Land Ownership and Development: Evidence from Postwar Japan

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Abstract

This paper analyzes the effect of land ownership on technology adoption and structural transformation using Japanese land reform as a natural experiment. The reform redistributed a large area of farmlands from landlords to tenants, or cultivators of these farmlands, who became land owners during the reform. The redistribution policy increased the adoption of new labor-saving technologies in agriculture which became available after the reform, and that, because of the technology adoption, it enabled the out-migration of young population from rural to urban areas when the urban sectors were growing. I also analyze the aggregate impact of labor reallocation on economic growth by using a simple growth model and micro data. I find that it increased GDP by about 12 percent of the GDP in 1974 during 1955-74. I also find a large and positive effect on agricultural productivity.

Keywords: Land ownership, property rights, technological change in agriculture, capital-labor substitution, industrialization, labor reallocation, structural transformation

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It is not paying no rent that makes the peasant proprietor industrious; it is that the land is his own.

- John Stuart Mill

Give a man the secure possession of a bleak rock, and he will turn it into a garden; give him a nine years' lease of a garden, and he will convert it into a desert

- Arthur Young

Recent scholars regard secure property rights as an important precondition for long-term economic development (North 1981, De Soto 2000, Sokoloff and Engerman 2000, Acemoglu et al. 2001, 2002, Besley and Persson 2011). There is also a considerable amount of micro evidence that is supportive of these arguments. However, although the effect of property rights has been studied quite extensively, the effect of land ownership has received much less attention. A famous quote by Arthur Young quoted above stresses the importance of land ownership for agricultural production.

It is also known that the extent to which society is willing to accept advanced technologies such as agricultural machinery differs considerably across regions.[2] Reflecting the fact that the adoption rates of the advanced technologies are typically low in developing countries, recent studies have uncovered barriers to technology adoption in agriculture. This paper provides new causal evidence to these strands of literature that the ownership of land (or the means of production) affects the adoption of new agricultural technologies.

The diffusion of advanced technologies in agriculture, and hence the increase in agricultural productivity, may also be associated with industrialization and structural transformation. According to W. W. Rostow (1959), a technological revolution in agriculture was one of the fundamental conditions for sustained industrialization of the British economy. Gollin et al. (2002) also show the importance of high agricultural productivity for industrialization in the United Kingdom. Despite these arguments, how property rights/ land ownership and technological advancement in agriculture are related to the development of urban sectors is still not fully understood.

A natural experiment which occurred in Japan after World War II transferred the ownership of land from landlords to tenants who had cultivated that land. It was one of the historically large land redistribution policies, and nearly all, or about 6 million, farm households were affected. Obtaining land ownership meant that farmers received the exclusive rights to manage their farmlands.[3] This facilitated long-term investments such as machines and land improvement.

To proceed to the empirical analysis, I construct a unique dataset of municipalities from historical documents and censuses. The data on the land reform, which contain detailed information about land transactions during the reform in almost all municipalities, have been digitized. Since other data, such as censuses, have not been available in digital format either, I have also assembled them. These data enable me to rigorously analyze the impact of land ownership reform.

[2]For example, farmers in East Asia have adopted tillers and tractors rapidly since the 1960s and 1970s, while those in Sub-Saharan Africa still mostly rely on human powers (FAO 2003, Pingali 2007).

[3]The ownership was also "secure" given that private property rights were already introduced in the late 19th century, and Land Act, which was enacted after the reform, prevented the re-accumulation of land by landlords.

In the empirical analysis, I compare municipalities with a high share of post-reform owner farmers to those with a low share of them (or those with a high share of post-reform tenant farmers), and examine whether the former municipalities react differently vis-á-vis the latter when agricultural machines become available and urban sectors are growing. The estimation method exploits the fact that post-reform distribution has been determined by the upper limits set by the central bureaucracy prior to the land reform.

As a robustness check, I also compare two adjacent municipalities along both sides of the prefectural boundary. These two municipalities were very similar until they received a different "shock" during the reform. One of them obtained more owner farmers relative to its counterpart because the prefectures to which these municipality belonged had received the different upper limits. I examine how these initially identical municipalities, which had become different from each other due to the reform, responded differently when agricultural machines became available. These two estimation methods yield similar results, suggesting that the exploited variation is arguably random.

I find that the municipalities with high post-reform owner share tended to experience a quick entry of new agricultural machines as compared to the municipalities with low post-reform owner share (or high post-reform tenant share). Moreover, since the new technology had a labor-saving effect, the adoption of these machines reduced the dependence on family labor in agriculture. This led to a reallocation of labor from agriculture to industrial and service sectors in urban centers when these sectors were growing. These migrants were young, and were second or younger sons, and daughters, who had just graduated from junior high or high schools. Figure 1 summarizes these findings as well as the main story of the paper.

Land ownership and technology adoption are likely to affect agricultural productivity. Figure 2 plots agricultural productivity which is defined as real agricultural GDP divided by agricultural employment. The solid line indicates average agricultural productivity for prefectures with a higher share of owner farmers after the reform with respect to the median value, while the dashed line is average agricultural productivity for the prefectures which have a lower share of them (or a higher share of tenant farmers).[4] Two lines seem to have diverged since around 1960, and the difference has become more salient since around 1965. Later, I will show that the pattern clearly corresponds to that of technology diffusion.

Land ownership may increase agricultural investment and hence, agricultural productivity.[5] For example, Banerjee, Gertler, and Ghatak (2002) find that improving the security of the tenure of sharecroppers and regulating land rents have a positive effect on agricultural productivity. Although their study focuses on the effect of strengthening tenant rights, this paper examines the impact of redistributing land from the landlord to the tenant.[6]

[4] I use data at the prefecture level because gross output is available only at that level. I interpolate agricultural employment for some years because the data are only available for every five years.

[5] Relatedly, the literature on secure property rights is quite vast, which shows the effect on; agricultural investment (Besley 1995, Jakoby et al. 2002, Hornbeck 2010), access to credit (Besley et al. 2012), labor supply and migration (Field 2007, de Janvry et al. 2015), poverty reduction (Besley and Burgess 2000), formation of beliefs (Di Tella et al. 2007), and firms' investment (Johnson et al. 2002). Who enjoys the property rights in society is of importance for agricultural investment (Banerjee and Iyer 2005, Goldstein and Udry 2008).

[6] Previous studies of the Japanese land reform examine the short-run effect by focusing on the 1940s and the 1950s,

The causal evidence of agricultural mechanization is very limited in the literature. An exception is Hornbeck and Naidu (2013), who find that, due to the outmigration of the black population caused by the flood in the American South, farm owners in the flooded area increased the capital intensity in agriculture over time.[7] In contrast to their study, this study compares the likelihood of owner farmers adopting agricultural machines to that of tenant farmers.[8]

The second part of the paper focuses on the impact of land ownership and technology adoption on labor reallocation and structural transformation in which I quantify the aggregate impact of the land ownership reform on the entire economy. Jones (2015) hints that agricultural mechanization is an underlying factor behind structural transformation in the United States:

> One useful reference point is the enormous transformation that occurred as the agricultural share of the U.S. labor force went from 2/3 to only 2 percent, largely because of mechanization and technological change. There is no doubt that this had a transformative [effect] on the labor market, but by and large this transformation was overwhelmingly beneficial (p. 27).

Similar to the United States, the mechanization of agriculture progressed in Japan when the economy rapidly grew and the agricultural employment share declined. Also, the similar pattern is observed in Korea and Taiwan (Figure 3).[9] These historical facts suggests that agricultural mechanization might be key for sustained economic growth.

I first extend a property-rights model à la Besley (1995) to include the capital-labor substitution effect in the farmer's production function. Traditional models of property rights do not contain that effect.[10] Therefore, the models may predict that property rights would make more workers *stay* in agriculture because there is an increase in the marginal product of labor.[11] In contrast, an extended model in this paper predicts that the property rights make farmers adopt more machines, which would lead to a decrease in labor if these inputs are substitutes. The model has not only the rural sector, but also the urban sector, as well as multiple locations. Workers can be reallocated across sectors and locations.[12]

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and find either a zero or a negative effect on agricultural productivity (Kawagoe 1995, Ramseyer 2015). In contrast, this paper studies the mid- to long-run effect by focusing on periods when agricultural machines become available (late 1950s-70s). Moreover, these previous studies either use prefectural data, or conduct descriptive analyses, while this study uses municipal data to estimate a causal effect, which substantially increases the sample size. Finally, none of these previous studies examines the impact on technology adoption or labor reallocation.

[7] In the Japanese case, labor was not enforced to outmigrate due to a natural disaster, nor was it the plantation owner's decision to compensate for the lack of workers with relatively cheaper capital.

[8] The literature shows various other barriers for technology adoption; profitability (Griliches 1957), imperfect information and learning (Foster and Rozenzweig 1995, Conley and Udry 2010, Hanna et al. 2014), high transaction costs (Suri 2011), time inconsistency (Duflo et al. 2011), and product quality (Bold et al. 2015). See Foster and Rosenzweig (2010) for an excellent review of recent literature.

[9] Recall that Korea and Taiwan also experienced land reforms after World War II.

[10] See Besley and Ghatak (2010).

[11] See also the discussion in de Janvry et al. (2015). A similar result can be obtained by increasing Hicks-neutral agricultural productivity. Labor will be pulled back to agriculture when the economy is open (Matsuyama 1992).

[12] The details of the model and the formal statement of prediction are found in Section 6. Note that the mechanism in this paper is very different from that of de Janvry et al. (2015), who find that alleviating a land use constraint through the issuance of certificates of property in Mexico has an effect on labor and land allocations. Labor real-

Next, I simulate the model using municipal data, which are used in the first part of the paper. I run counterfactual simulations to make a comparison with the baseline results. Compared to the counterfactual case which assumes that there was no land reform, I find that the land reform has a large positive effect on industrial development and economic growth. The reform yielded many owner farmers who were motivated to adopt labor-saving agricultural technologies. This made it possible to reallocate more workers to industries and service sectors in urban centers when these sectors were growing. The labor reallocation greatly increased the GDP growth rate during the transition period due to a great expansion of the urban sectors. Simulation results show that the cumulative effect of land reform during 1955-74 is about 12 percent of the 1974 GDP. This finding indicates that Japan would have been less prosperous if there had been no land reform.

Empirical studies of structural transformation are very scarce. An exception is Bustos, Caprettini, and Ponticelli (2016), who find that the labor-saving technological change in soy production in Brazil increases local industrial employment and out-migration. In their empirical study, the adoption of agricultural technologies is affected by the potential profitability of adopting them. In contrast, land ownership plays the crucial role in this paper.[13]

The rest of the paper is organized as follows. In the next section, the historical background is briefly explained. This consists of the land reform in the late 1940s, the diffusion of new agricultural technologies in the 1950s, and mass migration of young cohorts and structural transformation in the late 1950s and 1960s. Section 2 describes the data that will be used for the empirical analysis. In Section 3, the main empirical strategy is described. The main identification strategy employs a difference-in-differences estimation method. As a robustness check, I also compare two adjacent municipalities along both sides of the prefectural boundary. The results are shown in Section 4, and the underlying mechanisms are discussed in Section 5. In Section 6, I build a simple growth model which reflects the empirical findings to quantify the aggregate impact of the land reform. Finally, Section 7 concludes. Implications for other countries are also discussed in the same section.

1 Historical background

1.1 Land reform

A historically large-scale land reform occurred between 1947 and 1950 in Japan. The reform was enforced by the occupation forces, and would otherwise have been impossible to implement at that time (Dore 1959). Farmlands were redistributed from landlords to tenants. Tenants therefore suddenly became owners of the land that they had cultivated. This involved a change in the

location in Japan was not caused by alleviating the land-use constraint but, if anything, by reducing a technology adoption barrier.

[13] The literature on structural transformation is quite vast. Herrendorf et al. (2014) provide an excellent review. Related papers in theoretical macro literature are Rogerson (1987), Matsuyama (1992), Caselli and Coleman (2001), Kongsamut et al. (2001), Gollin et al. (2002), Ngai and Pissarides (2007), Acemoglu and Guerrieri (2008), Hansen and Prescott (2008), Hayashi and Prescott (2008), and Boppart (2014). Other related literature is misallocation (Hsieh and Klenow 2009), rural-urban migration (Lewis 1954, Harris and Todaro 1970, Foster and Rosenzweig 2008, Young 2013, Munshi and Rosenzweig 2016), and urbanization (Michaels et al. 2012, Desmet and Rossi-Hansberg 2014).

property rights of nearly all, or about 6 million, farm households, and about 2 million hectare of farmlands were redistributed.[14] There was a dramatic decrease in the share of tenanted land from 45.9 percent to 9.9 percent during the reform (MAF 1956). In contrast, there was a great decrease in the share of owner farmers' land.

Figure 4 shows the distributional shift in the owner share by municipality. The white bars show the distribution before the reform, while the shaded bars display the distribution after the reform. Before the reform, the mean and the standard deviation of the distribution were 0.57 and 0.15, respectively. The reform yielded more owner farmers all over Japan, and these values became 0.89 and 0.06, respectively. This dramatic change occurred within a few years.

The reform also yielded a new spatial distribution of owner farmers. Figure 5 shows the spatial distribution of the owner share across municipalities before the reform. Most of the municipalities have orange or red colors, reflecting the distribution in the previous figure. After the reform, the owner share increased all over the country, and a new cross-sectional variation emerged (Figure 6). The correlation between pre- and post-reform distribution is only 24 %. In other words, the post-reform distribution is quite different from the pre-reform distribution. The emergence of such post-reform variation was due to the upper limits set by the Ministry of Agriculture and Forestry.

Farmlands were purchased on behalf of prefectural governors. Prices were determined by multiplying fixed rental prices in 1945 by one of the multipliers depending on the type of farmland.[15] In addition, there was a compensation of about 220 yen per *tan* of paddy fields (*ta*) (130 yen for dry fields (*hatake*)) for about 3 *cho* (12 *cho* in Hokkaido) of purchase at the maximum.[16]

On average, the government paid about 980 yen per *tan* to a landlord for paddy fields, and paid about 580 yen per *tan* for dry fields.[17] For example, if a landlord had to sell 3 *cho* of his/her tenanted land, the compensation was less than 30,000 yen, which was, on average, less than a third of an annual salary in 1950.[18] Landlords were paid either in cash or in government bonds redeemable within thirty years at the annual interest of 3.6 percent.

Tenants paid the same price as the landlords' selling price to buy the farmland from the government, and it was paid either in cash or spread over thirty years at the annual interest of 3.2 percent. Given the postwar inflation until the end of 1940s and the fixed land price, the land became cheaper and cheaper over time.[19] Therefore, most tenants could complete their payments within a year or two of purchase (Dore 1959).[20]

[14] There were about 6 million hectare of cultivated areas in 1947 (Kayou 1977).

[15] The multiplier was 40 for paddy fields and 48 for dry fields. Since the rental prices were somewhat less than 20 yen for paddy fields and 10 yen for dry fields on average, the price per *tan* was approximately 760 yen for paddy fields and 450 yen for dry fields.

[16] One *tan* is approximately ten are. One *cho* is approximately one hectare, or ten *tan*.

[17] In 1941, tenanted land amounted to about 2.8 million *cho*, and about one half was rented by large landlords who had 5 *cho* or more of the tenanted land. Most of them were non-cultivators (Isozumi 1985).

[18] The annual salary of a worker in a firm with 30 or more employees was about 100,000 yen in 1950. The value was taken from the National Tax Agency's Statistical Survey (*Minkan Kyuuyo Jittai Toukei*).

[19] For example, the value of goods equivalent to 30,000 yen in 1947 would be about 52,000 in 1948 (at the inflation rate of 73.2 percent), and finally about 65,000 in 1949 (25.3 percent). The price data are taken from Statistics Japan's Annual Report (*Syouhisya Bukka Sisuu Nenpou*). Note that the CPI is based on the prices in Tokyo, excluding imputed rents, and the average price between 1934-36 is set as the baseline.

