scale Farm System in China. *Agricultural Economics* 47: 309–317.

Wang, Yamauchi, Huang, and Roselle (2020) used the same household panel used in Wang, Yamauchi, Otsuka, and Huang (2016) to investigate the role of land fragmentation in mechanization. It is clearly shown that fragmented farmlands discourage mechanization. All

conditions being equal, the consolidation of fragmented lands could improve production efficiency by lowering transaction costs in mechanization. More recently, Liu, Zhou, and Yamauchi (2021) show that plot size itself also significantly matters in the decision making on machine use.

Two recent movements in the PRC deserve special attention. First, in northeast PRC, machine service providers directly attempt to consolidate farmland by renting in land from smallholders to realize scale economies. However, such land rental contracts with small farmers are mainly short-term and often subject to annual renewals because small farmers feel insecure about renting out their land under long-term contracts because of the lack of private land ownership. They also expect the land rent to increase over time, and thus they hesitate to sign long-term contracts. Second, recently, farmland rental arrangements have been facilitated through the internet by local governments in nearly every province. These new institutional arrangements are induced by the increasing optimum size of farm operation in the PRC (Huang 2017).

There are papers that focus on the above issue in the context of India. Foster and Rosenzweig (2011) used rural, economic, and demographic survey panel data from India to examine the relationship between farm size and productivity based on a model incorporating agency costs favoring family workers, scale-dependent returns to mechanization arising from the fact that a larger contiguous land area is better suited for high-capacity machinery. Large farms that use substantially less labor per acre are more mechanized and more efficient. Foster and Rosenzweig (2017) seek to explain the U-shaped relationship between farm productivity and farm scale—the initial fall in productivity as farm size increases from its lowest levels and the continuous upward trajectory as scale increases after a threshold—observed across the world and in low-income countries. They showed that the existence of labor-market transaction costs can explain why the smallest farms are most efficient, slightly larger farms least efficient, and larger farms as efficient as the smallest farms. To explain the rising upper tail of the U characteristic of high-income countries requires there be economies of scale in the ability of machines to accomplish tasks at lower costs at greater operational scales. Using data from the India ICRISAT VLS panel survey, they find evidence consistent with these conditions, suggesting that there are too many farms, at scales insufficient to exploit locally available equipment capacity-scale economies.

In the similar line of discussion, Deininger et al. (2018) show that the inverse farm size–

productivity relationship has been weakened over time, especially in recent years. Labor market imperfection is highlighted in their work to play an important role in explaining changes in the inverse relationship.

Figure 4 shows trends in labor and land productivities in South Asia. In contrast to some countries in East Asia, we have not observed biased trend in increasing labor productivity while land productivity remains rather constant after some point. Though the possibility of mechanization has been in scope in the region, the figure suggests that scale economies have not been realized yet in South Asia; for example, India where the above research findings were concentrated. Changes in the average farm size in South Asia are also consistent with the above observations in Figure 2, i.e., farm size has not been increased even in very recent years.

On the other hand, Takeshima et al. (2021) report that mechanical tools have spread widely in South Asia over the past few decades, but possibly in ways not displacing substantial labor force in agriculture, which is appropriate in raising labor productivity in the labor-abundant environment. This has been achieved by the spread of various types of small-scale machines, including mechanical water-lifting tools, tens of millions of which are in South Asia (Mandal, Biggs, Justice 2017). Since the 1990s, the use of small-scale shallow tube wells and motorized pumps has increased the extraction of groundwater and surface water in Bangladesh, where importation of shallow tube wells was liberalized in the 1990s (Ahmed 1995), as well as Nepal and the Indo-Gangetic Plains region of India (Shah et al. 2009). Power tillers have spread as well for land preparation and local transportation. At the same time, four-wheeled, riding tractors that have been more common in India and Pakistan might have been more suitable in rice-nonrice crop rotation common in parts of South Asia like India, and mechanization might have led to significant area expansions, sustaining the overall demand for labor (Pingali 2007). The growth of the domestic manufacturing industry, such as in India, facilitated the development of small four-wheeled tractors that are more suitable on smallholder-dominated upland in the region (Pingali 2007). These mechanization patterns may explain why the land-labor ratio did not increase with the increases in tractor horse-power per worker (Appendix, Figure A2). The above discussion suggests that the phenomena currently observed in South Asia could be a prelude to mechanization in a larger scale, but the preconditions include the ease of land arrangements in order to increase the average operational size to enable machine use.

