The Effects of Barriers to Technology Adoption on the Japanese Prewar and Postwar Economic Growth*

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Abstract

Despite the modernization of the late 19th century, Japan's per-capita GDP had staggered around one-third of that of leading economies until a growth miracle took place after World War II. To address the prewar stagnation and postwar miracle, we propose and examine a hypothesis of barriers to technology adoption by building a dynamic model with endogenous technology adoption. The barriers, which we identify from data on relative price of investment, explains about one-fourth of a gap in per-capita GDP between Japan and the United Kingdom in the prewar period. The postwar reduction in the barriers stimulates technology adoption and matches the observed transitional dynamics of the relative price of investment, explaining about one-fourth of the catch-up attained in the postwar period. We argue from historical perspective that the barriers have to do with low capability for absorbing technology, economic and political instability, and less-competitive environment.

Keywords: Barriers to technology adoption; Relative price of investment; Japan's growth miracle

JEL Classification: N15; N75; O11; O41

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1 Introduction

Japan's modern economic growth began around the middle of 1880s following the Meiji Restoration of 1868.[1] Despite the modernization, Japan's per-capita GDP had staggered around one-third of that of leading economies such as the United Kingdom and the United States in the pre-World-War-II period, as shown in Figure 1(a). Japan had to wait for more than a half century since the modernization took place before she began catching up with the leading economies in 1950s. In the prewar period, why didn't a catch-up take place? What prevented a catch-up from materializing? In the post-war period, why did the growth miracle suddenly take place?

To address these questions, we propose and examine a hypothesis that barriers to technology adoption that existed in Japan in the prewar period were reduced just after the war. We formulate the hypothesis based on three observations. First, in the literature on Japan's economic history of technology such as Peck and Tamura (1976), Japan is regarded as an outstanding example of purposive national effort to apply technology to achieve economic growth in the postwar period. Second, Japan's postwar rapid growth was driven by a high growth rate of total factor productivity (TFP), as shown by the growth accounting studies such as Hayami and Ogasawara (1999) and the calibration studies such as Ostu (2009) and Esteban-Pretel and Sawada (2014). Third and the most importantly, data on technology adoption suggest that the number of technology adoption was much lower in the prewar period than in the postwar period. On the one hand, the number of contracts of technology adopted from abroad that existed in 1941 was 231 according to the government agency's survey, which is to our knowledge the only available official data in the prewar period. On the other hand, our calculation of its counterpart in 1960 based on official data is 1,413, more than six times of that in 1941.[2]

[1] Ohkawa and Rosovsky (1973), p.11.

[2] See Appendix A for the details of our calculation of the number of technology adoption that existed in 1960.

In addition, the number of patents registered in Japan by foreigners –one indicator of technology adoption from foreign countries[3]– had remained low until it started increasing sharply in the postwar period as shown in Figure 1(b).

Among various types of technology that could have been affected by barriers to technology adoption, this paper focuses on investment specific technology (IST). In both the prewar and postwar periods in the 20th century, Japanese technology importation put emphasis on capital goods such as machinery and equipment that embodied IST.[4] In addition, consistent with the hypothesis about barriers to technology adoption, the relative price of investment –a measure of the IST progress– of Japan had been much higher than that of the U.K. unitl it started decreasing and converging to that of the U.K. in the postwar period, as shown in Figure 1(c). The development of the ratio of the relative price of investment of Japan to that of the U.K. –a measure of the IST progress of Japan relative to the U.K– shown in Figure 1(d) suggests that Japan was much less developed than the U.K. regarding IST in the prewar period but caught up with the U.K. in the postwar period.[5] Moreover, an increase in IST could explain the aforementioned high growth rate of TFP in the postwar period because the IST progress is measured as TFP in a growth-accounting model without IST progress.

