Land Ownership, Technology Adoption, and Structural Transformation:
Evidence from Postwar Japan

Shuhei Kitamura[1]
Institute for International Economic Studies, Stockholm

May 15, 2016
(Original: September 15, 2015)

Abstract

This paper analyzes the effect of land ownership on technology adoption and structural transformation. A large-scale land reform in postwar Japan enforced a large number of tenant farmers who were cultivating land to become owners of this land. I find that the municipalities which had many owner farmers after the land reform tended to experience a quick entry of new agricultural machines which became available after the reform. The adoption of the machines reduced the dependence on family labor, and led to a reallocation of labor from agriculture to industries and service sectors in urban centers when these 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 advancement in agriculture, capital-labor substitution, industrialization, labor reallocation, structural transformation

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

- John Stuart Mill

[1]shuhei.kitamura@iies.su.se. I thank Torsten Persson and Jakob Svensson for their continued guidance and support. I also thank Timo Boppart, Jonathan de Quidt, Masayuki Kudamatsu, Takashi Kurosaki, Nils-Petter Lagerlöf, David Strömberg, Kensuke Teshima, and conference and seminar participants at the 4th Kyoto Summer Workshop on Applied Economics at Kyoto, the 14th EUDN PhD Workshop at Paris-Dauphine, the Oxford Development Economics Workshop at Oxford, Hiroshima, Hitotsubashi, IFN, NYU Abu Dhabi, Osaka, Otaru Commerce, SITE, and Yale-NUS for helpful comments and suggestions. I thank Kazuo Kishimoto for providing me with the data. Financial support from Handelsbanken's Research Foundations is gratefully acknowledged. Any remaining errors are my own.

1 Introduction

The idea that property rights constitute a key factor for agricultural development has a long history. According to the 18th century writer Arthur Young, the possession of land, as compared to the lease of it, would enhance agricultural investment.[2] More generally, recent scholars regard secure property rights as an important precondition for economic development (North 1981, De Soto 2000, Sokoloff and Engerman 2000, Acemoglu et al. 2001, 2002, Besley and Persson 2011). There is a considerable amount of micro evidence that is supportive of these arguments.[3] In addition to the property rights, the diffusion of advanced technologies in agriculture may be associated with economic development. According to W. W. Rostow (1959), a technological revolution in agriculture was one of the fundamental conditions for sustained industrialization of the British economy.[4] Despite these arguments, how the property rights and technological advancement in agriculture are related to industrialization and economic growth is not even fully understood nowadays. This paper tackles the issue by using two analyses.

The first part of the paper focuses on the effect of secure ownership of land on technology adoption. It is known that the extent to which society is willing to accept advanced technologies such as agricultural machinery differs to a considerable extent between areas. 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). Recent studies in development economics have uncovered barriers to technology adoption in agriculture, given that the adoption rates of the advanced technologies are typically low in developing countries. Such barriers include 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).[5] This paper provides new causal evidence that secure ownership of land has a positive effect on the adoption of new agricultural technologies.

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

[2] "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" in *Travels* (1792). Adam Smith writes in a similar way in his discussion of the Act of Ejectment in *Wealth of Nations* (Goldstein and Udry 2008).

[3] The property-right security increases agricultural investment (Besley 1995, Banerjee et al. 2002, Jakoby et al. 2002, Hornbeck 2010). Who enjoys the property rights in society is of importance (Banerjee and Iyer 2005, Goldstein and Udry 2008). More broadly, the property rights affect the access to credit (Besley et al. 2012), labor supply and migration (Field 2007, de Janvry et al. 2015), formation of beliefs (Di Tella et al. 2007), and firms' investment (Johnson et al. 2002).

[4] In contrast to the literature on property rights, micro empirical evidence on relationships between technological advancement in agriculture and industrialization is very scarce. Bustos et al. (2016) is one of the few micro empirical studies in this direction.

[5] See Foster and Rosenzweig (2010) for an excellent review of recent literature.

[6] The ownership was also "secure" given that private property rights were already introduced in the late 19th

short-term investment such as fertilizers and improved seeds. This paper examines the likelihood of these land-owning cultivators adopting new agricultural machines which became available during the postwar period and which dramatically changed the mode of agricultural production.

To proceed to the empirical analysis, I construct a unique dataset of municipalities from historical documents and censuses. The data on the land reform contain detailed information about land transactions which occurred during the reform in almost all municipalities.[7] Since other data have not been available in digital format either, I have explored and photocopied the data in libraries and ministries in Tokyo, and have assembled all photocopied data in digital format.[8] To the best of my knowledge, this is the first paper to evaluate one of the historically large land redistribution policies at such high spatial resolution. This makes it possible to rigorously analyze the impact of such policies.

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 affected by the formula set by the central bureaucracy prior to the land reform. The formula specified the total area of tenanted lands that each landlord in a particular area had to release. Thus, it affected how many tenant farmers that would become owner farmers during the reform. Such a systematic implementation of the land reform is a unique aspect of the Japanese land reform, and it makes the analysis possible using a plausibly exogenous variation in land ownership.

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 where more farmers remained tenants. This means that owner farmers are more likely to adopt agricultural machines than tenant farmers when the machines become available. 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 industries 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.

As a robustness check, I also compare two adjacent municipalities along both sides of 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 different shocks. 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

century, and a land law, which was enacted after the reform, prevented the re-accumulation of land by the landlords.

[7]The number of municipalities was above ten thousand at that time. I digitized and manually entered the data myself. The data on Wakayama were missing. Okinawa was not Japanese territory at that time.

[8]To digitize agricultural censuses, I have set up an "online RA team" through a Japanese online outsourcing company, and have remotely managed all data entry and checking processes.

methods yield similar results.

The causal evidence of mechanization in agriculture 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, land owners in the flooded area increased the capital intensity in agriculture over time.[9] In contrast to their study, this study compares the likelihood of owner farmers adopting agricultural machines to that of tenant farmers.

Land ownership may increase agricultural investment and hence, agricultural productivity (Besley 1995, Banerjee et al. 2002, Jakoby et al. 2002, Banerjee and Iyer 2005, Goldstein and Udry 2008, Hornbeck 2010).[10] For example, Banerjee, Gertler, and Ghatak (2002) find that improvement in the security of tenure of sharecroppers and regulation of land rents have a positive effect on agricultural productivity, although they do not explicitly study technology adoption.[11] In contrast, the impact of the land ownership reform on agricultural productivity in Japan indicates that the effect is most likely to appear when advanced agricultural technologies become available.[12]

Figure 1 plots agricultural productivity which is defined as real agricultural GDP divided by agricultural employment. The blue 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 red line is average agricultural productivity for the prefectures which have a lower share of owner farmers (or a higher share of tenant farmers).[13] 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 the pattern of technology diffusion. Although available technologies for farmers at the time of the study are often taken as given in empirical studies of property rights, this might suggest that technological advancement is a crucial complementary factor for secure property rights.

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

[9] 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.

[10] Yet the effects of land tenure on investment are quite mixed. See Fenske (2011) and Brasselle et al. (2002) for excellent surveys and discussions. Apart from agricultural investment and productivity, recent empirical studies find that the property rights affect 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 market-oriented beliefs (Di Tella et al. 2007), and firms' investment (Johnson et al. 2002). The macro-economic literature on agricultural productivity includes Hayami and Ruttan (1970a), Restuccia et al. (2008), Adamopoulos and Restuccia (2014), and Gollin et al. (2014). For example, Gollin et al. (2002) show the importance of high agricultural productivity for industrialization.

[11] Moreover, they examine a limited transfer of property rights, as opposed to a full transfer of ownership which is the focus of this paper, although they indeed 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)."

[12] Previous studies of the Japanese land reform examine the short-run effect by focusing on the 1940s and the 1950s and find either a zero or a negative effect on agricultural productivity (Kawagoe 1995, Ramseyer 2015). In contrast, this paper studies the 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.

[13] 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.

the land ownership reform on the entire economy.[14] Recall that Korea and Taiwan experienced land reforms after World War II. The mechanization of agriculture progressed rapidly when the economies grew and the agricultural employment share declined. Figures 2 and A.1 show that the capitalization of agriculture progressed when the structural transformation occurred in these economies as well as in Japan. These historical facts already suggest that the land reform may be a key to explain sustainable economic growth in these economies after World War II. The analysis uses a growth model and micro data given that the movement of labor makes it difficult to conduct the analysis using regressions. The model takes into account labor reallocation across sectors and locations.

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.[15] 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.[16] 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 inputs if these inputs are substitutes. The model also has urban sectors and labor can be reallocated across sectors and locations.[17]

Next, I simulate the model using data at the municipality level 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 growth rate of the GDP during the transition period due to the great expansion of the urban sectors. Simulation results show that the land reform increased the GDP by about 12 percent of the GDP in 1974 during 1955-74. 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 et al. (2016) which finds that the labor-saving technological change in soy production in Brazil increases

[14] The literature on the structural transformation is quite vast. Herrendorf et al. (2014) provide an excellent review of this. Related papers in theoretical macro literature are Rogerson (1987), Matsuyama (1992), Caselli and Coleman (2001), Kongsamut et al. (2001), 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 (Nunn and Qian 2011, Michaels et al. 2012, Desmet and Rossi-Hansberg 2014).

[15] See Besley and Ghatak (2010).

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

[17] The details of the model and the formal statement of prediction are found in Section 7. Note that the mechanism 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 reallocation in Japan was not caused by alleviating the land-use constraint but, if anything, by reducing a technology-adoption barrier.

local industrial employment.[18] In their empirical study, the adoption of agricultural technologies is affected by the potential profitability of adopting them. In contrast, this paper examines the impact of the land ownership reform on the structural transformation.[19] To the author's best knowledge, this is also the first paper to analyze the effect of land ownership/property rights on structural transformation. This may have implications for developing countries where secure property rights have not yet been established.

The idea that machines replace workers is not new and may at least date back to Swing Riots (for agricultural sectors) and Luddite (for non-agricultural sectors). The stories are echoed in a recent literature about automation in production (Zeira 1988, Sachs and Kotlikoff 2012, Hémous and Olsen 2014, Graetz and Michaels 2015). For example, in a recent book, *The Second Machine Age*, Erik Brynjolfsson and Andrew McAfee describe how the development of digital technologies has an impact on our lives and the economy. In contrast to previous studies which mainly look at manufacturing and service sectors, this paper focuses on mechanization *in agriculture*. For example, 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).

I show that the adoption of machines in agriculture *does* affect labor reallocation and structural transformation.

It may not be difficult to find similar patterns in other countries. According to Binswanger (1986), the United States after 1940 and Europe after 1955 followed a similar pattern to that of Japan where the use of tractors, combines and other machines increased at unprecedented rates and labor was reallocated to non-agricultural sectors. As mentioned above, Korea and Taiwan may also have experienced a similar pattern to that of Japan.

The rest of the paper is organized as follows. In the next section, the historical background is briefly explained. This consists of 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 3 describes the data that will be used for the empirical analysis. In Section 4, the main empirical strategy is described. The main identification strategy employs

[18] They also examine the effect on outmigration and find a positive effect.

[19] Moreover, I focus on agricultural machines rather than improved seeds (GM soy/second-harvest maize). The former type of technological change is called the M-process, while the latter type of technological change is called the BC-process, and the distinction is very stark in agriculture (Hayami and Ruttan 1971). For example, Hayami and Ruttan (1970b) show that the BC-process was followed by the M-process in Japan, while the opposite occurred in the United States, and they argue that relative endowments and accumulation of land and labor induced the different patterns of technological change. The diffusion of improved seeds already occurred in the late 19th century in Japan (Hayami and Yamada 1968). Another difference is that, while they focus on the shift in employment, I show that the labor reallocation increases GDP using a growth model.

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 5, and the underlying mechanisms are discussed in Section 6. The empirical findings are found in Section 7 where I build a simple growth model to quantify the aggregate impact of the land reform. I also run counterfactual simulations in this section. Finally, Section 8 concludes the paper. Implications for other countries are also discussed in this section.

2 Historical background

2.1 Land reform

Fixity of land tenure may either be accomplished by land titling, i.e. the state giving part of its property to the occupant of land, or land redistribution, i.e. the authority enforcing landlords to redistribute their property to tenants. The former is also a kind of redistribution of land, but from the state to land settlers, while the latter is the redistribution of land from landlords to tenants in the name of the state. The Japanese land reform after World War II took the second form.[20]

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 property rights of nearly all farm households, or about 6 million households, and about 2 million hectare of farmlands were redistributed from landlords to tenants.[21] 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 farmer's land.