[20] The fixed price is one of the major reasons why the Japanese land reform was "successful." This is in contrast

To complete the reform, the Agricultural Land Act (*Nouchi Hou*) was enacted in 1952, which perpetuated the land allocation by regulating the transaction of land.[21] The Act prevented the re-accumulation of the land by landlords.[22]

1.2 Diffusion of agricultural machines

The mechanization of agriculture in Japan was started by small and handy machines like power tillers, and was enhanced by large and powerful machines like tractors.[23] Thus, there seems to be a path dependency in the process of technology advancement in agriculture. This paper focuses on tilling machines, notably power tillers, as proxy for technological advancement in agriculture.

Before the introduction of power tillers, most farmers had largely tilled the soil by hand or using animals. Figure 8 shows pictures taken in 1956 near Hirosaki-shi in Aomori. The picture at the top shows farmers using traditional farm equipment called *Sanbon-guwa* to till the soil. In contrast, the picture at the bottom shows a farmer using a power tiller. The machines effectively reduced human labor which had previously been used in agricultural production. Hayami and Kawagoe (1989) write:

> Previously, farm operations in Japan had been largely based on manual labor. Especially, land preparation for rice cultivation had been a very arduous task requiring labor of young male workers. With the introduction of power tillers it became possible for female or old-aged workers alone to keep on farming; this enabled young to middle-aged males in farm households to engage mainly in non-farm economic activities (p. 227).

For example, Ishiwatari (1965) found that a farmer owning 3 hectare of farmland in the Shounai Region in Yamagata, who initially had four standing workers, reduced the number of the workers by two due to the adoption of power tillers.

Clayton Merry invented power tillers called "Merry Tiller" in 1947, and he and his brother-in-law started commercializing them in Edmonds, WA. The machines were imported to Japan in 1952, and a Japanese agricultural machine maker *Saiousha*, which made an agreement of technical

to the Korean land reform, for example. Since land prices were expressed in terms of the value of crops, the value of the land went up when the price of the crops increased due to inflation. Therefore, ex-tenants who bought farmlands under the program suffered from a heavy burden of payment (Kajii 1998).

[21] According to Dore (1958), the reason for enacting such a law was the following: "Many Western observers during the Occupation, suspicious of the apparent smoothness with which the reform was carried out, predicted that as soon as the Occupation troops were gone, 'the landlords would soon be back.' They have been proved wrong. The only post-Occupation legislation bearing on the land system has been the Agricultural Land Law of 1952 [...] which had the express purpose of freezing the Japanese system of land tenure in the state in which it emerged from the land reform (p. 185)."

[22] The enactment of such a law could be another reason for the successful land reform, although regulating land transaction may have had a negative effect on the competitiveness of Japanese agriculture in the long run by making the accumulation of farmlands difficult. I examine such a possibility in another project.

[23] The power tiller has several other names: rototiller, rotary tiller, hand tractor, walking tiller, garden tiller, etc. The paper uses the term "power tiller" to refer to two-wheel tractors and the term "tractor" to refer to four-wheel tractors. In Japan, a *torakutaa* usually refers to a four-wheel tractor, while a *kouun-ki* refers to a two-wheel tractor. Two-wheel tractors are very common in Asia, except for India, where four-wheel tractors are more common (FAO 2013).

cooperation with the company, started to sell them a year after.[24] The original power tillers had a 2 to 3 hp air-cooled high-speed engine with a simple structure, and were much lighter and cheaper than similar machines that Japanese makers had developed (Hokimoto 1999). The price of these power tillers were about one half of that of earlier existing similar machines (Kako 1987).[25]

However, the original machines had major defects such as insufficient land cultivation depth, complicated operating procedures, and small engine sizes. The introduction of low-cost power tillers, as well as the enactment of the Agricultural Mechanization Promotion Act, spurted the technological innovation race among Japanese makers.[26] The adaptive research and development made the machines more efficient, powerful, and suitable for land conditions in Japan.

Figure 7 shows that the rapid diffusion of tilling machines has occurred since around 1960. The machines diffused relatively quickly. It only took about ten years to reach 2 million machines.[27]

The rapid diffusion of power tillers was initiated by motivated farmers who obtained land during the land reform (Yanmar 2013). Initially, tenant farmers before the reform preferred relatively cheap and fast-acting short-term investments such as fertilizers and improved seeds (Kawano 1963, NKNC 1964).[28] After the land reform, they started to make long-term investments such as machines and land improvement (NKNC 1964). At the same time, effective and cheap agricultural machines became available to these farmers.

1.3 Migration and structural transformation

Structural transformation occurred when the economy experienced a rapid growth from the late 1950s until the early 1970s (*Koudo Keizai Seichou*).[29] The employment share of agriculture decreased from 39.7 percent to 15.3 percent during 1955-73, while that of industries (service sectors) increased from 23.7 percent to 34.2 percent (26.5 percent to 33.2 percent) during the same period.[30]

[24] The machines were called "Merry Tailor" by the Japanese.

[25] In 1957, *Kubota*'s 5-7 hp power tiller cost 113,700 yen and its 7-10 hp power tiller cost 205,700 yen, when a male agricultural worker's daily wage was 327 yen (Kayou 1977). Thus, one machine cost about a 1-2 year daily wage of a male agricultural worker depending on the engine size of the machine.

[26] Not only agricultural machine makers such as Kubota, Fujii, Takeshita, and Iseki, but also engine makers such as Mitsubishi, Kawasaki, and Honda started to produce their own power tillers (Hokimoto 1999).

[27] This is in contrast to tractors in the United States. It took about thirty-five years to reach the same number (Olmstead and Rhode 2001).

[28] This might be partly due to unstable tenancy contracts: the duration of the contract was often not in writing, and there was no formal agreement about the compensation for a tenant's investment (Kawano 1963). Moreover, the Japanese old custom called *Honke-Bunke* determined the relationship between households. Tenants were often from branches (*Bunke*), and they had to be supervised by the main household (*Honke*). If tenants initiated something new, it was regarded as socially impudent. Thus, the introduction of new technology, facilities, and machines was hardly initiated by the tenants (Ohuchi 1975). Until around the end of World War I, agricultural investment was mostly initiated by landlords who were cultivators themselves. They were often leaders of a village, and had a social responsibility to improve their community. However, the landlords' roles in investing in agriculture gradually disappeared, and they tended to become "parasitic" to land rents that their tenants paid (Toubata 1936). One possible reason for the change could be that it became less profitable for them to invest in agriculture because other investment opportunities outside of agriculture emerged (Ohuchi 1975). Fixed rents were more common, so that landlords had no incentive to invest in agriculture.

[29] The annual growth rate was above 9 percent on average, and real GDP increased from 47 trillion to 230 trillion between 1955 and 1973.

[30] Not only the share, but also actual agricultural employment declined.

The decline in agricultural employment was notably due to the outmigration of young people (Namiki 1957). During the rapid growth period, there was a mass migration of young cohorts from rural to urban areas.[31] In particular, three metropolitan areas (Tokyo, Nagoya, and Osaka) received a large net immigration. In 1962, for example, about 25 percent (166,000) of those who had just graduated from junior-high schools, and about 20 percent (122,000) of those who had just graduated from high schools, in the countryside got jobs in these areas (MHLW 2005). These young and low-cost workers were often called "golden eggs," who gained skills in companies and contributed to the growth of the economy.

The period of a quick diffusion of power tillers and that of a rapid decline in the share of agricultural employment clearly correspond to each other. The diffusion of agricultural machinery was a crucial factor which made such a decline possible (Minakawa 1967, Hayami and Kawagoe 1989). In the following sections, I examine the likelihood of owner farmers adopting agricultural machines as compared to tenant farmers. Moreover, I also examine its effect on labor reallocation and structural transformation.

2 Data and descriptive analysis

This section describes the data used in the empirical analysis. The paper mainly uses a historical municipal panel dataset between 1950 and 1965.[32] Prefectural data are also used in some analyses. This section focuses on describing the source and construction procedure of the municipal dataset. The source of the prefectural data is described in the Appendix.

2.1 Data

The historical analysis of the entire Japanese economy often uses data either at the national level or at the prefectural level.[33] Difficulties to obtain finer data may be part of the reason.[34] I have searched and collected such finer data in libraries and ministries in Tokyo with the aid of historical documents and own intuition. The data have been entered into digital format either by the author or by research assistants.

This paper uses data from 1930 to 1965, although the analysis focuses on the period between 1950 and 1965, i.e. the period in which agricultural mechanization has progressed in Japan.[35] To

[31] The phenomenon is called *Syuudan Syuusyoku* (Mass Employment). There were famous special trains and boats which sent a large numbers of young people from the countryside to distant big cities. For example, Figure 9 shows young people who arrived from Aomori greeting their new employer.

[32] Note that a prefecture contains municipalities, and that both are a political division. In 1965, for example, there were 46 prefectures and 3,466 municipalities (including special districts).

[33] Even with prefectural data, it is relatively difficult to conduct a rigorous analysis because there are only 47 prefectures. The number was 46 when Okinawa was the territory of the United States during 1945-72.

[34] Many official statistics are archived at an aggregated level. Even if disaggregated data may exist, they are less likely to be digitized.

[35] The main reason is that the data on tillers are available since 1950. This is also the period in which scale economies had not started functioning in Japanese agriculture. The scale economies seem to have appeared since the late 1960s (Hayami and Kawagoe 1989). The choice of the period may simplify the analysis because the scale economies often involve the increase in land sizes.

merge the data year-by-year to construct a panel dataset, I have had to deal with the issue of municipality mergers.[36] GIS techniques have been used to match municipalities over time.[37]

First of all, I have chosen the 1965 municipality, or the most aggregated unit in the data, as the unit of observation. Municipalities in earlier years have then been matched with the 1965 municipalities. For this purpose, I have first prepared polygon data of the municipalities for each year. The polygon data have been projected onto a two-dimensional space using the Sinusoidal projection. Next, the land area has been calculated for every municipal polygon, and the value has been assigned to each point which has been converted from the municipality polygon. The point data have been spatially matched with the 1965 municipality polygons. They have been aggregated at the 1965 municipality level, and these values have been compared with actual values. The observations within five square kilometer differences have been used to minimize the measurement errors.[38] In total, the 2,626 municipalities have been successfully matched, or about 76 percent of all municipalities in 1965.

The source of the data is described below.

Land reform data

The data of the land reform, which I have found in a library at University of Tokyo, contain information such as the number of farm households that have bought the land, the number of landlords that have sold the land, the total area of purchased and sold land, etc. for every municipality, except for those in Wakayama and Okinawa.[39]

Agricultural and demographic data

Data on agricultural technologies, draft animals, and the number of farm households have been taken from the agricultural census of 1950, 1955, 1960, and 1965.[40] Since the agricultural censuses have not been digitized, I have first photocopied them in libraries in Tokyo. To enter the photocopied data into digital format, I have set up an RA team through an online outsourcing company, and have remotely managed all digitization and data checking processes.

Since the 1955 agricultural census has been recorded at the 1957 municipality level, I have only used municipalities that have been intact, i.e. those that have not experienced any municipality merger during 1955-57, for the data of that year. This has reduced the sample size of that year as compared to the sample size of the other years. Finally, data on the education and the migration of farm household members have been taken from the 1960 agricultural census.

Data on population and agricultural employment have been taken from the national census of

[36] The major decline occurred between 1953 and 1955 after the enactment of the Act for the Promotion of Merger of Towns and Villages (*Chouson Gappei Sokushin Hou*) in 1953. The total number of municipalities declined from 10,560 in 1950 to 4,901 in 1955, to 3,598 in 1960, and to 3,466 in 1965. Municipality mergers may be another reason why disaggregated data have rarely been used by researchers.

[37] I have used ArcGIS for all GIS related tasks.

[38] I found that some municipalities were incorrectly matched by setting larger criteria.

[39] The data for Wakayama are missing. Okinawa was under the control of the United States until 1972.

[40] The first agricultural census was started in 1950 after World War II, and they have been conducted every five years since then.

1930, 1950, 1960, and 1965.[41] Since the 1955 values have not existed, I have interpolated the values for that year.

Since the names of the municipalities have sometimes been written using old Japanese characters (*Kyuujitai*), I have made a computer algorithm to convert them into new characters (*Shinjitai*). To calculate land sizes, I have used total farmland areas in 1945, and have divided them by agricultural employment in 1950, because I have found no data on the agricultural employment for that year.

Geography data

Terrain data have been taken from the National Aeronautics and Space Administration's (NASA) Shuttle Radar Topography Mission (SRTM3). The SRTM3 is high resolution raster data of 3 arc-seconds, or about 90 meters. Mean slope and mean elevation have been calculated from the data using GIS software.

Data on administrative boundaries, coastal lines, and the location of train stations have been taken from the Ministry of Land, Infrastructure, Transport and Tourism's (MLIT) National Land Numerical Information. I have used the location of the train stations that existed in 1965 because the unit of analysis is the 1965 municipality. I have used the location of prefectural governments for the location of three metropolitan areas (Tokyo, Osaka, and Nagoya).

Agricultural suitability data have been taken from the Food and Agriculture Organization's (FAO) Global Agro-Ecological Zones (GAEZ) data. I have used the crop suitability index for rain-fed cereals, and have taken the first-difference between the high-input and low-input level.[42] The high-input level assumes that the production is fully mechanized and improved varieties are used, while the low-input level assumes the subsistence-based farming system with labor-intensive production. Since the cell size of the original data (0.5-degree by 0.5-degree) has been too big for some small municipalities, I have resized each side of these cells into 0.005 degrees, or about 500 meters, before calculating values for each municipality.

2.2 Descriptive analysis

Summary statistics are shown in Table 1. It shows that the adoption of tilling machines had not "taken-off" by 1955. A similar tendency also appears in the following regression analyses. The owner share dramatically increased from 57 percent to 89 percent within a few years due to the land reform.[43] The population share aged 15-19 was about 10 percent in all years.

The top panel of Figure 10 shows the kernel density of the number of power tillers per farm household in 1950, 1960, and 1965. Horizontal lines indicate mean values. In the figures, municipalities

[41] The census data have recently been digitized by a team at Tsukuba University (Yamamoto and Kishimoto 2006, Takita et al. 2012, Satou and Kishimoto 2014). Although a more appropriate data point may be 1940, rather than 1930, the census of 1940 does contain enough information such as age distribution in municipalities.

[42] Cereals include wheat, wetland rice, dryland rice, maize, barley, sorghum, rye, pearl millet, foxtail millet, oat and buckwheat. Although it might have been more appropriate to use irrigated than rain-fed, such data have not been available for cereals. The reason for using cereals rather than any specific crop is that power tillers can be used for any type of these crops.

[43] All farmers are categorized either as owner farmers or tenant farmers.

are divided into quintiles based on the post-reform owner share. The municipalities in the fifth quintile are regarded as a treated group, while those in the first quintile are regarded as a control group. Although two groups have a very similar distribution in 1950, the treated municipalities have relatively more power tillers per farm household than the control municipalities in 1960 and in 1965. The bottom panel of Figure 10 shows the kernel density of the population share aged 15-19. It is clear that the treated municipalities have fewer young people in the population than the control municipalities in those years, although the distributions in 1950 are very similar.

Next, the change in power tillers per farm household and the change in the population share aged 15-19 are plotted in Figure 11, where I take the first-difference of each of these variables between particular years for the y-axis, and use the post-reform owner share for the x-axis, while controlling for e.g. prefecture fixed effects and municipal average land sizes.[44] These figures clearly show that the slope appears for the 1950-60 difference and for the 1950-65 difference, for both variables - a similar pattern shown in Figure 10.

The next section explains the empirical strategies.