We examine the hypothesis about barriers to technology adoption by building a two-sector dynamic model featuring endogenous adoption of IST and its barriers. The model provides a tight relationship between the degree of the barriers and the ratio of relative price of investment of Japan to the U.K., which allows us to quantify the degree of the barriers by using data on the relative price of investment. The model's simulation shows that the existence of the barriers explains about one-fourth of a gap in per-capita GDP

[3]Otsuka (1987) also uses the number of patents registered in Japan by foreigners as an indicator that measures the degree of adoption of technological knowledge from foreign countries in analyzing the development of cotton industries.

[4]For more in details, see Odagiri and Goto (1996) for the prewar period, and Goto (1993) for the postwar period.

[5]As studied by Hulten (1992) and Greenwood, Hercowitz, and Krusell (1997) for the U.S. economy, the level of the IST can be measured by the relative price of investment.

between Japan and the U.K. in the prewar period. Similarly, the reduction in the barriers explains about one-fourth of the catch-up attained in the postwar period.

In addition, the model explains a decrease in the ratio of the relative price of investment, which occurred around the period of 1945-1980 as shown in Figure 1(d). The model features costly technology adoption so that it takes time to adopt new technology even after the mitigation of the barriers. The costly technology adoption plays a critical role in replicating the transitory dynamics of the ratio of the relative price of investment in the postwar period.

In the model the barriers to technology adoption are something that makes it costly or difficult to adopt new technology. Then, concretely, what were barriers to technology adoption in the prewar period in Japan? We argue from historical perspective that the barriers had to do with low capability for absorbing technology, economic and political instability between Japan and foreign countries, and less-competitive environment. In the prewar period workers' capability for absorbing and making use of advanced technology was likely to be much lower than in the postwar period. This low capability must have been an obstacle for adopting advanced technology. In addition, economic and political instability between Japan and foreign countries due to a series of wars and military incidents since 1931 must have blocked technology adoption from the foreign countries. Moreover, due to a less-competitive environment and a vested interest, Zaibatsu companies –Japanese comglomerates– were likely to discourage new entries and investment of their subsidiaries. These factors must have made it costly or difficult to adopt new technology from abroad in the prewar period relative to the postwar period, and thereby correspond to the barriers in the model.

This paper is related to literature on the Japanese prewar stagnation and postwar miracle. In particular, this paper is motivated by Hayashi and Prescott (2008) who argue that barriers to labor mobility between agricultural and manufacturing sectors explain about one-fourth of a gap in per-capita GDP between Japan and the U.S. in the prewar period. Relatedly, Esteban-Pretel and Sawada (2014) argue that while the removal of barriers to labor mobility is one of major contributors to the Japanese postwar growth, it is the high growth of non-agricultural TFP that drives the growth miracle. Braun, Okada, and Sudo (2008) find that movements in the Japanese TFP are associated with prior movements in U.S. R&D expenditures, suggesting that technology adoption contributed to the Japan's growth miracle. Aoki, Esteban-Pretel, Okazaki, and Sawada (2010) report that the Japanese postwar growth in non-agricultural TFP occurred at first through the import of foreign technology via licensing. This paper complements these papers by focusing on barriers to the adoption of IST and explaining the movements of measured TFP that is driven by IST progress.

The idea that a reduction in barriers to technology adoption can explain the Japanese growth miracle is not new to this paper. Parente and Prescott (1994, 2000) argue that reductions in barriers to adoption of neutral technology explain the Japanese postwar growth dynamics in a version of the neo-classical growth model. Ngai (2004) considers the role of barriers to adoption of IST in the Japanese economic growth since 1820 within a two-period overlapping generations model. She shows that the reductions in the barriers in the late 19th century and in the postwar period capture the Japanese growth dynamics since 1820. This paper's contribution distinguished from theirs is twofold. First, this paper successfully explains the postwar transitional dynamics of the relative price of investment, which is driven by an increase in technology adoption as a result of a reduction in the barriers, and quantifies the effect of the reduction in the barriers on the Japanese postwar growth in a neo-classical growth framework. Second, this paper complements the model-based result with historical evidence regarding barriers to technology adoption.