Figure 3 shows the distributional shift in the share of owner farmers by municipality. The distribution before the reform is in white color, while the distribution after the reform is in blue color. 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 just a few years.

The reform also yielded a new spatial distribution of owner farmers. Figure 4 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 share of owner farmers increased across Japan, and a new cross-sectional variation emerged (Figure 5). 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-variation was due to the formula set by the Ministry of Agriculture and Forestry.[22]

[20] Therefore, it is distinct from e.g. Mexico's land titling programs. The Land Tax Reform (*Chiso Kaisei*) in the late 19th century introduced the Western private property rights in Japan for the first time.

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

[22] The details will be explained below.

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.[23] 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.[24]

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.[25] For example, if a landlord had to sell 3 *cho* of the tenanted land, the compensation was less than 30,000 yen which was, on average, less than a third of an annual salary in 1950.[26] Landlords were paid either in cash or in governmental bonds at the annual interest of 3.6 percent, which was redeemable within thirty years.

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.[27] Therefore, most tenants could complete their payments within a year or two of the purchase (Dore 1959).[28]

To complete the reform, the Agricultural Land Act (*Nouchi Hou*) was enacted in 1952 which perpetuated the land allocation by regulating the transaction of lands.[29] The Act prevented the re-accumulation of the land by landlords.[30]

[23]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.

[24]One *tan* is approximately ten acre. One *cho* is approximately one hectare, or ten *tan*.

[25]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).

[26]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*).

[27]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.

[28]The fixed price is one of the major reasons why the Japanese land reform was "successful." This is in contrast 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. Ex-tenants who bought farmlands under the program suffered from a heavy burden of payment (Kajii 1997).

[29]The reason for enacting such a law was, according to Dore (1958): "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)."

[30]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.

2.2 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.[31] Thus, there seems to be a path dependency in the process of technology advancement in agriculture. Such a transition pattern may be due to the availability of affordable machines, farmers' willingness to invest in more expensive technologies, and the change in land and labor supply. This paper focuses on tilling machines, notably power tillers, because these small machines have initiated agricultural mechanization in Japan, and land preparation having been a most labor-intensive task before the introduction of power tillers as described below.

The introduction of power tillers constituted a turning point for modernizing Japanese agriculture (Hayami and Kawagoe 1989, Yanmar 2013). The machines were introduced in the 1950s and have been diffused astonishingly quickly since then. Figure 6 shows the penetration rate of notable farm equipment. It is obvious that the diffusion of tilling machines was remarkably quick. Indeed, it only took about ten years to reach about 2 million machines.[32] The power tiller can not only be used for tilling the soil, but also for transporting people and goods, and for threshing crops. Such multifunctionality and handiness may be part of the reason for the quick diffusion of the machines.

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 cooperation with the company, started to sell them a year after.[33] The original machines had a 2 to 3 hp air-cooled high-speed engine with a simple structure, and it was much lighter and cheaper than similar machines that Japanese makers had developed (Hokimoto 1999). The price of the new machine was about one half of that of earlier existing similar machines (Kako 1987).[34]

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.[35] The adaptive research and development made the machines more efficient, powerful, and suitable for Japanese land conditions.

Before the introduction of power tillers, most farmers had largely tilled the soil by hand or using animals. Figure 7 shows pictures taken in 1956 near Hirosaki-shi in Aomori. The picture on the left shows farmers using traditional farm equipment called *Sanbon-guwa* to till the soil. In contrast, the picture on the right shows a farmer using a power tiller. It effectively reduced human labor

[31] 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 *torakutā* 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).

[32] 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).

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

[34] Kako (1987) and Francks (1983, 1996) describe the history of agricultural machinery in Japan.

[35] 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).

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 workers by two due to the adoption of power tillers.

The rapid diffusion of the machines was initiated by motivated farmers who obtained the land during the land reform (Yanmar 2013). Initially, tenant farmers before the reform preferred relatively cheap and fast-acting short-term investment such as fertilizers and improved seeds (Kawano 1963, NKNC 1964).[36] After the land reform, they started to make long-term investments such as machines and land improvement (NKNC 1964). When effective and cheap agricultural machines became available to these farmers, they quickly started to adopt them. The mechanization finally started on a full scale in the late 1950s.[37]

2.3 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*).[38] 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.[39]

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.[40] Figure 8 shows young people who arrived from Aomori greeting their new employer. In particular, three metropolitan areas (Tokyo, Nagoya, and Osaka) experienced a large net immigration. In 1962, for example, about 25 percent (166,000) of those who had just graduated from junior-high schools in the countryside, 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).

[36] Until around the end of World War I, agricultural investment was mostly initiated by landlords who were cultivators themselves, who were often leaders of a village and who 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).

[37] The investment cost for buying a power tiller was moderate. 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.

[38] The annual growth rate was above 9 percent on average, and real GDP increased about five-fold between 1955 and 1973. Real GDP increased from 47 trillion to 230 trillion during the same period.

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

[40] The phenomenon is called *Syuudan Syuusyoku* (Mass Employment). There were special trains and boats which sent a large numbers of young people from the countryside to distant big cities.

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.

3 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. 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.

3.1 Data

The historical analysis of the entire Japanese economy often uses data either at the national level or at the prefectural level.[41] Difficulties to obtain finer data may be part of the reason.[42] I have searched and collected data in libraries and ministries in Tokyo with the aid of historical documents and own intuition. The data have been entered into a 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.[43] To merge the data year-by-year to construct a panel dataset, I had to deal with the issue of municipality mergers.[44] 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.[45] GIS techniques have been used to match municipalities over time.[46] First of all, the 1965 municipalities have been chosen as the unit of observation because it is the most aggregated unit. The municipalities in earlier years have been matched with these 1965 municipalities. For this purpose, I have first prepared polygon data of the municipalities for each year. The polygon data

[41] 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.

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

[43] This is also the period in which scale economies had not started functioning in Japanese agriculture. In contrast, 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.

[44] 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.

[45] Municipality mergers may be another reason why disaggregated data have rarely been used by researchers.

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

have been projected onto a two-dimensional space using the Sinusoidal projection. Then, the land area has been calculated for every municipal polygon, and each 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. I have aggregated values at the 1965 municipality level, and have compared that value with the actual one. The observations within five square kilometer differences have been used to minimize the measurement errors.[47] 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.[48] I have taken pictures and manually entered the data myself.

Agricultural and Demographic Data

The 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.[49] Since the agricultural censuses have not been digitized, I first photocopied them in libraries in Tokyo. To enter the photocopied data into a digital format, I have set up an "online RA" team through an online outsourcing company, and have remotely managed all digitization and data checking processes from Sweden.

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. Data on education and 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 1930, 1950, 1960, and 1965.[50] 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). 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 the new characters (*Shinjitai*). To calculate land sizes, I have divided total farmland areas in 1945 by agricultural employment in 1950, because I have found no data for that year. Finally, since the 1955 values are missing, I have interpolated the values of these variables for that year.

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

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

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

[50] Although a more appropriate data point may be 1940, rather than 1930, the census of 1930 does contain enough information such as age distribution in municipalities.

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.

The 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 since the unit of analysis is the 1965 municipality. I have used the location of the prefectural office 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.[51] 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 data have used 0.5 degree-by-0.5 degree cells which have been too big for small municipalities, I have resized each side of these cells into 0.005 degrees, or about 500 meters, before calculating values per municipality.

3.2 Descriptive Analysis

Summary statistics are shown in Table 1. The unit of observation is the 1965 municipality as mentioned above. Note that a prefecture contains municipalities, and both are a political division. In 1965, for example, there were 46 prefectures and 3,466 municipalities.

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 share of owner farmers dramatically increased from 57 percent to 89 percent within a few years due to the land reform.[52] The population share aged between 15 and 19 was about 10 percent in all years.

The top panel of Figure 9 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 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 9 shows the kernel density of the population share aged between

[51] 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 cereals, 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.

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

15 and 19. It is clear that the treated municipalities had fewer young people in the population than the control municipalities in 1960 and in 1965, although the distributions are very similar in 1950.

Next, the change in technology adoption and the population share is plotted in Figure 10 where I take the first-difference of the dependent variables between particular years for the y-axis, and use the post-reform share of owner farmers for the x-axis.[53] These figures clearly show that the slope appears for the 1950-60 difference and for the 1950-65 difference, for both dependent variables.

The next section explains the empirical strategies.

4 Empirical framework

The main identification strategy uses a difference-in-differences (DID) estimation with fixed effects. I compare municipalities with a high share of post-reform owner farmers to those with a low share of post-reform owner farmers (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 was affected by the formula set by the central bureaucracy prior to the land reform. The formula specified the total area of tenanted lands that each landlord in a particular area had to release. Thus, it affected how many tenant farmers would become owner farmers during the reform in that area. As mentioned earlier, the post-reform distribution of owner farmers is very different from the pre-reform distribution of owner farmers. The following analysis uses this new variation in land ownership which has been created due to the land reform being a cross-sectional variation.

The next section briefly describes the formula.

4.1 Maximum Tenanted Land (MTL)

The intensity of the reform was determined by the formula (Maximum Tenanted Land, MTL) set by the central bureaucracy which specified the total area of tenanted land that each landlord in a particular municipality had to release. The value stretched from 0.6 cho in Hiroshima to 4 cho in Hokkaido, but the average had to be 1 cho on the mainland.[54]

The introduction of such an upper bound 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.[55] The proposal allowed the landlords to keep a certain amount of the tenanted land which was set to 1 cho.[56] The proposal was accepted by the SCAP

[53] An exception is the leftmost figure in the second row of Figure 10 in which I use the 1950 sample due to the lack of the 1955 census.

[54] 1 cho is approximately 1 hectare.

[55] Kitamura (2013) 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.

[56] 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

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:

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

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, and T_k the total area of tenanted land.[57] 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.[58]

Municipal MTLs were also determined by the Prefectural Land Committees and were approved by the Central Land Committee during 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.[59]

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 values of the criterion would have more owner farmers than the municipalities which were hardly affected. Since the formula is explicitly known, I can add relevant variables to control for confounding factors.

Still, adding control variables may not be enough to avoid omitted variables biases. As a robust-

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)."

[57] It is easy to show that the weighted arithmetic average of these values becomes one, i.e. the average value of MTL in the mainland. To see this, first multiply both sides by T_k in (1), take the sum of them, and finally divide both sides by $\sum_k T_k$.

[58] There are 11 different values.

[59] 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 Municipal Land Committee members were elected by farmers. In addition, two representatives from peasant unions and five university professors were included. 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 Prefectural Land Committees to claim a different prefectural MTL if they regarded the values to be unfair. Moreover, it allowed the Prefectural Land Committees to set a municipal MTL if needed. All changes required the approval of the Central Committee.

ness 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.

4.2 Empirical strategy

The main regression model is written by

$$y_{mpt} = \alpha_t + \mu_m + \sum_{j \in T} \beta_j \, \mathit{OwnerShare}_{mp} \times \mathit{Time}_j + \mathbf{x}_{mpt}\xi + \epsilon_{mpt}, \tag{2}$$

for municipality m in prefecture p in census year $t \in T$, where α is year fixed effects, μ municipality fixed effects, *OwnerShare* the share of owner farmers after the land reform, *Time* time dummies, $\mathbf{x}$ 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 between 15 and 19. I cluster standard errors at the prefecture level. Finally, prefecture-by-year fixed effects will be added in some specifications.

To validate such an 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 9, the distribution of outcome variables prior to the introduction of agricultural machines was very similar. In Figure 11, 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 treatment group, and those below the median are regarded as a control group. The figure shows the trend for the treated group and the control group. Since the 1940 census does not contain the information about age distribution in municipalities as mentioned earlier, I instead use the 1930 census. The left-hand panel 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 right-hand panel shows a similar pattern in terms of the population share aged between 15 and 19. In this case, however, the treated group tends to have fewer young people in the population than the control group after 1960 when the difference emerges. The parallel trend assumption seems to be satisfied according to these figures.

The next section shows the estimation results.

5 Results

5.1 Difference-in-differences estimates

Table 2 shows the effects of land ownership on technology adoption. The dependent variable is the number of power tillers per farm household. Column (1) includes year fixed effects. The effect did not appear by 1955 as expected. Column (2) adds municipality fixed effects and baseline controls which are average land sizes and the total area of tenanted farmlands before the land reform. Including these variables only changes the coefficient a little. Even adding the prefecture-by-year fixed effects in column (3) does not change the effect size to any considerable extent. 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.[60] Once more, excluding these regions does not change the coefficients to any considerable extent, which is reassuring.