In contrast to the conventional view of the small farm advantage, the evidence supports the dynamic shift of the relative advantage from small to large farms in Asia. That is, the inefficiency of small farms increases with rising real wages, whereas large farms increase their productivity by utilizing large-scale machines efficiently, saving increasingly costly labor, and thereby realizing scale economies. How far and how rapidly this trend continues will significantly affect the efficiency of farming in Asia in coming decades. Smooth transfer of farmland from those who exit from farming to those who expand farming is critically important, and this would be a solution for the labor shortage problem, including the intergenerational transfer of farming, discussed in the previous section.

The evidence suggests that the relationship between the land-labor ratio and the use of machinery is not simple because the development of land and land rental markets and that of machinery rental and service markets affect such a relationship. This is likely to explain why the relationship between land-labor ratio and machinery use per unit of land varies from country to country even in Asia.

V. CONCLUSION

This paper has reviewed historical paths of agricultural development and described economy-wide changes that had undeniable impacts on agricultural transformation in Asia. Though the region was heterogeneous in initial endowment, labor was relatively abundant (land is relatively scarce) and land productivity was augmented through intensifications such as labor-intensive production methods as well as applications of biochemical technologies. However, more recently, the region has encountered a dramatic change in relative factor prices because of successful industrialization by which labor was absorbed in nonagricultural sectors. In many countries, labor is not abundant anymore, and thus labor-saving methods had to be introduced; for example, replacing increasingly expensive labor by machines. Under such circumstances, the inverse productivity-size relationship is becoming less likely to hold and is being replaced by the positive relationship. Some countries are showing a divergence from the Asian path to the European path, both initially described by Hayami and Ruttan (1985).

Consistently, a reversal of the declining trend of average farm size has also been confirmed in some countries. For example, active land rental markets enable some farmers to increase

operational size, whereas other farmers exit from agriculture by renting out their lands. Emerging labor shortage in the region starts creating the advantage of large-scale farming, in contrast to the conventional small-farm advantage.

High income growth and fast urbanization introduced some other fundamental transformations, such as nutrition transitions on the demand side and modernization of value chains and emergence of contract farming on the supply side, that respond to diverse and new food demands especially driven by rapid urbanization and economic growth. However, Asia remains characterized by the duality of modern and traditional systems because of the sustained dominance of a large number of smallholders who may not meet the conditions required to enter the modern value chains. To sustain agricultural production in this region, large-scale institutional and technological innovations beyond the purview of Hayami and Ruttan (1985) are called for.

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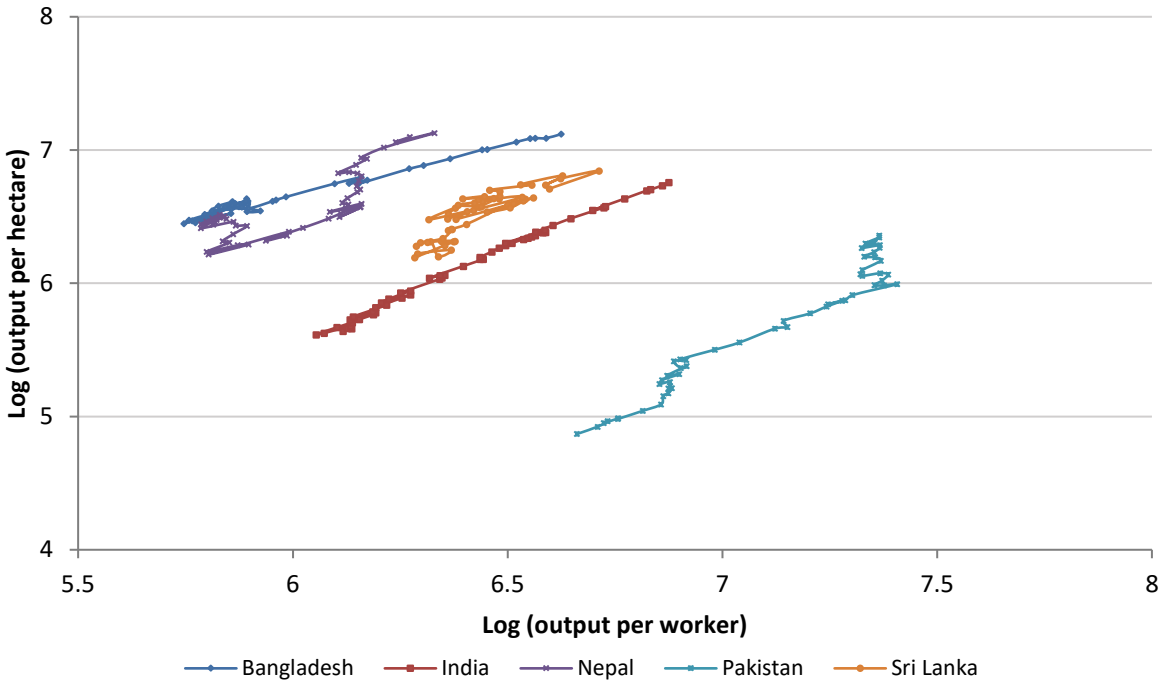
APPENDIX: SOUTH ASIA