The remainder of the paper proceeds as follows. Section 2 presents a dynamic model featuring endogenous technology adoption. Section 3 quantifies barriers to technology adoption, simulates the model, and presents the main result of this paper. Section 4 discusses sources of the barriers from historical perspective. Section 5 concludes.

2 Model

In this section we present a two-sector growth model in which technology adoption endogenously drives IST progress. The model features barriers to technology adoption that make it costly to invest for adopting new ideas. Slow technology adoption due to the barriers leads to a low level of IST, resulting in stagnated per-capita output.

The model is a simplified version of Comin and Gertler (2006), modified to introduce barriers to technology adoption. In the model economy, there are consumption-good firms, final-investment-good firms, intermediate-investment-good firms, technology-adoption firms, and households. The reminder of this section describes the behavior of these economic agents.

2.1 Consumption-good firms

There is a representative consumption-good firm. Under perfect competition, this firm produces consumption good $y_{c,t}$ in period t by combining capital $k_{c,t-1}$ and labor $n_{c,t}$ according to the Cobb-Douglas production function:

$$y_{c,t} = z_t k_{c,t-1}^{\alpha} n_{c,t}^{1-\alpha}, \quad 0 < \alpha < 1,$$

where $z_t = z_0 \gamma^t$ is the common exogenous neutral technology across the consumption and investment sectors, which grows at the constant rate of γ. The price of the consumption good is taken as a numeraire. Given the real wage w_t and the rental rate on capital r_t, profit maximization by the firm leads to:

$$w_t = (1-\alpha) z_t \left(k_{c,t-1}/n_{c,t}\right)^{\alpha}, \quad (1)$$

$$r_t = \alpha z_t \left(k_{c,t-1}/n_{c,t}\right)^{\alpha-1}. \quad (2)$$

2.2 Final-investment-good firms

There is a representative final-investment-good firm. Under perfect competition, this firm produces final-investment good $y_{I,t}$ by combining a continuum of intermediate-investment goods $\{y_{I,t}(i)\}$, $i \in [0, A_{t-1}]$ according to the CES production function:

$$y_{I,t} = \left(\int_0^{A_{t-1}} y_{I,t}(i)^{\frac{1}{\theta}} \, di \right)^{\theta}, \quad \theta > 1, \tag{3}$$

where A_{t-1} is the number of adopted ideas available in the beginning of period t. Given the price of final-investment good $p_{I,t}$ and the price of the i-th intermediate-investment good $p_{I,t}(i)$ for all i, the firm maximizes its profit $p_{I,t}y_{I,t} - \int_0^{A_{t-1}} p_{I,t}(i)\, y_{I,t}(i)\, di$ subject to (3). The resulting optimality condition yields a demand curve for the i-th intermediate-investment good:

$$y_{I,t}(i) = \left(\frac{p_{I,t}(i)}{p_{I,t}} \right)^{\frac{\theta}{1-\theta}} y_{I,t}. \tag{4}$$

The price of final-investment good is given by:

$$p_{I,t} = \left(\int_0^{A_{t-1}} p_{I,t}(i)^{\frac{1}{1-\theta}} \, di \right)^{1-\theta}. \tag{5}$$

2.3 Intermediate-investment-good firms

There are a continuum of intermediate-investment-good firms, each indexed by $i \in [0, A_{t-1}]$. For each i, the i-th intermediate-inevstment-good firm is monopolistically competitive and produces the i-th intermediate-investment good $y_{I,t}(i)$ by combining capital $k_{I,t-1}(i)$ and labor $n_{I,t}(i)$ according to the Cobb-Douglas production function

$$y_{I,t}(i) = z_t k_{I,t-1}(i)^{\alpha} \, n_{I,t}(i)^{1-\alpha}.$$

Given the factor prices, the firm minimizes its cost $r_t k_{I,t-1}(i) + w_t n_{I,t}(i)$ subject to the production function. The optimality conditions of the problem imply that the capital-labor ratio is identical for all i, so that the factor prices are given by:

$$w_t = mc_{I,t}(1-\alpha) z_t (k_{I,t-1}/n_{I,t})^{\alpha}, \quad (6)$$

$$r_t = mc_{I,t}\alpha z_t (k_{I,t-1}/n_{I,t})^{\alpha-1}, \quad (7)$$

where $mc_{I,t}$ is the marginal cost, $k_{I,t}$ is the capital in the investment sector, and $n_{I,t}$ is the labor employed in the investment sector. Combining equations (1), (2), (6), and (7) leads to $mc_{I,t} = 1$.