I find that the municipalities which had many owner farmers after the land reform tended to experience a quick penetration of new agricultural machines 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, while it increases the dependent variable by 0.84 standard deviations for 1965. The effect was nearly doubled in 1965.

Next, Table 3 shows the effects of land ownership on migration. The dependent variable is the population share aged between 15 and 19. Column (1) includes year fixed effects. Column (2) adds the 1930 sample, while column (3) adds municipality fixed effects and the baseline 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 lustrum shocks at the prefecture level in terms of migration. Column (5) uses all control variables. Finally, columns (6) and (7) show that removing the North-West regions of Japan does not alter the effect.

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

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, while it decreases the population share by 0.55 standard deviations for 1965, according to the full specification in column

[60] The reasons are the following. Hokkaido received a larger criterion (4 hectare compared to 1 hectare on average on the main lands). There may be a concern that the Tohoku region might send relatively more migrants to urban centers. Moreover, 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.

(5). The effect size is somewhat smaller for migration than technology adoption. This might be due to the fact 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 12. The pattern clearly corresponds to that in Figure 11.

5.2 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. As described above, the post-reform distribution has been affected by the formula set by the central bureaucracy. Since the formula is explicitly known, I can include relevant controls. Moreover, since including municipality fixed effects and a wide range of municipal controls does not change the coefficients to any considerable extent 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 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, the dependent variable is 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, and zero otherwise. The independent variables are the share of owner farmers before and after the land reform. I include "twin" fixed effects. The first two columns use OLS regressions, while the last column uses a logistic regression. The table shows that the owner share increased in municipalities whose prefectures got a lower upper bound. According to column (2), highly affected municipalities would increase the owner share by about 2 percentage points more than less affected municipalities. The size of the difference reflects 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 variables that have been used above. Table 5 shows the result. 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 farmlands before the land reform, which may be due to the fact that the variable is included in the formula (though as weights). I include this variable as the main control in the following regressions. I also show that adding other variables does not alter the result.

Table 6 shows the result. 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 between 15 and 19. Columns (1) and (4) include tenanted land before the land reform, in addition to municipality fixed effects, year fixed effects, and prefecture-by-year fixed effects. Columns (2) and (5) include other control variables. Finally, columns (3) and (6) also add the share of owner farmers before the land reform. Overall, the effects are very similar to what we have seen earlier.

5.3 Private vs. communal machines

In this section, I examine if land ownership also affects the adoption of communal power tillers. If the hypothesis is correct, we should not observe any effect on the adoption of communal power tillers unless tenant farmers are incentivized to adopt communal power tillers.[61] However, if the unobservables affect both land ownership and technology adoption, we may still observe a positive effect. Thus, this exercise is regarded as a sort of placebo test. 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 result. 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 may imply that the estimates in the previous results on technology adoption are less likely to be affected by such unobservables.

5.4 Opportunity costs

Another concern could be that municipalities with high owner shares might be affected by heterogeneous urban shocks. For example, this may be interpreted as heterogeneous shocks on relative wages. Municipalities with high owner shares 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 I divide municipalities into quartiles 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 larger effect must be observed for the sample of municipalities closer to these areas.

Table 8 shows the results. The effect appears in all quantiles. Moreover, the size of the effect 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 grew, but owner farm households were more likely to react and substitute machines for labor.

[61] In such a case, we may observe a negative effect.

5.5 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 prefecture interacted with time dummies.[62] Prefecture and year fixed effects are 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 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 may be that the owner farmers who adopted machines would no longer require young human power in agriculture and, therefore, these young generations could find permanent jobs in non-agricultural sectors in distant urban centers.

Second, using municipal migration data in 1960, I examine whether a household has any family member who graduated from a school and 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.

Table 10 shows the effects on each category. The dependent variable is the number of migrants of each category normalized by 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 the next generation. The non-eldest sons were able to outmigrate to cities to find other jobs, while the eldest sons had 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.

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 daughters is the reason for migration, i.e. if the migration was due to marriage or not. First of all, the result indicates that daughters of owner farm households have also been more likely to outmigrate, although the estimate is imprecise. 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.

[62] 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.

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.

5.6 Connection between technology and migration

As described in the background section, the causation should go from technology adoption to the reduction in family labor. 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 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 should be less likely to be related to the migration.

Table 11 shows the result. 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 tilling machines. 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 members in the population, but land ownership tends to mitigate this.

Overall, these results seem to support the causal direction that land ownership increased the adoption of new labor-saving technologies, which reduced the dependence on family labor.

5.7 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.

The question is related to a debate about whether education plays an important role for industrialization. For example, Galor and Moav (2006) find that the first phase of the Industrial Revolution did not require high skilled labor, although the second phase did due to technological advancement. Becker et al. (2011) also find that basic education was significantly associated with non-textile industrialization in nineteenth century Prussia. Finally, Goldin and Katz (1998) find that skills and technologies were complements in early twentieth century America. Formal education or learning-by-doing/on-the-job training - which of these would affect economic growth is another related argument (Arrow 1962, Becker 1965). Given that Japan experienced a rapid growth during this period, it might be interesting to examine if migrants might contribute to the development of industries through formal education, or through on-the-job-training/learning-by-doing in firms.

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

Table 12 shows the results. In column (1), I simply regress the number of household members who were studying, normalized by the agricultural population, on the share of owner farmers. The significant negative sign means that household members are less likely to study in these areas which have more owner farmers. This may indicate that the sons and daughters of owner farm households faced high opportunity costs to continue studying, relative to those of tenant farm households. 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 migrants have continued to study in higher education. The findings are 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.

6 Discussion - Mechanisms

This section discusses potential mechanisms for why owner farmers have been more likely to adopt such technologies than tenant farmers. There are two major plausible mechanisms - property rights and no rent.

Property rights

As mentioned in the introduction, the vast empirical literature finds that property rights increase agricultural investment. For example, the security of the property might encourage farmers to invest more (e.g. Besley 1995, Banerjee et al. 2002). If tenants expect that the tenancy contract will be abruptly terminated by the landlord, the investment incentivefor tenants may be reduced. A more sophisticated argument could be that the type of investment can be different, rather than its absolute amount. In Japan, tenant farmers were more likely to favor short-term investment like fertilizers and improved seeds before the land reform. Since then, farmers have shifted into long-term investment such as machines and soil improvement (Kawano 1963).

Second, owner farmers might be able to take a loan by using their farmland as collateral (Besley et al. 2012). Although farmland was commonly used as the collateral in Japan before the land reform, the commercial value of farmland was considerably reduced due to the Agricultural Land Act which regulated transfer of farmlands, as mentioned above. In 1956, for example, only 4.5 percent of the farm households used the farmland as collateral (NKK 1956). In addition, the major financial source for farmers was loans provided by agricultural cooperatives which were already established in almost all municipalities in the late 1940s and the 1950s (Ohuchi 1975). The loans taken from the cooperatives were based on 'no collateral' (61 percent), 'savings' (14 percent), and ‘others’ (25 percent) in 1961 (NRCK 1963).

In addition to the agricultural cooperatives, machine makers and dealers which collaborated with local banks also provided special loans to farmers. For example, an agricultural machine maker, Yanmar, invented a new payment system through which farmers were able to buy machines through installment payments (Yanmar 2013). Figure 13 shows Yanmar’s old advertisement about the installment payment to buy its diesel engine. It says that if an individual makes a deposit of 1/3 of the machine price into an account in a certain bank, the machine will be sent to the individual’s home. All one has to do is to put another 1/3 into the account after six months, and the last 1/3 one year after the purchase.

If one even considers the possibility that tenant farmers could potentially borrow the money from the landlord or could ask the landlord to be a guarantor for borrowing the money, tenant farmers should be able to access credit without difficulty. Although collateralizability of the land may be complementary to the change in investment incentives, it is a little hard to argue that this is the sole explanation for why owner farmers have been more likely to adopt agricultural machines.

Third, the change in social norms caused by the abolishment of the tenancy contracts might be another channel. The argument is related to the literature arguing that the power structure in rural societies affects agricultural investment (Goldstein and Udry 2008). There was a Japanese custom related to the household relationship which might reduce tenant farmers’ incentives. Tenant farmers were often from branches of the household network, and their initiating something new such as the introduction of new technologies was regarded as socially impudent. Kitamura (2016) finds that those tenant farmers who have become owner farmers during the land reform have been empowered. This might indicate that there was a considerable change in the social norms in local communities due to the reform, and that these empowered farmers might have been more motivated to adopt new agricultural technology.

No rent

Another possible mechanism might be that owner farmers were able to invest because they no longer paid high land rents to landlords. This is likely to be the case for the pre-reform period since tenants had to pay about a half of the output value in land rents to the landlords before the land reform. Such an interpretation is therefore more plausible if one compares owner farmers with tenant farmers *before* the reform, or if one compares the same farmer who became an owner farmer due to the reform before and after the reform.

Instead, this paper compares owner farmers and tenant farmers that existed in the post-reform period. So the question is whether owner farmers were richer than tenant farmers after the land reform. According to the Agricultural Land Act which was enacted in 1952, the rents for paddy fields (dry fields) were regulated at 25 percent (15 percent) of the output value. Moreover, the land rents were about 7 percent of the output value in practice in 1963 (Kawano 1963). This indicates that tenant farmers also no longer bore a heavy burden as compared to the pre-reform situation. Note that owner farmers could become richer by investing more in agriculture. If that is the case, the increase in wealth, if anything, is explained by the property rights argument above instead of the zero rent argument.

To sum up, a plausible explanation could be that farmers who became motivated to invest due to secure ownership of land or empowerment were more likely to adopt agricultural machines. Such an effect could be complemented by the availability of credit loans and/or the increase in wealth through investment.

7 Aggregate impact of land reform

This section assesses the impact on industrial development and economic growth of labor reallocation caused by the land ownership reform and technology adoption. 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 micro findings indicate that the land ownership reform and the technology adoption in agriculture seem to explain part of the labor reallocation. This section assesses how much these factors contributed to the growth of the Japanese economy.

The structural transformation is most likely associated with labor reallocation across sectors and locations. Ideally, one may want to have 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 result.

7.1 A simple model

The economy has N population. Let us denote a set of prefectures by $\mathscr{P} = [1, 46] \subset \mathbb{Z}$. Each prefecture contains a finite number of municipalities with equal size. A municipality either has 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 these characteristics of the municipalities do not change over time.[63]

Farmers use machines, labor, and land for production. The machine is only valued by the purchaser. It is imported and depreciates perfectly in the next period. Buying one machine requires a binding contract according to which the farmers would pay by the end of each period.[64] The land is rented from the landlord. The landlord can take over the land with some probability. I assume that the probability is location specific and it takes the same value over time once it

[63] 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.

[64] One period = 1 year. Yanmar offered a one-year installment payment as described above.

is initially drawn.[65] Thus, if the land is confiscated by the landlord, it only leaves the costs of the machine for the farmers. If not, the farmer hires workers and production takes place. Other interpretations of the confiscation probability may be a loss of control over land and social costs attached to tenancy contracts as discussed earlier. More generally, it can be interpreted as a kind of technology adoption barrier.

The production technology of a representative farm in village i in prefecture p 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 farm 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 $\tau^{pi} \in (0,1)$ is the probability of confiscation or a measure of the technology adoption barrier which can take different values across locations, w_t^{pi} the wage rate, and r the land rent. The world price of the machine is normalized to 1 for simplicity.

The production technology of a 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 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). Another way of stating the assumption is that the urban wage is the same across cities. This implies that there is a national labor market. The assumption may be plausible for this study given that inter-prefecture migration was very common during the rapid growth period as described above.[66] The shape of the production function may yield that the urban wage w_t 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

[65] In other words, there is no uncertainty in the model.

[66] Alternatively, one can analyze the case where the labor market is closed at the prefecture level.

every period:

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

Then, 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 effects are 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 the city when the economy grows. The reduction of labor in the village 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 the labor-saving machines become available. Moreover, if the machine cost is too high, farmers may use more labor.[67] 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.*

This prediction corresponds to the findings of the empirical section.

The next section parametrizes the model.

7.2 Calibration

The parameters and endowments to be determined are $\{\{\phi, \alpha, \gamma\}, \{g_a, g_u\}, N, \{A_{a0}^p, A_{u0}\}, \{\tau^{pi}\}\}$. 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;[68] the agricultural employment share in 1955 (0.397)

[67] The intuition is similar to the previous one - farmers facing high switching costs would use more labor.
[68] I use Python for the numerical analysis.