3 Empirical framework

The main identification strategy uses a difference-in-differences (DID) estimation method with fixed effects. I compare municipalities with a high share of post-reform owner farmers to those with a low share of them (or a high share of post-reform tenant farmers), and examine if the former municipalities react differently vis-á-vis the latter when the machines become available and the urban sectors are growing. This estimation method uses the fact that the post-reform distribution has been determined by the upper limits set by the central bureaucracy prior to the land reform. An upper limit specified the total area of tenanted land that each landlord in a particular area could keep. Thus, it affected how many tenant farmers would become owner farmers during the reform in that area. As mentioned in the background section, the post-reform distribution of owner farmers is very different from the pre-reform distribution. The following analysis uses this new variation in land ownership as a cross-sectional variation, which has emerged due to the land reform.

The next section describes the formula for computing these upper limits.

3.1 Maximum Tenanted Land (MTL)

As mentioned earlier, the intensity of the reform was determined by the upper limits (Maximum Tenanted Land, MTL) set by the central bureaucracy, which specified the total area of tenanted land that each landlord in a particular municipality could keep. The value stretched from 0.6 cho in Hiroshima to 4 cho in Hokkaido, but the average of the MTL in prefectures other than Hokkaido had to be 1 cho.[45]

[44] An exception is the leftmost figure in the second row of Figure 11 in which I use the 1950 sample due to the lack of the 1955 census.

[45] One cho is approximately 1 hectare.

The introduction of such upper limits was based on a proposal made by a Commonwealth representative, Dr. MacMahon Ball, in conjunction with his economic advisor, Eric E. Ward, during the sixth meeting of the Allied Council.[46] The proposal allowed the landlords to keep a certain amount of tenanted land which was set to 1 cho.[47] The proposal was accepted by the SCAP authorities in Japan "as the basis on which the latter eventually worked out with the Japanese Ministry of Agriculture a plan of which they could approve (Dore 1959, p. 137)."

Based on the proposal, the Ministry of Agriculture and Forestry of Japan made a ground plan by using a formula. According to the formula, prefecture p's MTL is the arithmetic mean of x_p and z_p where

$$x_p = \left(\frac{\sum_{k \in K} T_k}{\sum_{k \in K} a_k T_k} \right) \times a_p \quad \text{and} \quad z_p = \left(\frac{\sum_{k \in K} T_k}{\sum_{k \in K} b_k T_k} \right) \times b_p. \tag{1}$$

In this formula, a_p denotes the average land size of owned farmland, b_p the average land size of managed farmland, before the land reform, T_k the total area of tenanted land, and K is the set of prefectures.[48] The owned farmland was based on the 1940 value, and the managed farmland was based on the 1944 value (NKI 1951). All arable lands were included, but grass lands, rough grazing, and forest lands were excluded.

This a_p is regarded as the average land size of landowners, while b_p is simply the average land size of all farmers. Although these values are distinguished in the formula, they are highly correlated in the data (99.3 %). Therefore, one may simply regard them as the average farmland size at the prefecture level before the reform. Note that values in parentheses do not differ across prefectures - they are just weights. Finally, the values are rounded at one-decimal point, so that several prefectures take the same value.[49]

Municipal MTLs were also determined by the Prefectural Land Committees and were approved by the Central Land Committee prior to the land reform by using the same formula, but the values were constrained by the prefectural MTL in the sense that the average of the municipal MTLs in a prefecture had to be equal to the MTL of that prefecture.[50]

[46] Kitamura (2016) describes this in more detail. There was clearly a dissonance between American-Commonwealth delegates and Russian delegates in terms of occupation policies. Russia announced reservations to Dr. Ball's proposal, for example.

[47] The value was proposed without any detailed calculation: "According to Dr. MacMahon Ball's explanation his reasoning was as follows. It would be 'precipitous' to abolish tenancy altogether, hence the question is: how much should be left? Since the average size of holding is about 1 cho and since it is desirable that the tenants who remain should have a viable holding, 1 cho would seem to be the answer (Dore 1959)."

[48] It is easy to show that the weighted arithmetic mean of these values becomes one, i.e. the average value of the MTL in prefectures other than Hokkaido. To see this, first multiply both sides by T_k in (1), take the sum of them, and finally divide both sides by $\sum_{k \in K} T_k$.

[49] There are 11 different values.

[50] The procedure was the following. First, the plan made by the MAF was sent to the Central Land Committee, and the Committee discussed the plan. The Committee consisted of 16 representatives from Prefectural Land Committees which were 8 representatives of tenants and 8 representatives of landlords, recommended by prefectural governors. Prefectural Land Committee members were elected by Municipal Land Committee members, and the Municipal Land Committee members were elected by farmers. In addition, two representatives from peasant unions and five university professors were included in the Central Committee. They were selected on behalf of the Minister of Agriculture and Forestry and appointed by the Yoshida Cabinet (NKI 1951). The original plan was approved without changing values, except that they allowed the Prefectural Land Committees to claim a different prefectural MTL if they regarded the

Thus, the municipalities in a prefecture received a different shock than the municipalities in another prefecture if the composition of the municipalities differs between these two prefectures. The municipalities which received lower limits would have more owner farmers than the municipalities which were hardly affected. Since the formula for calculating these limits is explicitly known, I can add relevant variables to control for confounding factors.

Still, adding control variables may not be enough to avoid omitted-variable bias. As a robustness check, I also compare two adjacent municipalities along both sides of the prefectural boundary. These two municipalities had been very similar until they received a different "shock" during the land reform. One of the "twin municipalities" obtained more owner farmers relative to its counterpart because the prefectures to which the municipality had belonged received different shocks. I examine how these initially identical two municipalities which received the different shocks in a tractable manner during the land reform would react differently when agricultural machines became available.

The next section describes the identification strategy.

3.2 Empirical strategy

The main regression model is written by

$$y_{mpt} = \sigma_t + \mu_m + \sum_{j \in \Omega} \beta_j \, OwnerShare_{mp} \times Time_{jt} + \mathbf{x}_{mpt}\xi + \epsilon_{mpt}, \tag{2}$$

for municipality m in prefecture p in census year t, where σ is year fixed effects, μ municipality fixed effects, *OwnerShare* the share of owner farmers after the land reform, $Time_{jt}$ a time dummy which takes the value of one in year j, and zero otherwise, Ω a set of census years, $\mathbf{x}$ municipal controls, and ϵ the error term. The main outcome variables are the number of power tillers per farm household and the share of the population aged 15-19. I cluster standard errors at the prefecture level. Finally, prefecture-by-year fixed effects will be added in some specifications.

To validate the identification strategy, the treated municipalities which had more owner farmers after the reform would have behaved similarly as the control municipalities which had fewer owner farmers if no machines had become available. As already shown in Figure 10, the distribution of outcome variables prior to the introduction of agricultural machines was very similar. In Figure 12, I divide the sample into two groups based on the share of owner farmers after the reform. The municipalities above the median are regarded as a treated group, and those below the median are regarded as a control group. The figure shows the trend for these two groups.[51] The top panel of the figure shows that the two groups have a similar trend by 1955. After that, the treated group tends to adopt more machines relative to the control group. The bottom panel shows a similar pattern in terms of the population share aged 15-19. In this case, the treated group tends to have

values to be unfair. Moreover, it allowed the Prefectural Land Committees to set a municipal MTL if needed. All changes and proposals required the approval of the Central Committee.

[51] Since the 1940 census does not contain the information about age distribution in municipalities as mentioned earlier, I instead use the 1930 values.

fewer young people in the population as compared to the control group after 1960. The parallel trend assumption seems to be satisfied according to these figures.

The next section shows the estimation results.

4 Results

4.1 Difference-in-differences estimates

Table 2 shows the effect of land ownership on technology adoption. The dependent variable is the number of power tillers per farm household. Column (1) only includes year fixed effects as control. The effect did not appear by 1955 as expected. Column (2) adds municipality fixed effects and baseline municipal controls which are average land sizes and the total area of tenanted land before the land reform. The estimates remain nearly unchanged. Even adding the prefecture-by-year fixed effects in column (3) barely changes the coefficients. In column (4), I also control for agricultural suitability, several geography and distance measures, agricultural employment share, population, and cattle per farm household. Overall, the coefficients are very similar to those in column (3). Finally, columns (5) and (6) exclude the North-West regions of Japan - Hokkaido and Tohoku.[52] Once again, excluding these regions does not change the coefficients to a considerable extent, which is reassuring.

I find that the municipalities which had many owner farmers after the land reform tended to experience a quick entry of new agricultural machines as compared to the municipalities in which more farmers remained as tenants. To calculate the effect size, let us use the full specification in column (4). Increasing the independent variable by one standard deviation (0.4) increases the power tillers per farm household (pooled) by 0.37 standard deviations for 1960, and by 0.84 standard deviations for 1965. The effect was nearly doubled in 1965.

Next, Table 3 shows the effect of land ownership on migration. The dependent variable is the population share aged 15-19. Column (1) includes year fixed effects. Column (2) adds the 1930 sample, while column (3) adds municipality fixed effects and the baseline municipal controls. The change in the coefficients is very small. Adding prefecture-by-year fixed effects in column (4) decreases the size slightly more. This indicates the importance of controlling for common shocks at the prefecture level in terms of migration. Column (5) includes other control variables. Finally, columns (6) and (7) show that removing the North-West regions of Japan does not alter the results.

The table shows that the municipalities with more owner farmers tend to have fewer young people in the population than the municipalities where more farmers remained as tenants. I will show below that these young people indeed outmigrated from the municipalities. Moreover, I will provide the supporting evidence that the migration has been affected by the adoption of labor-saving agricultural technologies.

[52] First, Hokkaido received a larger upper limit (4 hectare compared to 1 hectare on average in the other prefectures). Second, there may be a concern that the Tohoku region might send relatively more migrants to urban centers. Since the Tohoku region has been relatively poor, it may also serve as a robustness check that the effects are not simply explained by wealth.

The magnitude is moderate. Increasing the independent variable by one standard deviation (0.42) decreases the population share by 0.42 standard deviations for 1960, and by 0.55 standard deviations for 1965, according to the full specification in column (5). The effect size is somewhat smaller for migration than technology adoption. A plausible explanation might be that migration is only indirectly affected, while technology adoption is directly affected, by land ownership.

The DID estimates for both dependent variables are plotted in Figure 13. The pattern clearly corresponds to that in Figure 12.

4.2 Comparing adjacent municipalities

The DID estimation method relies on the assumption that the variation of the variable of interest is not related to other time-variant factors that might affect technology adoption and/or migration. As described above, the post-reform distribution has been affected by the upper limits set by the central bureaucracy. Since the formula for calculating them is explicitly known, I can include relevant controls. Moreover, since including municipality fixed effects and a wide range of municipal controls barely changes the coefficients as seen above, it is less likely that the municipalities with many owner farmers after the land reform differ systematically from the rest of the municipalities in any other dimensions.

To take a more conservative approach, I also compare two adjacent municipalities along both sides of the prefectural boundary. As described above, the MTL of municipalities was constrained by the MTL of the prefecture of these municipalities. Therefore, two municipalities along both sides of the prefectural boundary which would otherwise have been very similar might have received different shocks during the land reform only because these municipalities belonged to different prefectures.

To validate the identification strategy, I first check if such a shock indeed occurred during the reform. In Table 4, I use the dummy variable which takes the value of one if a municipality belongs to the prefecture whose MTL is smaller than that of its counterpart as the dependent variable. The independent variables are the share of owner farmers before and after the land reform. I also include "twin" fixed effects. The first column uses an OLS regression, while the second column uses a logistic regression. The table shows that the owner share increased in a municipality whose prefecture got a lower upper bound as compared to its counterpart. According to column (1), highly affected municipalities would increase the owner share by about 2 percentage points more than less affected municipalities. The size of the difference may reflect that the mean of the post-reform owner share in the control is already about 0.9 and the standard deviation is about 0.06.

Next, I check if paired municipalities are identical, by regressing the same dummy variable on each of variables that have been used above one-by-one. Table 5 shows the results. I find that the two municipalities are identical in terms of population, agricultural employment share, average land sizes, topographic characteristics, agricultural suitability, several distance measures such as the distance to metropolitan areas, and the availability of animal power. It is particularly important that two municipalities are identical in terms of the average land sizes. An exception is the total area of tenanted land before the land reform, which may be due to the fact that the variable is

included in the formula (though as weights). I will show that controlling for this variable as well as the other variables does not alter the results.

Table 6 shows the results of the "twin" estimation. The dependent variable for columns (1) through (3) uses the number of power tillers per farm household, while the dependent variable for columns (4) through (6) uses the population share aged 15-19. Columns (1) and (4) include the total area of tenanted land before the land reform, in addition to various fixed effects. Columns (2) and (5) include other control variables used in Tables 2 and 3. Finally, columns (3) and (6) also add the share of owner farmers before the land reform (1945). Overall, the effects are very similar to what we have seen earlier.

4.3 Private vs. communal machines

In this section, I examine if land ownership also affects the adoption of communal power tillers. Since tenant farmers might also be interested in adopting the communal machines,[53] we might observe either zero or even negative effects. Since the data are only available for the agricultural census of 1960 and 1965, I run OLS regressions by only using cross-sectional variations.

Table 7 shows the results. Columns (1) and (3) use private power tillers, while columns (2) and (4) use communal power tillers. The effect appears for the private ones, but not for the communal ones. This holds for both census years. This might indicate either that there is no systematic difference between two types of farmers in terms of adopting communal tillers, or that we do not have a sufficient variation.

4.4 Opportunity costs

One concern could be that municipalities with a high owner share might be affected by heterogeneous urban shocks. For example, this may be interpreted as heterogeneous shocks on relative wages. Municipalities with a high owner share might have higher/lower opportunity costs, although the results are robust to the inclusion of distance measures as shown above. To examine this possibility even further, I use the same DID regressions as before but divide municipalities into quantiles based on the distance to the nearest metropolitan areas (Tokyo, Nagoya, and Osaka). If farmers closer to the metropolitan areas were more likely to respond to high opportunity costs, the effect may only appear for the municipalities closer to these areas.

Table 8 shows the results. The effects appear in all quantiles. Moreover, the size of the effects is very similar in all quantiles. These results indicate that the effects were not driven by heterogeneous shocks related to opportunity costs. Rather, it is more likely that owner and tenant farm households faced the same opportunity costs when the urban sectors were growing, but owner farm households were more likely to react to it.

[53] For example, landlords might buy the machine, and lease it to their tenants.

4.5 Destination and type of migrants using migration data

This section checks if these young people have indeed outmigrated to big cities using two sets of migration data. First, using the prefectural origin-destination migration data, I examine whether the land ownership reform in origin prefectures affects migration to big cities. For this purpose, I run a panel regression in which the dependent variable is either the number, or the fraction, of immigrants to big cities, and the independent variable is the share of owner farmers in 1950 in the origin prefectures interacted with time dummies.[54] Prefecture and year fixed effects are also included.

Table 9 shows the results. Column (1) is the fraction of immigrants, while column (2) is the number of immigrants (log), to the big cities. The significant positive effect in both specifications means that migrants from prefectures with many owner farmers have been more likely to go to these cities since 1960. The timing of the effect corresponds to the pattern of migration that we have observed in the previous section. It also corresponds to the period of rapid growth. The reason why these prefectures with a high owner share tended to send more migrants to distant metropolitan areas than anywhere else as shown in column (1) may be that the owner farmers who adopted machines would no longer require young human power in agriculture and, therefore, these young generations could permanently be reallocated to non-agricultural sectors in distant urban centers.

Second, using municipal migration data in 1960, I examine whether a household has any family member who has graduated from a school and has outmigrated in the past year. Since the data also contain information about migrants' age and birth order (e.g., if a person is the eldest son, the second eldest son, etc.), I also examine if the migrants have any specific characteristics in this regard.

Table 10 shows the effect on each category. The dependent variable is the number of migrants of each category per agricultural population. Columns (1) through (5) show the results for sons. Column (2) indicates that the migrants were most likely second or younger sons. Interestingly, slightly older eldest sons instead tended to stay, although the effect is less precise. This might be explained by the custom of primogeniture in Japan that the eldest son usually inherits *ie*, or a family's lineage. The custom may have been strengthened in the sense that the land reform basically gave tenant farmers the property (land) which could be inherited by descendants. The eldest sons might be more likely to stay in agriculture to inherit the family's property. According to Namiki (1957), such a tendency was at least observed in the Tohoku region. In contrast, the non-eldest sons were able to migrate to cities to find other jobs.