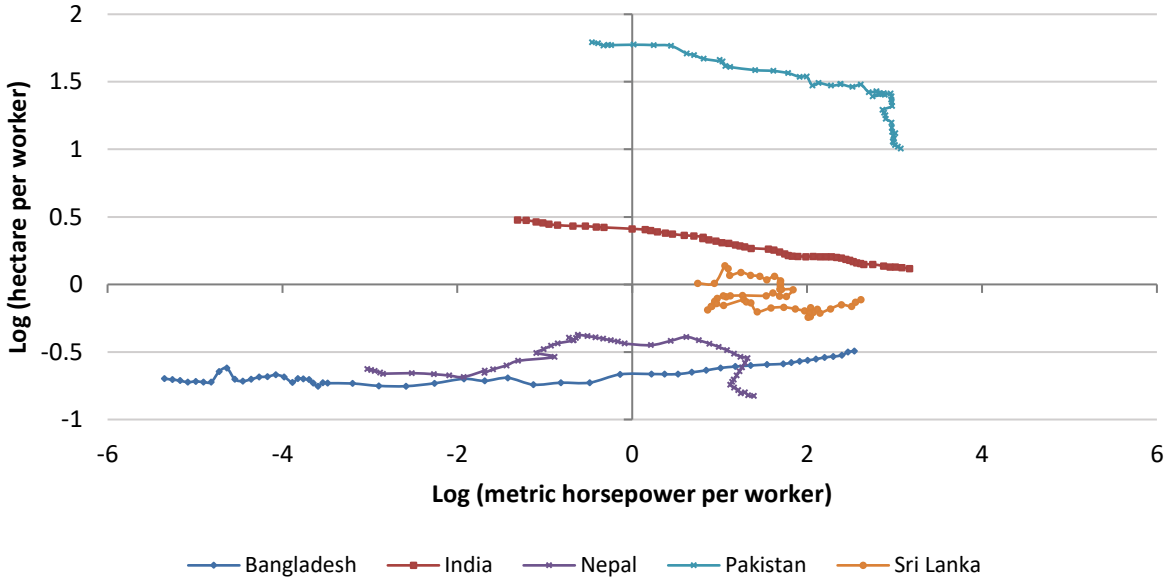
Figure A1: Output per Worker versus Output per Agricultural Land in South Asia, 1961–2014



Note: Gross agricultural output in 2005 United States dollars per the number of economically active adults in agriculture is on the *x*-axis; gross agricultural output in 2005 United States dollars per total agricultural land in hectares of rainfed cropland equivalents is on the *y*-axis. They are both log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