Model parameters

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

and the agricultural labor share (0.46) from Valentinyi and Herrendorf (2008). This procedure yields $\phi = 0.93$ and $\gamma = 0.25$.[69]

For g_u, I take the average of the annual growth rate of non-agricultural real GDP between 1955-74.[70] To get g_a, I multiply $1-\alpha$ with the average of the annual growth rate of agricultural capital.[71] I use the total labor force in 1955 for N. Initial TFPs are calculated from production functions.[72]

Finally, I calculate τ^{ip} across locations using the municipality data. This parameter is most important in the model and is distinguished from standard sectoral models. To measure a τ in a municipality, I use a proxy which is the share of owner farmers in the municipality which was used in the empirical analysis above. The motivation comes from the empirical finding above - owner farmers were more likely to adopt agricultural machines. Since the parameter is interpreted as a technology adoption barrier, the owner share may be a good proxy for τ. Since all values will be aggregated at the prefecture-level after calculation, I used the 1950 municipality as the unit of observation because this is the original unit which contains land reform data. The number of municipalities 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 defined above, 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,

[69] 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.

[70] 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).

[71] 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).

[72] The procedure is available in the Appendix.

the agricultural production function of a prefecture for the benchmark economy may be written as:

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

where $e^p := \frac{1}{1-\tau^p}$.[73] Then, 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.[74] 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.[75] Formally, the regression model for prefecture p is written by:

$$e^{p,model} = \alpha + \sum_{k\leq 3} \beta_k (OwnerShare_p)^k + \epsilon_p, \tag{9}$$

where *OwnerShare* is the share of owner farmers after the land reform. This gives the coefficients $\beta_1 = -11.681$ (3.196), $\beta_2 = 13.162$ (3.602), and $\beta_3 = -4.942$ (1.353) where the standard errors are in parenthesis ($R^2 = 0.29$). I keep the coefficients and then I get out-of-sample predictions of municipal e's using the share of owner farmers at the municipality level. Finally, I calculate $\hat{\tau} = 1/R$, and normalize them so that the values are in (0,1).

Using these parameters and the endowment, I calculate all values at the municipality level. Then, I aggregate them to the national level.

7.3 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 result to quantify how much the land reform contributed to industrial development and economic growth. As mentioned 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

[73] I set the productivities to one by following Adamopoulos and Restuccia (2014).
[74] See the Appendix for the data source.
[75] The cubic polynominals 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

industries and service sectors might even have fueled the growth of urban sectors. To assess the scenario, I use the pre-reform variation in the owner share at the municipality level. The second scenario examines a most radical case in which no tenant farmers would exist after the reform.

7.4 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 are very small as compared to the no land reform case, meaning that it substantially decreased the technology adoption barrier across the country. This may reflect the fact that the distribution of the owner share shifted radically after the land reform as shown in Figure 3.

Next, Figure 14 shows the behavior of the model for the baseline and Scenario 1. Blue lines are the baseline results, while red lines are the results with no land reform (Scenario 1). The upper left panel shows the 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 were more likely to adopt agricultural technologies. The difference in the likelihood of the technology adoption also affects agricultural GDP which is shown in the upper right panel.[76] There is a declining trend in both cases because workers are leaving the villages due to the increase in the urban wage in the cities. Although labor reallocation is more likely to occur in the baseline case, the decline is compensated by the radical increase in machines. Thus, agricultural GDP starts to increase in the early 1960s. These results may imply that if the technology adoption is insufficient, the agricultural development might be retarded.

The adoption of technologies in the villages 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 level. 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 the 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. Although the role of the urban sectors often tends to be stressed as a plausible explanation for the Japanese rapid growth, the labor reallocation caused by the land reform and the technology adoption could be a complementary explanation.

Table 13 shows the average growth rate of the GDP between 1955-74 based on the simulation

[76]Note that the values are logged.

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 the τ's have already become very small due to a massive land reform.

Similarly, Table 14 shows the average growth rate of agricultural GDP between 1955-74. As mentioned earlier, the agricultural GDP would have declined if there had been no reform. If I take 10 years since 1955, agricultural GDP increased by about a quarter of 1964 agricultural GDP. Agricultural productivity increased about four-fold in the same period. The effects were driven by the adoption of the technologies as mentioned above. Finally, similar to the case of the GDP, Scenario 2 would not have changed agricultural GDP to any large extent, even with the full land reform.

7.5 Discussion

Although this paper deliberately adopts a simple growth model to elicit the effect found in the empirical analysis, the model can potentially be extended in several ways. For example, urban TFP could be endogenized by incorporating learning-by-doing. In that case, the increase in the urban wage (or urban TFP) in Equation 7 can be a function of urban employment.

Second, although the agricultural production function assumes a Hick-neutral technical change, a capital-augmenting technical change can be incorporated. In that case, an additional term appears in Equation 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 the structural transformation. If one incorporates preferences and the general equilibrium effect in the model, the growth rate of the agricultural sector might be non-negative, although the substitution effect might be still stronger in the land reform case. The transition effect on the GDP growth rate might be mild in that case.

Finally, although the above model implicitly assumes that cities are homogenous, and there is a one-way migration from the countryside to the cities, more complicated migration patterns can be incorporated if one includes consumers' migration decision and heterogeneous land rents across locations (Desmet et al. 2015).

8 Conclusion

Despite the historical argument that property rights and technological advancement in agriculture may be 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 might be applied to analyze labor reallocation and structural transformation in other countries.

The first part of the paper examines the causal effect of secure ownership of land on technology adoption in agriculture. I exploit a natural experiment tied to the Japanese land reform during the occupation period to get an exogenous variation in land ownership. I find that land ownership 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 land reform and the labor reallocation caused by the technology adoption contributed to economic growth. To tackle this issue, I simulate a simple growth model using micro data by reflecting the findings in the first part. I find that labor reallocation had a large positive effect on economic growth by fueling the development of urban sectors. Since the land reform yielded 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 rather than the reallocation of labor from agriculture to non-agriculture.

Overall, the findings of the paper indicate a relationship:

$$\text{Land ownership/Property rights} \rightarrow \text{Technology adoption} \rightarrow \text{Structural transformation}$$

Note that this paper does not claim that the adoption of labor-saving technology always leads to structural transformation or even 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 property rights and advanced 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.

References

[1] Acemoglu, D. and V. Guerrieri (2008). “Capital Deepening and Nonbalanced Economic Growth.” *Journal of Political Economy*, 116, 467-498.

[2] Acemoglu, D., S. Johnson, and J. A. Robinson (2001). “The Colonial Origins of Comparative Development: An Empirical Investigation.” *American Economic Review*, 91 (5), 1369-1401.

[3] Acemoglu, D., S. Johnson, and J. A. Robinson (2002). “Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution.” *Quarterly Journal of*

Economics, 117 (4), 1231-1294.

[4] Adamopoulos, T. and D. Restuccia (2014). "The Size Distribution of Farms and International Productivity Differences." *American Economic Review*, 104 (6), 1667-1697.

[5] Arrow, K. (1962). "The Economic Implications of Learning by Doing." *Review of Economic Studies*, 29 (3), 155-173.

[6] Banerjee, A. V., P. J. Gertler, and M. Ghatak (2002). "Empowerment and Efficiency: Tenancy Reform in West Bengal." *Journal of Political Economy*, 110 (2), 239-280.

[7] Banerjee, A. V. and L. Iyer (2005). "History, Institutions, and Economic Performance: The Legacy of Colonial Land Tenure Systems in India." *American Economic Review*, 95 (4), 1190-1213.

[8] Becker, G. (1965). *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*. New York: Columbia University Press.

[9] Becker, S. O., E. Hornung, and L. Woessmann (2011). "Education and Catch-up in the Industrial Revolution." *American Economic Journal: Macroeconomics*, 3 (3), 92-126.

[10] Besley, T. J. (1995). "Property Rights and Investment Incentives: Theory and Evidence from Ghana." *Journal of Political Economy*, 103 (5), 903-937.

[11] Besley, T. J., K. B. Burchardi, and M. Ghatak (2012). "Incentives and the De Soto Effect." *Quarterly Journal of Economics*, 127 (1), 237-282.

[12] Besley, T. J. and R. Burgess (2000). "Land Reform, Poverty Reduction and Growth: Evidence from India." *Quarterly Journal of Economics*, 115 (2), 389-430.

[13] Besley, T. J. and M. Ghatak (2010). "Property Rights and Economic Development." In D. Rodrik and M. Rosenzweig (Eds.), *Handbook of Development Economics*, Vol. 5, Amsterdam: North Holland, 4325-4595.

[14] Besley, T. J. and T. Persson (2011). *Pillars of Prosperity: The Political Economics of Development Clusters*. Princeton: Princeton University Press.

[15] Binswanger, H. (1986). "Agricultural Mechanization: A Comparative Historical Perspectives." *The World Bank Research Observer*, 1 (1), 27-56.

[16] Bold, T., K. C. Kaizzi, J. Svensson, D. Yanagizawa-Drott. (2015). "Low Quality, Low Returns, Low Adoption: Evidence from the Market for Fertilizer and Hybrid Seed in Uganda." *Mimeo*

[17] Boppart, T. (2014). "Structural Change and the Kaldor Facts in a Growth Model with Relative Price Effects and Non-Gorman Preferences." *Econometrica*, 82 (6), 2167-2196.

[18] Brasselle, A.-S., F. Gaspart, and J.-P. Platteau (2002). "Land Tenure Security and Investment Incentives: Puzzling Evidence from Burkina Faso." *Journal of Development Economics*, 67 (2), 373-418.

[19] Bustos, P., B. Caprettini, and J. Ponticelli (2016). "Agricultural Productivity and Structural Transformation. Evidence from Brazil." *American Economic Review*, 106 (6), 1320-1365.

[20] Caselli, F. (2005). "Accounting for cross-country income differences." In P. Aghion and S. N. Durlauf (Eds.), *Handbook of Economic Growth*, Vol. 1, Amsterdam: North Holland, 679-741.

[21] Caselli, F. and W. J. Coleman II (2001). "The US Structural Transformation and Regional Convergence: A Reinterpretation." *Journal of Political Economy*, 109 (3), 584-616.

[22] Conley, T. G. and C. R. Udry (2010). "Learning about a New Technology: Pineapple in Ghana." *American Economic Review*, 100 (1), 35-69.

[23] de Janvry, A., K. Emerick, M. Gonzalez-Navarro, and E. Sadoulet (2015). "Delinking Land Rights from Land Use: Certification and Migration in Mexico." *American Economic Review*, 105 (10), 3125-3149.

[24] Desmet, K. and E. Rossi-Hansberg (2014). "Spatial Development." *American Economic Review*, 104 (4), 1211-43.

[25] Desmet, K., D. K. Nagy, and E. Rossi-Hansberg (2015). "The Geography of Development: Evaluating Migration Restrictions and Coastal Flooding." *Mimeo.*

[26] De Soto, H. (2000). *The Mystery of Capital.* New York: Basic Books.

[27] Di Tella, R., S. Galiani, E. Schargrodsky (2007). "The Formation of Beliefs: Evidence from the Allocation of Land Titles to Squatters." *Quarterly Journal of Economics*, 122 (1), 209-241.

[28] Dore, R. P. (1958). "The Japanese Land Reform in Retrospect." *Far Eastern Survey*, 27 (12), 183-188.

[29] Dore, R. P. (1959). *Land Reform in Japan.* London: Oxford University Press.

[30] Duflo, E., M. Kremer, and J. Robinson (2011). "Nudging Farmers to Use Fertilizer: Theory and Evidence from Kenya." *American Economic Review*, 101 (6), 2350-2390.

[31] FAO (2003). *World Agriculture: Towards 2015/2030 - An FAO Perspective.* London: Earthscan Publications Ltd.

[32] FAO (2013). *Mechanization for Rural Development: A review of patterns and progress from around the world.* Integrated Crop Management, 20.

[33] Fenske, J. (2011). "Land Tenure and Investment Incentives: Evidence from West Africa." *Journal of Development Economics*, 95 (2), 137-156.

[34] Field, E. (2007). "Entitled to Work: Urban Property Rights and Labor Supply in Peru." *Quarterly Journal of Economics*, 122 (4), 1561-1602.

[35] Foster, A. D. and M. R. Rosenzweig (1995). "Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture." *Journal of Political Economy*, 103 (6), 1176-1209.