Columns (6) through (8) show the results for daughters. Unfortunately, the agricultural census does not contain any information about the age or birth order of migrated daughters. Instead, the only available information for the daughters is the reason for migration, i.e. if the migration was due to marriage or not. First of all, the results indicate that daughters of owner farm households

[54] Big cities are Tokyo, Nagoya, and Osaka. The data are only available in 1954 and then every five years since 1955. I used the data between 1954 and 1975.

have also been more likely to outmigrate, although the estimate is less precise. However, there is no clear indication of why the daughters have outmigrated.

These findings seem to correspond to the historical facts described in the background section: those who outmigrated from the countryside during the rapid growth period were young, and were second or younger sons, and daughters, who had just graduated from junior high or high schools. The migration was affected by the land ownership reform and the adoption of labor-saving agricultural technologies, according to the above results.

4.6 Work or education

This section examines the purpose of migration. Although historical facts are such that most young cohorts have migrated to work, but not to study, these will be tested empirically using the data.

Fortunately, the 1960 agricultural census contains information about the number of household members who have been enrolled in the high school or higher education, regardless of where schools have been located. However, although the information is restricted to farm households, it is impossible to know how many of them have actually outmigrated. Therefore, I interact the owner share with the migration variables used in Table 10. Since I find a significant effect in column (5) of that table, I use the dependent variable in that column for male migrants. For female migrants, I use total female migrants used in column (8).

Table 11 shows the results. In column (1), I simply regress the number of household members who were studying per agricultural population on the share of owner farmers. The significant negative sign means that household members from the areas with a high share of owner farmers are less likely to study. Finally, I only use *male* household members for the dependent variable in column (2), while I only use *female* household members for the dependent variable in column (3). I find similar results here as well. These results as well as the results in Table 9 suggest that young members of owner farm households have migrated to urban centers to *work* in non-agricultural sectors.

Overall, I find no evidence that these migrants have continued to study in higher education. Of course, this does not mean that higher education is not important for economic development. The findings are at least consistent with the historical facts that the Japanese rapid growth has been fueled by relatively young low-skilled workers who have accumulated skills in firms through on-the-job-training/learning-by-doing.

4.7 Connection between technology and migration

As described in the background section, the causation is most likely to go from technology adoption to migration. To check this, I create a proxy which is most likely to affect technology adoption, but not migration. For such a variable, I use geological conditions, or the share of the land area which consists of clay. The motivation for using such a variable is that power tillers, especially early models which tend to have smaller engines, have not worked properly in places where the

soil has been too hard. Moreover, such geological conditions must be less likely to be related to migration.

Table 12 shows the results. According to columns (1) and (3), the variables seem to show the predicted signs. Farmers in places where the soil is too hard are less likely to adopt power tillers. However, land ownership tends to offset the negative effect, or even increases the technology adoption. Interestingly, columns (2) and (4) show the opposite signs: places with hard soil tend to have more young people in the population, but the land ownership tends to mitigate this.

Overall, these results seem to support the causal direction from technology adoption to migration rather than in the opposite direction.

5 Discussion

The previous sections show that owner farmers have been more likely to adopt new agricultural technologies than tenant farmers. This section discusses potential mechanisms.

Land ownership by cultivators

Old thinkers such as Arthur Young and John Stuart Mill, as well as policy makers of 19th and 20th century Europe, have already recognized the importance of redistributing land ownership to those who till the soil (see e.g. Liversage 1945). For example, Arthur Young writes: "The magic of property turns sand into gold." In the Japanese case, this "magic" is possibly explained by the following mechanisms for this.

The first mechanism relates to the argument that the power structure in rural societies affects agricultural investment and human-capital promoting institutions (Banerjee et al. 2002, Goldstein and Udry 2008, Galor et al. 2009). The motivation behind the Japanese land reform was the empowerment of tenants and the democratization of rural societies. For example, an instruction note sent to the Japanese authority also known as "MacArthur's Peasant Liberalization Directive" states that:

> In order [...] [to] remove economic obstacles to the revival and strengthening of democratic tendencies, establish respect for the dignity of men, and destroy the economic bondage which has enslaved the Japanese farmer to centuries of feudal oppression, the Japanese Imperial Government is directed to take measures to insure that those who till the soil of Japan shall have a more equal opportunity to enjoy the fruits of their labor. [...] The purpose of this order is to exterminate those pernicious ills which have long blighted the agrarian structure of a land where almost half the population is engaged in husbandry.

Due to the breakup of the landlord-tenant relationship during the land reform, the former tenants might have been unconstrained and empowered.

First, eliminating agency costs due to the full-transfer of property rights might have increased investment. For example, a related study, Banerjee, Gertler, and Ghatak (2002), finds that a limited

transfer of property rights by improving the security of tenure of sharecroppers and regulating land rents has a positive effect on agricultural productivity in West Bengal.[55] In contrast to a "limited transfer of property rights," this paper shows that a "full transfer of property rights" affects technology adoption. Moreover, Kitamura (2016) finds that farmers who have obtained land during the reform have been politically empowered. Such farmers might also have been more motivated to adopt new agricultural technologies. Finally, there might also exist indirect effects of land ownership: owner farmers might be able to take a loan by using their farmland as collateral (Besley et al. 2012).

No rents

Another possible mechanism might be that owner farmers were able to invest because they no longer paid high land rents to landlords. However, this effect might be limited. Recall that this paper compares owner farmers and tenant farmers who existed in the post-reform period. According to the Agricultural Land Act, the rents for paddy fields (dry fields) were regulated at 25 percent (15 percent) of the output value. In practice, the land rents were about 7 percent of the output value in 1963 (Kawano 1963). Therefore, tenant farmers also no longer bore a heavy burden as compared to the pre-reform situation.

6 Aggregate impact of land reform

This section assesses the impact of labor reallocation and technology adoption caused by the land ownership reform on industrial development and economic growth. As described in the background section, Japan experienced a rapid growth between the late 1950s and the early 1970s when many young cohorts migrated from the countryside to big cities to work in industries and service sectors. The above findings indicate that the land ownership reform and the technology adoption in agriculture seem to explain part of such migration. This section assesses how much these factors contributed to the growth of the economy.

Structural transformation is most likely to be associated with labor reallocation across sectors and locations. Ideally, one may want the data that keep track of each individual's migration pattern as well as occupation, but such data are not available for Japan during the period studied. To tackle this issue, I adopt a simple growth model to quantify the impact. The model reflects the above micro findings, and uses micro data to get parameter values for each municipality. I also run a couple of counterfactual simulations using the model to make a comparison with the baseline results.

[55] They even make a conjecture that "a full transfer of landownership that would completely eliminate agency costs is likely to have positive effects on productivity [...] (p. 240).".

6.1 A simple model

The economy has N population. Let us denote the set of prefectures by $\mathscr{P}$. Each prefecture contains a finite number of municipalities with equal size. A municipality has either farmers or firms. I call the municipality with farmers a village (with notation a), and the municipality with firms a city (with notation u). A prefecture consists of many villages and cities. I denote the non-empty set of villages in prefecture $p \in \mathscr{P}$ by $\mathscr{A}_p$ and that of the cities by $\mathscr{U}_p$. I assume that farmers and firms do not move across municipalities, and the characteristics of the municipalities do not change over time.[56]

Farmers use machines, labor, and land for production. The machine is only valued by its purchaser. It is imported and depreciates perfectly in the next period. The land is rented from the landlord.

I assume that there is a "wedge" for adopting the machines. The wedge is location specific, and takes the same value over time. It may be interpreted as a technology adoption barrier caused by the landlord-tenant relationship.

The production technology of the representative farmer in village i in prefecture p in period t takes a CES form:

$$Y_{at}^{pi} = A_{at}^{p}[\gamma(M_t^{pi})^{\phi} + (1-\gamma)(N_{at}^{pi})^{\phi}]^{\frac{\alpha}{\phi}}(L^{pi})^{1-\alpha}, \tag{3}$$

where A_{at}^{p} is agricultural TFP, which is assumed to grow at a constant rate $g_a > 0$, M_t^{pi} machines, N_{at}^{pi} agricultural labor, and L^{pi} land. The parameter $\phi \leq 1$ relates to the elasticity of substitution between the machine and labor. The parameter $\alpha \in (0,1)$ measures the share of factors other than land in production. Finally, the parameter $\gamma \in (0,1)$ captures the relative importance of machines in production. The following analysis assumes that $\alpha < \phi < 1$, which implies that the machine and labor are substitutes. Since the land has no alternative use other than production, it is set as $L^{pi} = 1$ for all i and for all p. The TFP being indexed by prefecture implies that initial agricultural TFPs can differ across prefectures.

By assumption, the static profit maximization of the representative farmer of village i in prefecture p becomes

$$\max_{N_{at}, M_t \geq 0} \quad (1-\tau^{pi})(Y_{at}^{pi} - w_t^{pi} N_{at}^{pi} - r) - M_t^{pi}, \tag{4}$$

where $\tau^{pi} \in (0,1)$ reflects the wedge or the technology adoption barrier, which can take different values across locations, w_t^{pi} the wage rate, and r land rents. The world price of the machine is normalized to 1 for simplicity.

The production technology of the representative firm in city j in the same prefecture is written by

$$Y_{ut}^{pj} = A_{ut} N_{ut}^{pj}, \tag{5}$$

where A_{ut} is non-agricultural "TFP" (including capital), which is assumed to grow at a constant

[56] Therefore, the model may not be suitable for analyzing very long-run effects. In contrast, Michaels et al. (2012) allow for the change in locational characteristics in order to analyze urbanization in the United States in the period 1880-2000.

rate $g_u > g_a$, and N_{ut}^{pj} labor. I assume that initial non-agricultural TFP is the same across cities (A_{ut} is not indexed by prefecture).[57] The shape of the production function may yield that the urban wage is equated to A_{ut} in every period.

Workers move freely, so that the wage is equated across sectors and locations, $w_t^{pi} = w_t$ for all i and for all p. Finally, to close the model, the following labor market clearing condition must hold every period:

$$N = \sum_{p \in \mathscr{P}} \left(\sum_{i \in \mathscr{A}_p} N_{at}^{pi} + \sum_{j \in \mathscr{U}_p} N_{ut}^{pj} \right). \tag{6}$$

It can be shown that

Proposition 1: *All variables asymptotically grow at constant rates.*
Proof: See the Appendix.

Next, I derive a prediction of the model. The first-order conditions derived from the representative farmer's profit maximization problem yield

$$m_t^{pi} := \frac{M_t^{pi}}{N_{at}^{pi}} = \left[\frac{\gamma}{1-\gamma} (1 - \tau^{pi}) w_t \right]^{\frac{1}{1-\phi}}, \tag{7}$$

such that $\frac{\partial m}{\partial w} > 0$ and $\frac{\partial^2 m}{\partial w \partial \tau} < 0$. Thus, the farmers facing small τ^{pi} use more machines and less labor, and the effect becomes larger over time as w_t ($= A_{ut}$) increases. Note that the effect is driven by *both* the numerator (increase in M) and the denominator (decrease in N_a).

The intuition is the following. Workers have more incentives to work in a city when the economy grows. The reduction of labor would raise the agricultural wage until it is equated to the urban wage, or until no arbitrage condition holds, in every period. As the labor costs increase over time, farmers tend to use more machines. However, farmers facing a lower barrier are more likely to switch because it is cheaper for them to do so than for farmers facing a higher barrier.

Note that although the model presumes that machines do exist, this process only occurs when such labor-saving technologies become available. Moreover, if the machine cost is too high, farmers may tend to use more labor. Thus, the availability of affordable labor-saving machines is crucial for this mechanism to work.

Prediction 1: *Farmers facing a lower technology adoption barrier use more machines and less labor than farmers facing a higher barrier when labor-saving machines become available. The effect becomes larger over time as the economy grows.*

This prediction corresponds to the findings of the empirical section.

The next section parametrizes the model.

[57] Another way of stating the assumption is that the urban wage is the same across cities. Alternatively, one can analyze the case where the labor market is closed at the prefecture level.

Model parameters

ϕ	α	γ	g_a	g_u	$\bar{N}$
0.93	0.66	0.25	0.03	0.09	35,624,957

6.2 Calibration

The parameters and endowments to be determined are $\{\{\phi,\alpha,\gamma\}, \{g_a,g_u\}, N, \{A^p_{a0},A_{u0}\}, \{\tau^{pi}\}\}$. First, I set α, which measures the non-land factor share in agriculture, to 0.66, which is similar to the value in Valentinyi and Herrendorf (2008) and Hansen and Prescott (2002). Then, I pin down $\{\phi,\gamma\}$ to match two targets simultaneously:[58] the agricultural labor share (0.46) taken from Valentinyi and Herrendorf (2008) and the agricultural employment share in 1955 (0.397). This procedure yields $\phi = 0.93$ and $\gamma = 0.25$.[59]

For g_u, I take the average of the annual growth rate of non-agricultural real GDP between 1955-74.[60] To get g_a, I multiply $(1-\alpha)$ with the average of the annual growth rate of agricultural capital in the same period.[61] I use the total labor force in 1955 for N. Initial TFPs are calculated from production functions.[62]

Finally, I calculate τ^{pi} across locations using the municipality data. This parameter is most important in the model, and makes the current model be different from standard two-sector models. To measure the τ of a municipality, I use a proxy which is the share of owner farmers in the municipality, which has been used in the empirical analysis above. The motivation comes from the empirical finding: owner farmers were more likely to adopt agricultural machines than tenant farmers. Since the parameter can be interpreted as a technology adoption barrier, the owner share may be a good proxy for τ.

Since all values have been aggregated at the prefecture-level after calculation, I have used the 1950 municipality as the unit of observation because the original land reform data have been stored at this level. The number of municipalities in the sample is therefore 10,040. I define *shi* (city) and *ku* (special districts) as cities, and *machi* (town) and *mura* (village) as villages. In total, there are 266 cities and 9,774 villages in the data. I calculate τ's for all villages.

First of all, using the first-order conditions and the production function of the representative farmer, I get the model's τ's. Since the agricultural GDP data are only available at the prefecture level, I first derive the prefecture-level τ's, and then derive the municipality-level τ's.

Using the first-order conditions, the production function of the representative farmer in prefecture

[58] I use Python for the numerical analysis.

[59] In other words, the capital share is assumed to be 0.2 in agriculture, which is between Hansen and Prescott (2002) (0.1) and 1/3.

[60] This is motivated by the fact that the growth rate of non-agricultural TFP is equal to that of non-agricultural GDP in the long run (see the proof of Proposition 1).

[61] This is motivated by the fact that the growth rate of agricultural TFP will be that of agricultural machines multiplied by $(1-\alpha)$ in the long run (see the proof of Proposition 1).