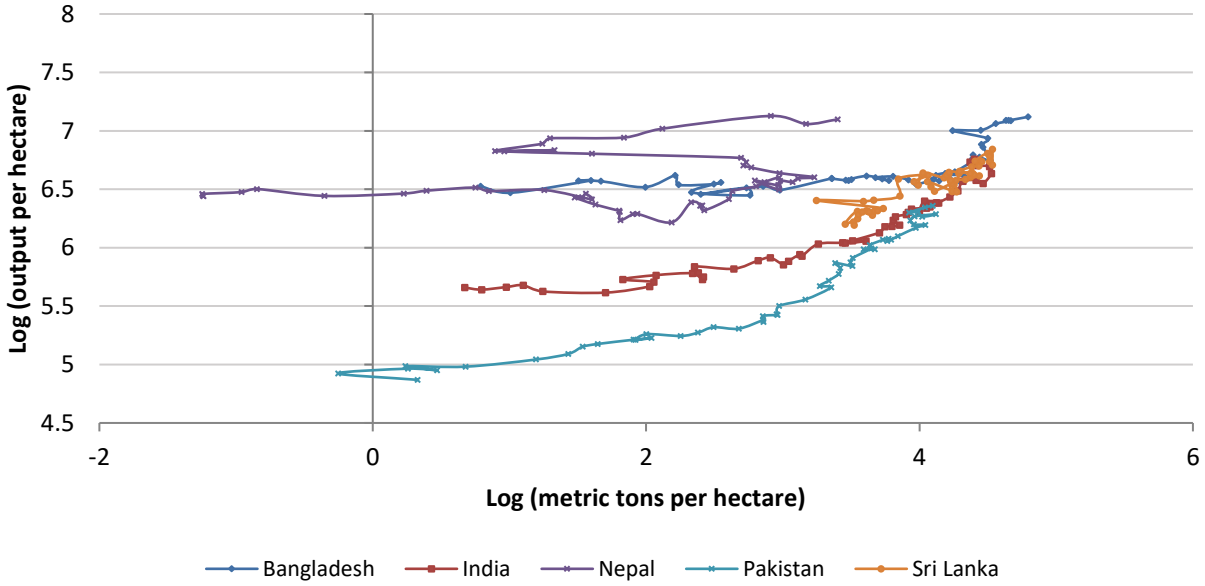
Figure A2: Land-Labor Ratio and Machine Use per Worker in South Asia, 1961–2014



Note: Metric horsepower of machinery per the number of economically active adults in agriculture is on the *x*-axis; total agricultural land in hectares of rainfed cropland equivalents per the number of economically active adults in agriculture is on the *y*-axis. Both are log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

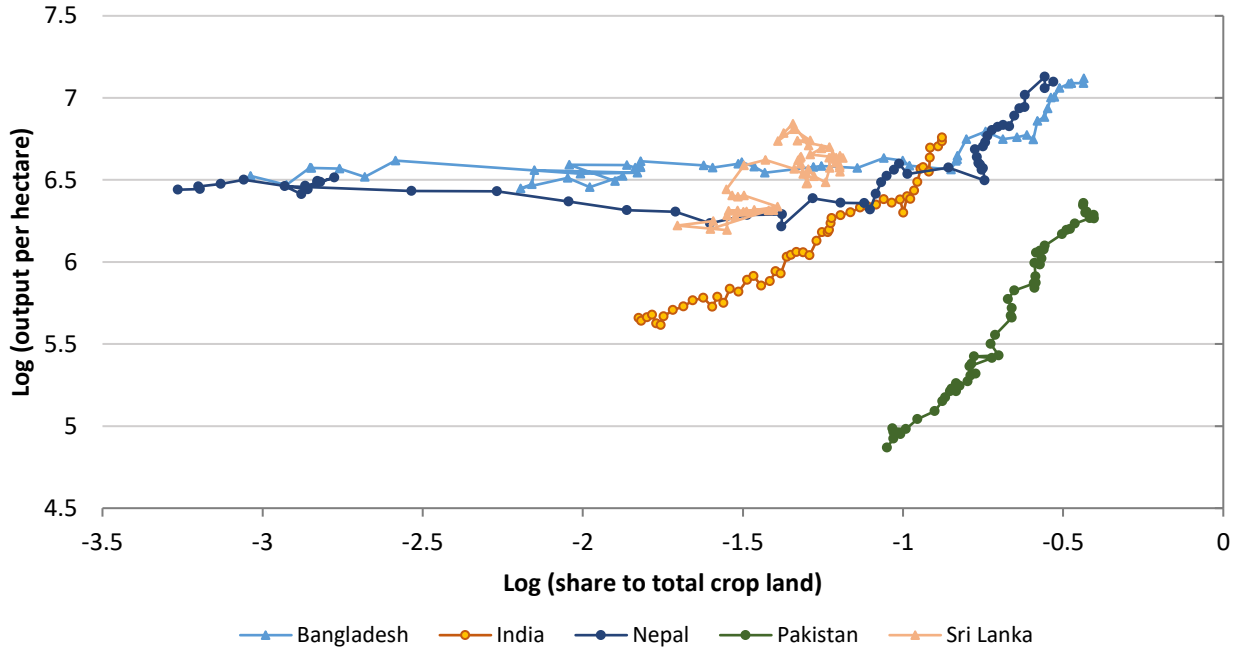
Figure A3: Land Productivity and Fertilizer Input per Hectare in South Asia, 1961–2014