[36] Foster, A. D. and M. R. Rosenzweig (2008). "Economic Development and the Decline of Agricultural Employment." In T. P. Schultz and J. A. Strauss (Eds.), *Handbook of Development Economics*, Vol. 4, Amsterdam: North Holland, 3051-3083.

[37] Foster, A. D. and M. R. Rosenzweig (2010). "Microeconomics of Technology Adoption." *Annual Review of Economics*, 2, 395-424.

[38] Francks, P. (1983). *Technology and Agricultural Development in Pre-War Japan.* New Haven: Yale University Press.

[39] Francks, P. (1996). "Mechanizing Small-Scale Rice Cultivation in an Industrializing Economy: The Development of the Power-Tiller in Prewar Japan." *World Development*, 24 (4), 781-791.

[40] Fukao, K. and X. Yue (2000). "Sengo Nihon Kokunai ni Okeru Keizai Syuusoku to Seisan Youso Tounyuu - Sorow Seichou Moderu ha Tekiyou Dekiruka." *Keizai Kenkyuu*, 51 (2), 136-151.

[41] Galor, O. and O. Moav (2006). "Das Human-Kapital: A Theory of the Demise of the Class Structure." *Review of Economic Studies*, 73 (1), 85-117.

[42] Goldin, C. and L. F. Katz (1998). "The Origins of Technology-Skill Complementarity." *Quarterly Journal of Economics*, 113 (3), 693-732.

[43] Goldstein, M. and C. Udry (2008). "The Profits of Power: Land Rights and Agricultural Investment in Ghana." *Journal of Political Economy*, 116 (6), 981-1022.

[44] Gollin, D., D. Lagakos, and M. E. Waugh (2014). "The Agricultural Productivity Gap." *Quarterly Journal of Economics*, 129 (2), 939-993.

[45] Gollin, D., S. Parente, and R. Rogerson (2002). "The Role of Agriculture in Development." *American Economic Review: Papers and Proceedings*, 92 (2), 160-164.

[46] Graetz, G. and G. Michaels (2015). "Robots at Work." *CEP Discussion Paper.*

[47] Griliches, Z. (1957). "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica*, 25 (4), 501-522.

[48] Hanna, R., S. Mullainathan, and J. Schwartzstein (2014). "Learning Through Noticing: Theory and Evidence from a Field Experiment." *Quarterly Journal of Economics*, 129 (3), 1311-1353.

[49] Hansen, G. D. and E. C. Prescott (2008). "Malthus to Solow." *American Economic Review*, 92 (4), 1205-1217.

[50] Harris, J. R. and M. P. Todaro (1970). "Migration, Unemployment and Development: A Two-Sector Analysis." *American Economic Review*, 60 (1), 126-142.

[51] Hayami, Y. and T. Kawagoe (1989). "Farm Mechanization, Scale Economies and Polarization." *Journal of Development Economics*, 31 (2), 221-239.

[52] Hayami, Y. and V. W. Ruttan (1970a). "Agricultural Productivity Differences Among Countries." *American Economic Review*, 60 (5), 895-911.

[53] Hayami, Y. and V. W. Ruttan (1970b). "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960." *Journal of Political Economy*, 78 (5), 1115-1141.

[54] Hayami, Y. and V. W. Ruttan (1971). *Agricultural Development: An International Perspective*. Baltimore and London: The Johns Hopkins Press.

[55] Hayami, Y. and S. Yamada (1973). "Kougyouka no Shihatsuki ni Okeru Nougyou no Seisansei." In S. Kawano and Y. Katou (Eds.), *Nihon Nougyou to Keizai Seichou*. Tokyo: Sobunsha.

[56] Hayashi, F. and E. C. Prescott (2008). "The Depressing Effect of Agricultural Institutions on the Prewar Japanese Economy." *Journal of Political Economy*, 116 (4), 573-632.

[57] Herrendorf, B., R. Rogerson, and A. Valentinyi (2014). "Growth and Structural Transformation." In P. Aghion and S. N. Durlauf (Eds.), *Handbook of Economic Growth*, Vol. 2B, Amsterdam: North Holland, 855-941.

[58] Hémous, D. and M. Olsen (2014). "The Rise of the Machines: Automation, Horizontal Innovation and Income Inequality." *Mimeo*.

[59] Hokimoto, T. (1999). "Nihon Nougyou Kikai Shijyou no Rekishiteki Hatten Katei to Sono Bunseki." *Yamagata Daigaku Kiyou (Nougaku)*, 13 (2), 117-143.

[60] Hornbeck, R. (2010). "Barbed Wire: Property Rights and Agricultural Development." *Quarterly Journal of Economics*, 125 (2), 767-810.

[61] Hornbeck, R. and S. Naidu (2014). "When the Levee Breaks: Black Migration and Economic Development in the American South." *American Economic Review*, 104 (3), 963-990.

[62] Hsieh, C.-T. and P. J. Klenow (2009). "Misallocation and Manufacturing TFP in China and India." *Quarterly Journal of Economics*, 124 (4), 1403-1448.

[63] Ishiwatari, S. (1965). *Nihon Nougyou no Seisanryoku Kouzou*. Tokyo: Ochanomizu Shobou.

[64] Isozumi, T. (1985). "'Nouchi Tou Kaihou Jisseki Chousa' no Zenkoku Syuukei Houkoku." In Y. Kondou (Ed.), *Syouwa Kouki Nougyou Mondai Ronsyuu 1: Nouchi Kaikakuron I*. Tokyo: Nousan Gyoson Bunka Kyoukai.

[65] Jakoby, H. G., G. Li, and S. Rozelle (2002). "Hazards of Expropriation: Tenure Insecurity and Investment in Rural China." *American Economic Review*, 92 (5), 1420-1447.

[66] Johnson, S., J. McMillan, C. Woodruff (2002). "Property Rights and Finance." *American Economic Review*, 92 (5), 1335-1356.

[67] Jones, C. I. (2015). "The Facts of Economic Growth." *NBER Working Paper*.

[68] Kajii, I. (1997). "Land Reform - Starting Point of Postwar Agriculture in Japan" in *Changes in Japan's Agrarian Structure*. Tokyo: FAPRC.

[69] Kako, T. (1987). "Development of the Farm Machinery Industry in Japan: A Case Study of the Walking Type Tractor." *Hitotsubashi Journal of Economics*, 28 (2), 155-171.

[70] Kawagoe, T. (1995). "Sengo Nihon no Nouchi Kaikaku." *Keizai Kenkyuu*, 46 (3), 249-259.

[71] Kayou, N. (1977). *Nihon Nougyou Kiso Toukei*. Tokyo: Nourin Toukei Kyoukai.

[72] Kawano, S. (1963). "Nouchi Kaikaku no Keizai Kouka." In K. Ohkawa (Ed.), *Nihon Nougyou no Seichou Bunseki*. Tokyo: Taimeidou.

[73] Kitamura, S. (2016). "Loyalty and Treason: Theory and Evidence from Land Reform in Occupied Japan." *Mimeo*.

[74] Kongsamut, P., S. Rebelo, and D. Xie (2001). "Beyond Balanced Growth." *Review of Economic Studies*, 68 (4), 869-882.

[75] Larson, D. F., R. Butzer, Y. Mundlak, and A. Crego (2000). "A Cross-Country Database for Sector Investment and Capital." *The World Bank Economic Review*, 14 (2).

[76] Lewis, W. A. (1954). "Economic Development with Unlimited Supplies of Labour." *The Manchester School*, 22 (2), 139-191.

[77] MAF (1956). "Nouchi Tou Kaihou Jisseki Chousa." Tokyo: Nourinsyou Nouchikyoku Kanribu Nouchika.

[78] Matsuyama, K. (1992). "Agricultural Productivity, Comparative Advantage, and Economic Growth." *Journal of Economic Theory*, 58 (2), 317-334.

[79] MHLW (2005). *Roudou Keizai no Bunseki*. Tokyo: Kousei Roudousyou.

[80] Michaels, G., F. Rauch, and S. J. Redding (2012). "Urbanization and Structural Transformation." *Quarterly Journal of Economics*, 127 (2), 535-586.

[81] Minakawa, I. (1967). "Nouka Jinkou no Idou." *Jinkou Mondai Kenkyuu*, 101, 7-11.

[82] Munshi, K. and M. Rosenzweig (2016). "Networks and Misallocation: Insurance, Migration, and the Rural-Urban Wage Gap." *American Economic Review*, 106 (1), 46-98.

[83] Namiki, S. (1957). "Sengo ni Okeru Nougyou Jinkou no Hojuu Mondai." *Nougyou Sougou Kenkyuu*, 12 (1), 89-139.

[84] Ngai, L. R. and C. A. Pissarides (2007). "Structural Change in a Multisector Model of Growth." *American Economic Review*, 97 (1), 429-443.

[85] NKI (1951). *Nouchi Kaikaku Tenmatsu Gaiyou.* Tokyo: Nousei Chousa Kai.

[86] NKK (1956). *Dai 6ji Zenkoku Nousan Gyoson Kinyuu Jijyou Chousa Houkoku.* Tokyo: Nourin Kinyuu Kenkyuukai.

[87] NKNC (1964). *Nouchi Kaikaku ga Nougyou Seisanryoku to Kokunai Shijyou ni Ataeta Eikyou.* Tokyo: Naikaku Souri Daijin Kanbou Rinji Nouchi Tou Hibaisyuusya Mondai Chousa Shitsu.

[88] North, D. (1981). *Structure and Change in Economic History.* New York: W. W. Norton.

[89] NRCK (1963) *Noukyou Shinyou Jigyou Jittai Chousa Houkokusyo.* Tokyo: Nourin Chuuou Kinko.

[90] Nunn, N. and N. Qian (2011). "The Potato's Contribution to Population and Urbanization: Evidence From A Historical Experiment." *Quarterly Journal of Economics*, 126 (2), 593-650.

[91] Ohuchi, T. (1975). "Nouchi Kaikakugo no Nougyou no Hatten." In Toukyou Daigaku Syakai Kagaku Kenkyuujyo (Ed.), *Sengo Kaikaku 6: Nouchi Kaikaku.* Tokyo: Toukyou Daigaku Shuppan Kai.

[92] Olmstead, A. L. and P. W. Rhode (2001). "Reshaping The Landscape: The Impact And Diffusion Of The Tractor In American Agriculture, 1910-1960." *Journal of Economic History*, 61 (3), 663-698.

[93] Pingali, P. (2007). "Agricultural Mechanization: Adoption Patterns and Economic Impact." In R. Evenson and P. Pingali (Eds.), *Handbook of Agricultural Economics*, Vol. 3, Amsterdam: North Holland, 2779-2805.

[94] Ramseyer, M. (2015). "The Fable of Land Reform: Leases and Credit Markets in Occupied Japan." *Journal of Economics and Management Strategy*, 24 (4), 934-957.

[95] Restuccia, D., D. T. Yang, and X. Zhu (2008). "Agriculture and Aggregate Productivity: A Quantitative Cross-Country Analysis." *Journal of Monetary Economics*, 55, 234-250.

[96] Rogerson, R. (1987). "An Equilibrium Model of Sectoral Reallocation." *Journal of Political Economy*, 95 (4), 824-834.

[97] Rostow, W. W. (1959). "The Stages of Economic Growth." *The Economic History Review*, 12 (1), 1-16.

[98] Sachs, J. D. and L. J. Kotlikoff (2012). "Smart Machines and Long-Term Misery." *NBER Working Paper.*

[99] Satou, T. and K. Kishimoto (2014). "Kokusei Chousa (1930 Nen) Shikuchouson-betsu Deeta Beesu no Sakusei ni Tsuite." *Tamokuteki Toukei Deeta Banku Nenpou*, No. 91, 1-5.

[100] Sokoloff, K. L., and S. L. Engerman (2000). "History lessons: Institutions, Factor Endowments, and Paths of Development in the New World." *Journal of Economic Perspectives*, 14 (3), 217-232.

[101] Suri, T. (2011). "Selection and Comparative Advantage in Technology Adoption." *Econometrica*, 79 (1), 159-209.

[102] Takita, D., Y. Ogasawara, and K. Kishimoto (2012). "Kokusei Chousa (1950 Nen) Shikuchouson-betsu Deeta Beesu Sakusei ni Tsuite." *Tamokuteki Toukei Deeta Banku Nenpou*, No. 89, 1-6.

[103] Timmer, M. P., G. de Vries, and K. de Vries (2014). "Patterns of Structural Change in Developing Countries." *GGDC Research Memorandum*, 149.