[62] The procedure is described in the Appendix.

p for the benchmark economy may be written by

$$Y_a^{p,model}(e^p) = \left\{ \gamma \left\{ \frac{\left(\frac{\alpha\gamma}{e^p}\right)^{\phi}}{\left[\gamma + (1-\gamma)\left(\frac{1-\gamma}{\gamma}e^p\right)^{\frac{\phi}{1-\phi}}\right]^{\phi-\alpha}} \right\}^{\frac{1}{1-\alpha}} + (1-\gamma) \left\{ \frac{[\alpha(1-\gamma)]^{\phi}}{\left[\gamma\left(\frac{\gamma}{1-\gamma}\frac{1}{e^p}\right)^{\frac{\phi}{1-\phi}} + (1-\gamma)\right]^{\phi-\alpha}} \right\}^{\frac{1}{1-\alpha}} \right\}^{\frac{\alpha}{\phi}}, \tag{8}$$

where $e^p := \frac{1}{1-\tau^p}$.[63]

Next, I find a root of $Y_a^{p,model}(e^p) - Y_a^{p,data} = 0$ for each p by using the Levenberg-Marquardt algorithm, where $Y_a^{p,data}$ is the prefectural agricultural real GDP in 1955.[64] Let the root for prefecture p be $e^{p,model}$. Then, I use the vector of roots as the dependent variable, and fit cubic polynomials with the prefectural data by using non-linear least squares.[65] Formally, the regression model for prefecture p is written by

$$e^{p,model} = \varphi_0 + \sum_{k\in\{1,2,3\}} \varphi_k \, OwnerShare_p^k + u_p, \tag{9}$$

where *OwnerShare* is the share of owner farmers after the land reform and u is the error term. This gives the coefficients $\varphi_1 = -11.681$ (3.196), $\varphi_2 = 13.162$ (3.602), and $\varphi_3 = -4.942$ (1.353), where the standard errors are in parentheses ($R^2 = 0.29$). I keep the coefficients and perform the out-of-sample prediction of municipal e's using the share of owner farmers at the municipality level as the independent variable. Finally, I calculate $\hat{\tau} = 1/\hat{e}$, where $\hat{e}$ is the predicted value at the municipality level, and normalize them so that the values are in (0,1).

Using these parameters and endowments, I calculate all economic variables at the municipality level. I then aggregate them at the national level.

6.3 Counterfactual simulations

The paper also conducts counterfactual simulations. In particular, I examine two scenarios:

Scenario 1: No land reform.

Scenario 2: All villages get $\tau = 0$ (full land reform).

The first scenario is motivated to make a comparison with the baseline results to quantify how much the land reform contributed to industrial development and economic growth. As mentioned

[63] I set the productivities to one by following Adamopoulos and Restuccia (2014).

[64] See the Appendix for the data source.

[65] The cubic polynomials are the lowest order which fit the data well.

τ

	Mean	S.d.
Land reform	0.02	0.0004
No land reform	0.76	0.0191

earlier, the Japanese economy grew rapidly between the late 1950s and the early 1970s. Although the urban sectors were growing during that period, the reallocation of workers from agriculture to industries and service sectors might even have fueled the growth of those sectors. To assess this, I use the pre-reform variation in the owner share at the municipality level. The second scenario examines a most radical case in which there are no barriers to technology adoption.

6.4 Simulation results

Calculated τ's in the above table show a very different distribution between the baseline and Scenario 1 (no land reform). The τ's for the baseline are very small as compared to the no-land reform case, meaning that the land reform substantially decreased the technology adoption barrier across the country. This may reflect the fact that the distribution of the owner share shifted radically due to the land reform as shown in Figure 4.

Next, Figure 14 shows the behavior of the model for the baseline and Scenario 1. Solid lines are the baseline results, while dashed lines are the results with no land reform (Scenario 1). The upper left panel shows the result for technology adoption. It starts increasing dramatically around 1960 in the baseline, while nothing happens in the no-land reform case. This is due to the fact that the land reform has yielded many owner farmers who have been more likely to adopt agricultural technologies. The difference in the likelihood of the technology adoption also affects agricultural productivity, or agricultural GDP divided by agricultural employment, as shown in the upper right panel. It shows that the difference between two cases appears in the early 1960s. For both cases, a gradual increase in agricultural productivity is explained by a gradual decrease in agricultural employment. However, the agricultural productivity starts increasing more rapidly in the baseline because more farmers adopt technologies and reallocate labor off-farm.

The adoption of technologies quickens the process of labor reallocation from agriculture to non-agriculture. This leads to a rapid increase in production in urban sectors, which is reflected in the increase in the GDP growth rate shown in the lower-left panel. Once the transition path has been completed, the growth rate converges to the long-run value. In contrast, there is no such temporary increase in the growth rate in the no-land reform case since the transition is slow due to insufficient technology adoption and labor reallocation. The increase in the growth rate affects GDP, which is shown in the lower-right panel. The GDP starts to diverge from that of the no-land reform case in the early 1960s.

Table 13 shows the average growth rate of the GDP between 1955-74 based on the simulation and in the data. Compared to the no reform case, the land reform increased the growth rate by

above 1/2 percentage points for 20 years. The total effect is about 12 percent of the 1974 GDP. In contrast, there is no difference between the baseline and Scenario 2. This may be because of the τ's already being very small due to a massive land reform.

Overall, these results suggest that although the role of urban sectors tends to be emphasized regarding the Japanese rapid growth, the role of the agricultural sector should not be ignored.

6.5 Discussion

Although this paper uses a simple growth model, the model can be extended in several ways. For example, urban TFP can be endogenized by incorporating learning-by-doing. In that case, the increase in the urban wage (or urban TFP) in (7) becomes a function of urban employment.

Second, although the agricultural production function assumes a Hicks-neutral technical change, a capital-augmenting technical change can be incorporated. In that case, an additional term appears in (7), but its effect on the substitution of machines for labor is essentially the same as that of the urban wage.

So far, the results are driven by the supply side. In contrast, the change in consumption patterns over time exemplified by Engel's law is another crucial factor for structural transformation. If I incorporate preferences and the general equilibrium effect in the model, the transition effect on the GDP growth rate might become relatively mild, although the substitution effect might be still stronger in the land reform case.

Finally, although the model implicitly assumes that cities are homogeneous, and that there is a one-way migration from the countryside to the cities, more complicated migration patterns can be incorporated if I include consumers' migration decision across locations (see e.g. Desmet et al. 2015).

7 Conclusion

Despite the historical argument that property rights and technological advancement in agriculture are important for development, these relationships are not fully understood even nowadays. This paper tackles the issue by using a novel approach by combining micro findings to macro modeling and simulations. The framework of the paper can be applied to analyze other countries.

The first part of the paper examines the causal effect of land ownership by cultivators on technology adoption in agriculture. I exploit a natural experiment tied to the Japanese land reform during the occupation period to get a plausibly exogenous variation in land ownership. I find that the land ownership by cultivators increased the adoption of new labor-saving agricultural technologies which became available after the reform. The technology adoption reduced the dependence on family labor. Thus, family members, notably non-eldest sons, and daughters, were able to migrate to big cities to work in industries and service sectors when these sectors were growing.

The second part of the paper quantifies how much the labor reallocation caused by the land reform and technology adoption contributed to economic growth. To tackle this issue, I simulate

a simple growth model using micro data by reflecting the empirical findings in the first part. I find that the labor reallocation had a large positive effect on economic growth by fueling the development of urban sectors. Since the land reform yielded many owner farmers who were more likely to substitute agricultural machines for family labor, more workers were able to migrate to big cities when urban sectors were growing. In addition, I find a large positive effect in agricultural productivity. The effect was largely driven by the adoption of technologies (and the reduction of labor) rather than the reallocation of labor from agriculture to non-agriculture *per se*.

Note that this paper does not claim that the adoption of labor-saving technology always leads to rural-urban migration. *If urban sectors do not grow, redundant labor may stay in agriculture or may become unemployed.* The adoption of labor-saving technologies may be most likely to foster structural transformation when non-agricultural sectors provide sufficient jobs. Therefore, it must be of great importance to have urban growth (or a pull factor), besides land ownership and the adoption of labor-saving technologies (or push factors), in order to sustain rural-urban migration and structural transformation.

The substitution of capital for labor in agriculture is a historical phenomenon in many countries. The fact that Korea and Taiwan also experienced land reforms and rapid growth thereafter suggests that a similar mechanism might have worked in these countries. The United States and Europe might also have experienced a similar capital-labor substitution in agriculture. Further research may be needed.

Finally, the findings of the paper may also raise an interesting question: does the society based on private ownership stimulate economic activity and improve social welfare? Changing the number and the distribution of "owners" in society seems to have different welfare implications.

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Tables and Figures

Table 1: Summary statistics

	Mean	Std.dev.	Obs.
A. Agriculture			
Power tillers per farm household (1950)	0.01	0.04	2545
Power tillers per farm household (1955)	0.01	0.02	2054
Power tillers per farm household (1960)	0.03	0.05	2574
Power tillers per farm household (1965)	0.07	0.09	2560
Power tillers per farm household (all years)	0.03	0.06	9733
Owner share (1945)	0.57	0.15	2497
Owner share (1950)	0.89	0.06	2488
Tenanted land (cho, 1945)	631.00	770.01	2498
Average land size (cho)	0.34	0.65	2497
Cattle per farm household (1950)	0.35	0.32	2545
B. Demography			
Population share 15-19 years old (1930)	0.09	0.02	1880
Population share 15-19 years old (1950)	0.10	0.01	2584
Population share 15-19 years old (1960)	0.08	0.02	2536
Population share 15-19 years old (1965)	0.09	0.02	2582
Population share 15-19 years old (all years)	0.09	0.02	9582
Population	21552.69	43507.42	10335
Employment share in agriculture	0.57	0.21	10325
C. Geography			
Distance to nearest metropolitan area (km)	254.07	239.77	2590
Distance to nearest train station (km)	7.22	16.02	2590
Distance to nearest coastline (km)	26.73	26.11	2590
Mean slope	19.38	13.41	2590
Mean elevation	282.25	298.95	2590
Agricultural suitability index	0.61	1.91	2590

Notes: See the data section for a more detailed description of the data source and construction procedure.

Table 2: Effects of land ownership on technology adoption

	Power tillers per farm household					
	(1)	(2)	(3)	(4)	(5)	(6)
Owner share	0.008					
	(0.018)					
× 1955	0.011	0.010	0.001	0.009	0.006	0.001
	(0.009)	(0.012)	(0.013)	(0.011)	(0.012)	(0.012)
× 1960	0.055	0.051	0.055	0.058	0.043	0.043
	$(0.022)^{**}$	$(0.022)^{**}$	$(0.018)^{***}$	$(0.016)^{***}$	$(0.014)^{***}$	$(0.013)^{***}$
× 1965	0.122	0.110	0.116	0.130	0.091	0.099
	$(0.061)^{*}$	$(0.044)^{**}$	$(0.032)^{***}$	$(0.034)^{***}$	$(0.032)^{***}$	$(0.033)^{***}$
Mean of dep. variable	0.030	0.030	0.030	0.028	0.026	0.025
Controls	no	yes	yes	yes′	yes′	yes′
Municipality F.E.	no	yes	yes	yes	yes	yes
Year F.E.	yes	yes	yes	yes	yes	yes
Prefecture-by-year F.E.	no	no	yes	yes	yes	yes
R^2	0.20	0.37	0.44	0.49	0.49	0.47
Adj. R^2	0.20	0.37	0.44	0.48	0.48	0.46
Number of obs.	9409	9392	9392	9105	8474	7248

Notes: Standard errors are clustered at the prefecture level. $^{*}p < 0.1,^{**} < 0.05,^{***} < 0.01$. The dependent variable uses power tillers per farm household. Column (1) includes year fixed effects. Column (2) adds municipality fixed effects and municipal controls: average land sizes and the total area of tenanted land before the land reform (log). Column (3) adds prefecture-by-year fixed effects. Column (4) adds more municipal controls: agricultural employment share, population (log), cattle per farm household, distance to three metropolitan areas (log), distance to the nearest train station (log), distance to the coastal line (log), slope and elevation (log), and agricultural suitability index. All time invariant variables are interacted with time dummies. Columns (5) and (6) use the same specification as column (4) but exclude Hokkaido, and Hokkaido and Tohoku, respectively.

Table 3: Effects of land ownership on migration

	Population share aged 15-19						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Owner share	0.006	−0.007					
	(0.009)	(0.010)					
× 1960	−0.081	−0.068	−0.083	−0.044	−0.020	−0.022	−0.025
	(0.020)***	(0.018)***	(0.018)***	(0.009)***	(0.007)***	(0.007)***	(0.008)***
× 1965	−0.070	−0.058	−0.074	−0.044	−0.026	−0.024	−0.025
	(0.014)***	(0.012)***	(0.011)***	(0.008)***	(0.008)***	(0.008)***	(0.009)***
Mean of dep. variable	0.093	0.091	0.093	0.093	0.092	0.092	0.091
Controls	no	no	yes	yes	yes′	yes′	yes′
Municipality F.E.	no	no	yes	yes	yes	yes	yes
Year F.E.	yes	yes	yes	yes	yes	yes	yes
Prefecture-by-year F.E.	no	no	no	yes	yes	yes	yes
R^2	0.16	0.16	0.45	0.59	0.67	0.68	0.65
Adj. R^2	0.16	0.16	0.45	0.59	0.67	0.67	0.64
Number of obs.	7414	9226	7399	7399	7159	6667	5701

Notes: Standard errors are clustered at the prefecture level. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variable uses the share of the population aged 15-19. Column (1) includes year fixed effects. Column (2) adds the 1930 sample, while column (3) adds municipality fixed effects and municipal controls: average land sizes and the total area of tenanted land before the land reform (log). Column (4) adds prefecture-by-year fixed effects. Column (5) adds more municipal controls: agricultural employment share, population (log), cattle per farm household, distance to three metropolitan areas (log), distance to the nearest train station (log), distance to the coastal line (log), slope and elevation (log), and agricultural suitability index. All time invariant variables are interacted with time dummies. Columns (6) and (7) use the same specification as column (5) but exclude Hokkaido, and Hokkaido and Tohoku, respectively.

Table 4: Emergence of difference within paired municipalities

	OLS	Logit
	(1)	(2)
Owner share (1945)	0.0116	0.0229
	(0.1450)	(0.2985)
Owner share (1950)	1.9600	4.5198
	$(0.3165)^{***}$	$(0.7701)^{***}$
Twin F.E.	yes	yes
R^2	0.03	
Pseudo R^2		0.02
Number of obs.	3362	2812

Notes: Standard errors are clustered at the twin level. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variable is the dummy which takes the value of one if a municipality belongs to the prefecture whose MTL is smaller than that of its counterpart. All models include twin fixed effects.

Table 5: Balance check (municipal twins)

	Coeff.
A. Agriculture	
Agricultural employment share	−0.140
	(0.142)
Population	0.010
	(0.027)
Oxen per farm household	0.098
	(0.124)
Land size	−0.323
	(0.295)
Tenanted land before reform	−0.045
	(0.018)**
B. Geography	
Slope	−0.002
	(0.003)
Elevation	0.059
	(0.047)
Distance to metropolitan areas	−0.207
	(0.186)
Distance to nearest train station	−0.009
	(0.025)
Distance to coast	0.060
	(0.056)
Agricultural suitability index	−0.036
	(0.025)

Note: Standard errors are clustered at the twin level. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variable is the dummy which takes the value of one if a municipality belongs to the prefecture whose MTL is smaller than that of its counterpart. The 1950 values are used for agricultural employment share, population, and oxen per farm household. All models include twin fixed effects.

Table 6: Effects of land ownership on technology adoption and migration using adjacent municipalities

	Power tillers			Population 15-19		
	(1)	(2)	(3)	(4)	(5)	(6)
Owner share × 1955	0.009	−0.007	−0.011			
	(0.005)	(0.007)	(0.010)			
× 1960	0.059	0.040	0.055	−0.061	−0.049	−0.059
	(0.013)***	(0.013)***	(0.017)***	(0.018)***	(0.016)***	(0.015)***
× 1965	0.109	0.097	0.129	−0.046	−0.039	−0.049
	(0.025)***	(0.023)***	(0.030)***	(0.017)***	(0.016)**	(0.016)***
Mean of dep. variable	0.024	0.024	0.024	0.087	0.086	0.086
Controls	yes	yes′	yes″	yes	yes′	yes″
Twin F.E.	yes	yes	yes	yes	yes	yes
Year F.E.	yes	yes	yes	yes	yes	yes
Prefecture-by-year F.E.	yes	yes	yes	yes	yes	yes
R^2	0.51	0.54	0.54	0.67	0.74	0.74
Adj. R^2	0.50	0.52	0.52	0.66	0.73	0.73
Number of obs.	3757	3678	3678	2970	2895	2895

Notes: Standard errors are clustered at the twin level. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variable for columns (1)-(3) uses the power tillers per farm household. The dependent variable for columns (4)-(6) uses the population share aged 15-19. Columns (1) and (4) are the baseline results which include the total area of tenanted land before the land reform (log) as a control, in addition to twin fixed effects, year fixed-effects, and prefecture-by-year fixed effects. Columns (2) and (5) add more municipal controls as in Tables 2 and 3. Columns (3) and (6) also control for the share of owner farmers before the land reform (1945).