Note: Metric tons of fertilizer per total agricultural land in hectares of rainfed cropland equivalents is on the *x*-axis; gross agricultural output (2005 United States dollars) per total agricultural land in hectares of rainfed cropland equivalents is on the *y*-axis. Both are log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

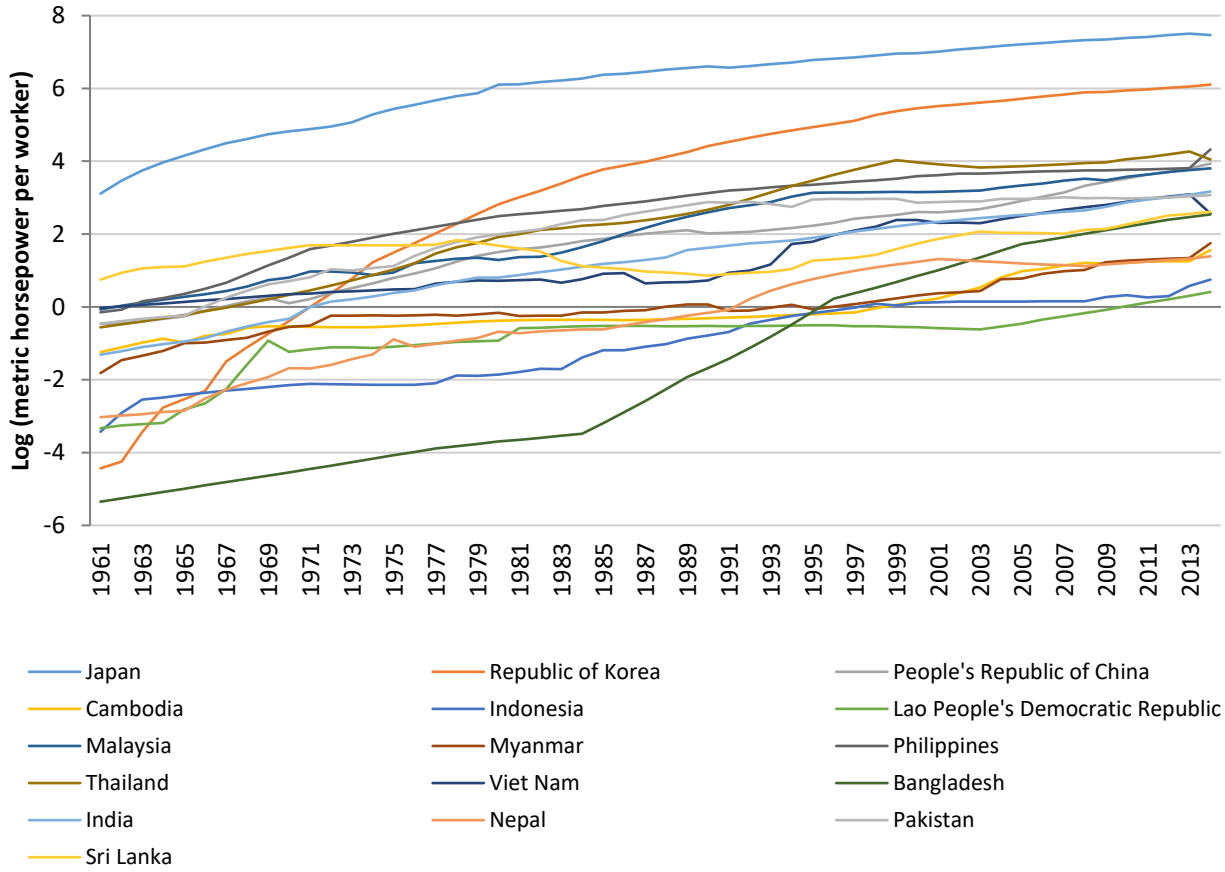
Figure A4: Irrigation and Land Productivity in South Asia, 1961–2014