[104] Valentinyi, Á. and Herrendorf, B. (2008). "Measuring factor income shares at the sectoral level." *Review of Economic Dynamics*, 11 (4), 820-835.

[105] Yamamoto, M. and K. Kishimoto (2006). "Kokusei Chousa Shikuchouson-betsu Deeta Beesu no Sakusei - 1960 Nen Oyobi 1965 Nen." *Tamokuteki Toukei Deeta Banku Nenpou*, No. 82, 41-47.

[106] Yanmar (2013). "Yanmar Hyakunenshi: 1912-2012."

[107] Young, A. (2013). "Inequality, the Urban-Rural Gap, and Migration." *Quarterly Journal of Economics*, 128 (4), 1-59.

[108] Zeira, J. (1998). "Workers, Machines, and Economic Growth." *Quarterly Journal of Economics*, 113 (4), 1091-1117.

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 controls; average land sizes and the total area of tenanted farmlands before the land reform (log). Column (3) adds prefecture-by-year fixed effects. Column (4) adds more 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. 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 between 15 and 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 between 15 and 19. Column (1) includes year fixed effects. Column (2) adds the 1930 sample, while column (3) adds municipality fixed effects and controls; average land sizes and the total area of tenanted farmlands before the land reform (log). Column (4) adds prefecture-by-year fixed effects. Column (5) adds more 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. 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)	(3)
Owner share (1945)	0.0343	0.0116	0.0229
	(0.1215)	(0.1450)	(0.2985)
Owner share (1950)	1.4487	1.9600	4.5198
	(0.2485)***	(0.3165)***	(0.7701)***
Twin F.E.	yes	yes	yes
R^2	0.02	0.03	
Pseudo R^2			0.02
Number of obs.	4120	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. 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	0.008	−0.007	−0.011			
	(0.005)	(0.007)	(0.010)			
× 1960	0.057	0.040	0.055	−0.061	−0.049	−0.059
	(0.013)***	(0.013)***	(0.017)***	(0.018)***	(0.016)***	(0.015)***
× 1965	0.107	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	0.52	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.	3730	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 between 15 and 19. Columns (1) and (4) are the baseline results which include tenanted farmlands 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; average land sizes, 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. 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 between 15 and 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. 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 share of migrants among the 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 between 20 and 24 years 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, while column (8) takes the sum of them, as the dependent variable. These categories are already defined in the agricultural censuses. 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 total area of tenanted farmlands before the land reform (log).

Table 11: 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 between 15 and 19. *Clay* is the share of land areas which consist of clay. I include prefecture fixed effects and municipal controls; average land sizes and total area of tenanted farmlands before the land reform (log).

Table 12: 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 share of those who were studying in a high school or a higher educational institution in February in 1960 among the agricultural population. Columns (2) and (3) use the same dependent variable, except that they only use male members and female members, respectively. *Male Migrant* is the share of second or younger migrated sons who are 24 years or younger. *Female Migrant* is the the share of migrated daughters. The control variables are prefecture fixed effects and municipal controls; average land sizes and total area of tenanted farmlands before the land reform (log).

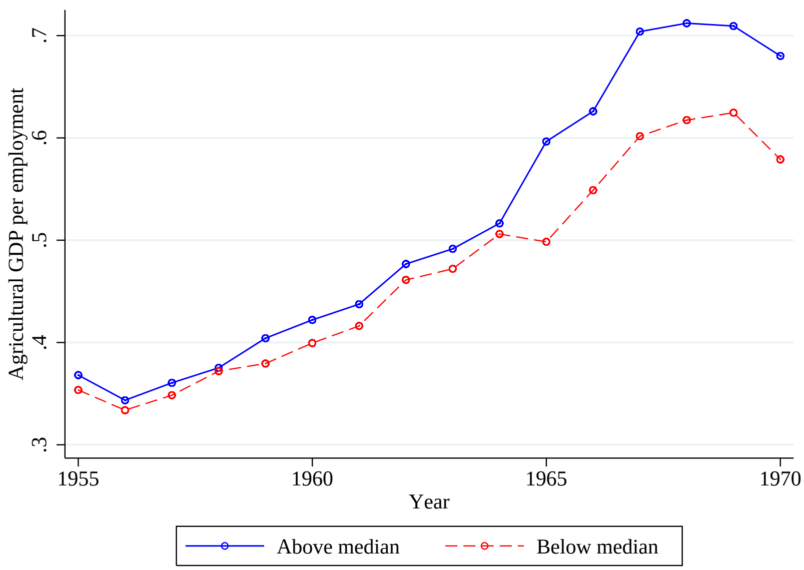
Table 13: GDP growth rate

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

Table 14: Agricultural GDP growth rate

	Simulation	Data
Baseline	2.2 %	2.1 %
Scenario 1 (No reform)	-7.4 %	
Scenario 2 ($\tau = 0$)	2.3 %	

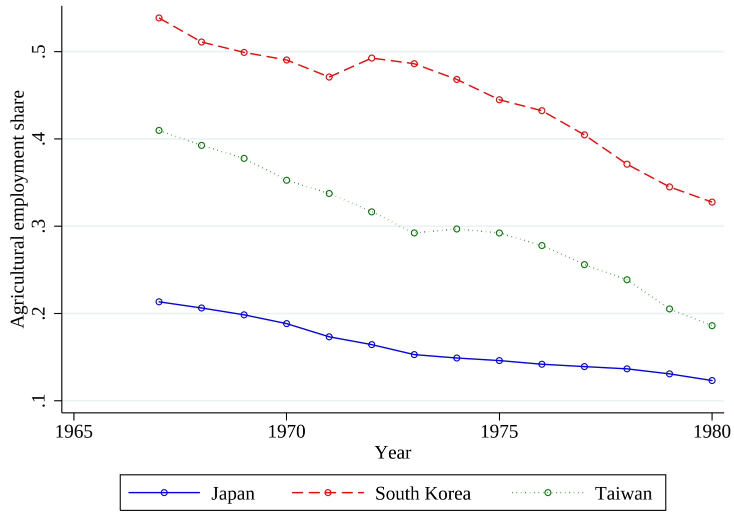
Figure 1: Agricultural productivity



Source: Statistical Yearbook of Ministry of Agriculture and Forestry.

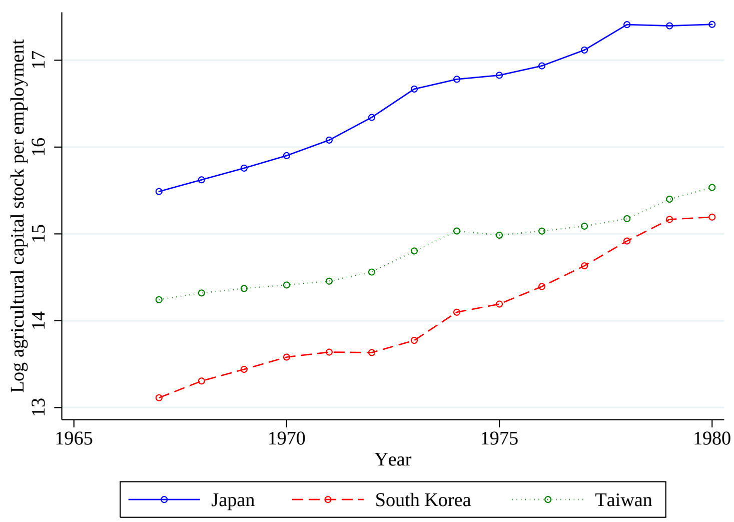
Notes: Agricultural productivity is calculated as dividing real agricultural GDP by agricultural employment. I interpolate the agricultural employment because the data are only available for every five years. All data are at the prefecture level.

Figure 2: East Asian experience



(a) Agricultural employment share

Source: Timmer et al. (2014).



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

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

Figure 3: Share of owner farmers by municipality before and after the land reform