Table 7: Effects of land ownership on adoption of private v.s. communal power tillers

	1960		1965	
	Private	Communal	Private	Communal
	(1)	(2)	(3)	(4)
Owner share	0.054	0.007	0.115	0.005
	$(0.015)^{***}$	(0.006)	$(0.035)^{***}$	(0.005)
Controls	yes	yes	yes	yes
Prefecture F.E.	yes	yes	yes	yes
R^2	0.31	0.42	0.25	0.40
Adj. R^2	0.29	0.41	0.23	0.39
Number of obs.	2380	2380	2415	2415

Notes: Standard errors are clustered at the prefecture level. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. Columns (1) and (2) use the data for 1960, while columns (3) and (4) use the data for 1965. The dependent variable for columns (1) and (3) uses the private power tillers per farm household, while the dependent variable for columns (2) and (4) uses the communal power tillers per farm household. I include prefecture fixed effects and the same municipal controls as in column (4) of Table 2.

Table 8: Heterogeneous effects by the distance to metropolitan areas

	Power Tillers		Population 15-19	
	(1)	(2)	(3)	(4)
Owner share × 1955 q1	0.018	0.012		
	(0.012)	(0.012)		
× 1955 q2	0.014	0.011		
	(0.011)	(0.012)		
× 1955 q3	0.010	0.007		
	(0.012)	(0.011)		
× 1955 q4	0.005	0.003		
	(0.012)	(0.012)		
× 1960 q1	0.067	0.057	−0.028	−0.022
	(0.018)***	(0.016)***	(0.010)**	(0.007)***
× 1960 q2	0.071	0.064	−0.027	−0.020
	(0.017)***	(0.017)***	(0.009)***	(0.007)***
× 1960 q3	0.066	0.059	−0.027	−0.022
	(0.017)***	(0.016)***	(0.009)***	(0.007)***
× 1960 q4	0.054	0.053	−0.024	−0.019
	(0.017)***	(0.019)***	(0.010)**	(0.007)***
× 1965 q1	0.157	0.142	−0.026	−0.024
	(0.043)***	(0.038)***	(0.009)***	(0.008)***
× 1965 q2	0.130	0.135	−0.025	−0.026
	(0.033)***	(0.037)***	(0.009)***	(0.008)***
× 1965 q3	0.113	0.140	−0.030	−0.031
	(0.029)***	(0.035)***	(0.009)***	(0.008)***
× 1965 q4	0.105	0.113	−0.032	−0.027
	(0.029)***	(0.033)***	(0.009)***	(0.008)***
Municipality F.E.	yes	yes	yes	yes
Year F.E.	yes	yes	yes	yes
Prefecture-by-year F.E.	no	yes	no	yes
R^2	0.43	0.49	0.60	0.67
Adj. R^2	0.42	0.48	0.60	0.67
Number of obs.	9105	9105	7147	7147

Notes: Standard errors are clustered at the prefecture level. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variable for columns (1) and (2) uses power tillers per farm household. The dependent variable for columns (3) and (4) uses the share of the population aged 15-19. The municipalities are split into quantiles based on the distance to metropolitan areas (Tokyo, Nagoya and Osaka). Columns (1) and (2) include year fixed effects, municipality fixed effects, and the same municipal controls as in column (4) of Table 2. Finally, columns (2) and (4) add prefecture-by-year fixed effects.

Table 9: Destination of migrants

	Migrants to big cities	
	Fraction	Log
	(1)	(2)
Owner share × 1954	0.090	−0.300
	(0.061)	(2.135)
× 1955	0.094	−0.000
	(0.061)	(2.135)
× 1960	0.172	4.341
	(0.061)***	(2.135)**
× 1965	0.126	3.716
	(0.061)**	(2.135)*
× 1970	0.123	3.713
	(0.061)**	(2.135)*
Year F.E.	yes	yes
Prefecture F.E.	yes	yes
R^2	0.04	0.48
Number of obs.	252	252

Notes: Robust standard errors are in parentheses. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variables are either the number (log), or the fraction, of immigrants to big cities. The big cities are three metropolitan areas (Tokyo, Nagoya, Osaka). Year and prefecture fixed effects are included in all specifications. The year 1975 is used as the baseline. The unit of observation is prefecture.

Table 10: Type of migrants

	Son: 19 years old or younger		Son: 20-24 years old		Son	Daughter		
	Eldest	2nd or younger	Eldest	2nd or younger	Total	Marriage	Non-marriage	Total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Owner share	−0.0001	0.0013	−0.0003	0.0006	0.0015	0.0013	0.0020	0.0033
	(0.0003)	(0.0003)***	(0.0002)*	(0.0003)	(0.0007)**	(0.0010)	(0.0015)	(0.0018)*
Controls	yes	yes	yes	yes	yes	yes	yes	yes
Prefecture F.E.	yes	yes	yes	yes	yes	yes	yes	yes
R^2	0.11	0.21	0.17	0.20	0.28	0.15	0.36	0.26
Adj. R^2	0.09	0.20	0.16	0.19	0.27	0.13	0.35	0.25
Number of obs.	2480	2480	2480	2480	2480	2480	2480	2480

Notes: Standard errors are clustered at the prefecture level. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variable is the number of migrants of each category per agricultural population. The migrants were those who graduated from a school before 1959. Columns (1) and (2) use male migrants who are younger or equal to 19 years old as the dependent variable, while columns (3) and (4) use male migrants who are aged 20-24 as the dependent variable. Columns (5) takes the sum of them. Columns (6) through (8) use female migrants as the dependent variable. Columns (6) and (7) use the number of female migrants whose reason for migration was marriage and non-marriage, respectively, as the dependent variable, while column (8) takes the sum of them. The main independent variable is the share of owner farmers in 1950. All models include prefecture fixed effects and municipal controls: average land sizes and the total area of tenanted land before the land reform (log).

Table 11: Agricultural population who studies in higher education

	All	Male	Female
	(1)	(2)	(3)
Owner share	−118.814	−0.022	−0.017
	(47.480)**	(0.006)***	(0.004)***
× Male migrants		−0.694	
		(0.160)***	
× Female migrants			−0.369
			(0.087)***
Controls	yes	yes	yes
Prefecture F.E.	yes	yes	yes
R^2	0.48	0.35	0.45
Adj. R^2	0.47	0.34	0.43
Number of obs.	2480	2480	2480

Notes: Robust standard errors are in parentheses. $^{*}p < 0.1, ^{**} < 0.05, ^{***} < 0.01$. The dependent variable in column (1) is the number of farm household members who were studying in the high school or the higher educational institution in February in 1960 per agricultural population. Columns (2) and (3) use the same dependent variable, except that they only use male members and female members, respectively. *Male migrants* is the dependent variable used in column (5) in Table 10. *Female migrants* is the dependent variable used in column (8) in the same table. The control variables are prefecture fixed effects and municipal controls: average land sizes and the total area of tenanted land before the land reform (log).

Table 12: Connection between technology adoption and migration

	1960		1965	
	Tillers	Pop. 15-19	Tillers	Pop. 15-19
	(1)	(2)	(3)	(4)
Clay	−0.241	0.091	−0.430	0.065
	$(0.096)^{**}$	$(0.019)^{***}$	$(0.155)^{***}$	$(0.015)^{***}$
Owner share × Clay	0.337	−0.074	0.564	−0.048
	$(0.119)^{***}$	$(0.021)^{***}$	$(0.187)^{***}$	$(0.017)^{***}$
Controls	yes	yes	yes	yes
Prefecture F.E.	yes	yes	yes	yes
R^2	0.32	0.46	0.25	0.46
Adj. R^2	0.31	0.45	0.23	0.45
Number of obs.	2480	2436	2467	2480

Notes: Standard errors are clustered at the prefecture level. $^{*}p < 0.1,^{**} < 0.05,^{***} < 0.01$. Columns (1) and (2) use the data for 1960, while columns (3) and (4) use the data for 1965. The dependent variable for columns (1) and (3) uses the number of power tillers per farm household, while the dependent variable for columns (2) and (4) uses the share of the population aged 15-19. *Clay* is the share of land areas which consist of clay. I include prefecture fixed effects and municipal controls: average land sizes and the total area of tenanted land before the land reform (log).

Table 13: GDP growth rate

	Simulation	Data
Baseline	8.9 %	8.5 %
Scenario 1 (No reform)	8.3 %	
Scenario 2 ($\tau = 0$)	8.9 %	

Figure 1: The relationship between owner share and structural transformation

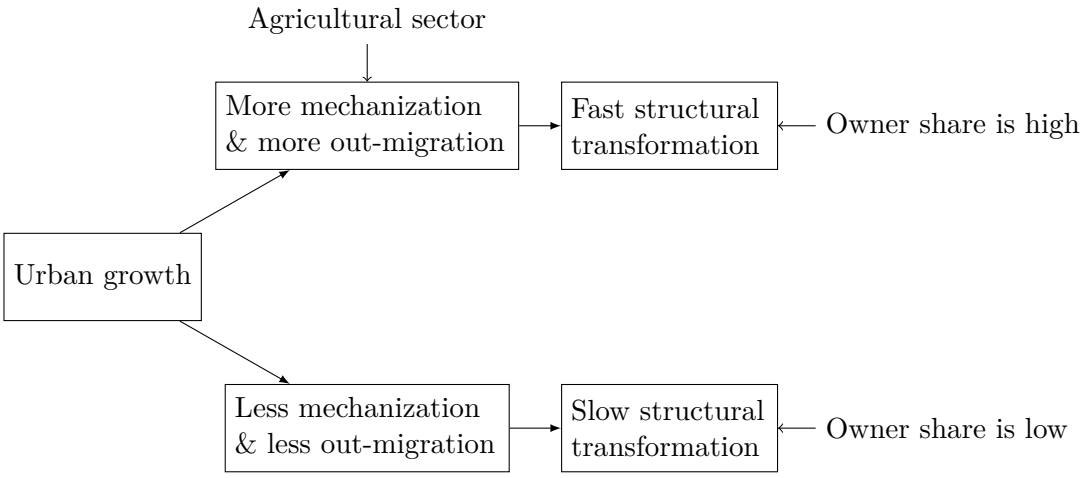
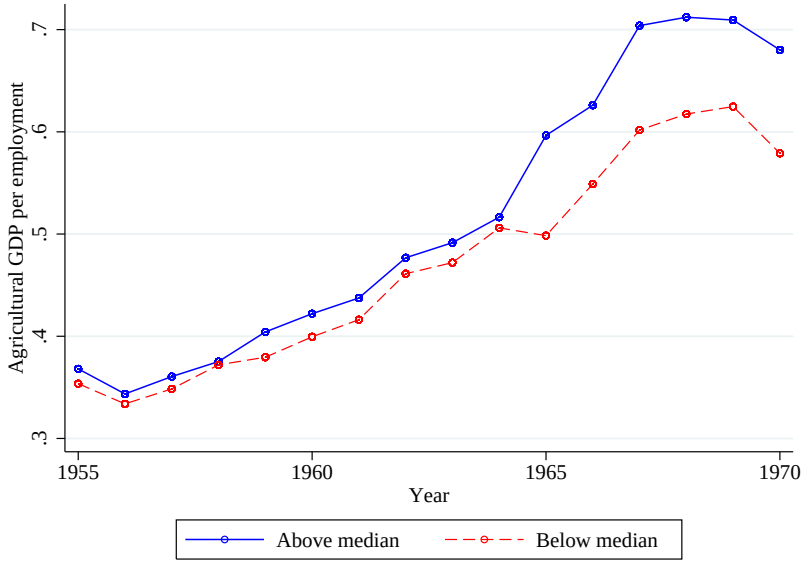


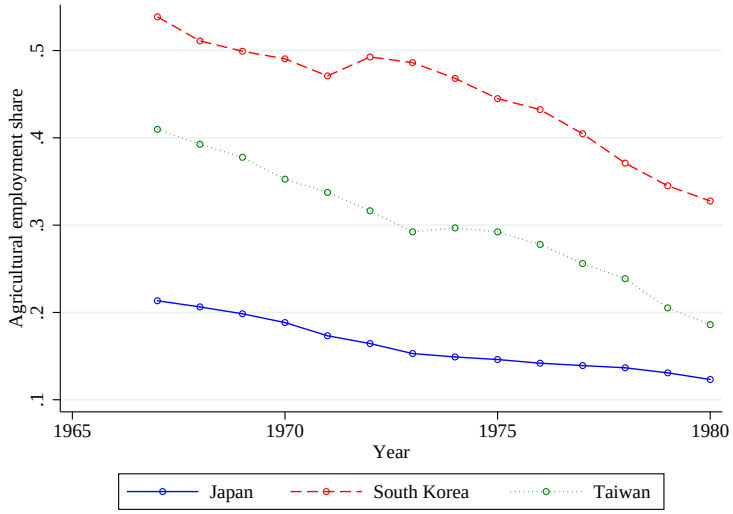
Figure 2: Agricultural productivity



Notes: Agricultural productivity is calculated as dividing real agricultural GDP by agricultural employment. I interpolate the agricultural employment because the data are only available for every five years. All data are at the prefecture level.

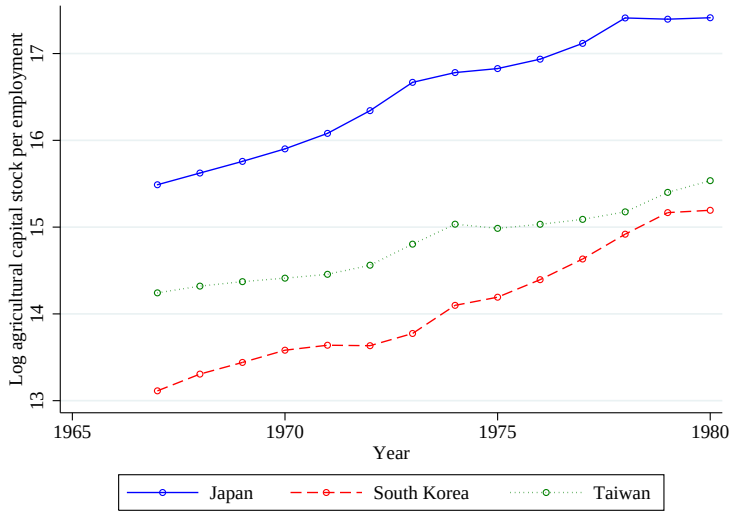
Source: Statistical Yearbook of Ministry of Agriculture and Forestry.

Figure 3: East Asian experience



(a) Agricultural employment share

Source: Timmer et al. (2014).



(b) Agricultural capital stock per agricultural employment (log)

Source: Larson et al. (2000), Timmer et al. (2014). Measured in USD (1990).