The firm maximizes its profit $p_{I,t}(i)\, y_{I,t}(i) - mc_{I,t} y_{I,t}(i)$ subject to the demand curve (4). The optimality condition yields $p_{I,t}(i)$ as:

$$p_{I,t}(i) = \theta mc_{I,t} = \theta. \quad (8)$$

A substitution of (8) into (5) leads to the price of investment as:

$$p_{I,t} = \frac{\theta}{A_{t-1}^{\theta-1}}. \quad (9)$$

Because the price of consumption is taken as a numeraire, $p_{I,t}$ corresponds to the relative price of investment.

From equations (3), (4), and (8), the final-investment good $y_{I,t}$ is given by:

$$y_{I,t} = A_{t-1}^{\theta-1} z_t k_{I,t-1}^{\alpha} n_{I,t}^{1-\alpha}. \quad (10)$$

In equation (10) the number of adopted ideas A_{t-1} constitutes the level of IST.

Because the intermediate-investment-good firms have market power over their product, they earn positive profit every period, which is given by $\Pi_{I,t}(i) = (\theta-1) A_{t-1}^{-\theta} y_{I,t} = (\theta-1) A_{t-1}^{-1} z_t k_{I,t-1}^{\alpha} n_{I,t}^{1-\alpha}$ for all $i \in [0, A_{t-1}]$. Note that the profit is the same for all i. Then, the value of an intermediate-investment-good firm V_t is expressed in a recursive form as

$$V_t = (\theta - 1) A_{t-1}^{-1} z_t k_{I,t-1}^{\alpha} n_{I,t}^{1-\alpha} + m_{t,t+1} V_{t+1}, \tag{11}$$

where $m_{t,t+1}$ is the discount factor of households.

2.4 Technology-adoption firms

There is a continuum of technology-adoption firms, each of which owns a not-yet-adoped idea in the interval $(A_{t-1}, Z_{t-1}]$, where Z_{t-1} is the frontier of ideas in the beginning of period t. The frontier of ideas grows exogenously at the rate of γ_z.

Each adoption firm invests consumption good $i_{a,t}$ to transform its own idea into an idea in practical use. The firm successfully adopts the idea with probability λ_t, which, as in Comin and Gertler (2006), is an increasing function of adoption investment $i_{a,t}$:

$$\lambda_t = \frac{\lambda_0}{\pi} \left(\frac{A_{t-1}}{A_{t-1}^*} i_{a,t} \right)^{\omega}, \; 0 < \omega < 1, \; \lambda_0 > 0, \tag{12}$$

where $\pi > 0$ represents barriers to technology adoption. An increase in the barriers π makes it costly for adoption firms to successfully adopt their ideas and lower the probability of technology adoption. The presence of A_{t-1} in (12) reflects a spillover effect from already adopted ideas to individual adoption and the presence of $A_{t-1}^* \equiv z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{(\theta-1)\alpha}{1-\alpha}}$ keeps the probability λ_t stationary. Because $A_{t-1}/A_{t-1}^* = z_t^{-\frac{1}{1-\alpha}} A_{t-1}^{\frac{1-\alpha\theta}{1-\alpha}}$, the spillover effect is positive as long as $\alpha\theta < 1$, which holds under our parameterization of the model presented in the next section.