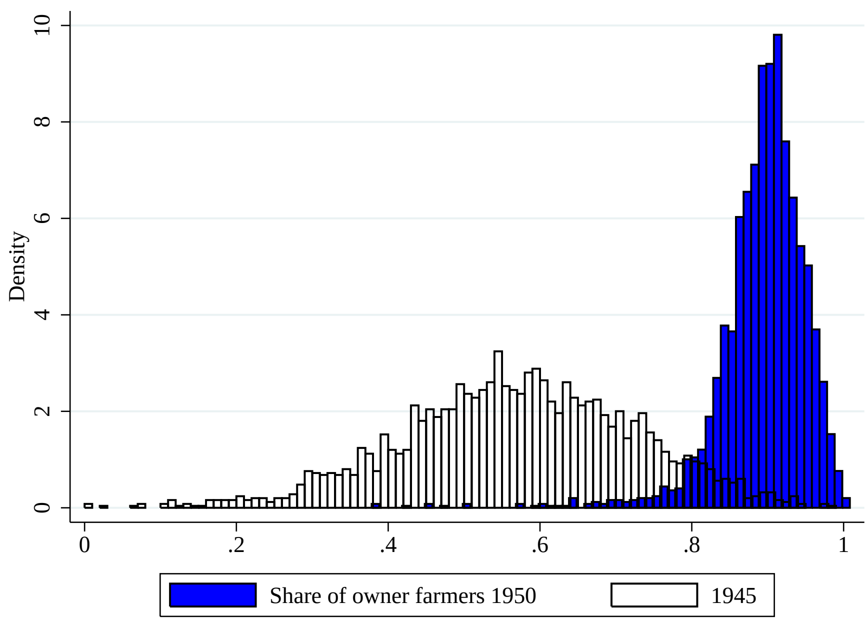


Figure 4: Share of owner farmers before the land reform

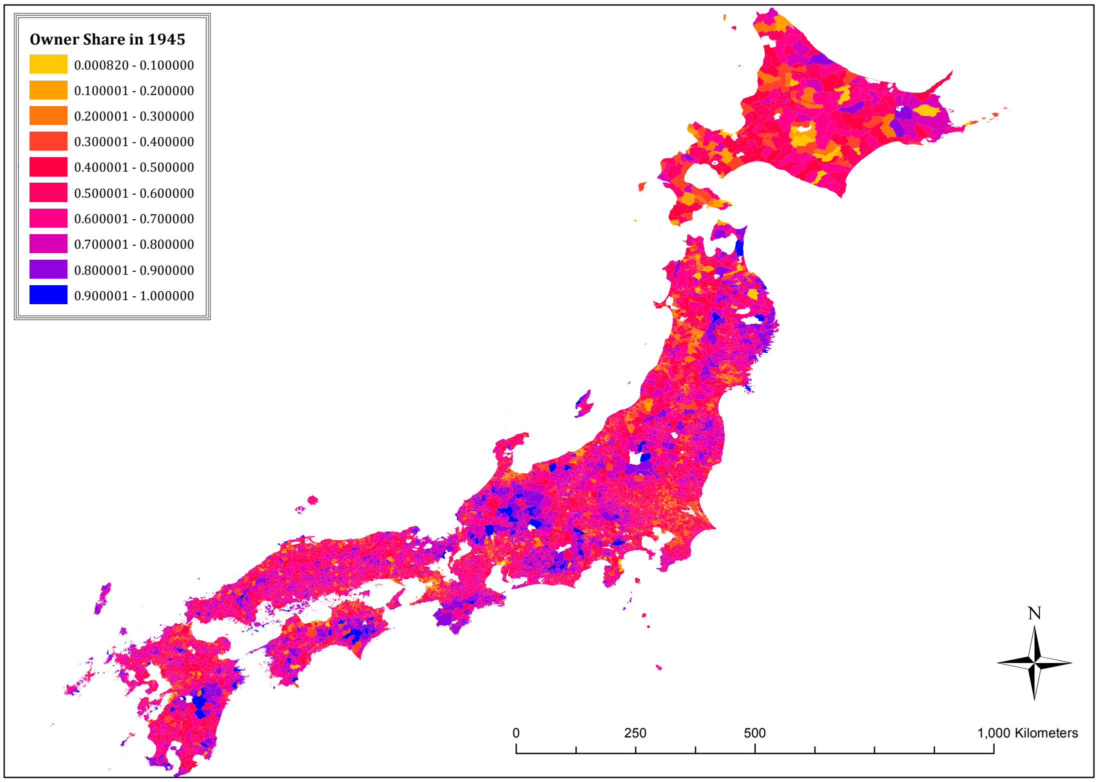


Figure 5: Share of owner farmers after the land reform

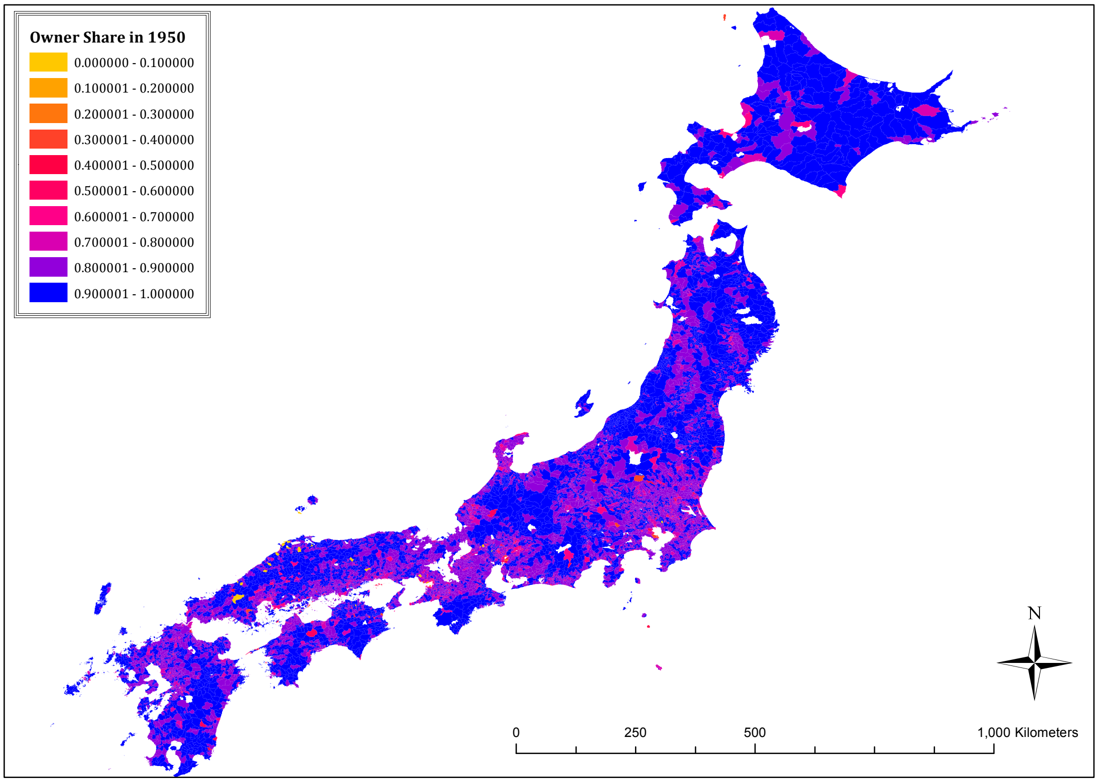
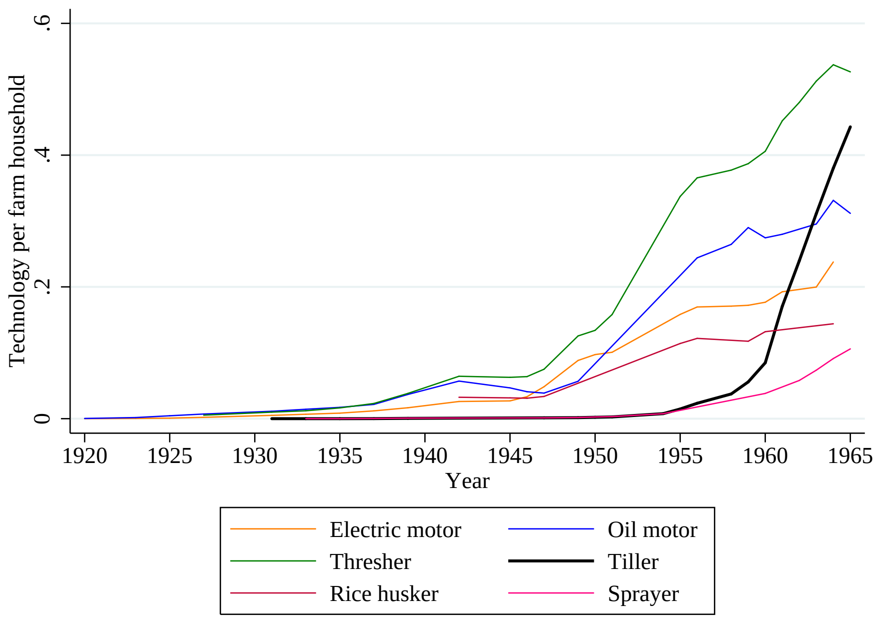


Figure 6: Penetration of technologies, 1920-1965



Source: Statistical Yearbook of Ministry of Agriculture and Forestry.

Notes: I interpolate the number of farm households in 1945, 1948, 1949, 1951-54, 1956-59, and 1961-64 since the data are missing for those years. The tiller includes trailing type (*ken-in gata*) and automated type (*kudou gata*).

Figure 7: Change in farming methods

(a) Tilling by hand

(b) Tilling by machine

Source: Aomori Kyoudo Kan.

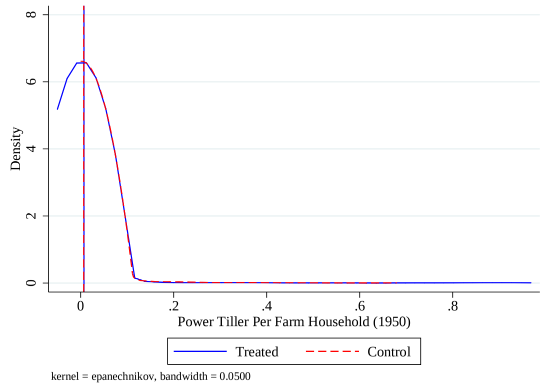
Notes: Both pictures were taken in 1956 near Hirosaki-shi, Aomori.

Figure 8: Mass migration to big cities

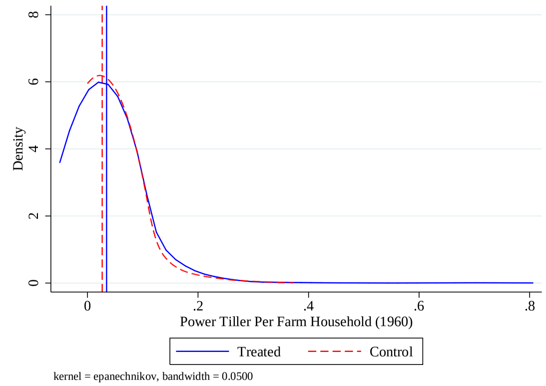
Source: Asahi Shinbun.

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

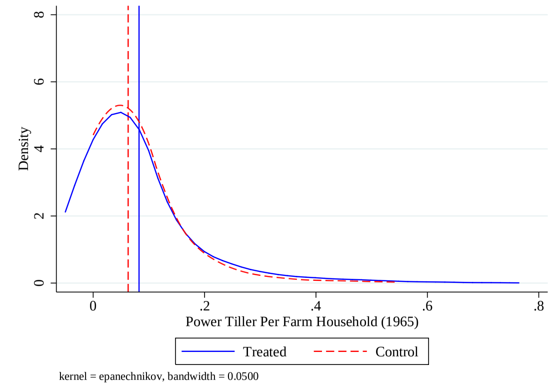
Figure 9: Distributional change between 1950 and 1965



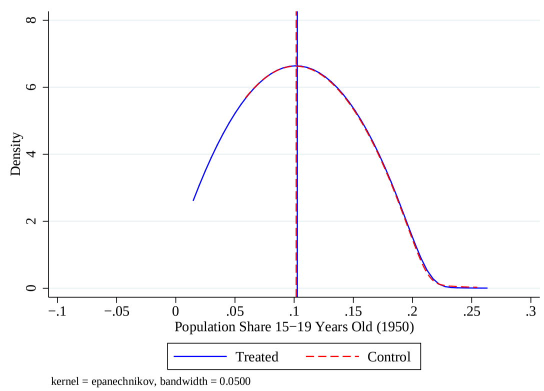
(a) Power tillers per farm household 1950



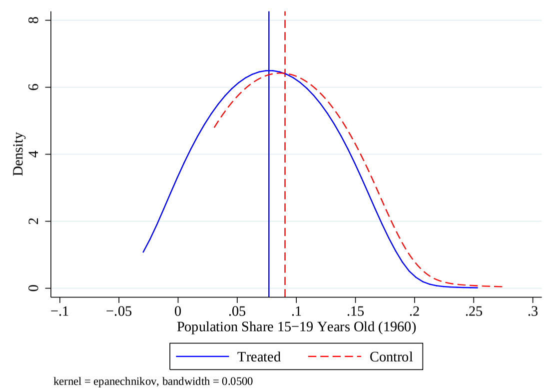
(b) 1960



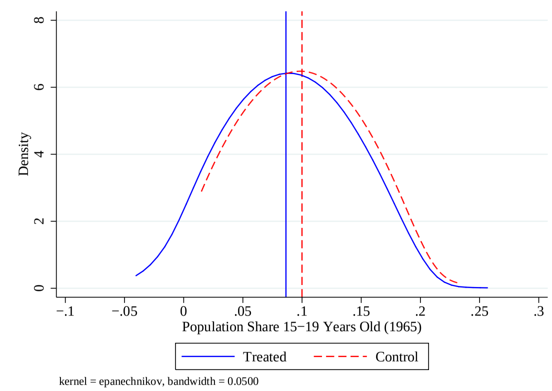
(c) 1965



(d) Population share 15-19 years old 1950



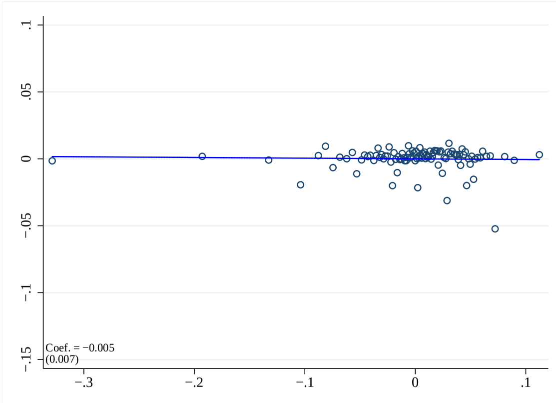
(e) 1960



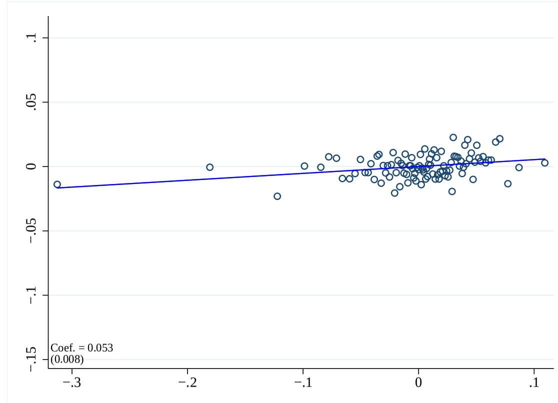
(f) 1965

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.