Figure 4: Owner share by municipality before and after the land reform

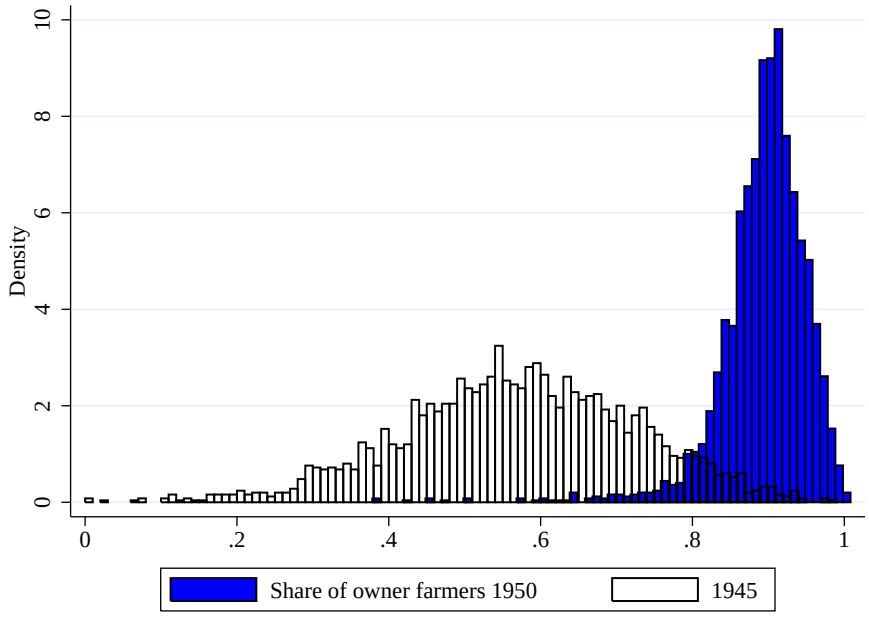


Figure 5: Owner share before the land reform

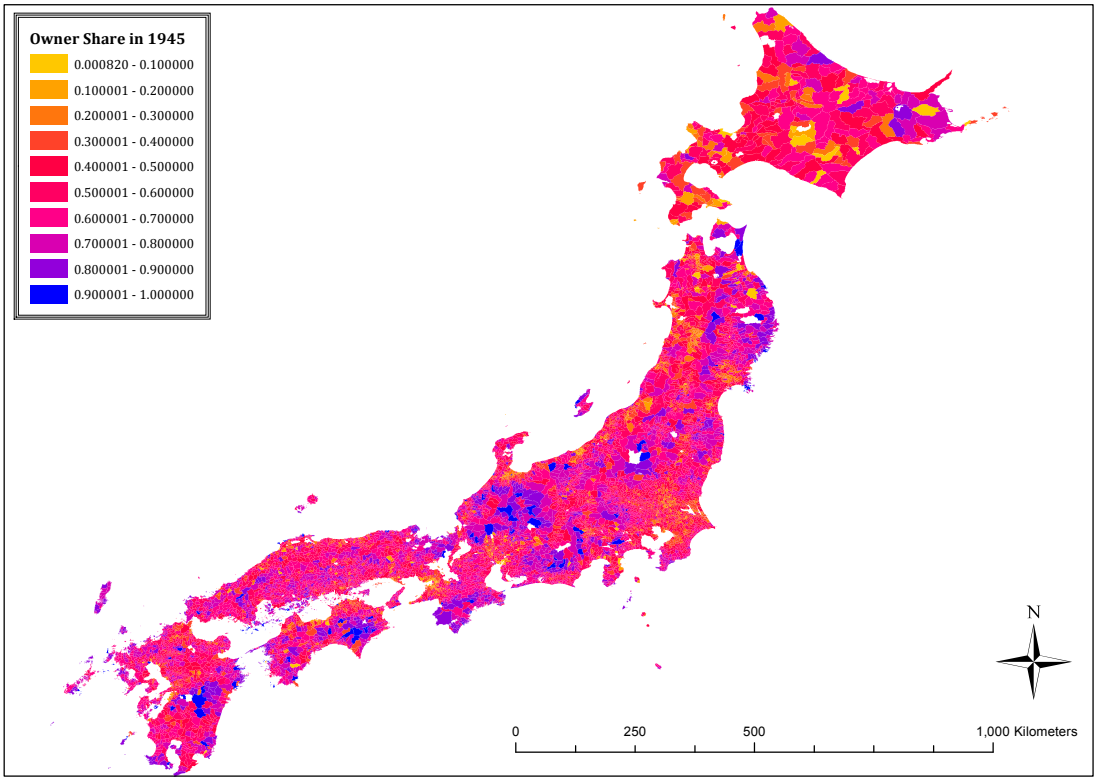


Figure 6: Owner share after the land reform

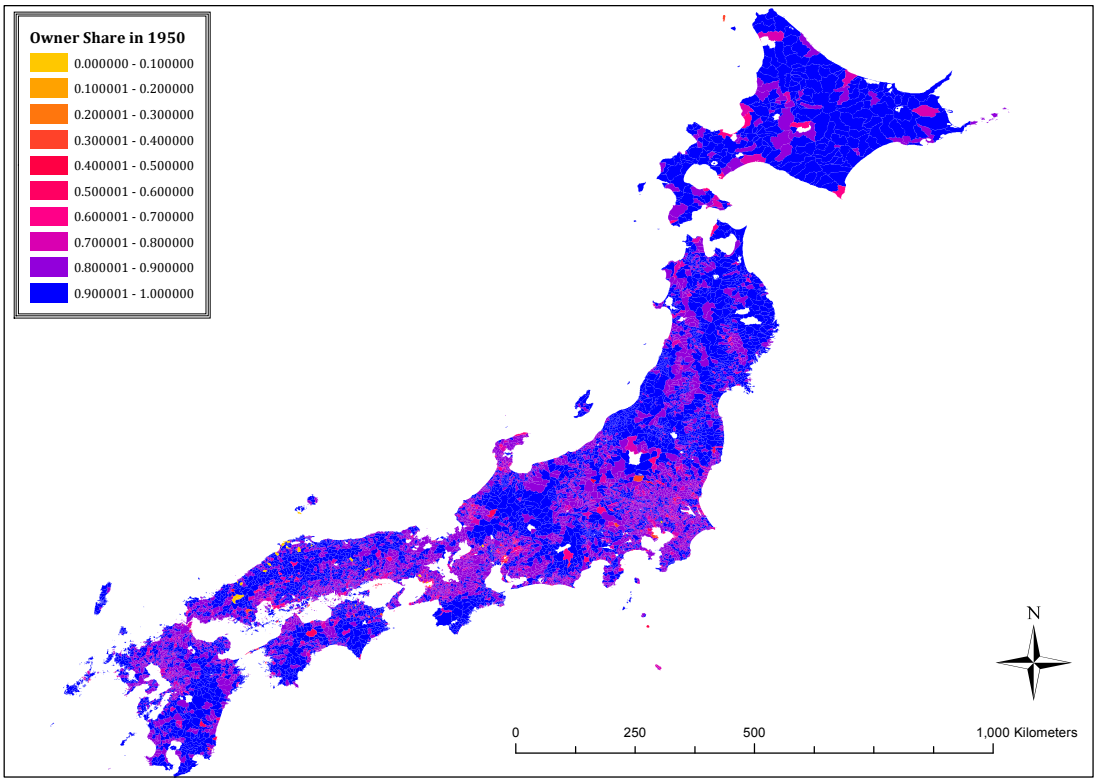
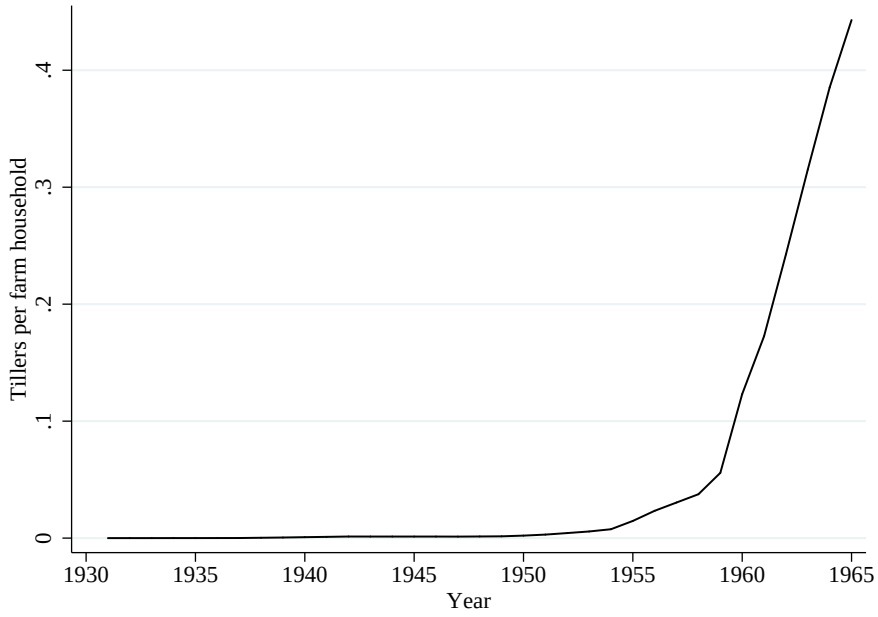


Figure 7: Penetration of tillers, 1931-65



Notes: I interpolate the number of tillers in 1932, 1934, 1936, 1938, 1940-41, 1943-46, 1948, 1952, and 1956-59, and the number of farm households in 1945, 1948, and 1956-59. The tiller includes trailing type (*ken-in gata*) and automated type (*kudou gata*).

Source: Kayou (1977).

Figure 8: Change in farming methods



(a) Tilling by hand



(b) Tilling by machine

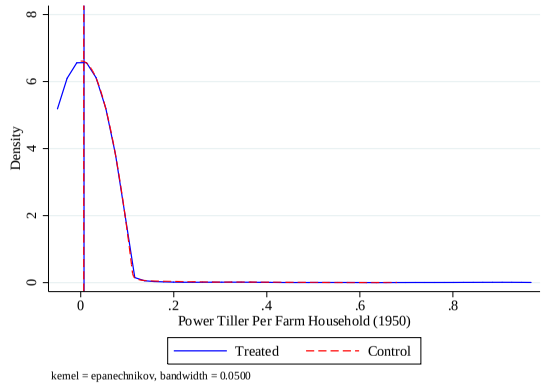
Notes: Both pictures were taken in 1956 near Hirosaki-shi, Aomori.
Source: Aomori Kyoudo Kan.

Figure 9: Mass migration to big cities

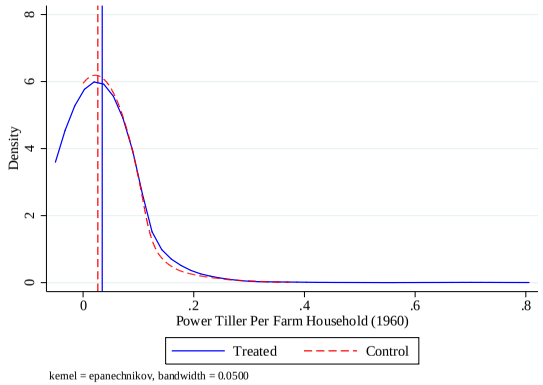


Notes: Group of young people arrived from Aomori, greeting their new employer in Tokyo (1959).
Source: Asahi Shinbun.

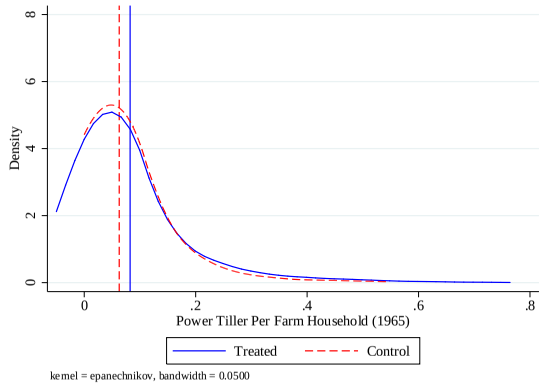
Figure 10: Distributional change between 1950 and 1965



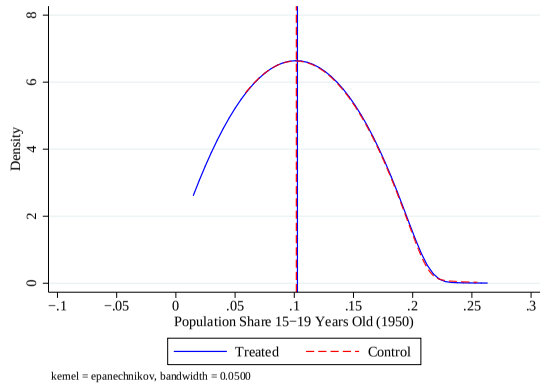
(a) Power tillers per farm household 1950



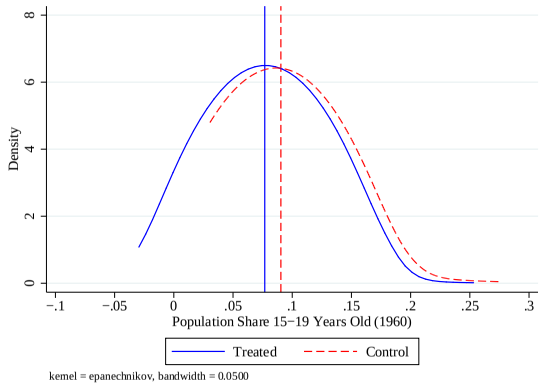
(b) 1960



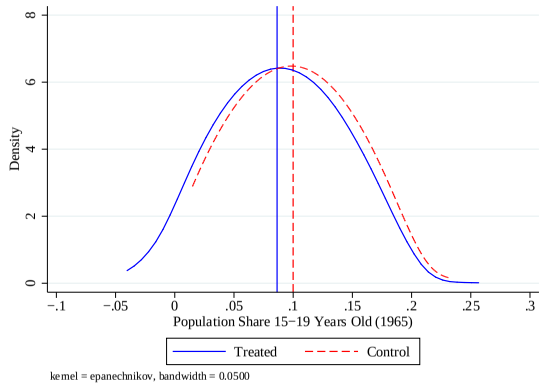
(c) 1965



(d) Population share 15-19 years old 1950



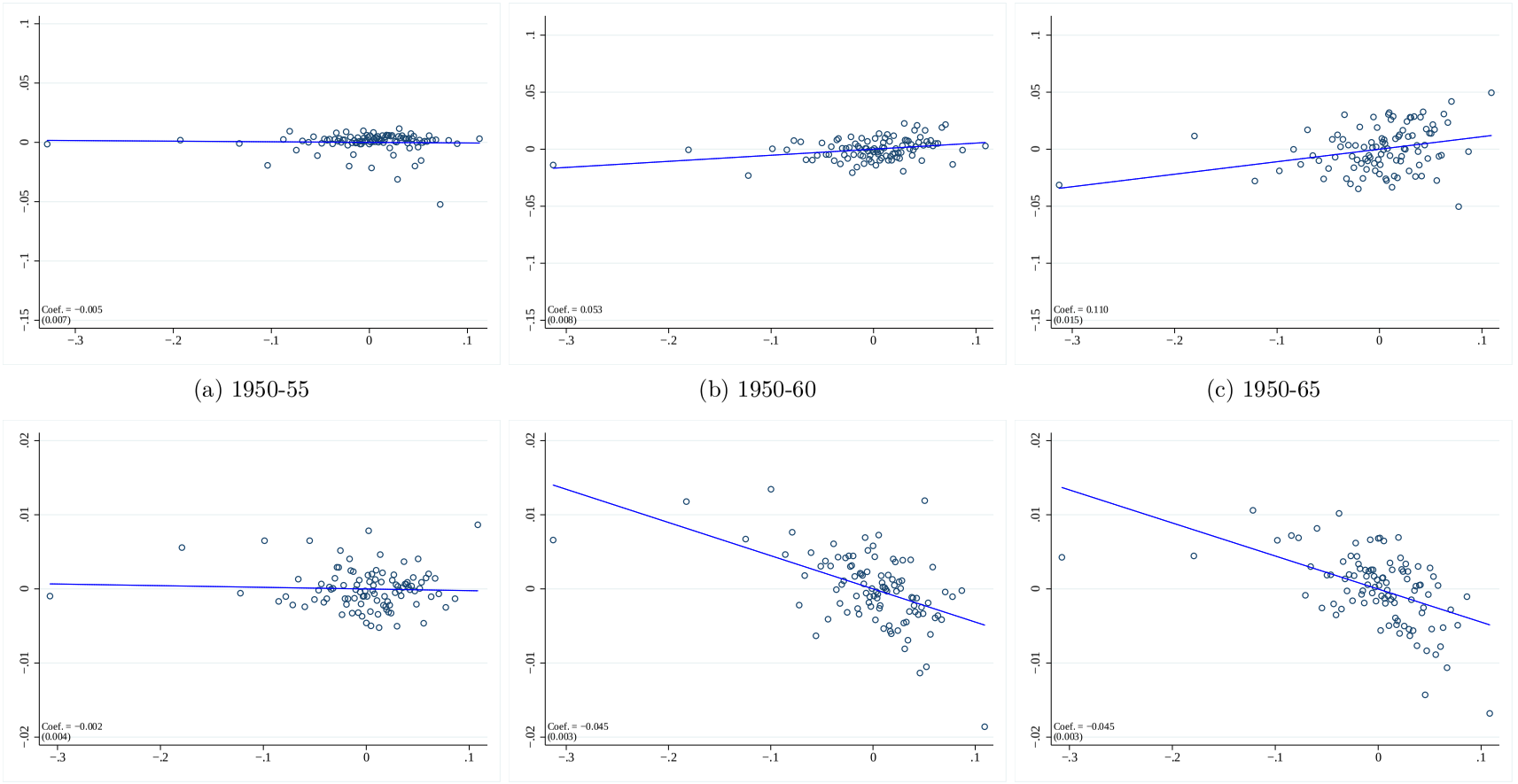
(e) 1960



(f) 1965

Notes: Municipalities are divided into quintile based on the post-reform owner share. The municipalities in the fifth quintile are regarded as a treated group, while those in the first quintile are regarded as a control group.