Each adoption firm chooses the amount of adoption investment $i_{a.t}$ to maximize the value of its own idea J_t. The idea, if adopted, is sold as an intermediate-investment good at the price V_{t+1} in the next period. Thus, the present value of the idea is given by:

$$J_t = \max_{\{i_{a,t}\}} \left\{ -i_{a,t} + m_{t,t+1} \left[\lambda_t V_{t+1} + (1 - \lambda_t) J_{t+1} \right] \right\}. \tag{13}$$

The optimality condition with respect to $i_{a,t}$ yields:

$$1 = \frac{\lambda_0 \omega}{\pi} \left(\frac{A_{t-1}}{A^*_{t-1}} i_{a,t} \right)^{\omega-1} \frac{A^*_{t-1}}{A_{t-1}} m_{t,t+1} \left(V_{t+1} - J_{t+1} \right). \tag{14}$$

Equation (14) implies that adoption investment $i_{a,t}$ is increasing in a difference between the return in the case of successful adoption V_{t+1} and the value of the not-yet-adopted idea J_{t+1}.

In aggregate new ideas amounting to $\lambda_t \left(Z_{t-1} - A_{t-1} \right)$ are adopted in period t and added to the existing pool of ideas in practical use. Thus, a law of motion for adopted ideas is given by:

$$A_t = A_{t-1} + \lambda_t \left(Z_{t-1} - A_{t-1} \right). \tag{15}$$

2.5 Households

A representative household owns capital stock and all firms in the economy, and supplies one unit of labor inelastically. The household chooses consumption c_t, investment $y_{I,t}$, and capital stock k_t to maximize the utility:

$$\sum_{t=0}^{\infty} \beta^t \log \left(c_t \right),$$

subject to the budget constraint and the law of motion for capital:

$$c_t + p_{I,t} y_{I,t} = w_t + r_t k_{t-1} + T_t,$$
$$k_t = \left(1 - \delta \right) k_{t-1} + y_{I,t},$$

where T_t is the net profit brought by the firms and $0 < \delta < 1$ is the capital depreciation rate. The optimality conditions of the household problem yields the consumption Euler equation:

$$1 = m_{t,t+1} \left[\frac{r_{t+1} + p_{I,t+1} \left(1 - \delta \right)}{p_{I,t}} \right], \tag{16}$$

where the preference discount factor $m_{t,t+1}$ is given by $m_{t,t+1} = \beta c_t / c_{t+1}$. A substitution of (10) for $y_{I,t}$ into the law of motion for capital yields:

$$k_t = (1-\delta)\, k_{t-1} + A_{t-1}^{\theta-1} z_t k_{I,t-1}^{\alpha} n_{I,t}^{1-\alpha}. \tag{17}$$

2.6 Equilibrium

The model economy is closed by market clearing conditions regarding the consumption good, capital stock, and labor, which are given, respectively, by:

$$z_t k_{c,t-1}^{\alpha} n_{c,t}^{1-\alpha} = c_t + (Z_{t-1} - A_{t-1})\, i_{a,t}, \tag{18}$$

$$k_t = k_{c,t} + k_{I,t}, \tag{19}$$

$$1 = n_{c,t} + n_{I,t}. \tag{20}$$

Output y_t in this economy is defined as $y_t \equiv y_{c,t} + p_{I,t} y_{I,t}$ so that it is given by:

$$y_t = z_t k_{c,t-1}^{\alpha} n_{c,t}^{1-\alpha} + p_{I,t} A_{t-1}^{\theta-1} z_t k_{I,t-1}^{\alpha} n_{I,t}^{1-\alpha}. \tag{21}$$

The equilibrium conditions for this economy consist of the fifteen equations, (1), (2), (6), (7), (9), (11), and (13)-(21), with the same number of endogenous variables, $\{y_t$, c_t, $i_{a,t}$, $n_{c,t}$, $n_{I,t}$, k_t, $k_{c,t}$, $k_{I,t}$, $p_{I,t}$, $mc_{I,t}$, A_t, V_t, J_t, r_t, $w_t\}$. Appendix B presents the simplified and stationarized equilibrium conditions and the derivation of the steady state.

3 Quantitative Analyses

In this section we quantitatively analyze the effect of barriers to technology adoption on the Japanese prewar stagnation and postwar growth miracle within the model presented in the previous section. This section starts from the description of our simulation strategy and proceeds to the description of the model's parameterization. It then presents our main findings and some extensions of the model.