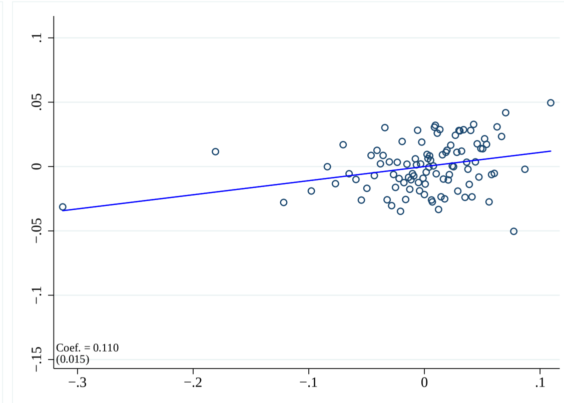
Figure 10: Correlation - Power tillers (above) and population 15-19 years old (below)



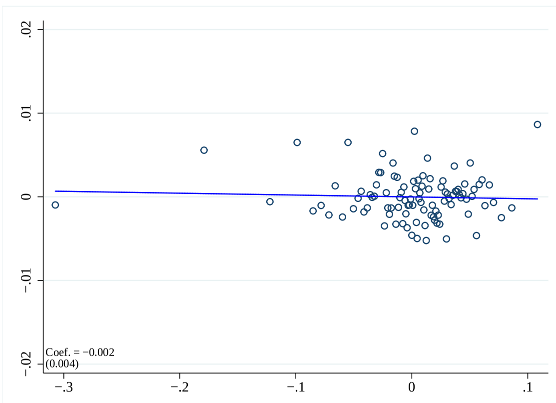
(a) 1950-55



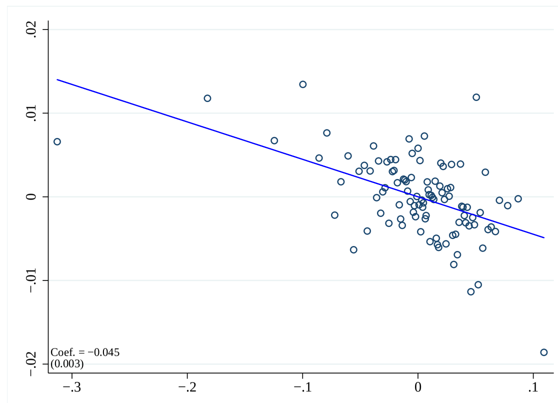
(b) 1950-60



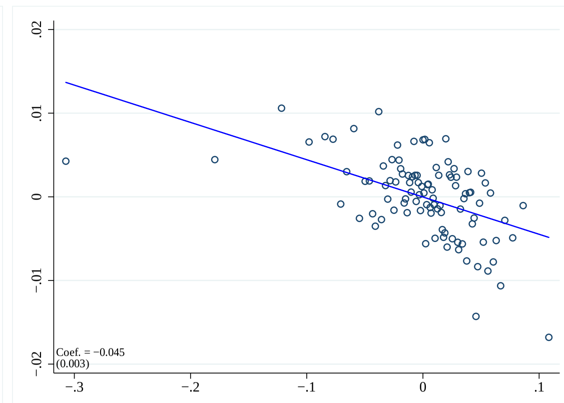
(c) 1950-65



(d) 1950



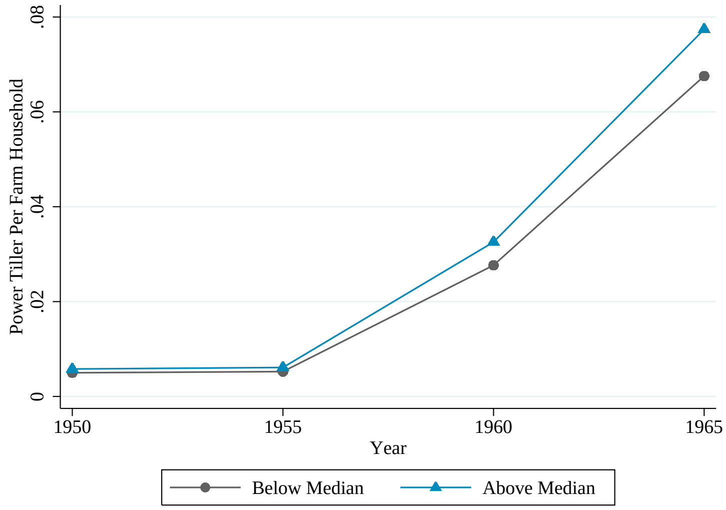
(e) 1950-60



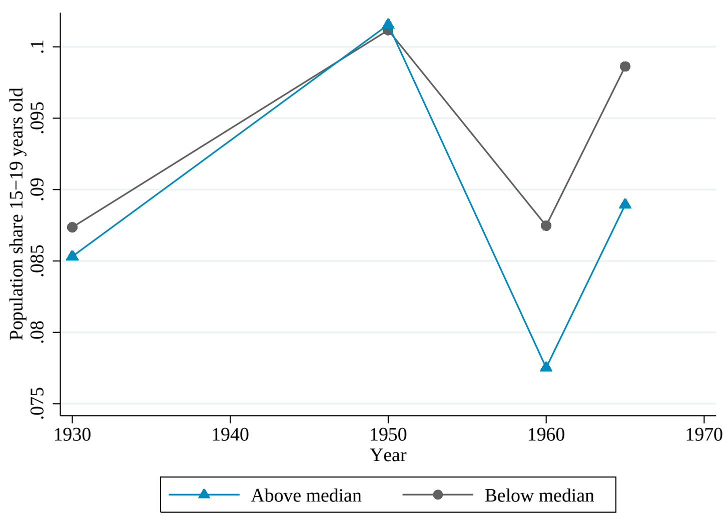
(f) 1950-65

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 between 15 and 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 tenanted farmland before the land reform (log).

Figure 11: Parallel trends



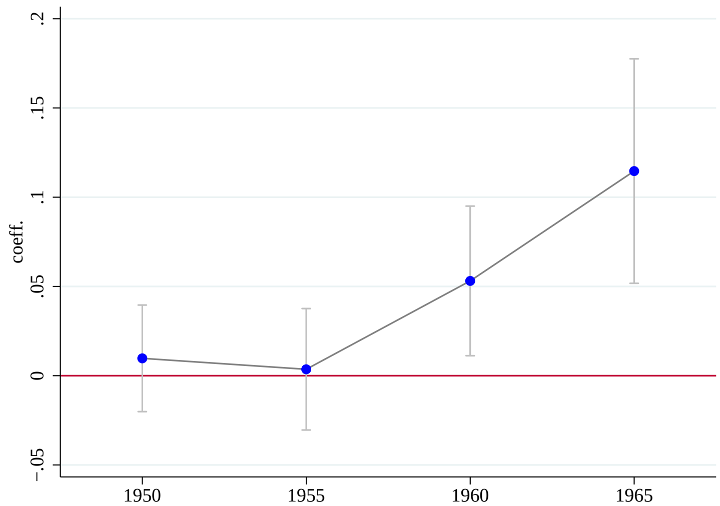
(a) Power tillers per farm household



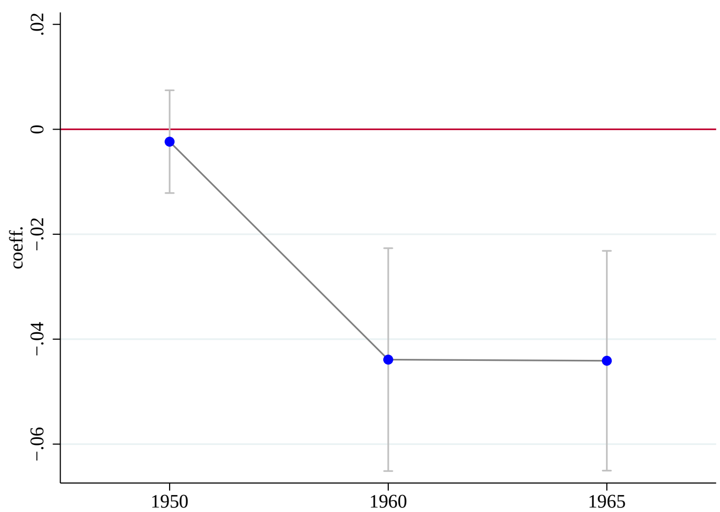
(b) Population share 15-19 years old

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 12: Coefficient plots of DID estimates



(a) Power tillers per farm household



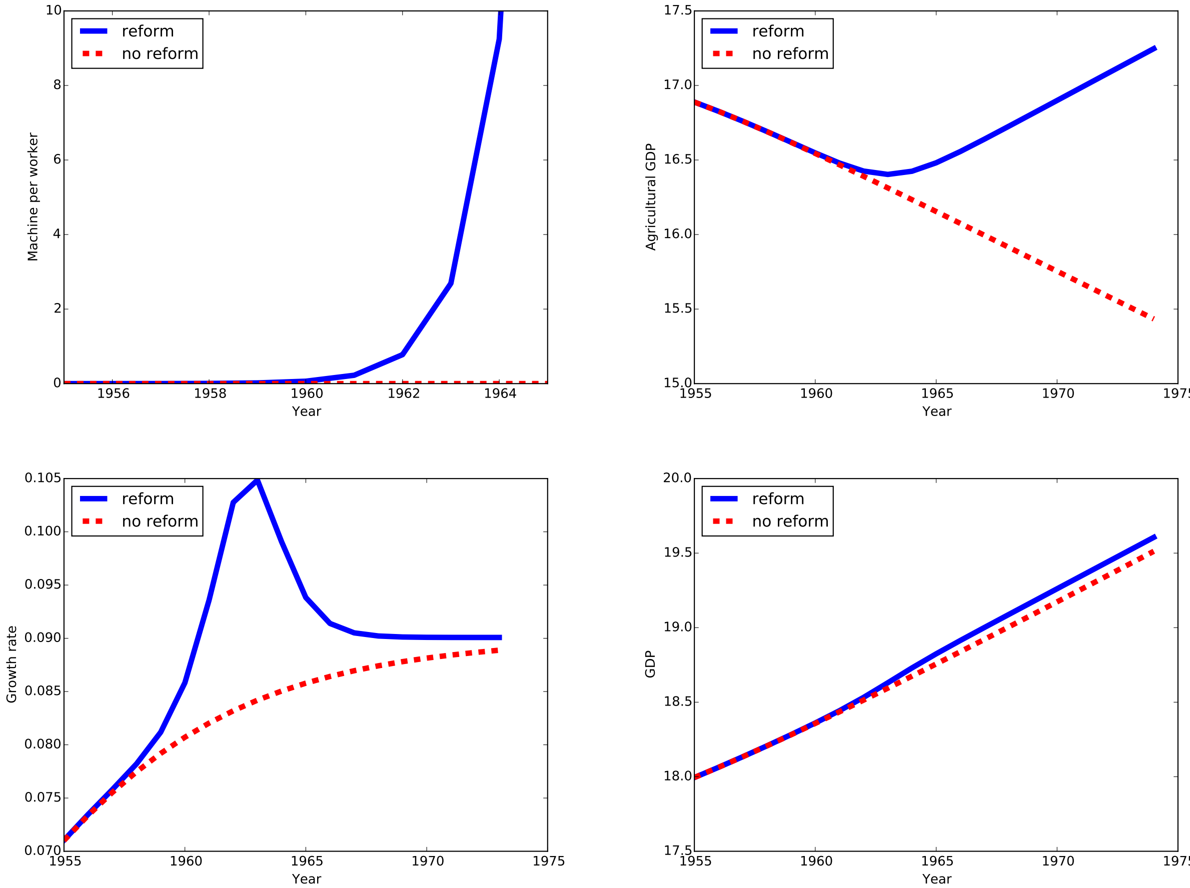
(b) Population share 15-19 years old

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 between 15 and 19. Year fixed effects, prefecture-by-year fixed effects, and municipal controls; average farmland sizes and tenanted farmland before the land reform (log) are included.

Figure 13: Agricultural machine maker's old advertisement about installment payment (1959)

Source: Yanmar.

Figure 14: Simulation results



Notes: The solid line is the baseline, while the dashed line is the counterfactual simulation in which no land reform in assumed.

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 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 productivity. 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:

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

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 productivity, g_u. Hence, all variables asymptotically grow at constant rates. Q.E.D.

A.2 Prefectural Data

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

$$A_{a0}^p = \frac{Y_{a0}^p}{[\gamma(M_0^p)^\phi + (1-\gamma)(N_{a0}^p)^\phi]^{\frac{\alpha}{\phi}}}. \tag{15}$$

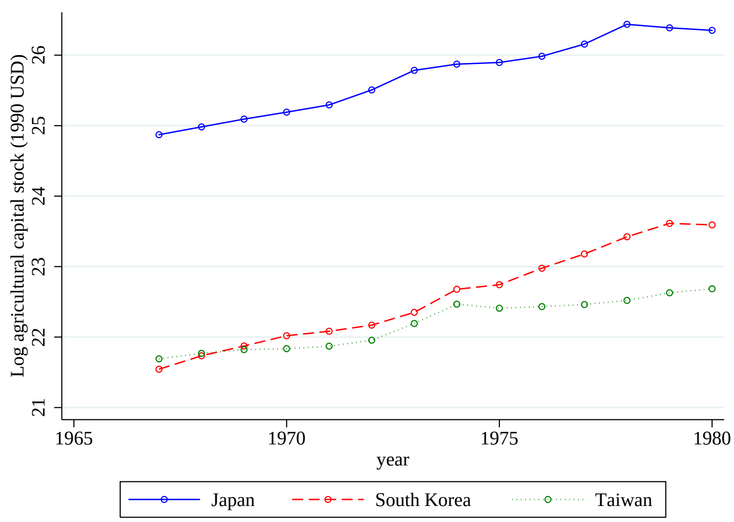
Second, I use prefectural non-agricultural real GDP and non-agricultural employment in 1955 to calculate initial non-agricultural TFP by:

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

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

A.4 Figure

Figure A.1: Capital stock in agriculture



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