Figure 11: Correlation - Power tillers (above) and population 15-19 years old (below)

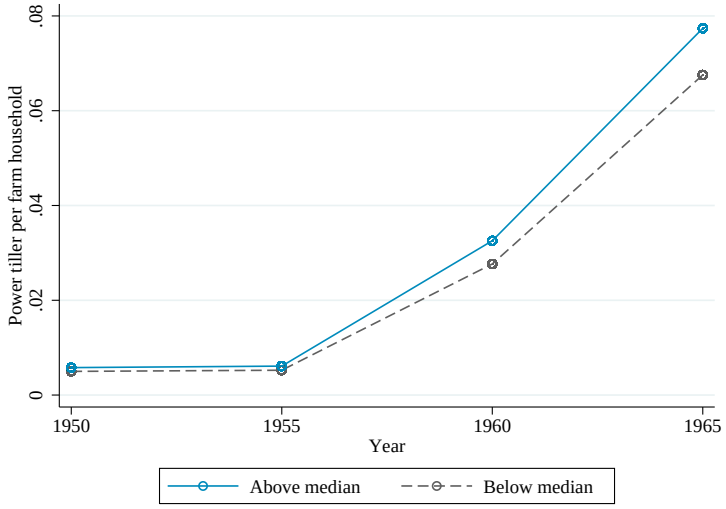


(a) 1950-55 (b) 1950-60 (c) 1950-65

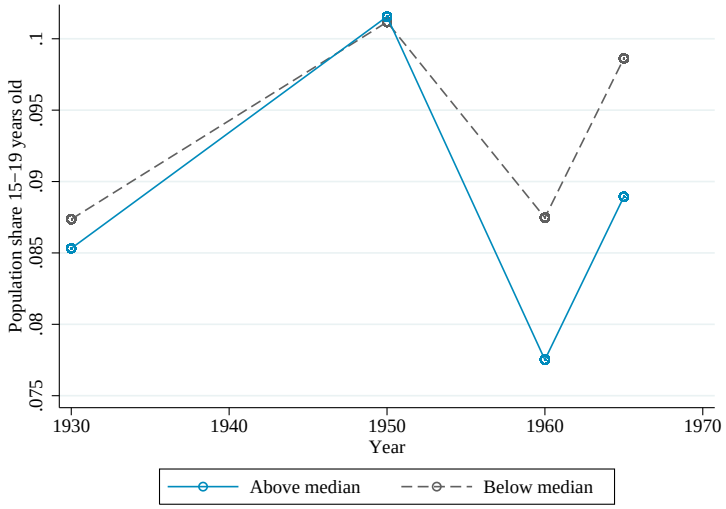
(d) 1950 (e) 1950-60 (f) 1950-65

Notes: The figures in the first row show partial correlation between the difference in power tillers per farm household for particular years (y-axis) and the share of owner farmers in 1950 (x-axis). The figures in the second row show partial correlation between the difference in the population share aged 15-19 for particular years (y-axis) except for the leftmost figure, which uses the 1950 sample, and the share of owner farmers in 1950 (x-axis). Control variables are prefecture fixed effects and municipal controls: average farmland sizes and the total area of tenanted land before the land reform (log).

Figure 12: Parallel trends



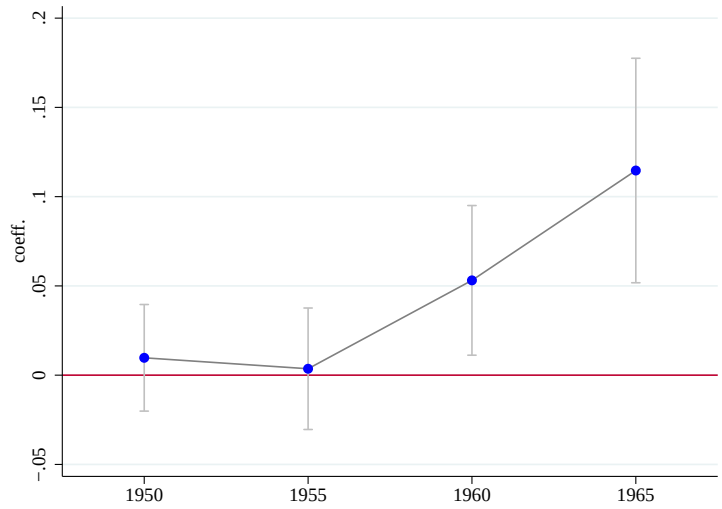
(a) Power tillers per farm household



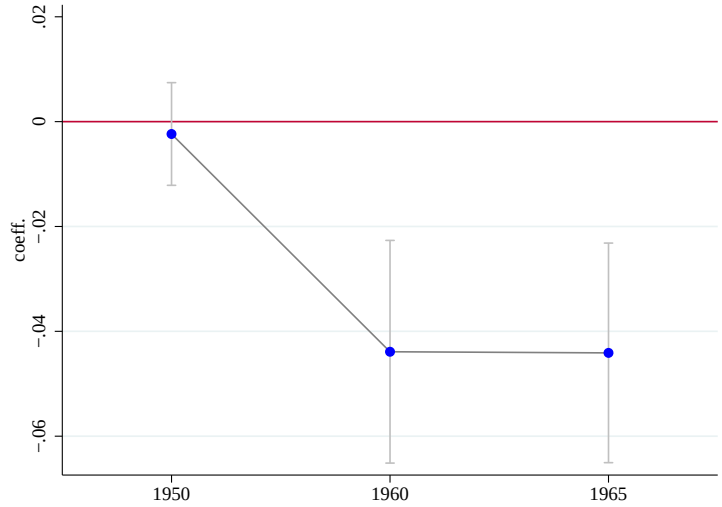
(b) Population share 15-19 years old

Notes: Municipalities are divided into two groups based on the post-reform owner share. The municipalities above median are regarded as a treated group, while those below median are regarded as a control group.

Figure 13: Coefficient plots of DID estimates



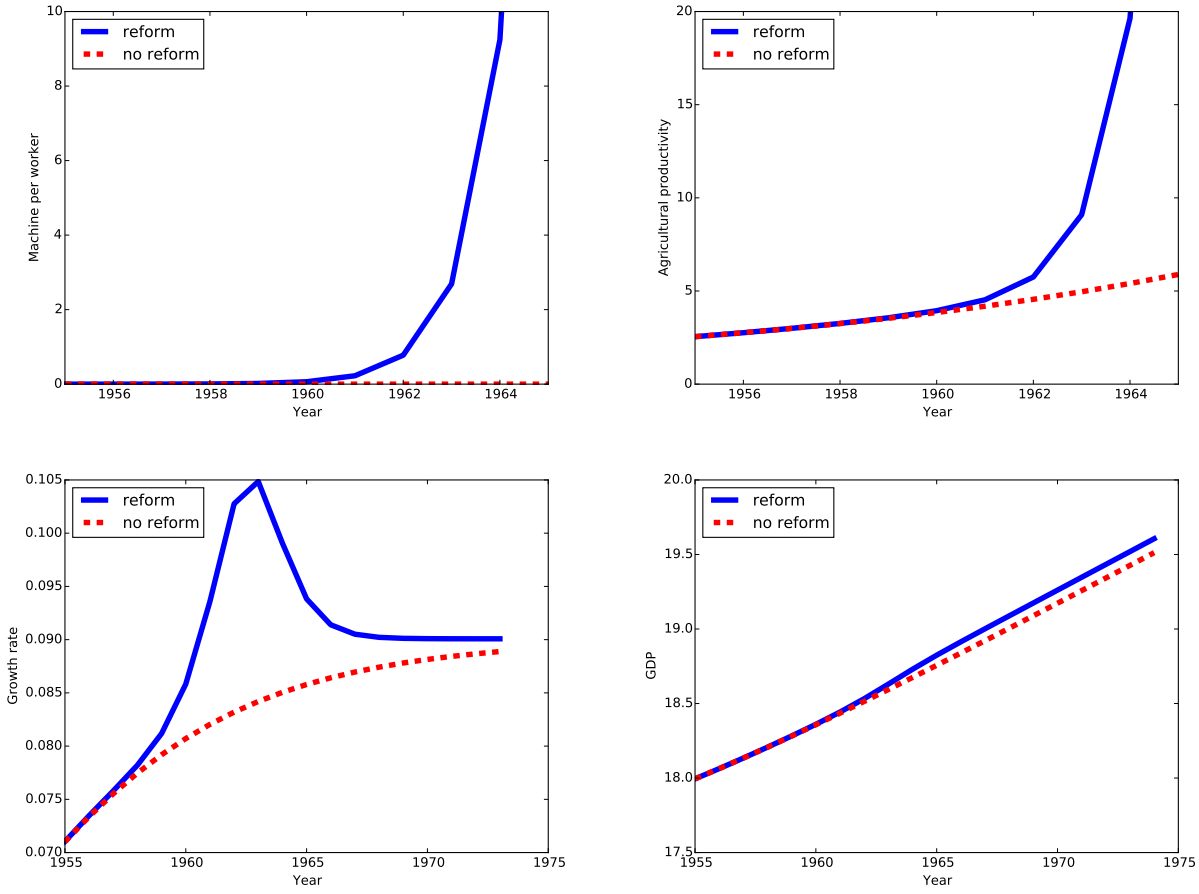
(a) Power tillers per farm household



(b) Population share 15-19 years old

Notes: The dependent variable of the top panel is the number of power tillers per farm household. The dependent variable of the bottom panel is the population share aged 15-19. Year fixed effects, prefecture-by-year fixed effects, and municipal controls: average farmland sizes and the total area of tenanted land before the land reform (log) are included.

Figure 14: Simulation results



Notes: The solid line is the baseline, while the dashed line is the counterfactual case which assumes that there was no land reform.

Appendix

A.1 Proof of Proposition 1

Using the first-order conditions, one can derive the optimal input levels in terms of exogenous variables:

$$M_t^{pi} = \left\{ \frac{1}{\gamma} \left\{ \left[\frac{w_t}{\alpha(1-\gamma)A_{at}^p} (N_{at}^{pi})^{1-\phi} \right]^{\frac{-\phi}{\phi-\alpha}} - (1-\gamma)(N_{at}^{pi})^{\phi} \right\} \right\}^{\frac{1}{\phi}}, \tag{10}$$

and

$$N_{at}^{pi} = \left\{ \frac{1}{1-\gamma} \left\{ \left[\frac{1}{\alpha\gamma(1-\tau^{pi})A_{at}^p} (M_t^{pi})^{1-\phi} \right]^{\frac{-\phi}{\phi-\alpha}} - \gamma(M_t^{pi})^{\phi} \right\} \right\}^{\frac{1}{\phi}}. \tag{11}$$

Next, using (10), it can be shown that

$$\frac{d\log M_t^{pi}}{dt} = \frac{g_a}{1-\alpha} + \frac{g_u}{1-\phi}\frac{\phi-\alpha}{1-\alpha} \frac{(1-\gamma)\left[\frac{1-\gamma}{\gamma}\frac{1}{(1-\tau^{pi})A_{ut}}\right]^{\frac{\phi}{1-\phi}}}{\gamma + (1-\gamma)\left[\frac{1-\gamma}{\gamma}\frac{1}{(1-\tau^{pi})A_{ut}}\right]^{\frac{\phi}{1-\phi}}}, \tag{12}$$

where the second term is positive, and is decreasing with respect to A_{ut}. Thus, as $t \to \infty$, the growth rate of M_t^{pi} converges to $\frac{g_a}{1-\alpha}$. Similarly, using (11), it can be shown that

$$\frac{d\log N_{at}^{pi}}{dt} = \frac{g_a - g_u}{1-\alpha} - \frac{g_u}{1-\phi}\frac{\phi-\alpha}{1-\alpha} \frac{\gamma\left[\frac{\gamma}{1-\gamma}(1-\tau^{pi})A_{ut}\right]^{\frac{\phi}{1-\phi}}}{(1-\gamma) + \gamma\left[\frac{\gamma}{1-\gamma}(1-\tau^{pi})A_{ut}\right]^{\frac{\phi}{1-\phi}}}. \tag{13}$$

Thus, if $g_u > g_a$, agricultural labor decreases over time. For a sufficiently large t, $N_{at}^{pi} \to 0$. Asymptotically, the farm therefore only uses machines in production. This means that the growth rate of Y_{at}^{pi} will only depend on the growth rate of the machine and that of urban TFP. The production function becomes Cobb-Douglas when $N_{at}^{pi} \to 0$, and the growth rate will be equivalent to that of the machine. Formally, using the production function, one can derive

$$\frac{d\log Y_{at}^{pi}}{dt} = g_a + \frac{\alpha}{1-\alpha} \frac{\left[\gamma(M_t^{pi})^{\phi} + (1-\gamma)(N_{at}^{pi})^{\phi}\right] g_a - (1-\gamma)N_{at}^{pi} g_u}{\left[\gamma(M_t^{pi})^{\phi} + (1-\gamma)(N_{at}^{pi})^{\phi}\right]}. \tag{14}$$

We know that $N_{at}^{pi} \to 0$ as $t \to \infty$. Thus, the growth rate of Y_{at}^{pi} converges to $\frac{g_a}{1-\alpha}$, which is the growth rate of the machine. Finally, due to the labor market clearing condition, all workers are hired by the firms as $t \to \infty$. Since the total population is constant, the growth rate of Y_{ut}^{pi} will converge to the growth rate of urban TFP, g_u. Hence, all variables asymptotically grow at constant rates. Q.E.D.

A.2 Prefectural data

The origin-destination migration data have been taken from the Statistics Bureau's *Jyuumin Kihon Daichou Idou Houkoku*. Sectoral GDP, total GDP, and the GDP deflater have been taken from Cabinet Office's *Kenmin Keizai Keisan*. Prices are based on the 1980 value. Data on the labor force have been taken from Fukao and Yue (2000). Agricultural employment data have been taken from the Census of Agriculture and Forestry. Finally, the number of power tillers has been taken from the MAFF's *Nourinshou Toukei*.

A.3 Calculation of initial TFPs

First, I use prefectural agricultural real GDP, agricultural machines, and agricultural employment in 1955 to calculate initial agricultural TFPs by

$$A_{a0}^{p} = \frac{Y_{a0}^{p}}{[\gamma(M_{0}^{p})^{\phi} + (1-\gamma)(N_{a0}^{p})^{\phi}]^{\frac{\alpha}{\phi}}}. \tag{15}$$

Second, I use prefectural non-agricultural real GDP and non-agricultural employment in 1955 to calculate initial non-agricultural TFP by

$$A_{u0}^{p} = \frac{Y_{u0}^{p}}{N_{u0}^{p}}. \tag{16}$$

Finally, I take the average to get A_{u0}.