Note: The share of irrigated land in total cropland is on the x-axis; gross agricultural output (2005 United States dollars) per total agricultural land in hectares of rainfed cropland equivalents is on the y-axis. Both are log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

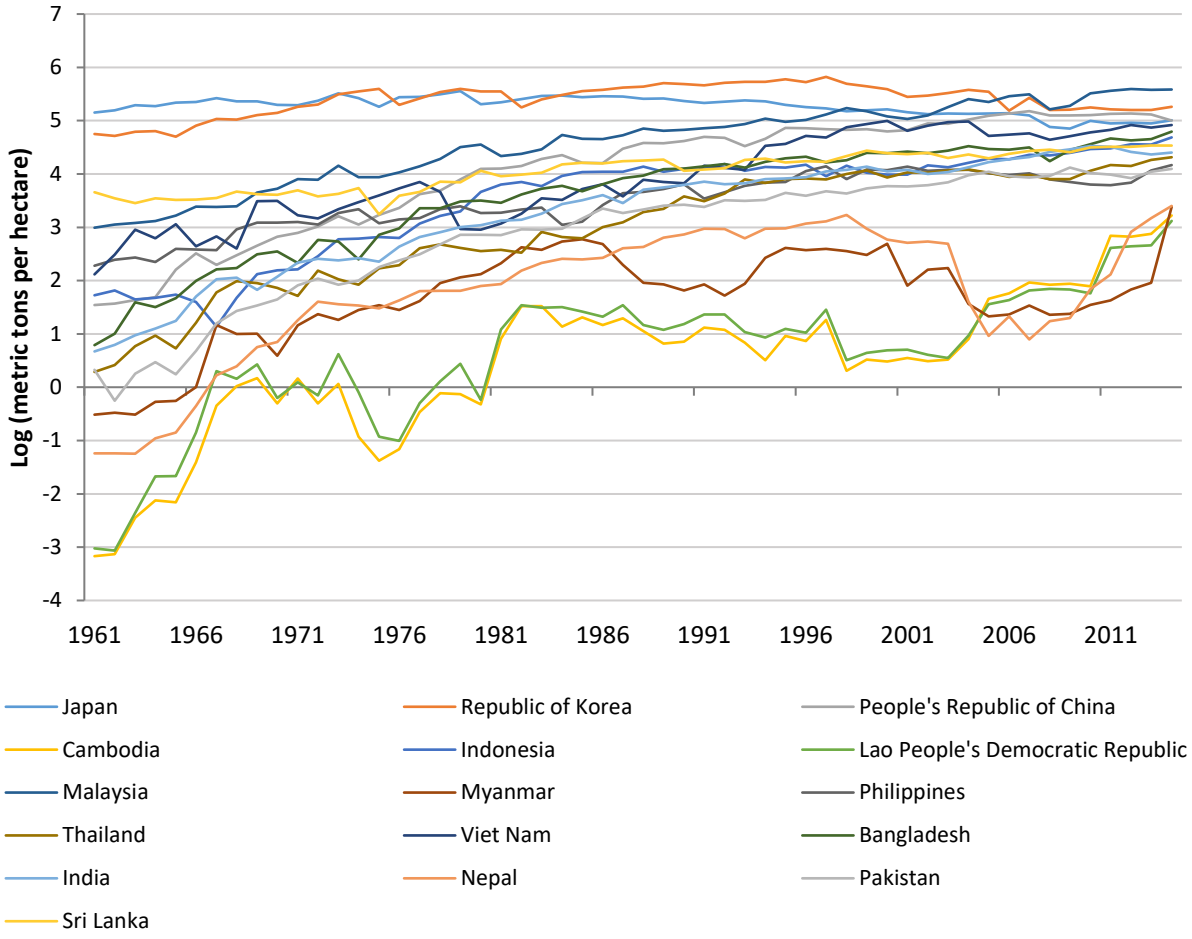
Figure A5: Machine Use per Worker over Time



Note: Metric horsepower of machinery per the number of economically active adults in agriculture is on the y-axis in log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).

Figure A6: Fertilizer Use over Time



Note: Metric tons of fertilizer per total agricultural land in hectares of rainfed cropland equivalents is on the y-axis in log transformed.

Source: U.S. Department of Agriculture. Economic Research Service. www.ers.usda.gov (accessed 7 October 2019).