3.1 Simulation strategy

Our main simulation strategy is to quantify barriers to technology adoption in Japan and the U.K. from the data on the relative price of investment presented in Figure 1(b) and then to examine the effect of a reduction in the barriers in Japan after World War II. To this end, we consider two model economies: one corresponds to Japan and another corresponds to the U.K. Each model economy is identical to the model presented in the previous section except for the degree of barriers to technology adoption π and the initial level of neutral technology z_0, where the initial level of neutral technology in the U.K. is normalized to unity: $z_{0,\mathrm{UK}} = 1$. This setup implies that both Japan and the U.K. share the same frontier of not-yet-adopted technology, Z_t, which is regarded as the common world technology frontier. The common technology frontier is more or less consistent with the fact that Japanese government realized the importance of the adoption of new technology developed in western countries even before the modernization took place around the 1880s.

We formulate our simulation strategy by applying to the model key features of the data on per-capita output and the relative price of investment for Japan and the U.K., presented in Panels (a) and (d) of Figure 1. The data lead to the following four assumptions on our simulation. First, the U.K. model economy is assumed to be on the balanced growth path in which the degree of barriers to technology adoption is constant at π_{UK} for all periods. This assumption is consistent with the data that per-capita output in the U.K. is on a stable growth path in the long run. Second, because per-capita output in Japan had been about one-third of that in the U.K. in the prewar period, the Japanese model economy is also assumed to be on the balanced growth path in which the degree of barriers to technology adoption is π_{JP} in the prewar period. Third, to capture a sharp drop in per-capita output in Japan in the end of the war, unexpected one-time capital destruction is introduced as in Christiano (1989). Fourth and the most importantly, in view of historical evidence presented in the next section, barriers to technology adoption in Japan are assumed to be reduced after the war. In particular, the degree of the barriers is unexpectedly changed from π_{JP} to π'_{JP}, where the value of π'_{JP} is normalized to unity: $\pi'_{\text{JP}} = 1$.

These four assumptions allow us to identify the values of π_{JP}, π_{UK}, and $z_{0,\text{JP}}$ in the model economies, given the data presented in Panels (a) and (d) of Figure 1 and the other parameter values. From equation (9), the relative price of investment is given by $p_{I,t} = \theta / \left(a_{t-1} Z_{t-1}\right)^{\theta-1}$, where $a_{t-1} = A_{t-1}/Z_{t-1} \in (0, 1]$ measures distance to the frontier. As a_{t-1} becomes smaller, the distance becomes greater. Because Japanese and the U.K. model economies share the same frontier of unadopted technology, Z_{t-1}, the ratio of the relative price of investment in Japan to that in the U.K. in the prewar period is given by

$$\frac{p_{I,\text{JP}}}{p_{I,\text{UK}}} = \left(\frac{a_{\text{UK}}}{a_{\text{JP}}}\right)^{\theta-1}, \tag{22}$$

where variables without subscript t denote those in steady state. Given the ratio of the relative price, which is set at its sample average between 1890 and 1938, equation (22) gives the ratio $a_{\text{UK}}/a_{\text{JP}}$. Similarly, the ratio of the relative price in the postwar period in steady state is given by

$$\frac{p'_{I,\text{JP}}}{p_{I,\text{UK}}} = \left(\frac{a_{\text{UK}}}{a'_{\text{JP}}}\right)^{\theta-1}, \tag{23}$$

where variables with superscript $'$ denote those in the steady state in which the degree of barriers to technology adoption is reduced to π'_{JP}. With $p'_{I,\text{JP}}/p_{I,\text{UK}}$ set at its sample average between 1980 and 2000, equation (23) gives the ratio $a_{\text{UK}}/a'_{\text{JP}}$. Because π'_{JP} is normalized to unity, the value of a'_{JP} is already known from the steady state. With $a_{\text{UK}}/a_{\text{JP}}$ and $a_{\text{UK}}/a'_{\text{JP}}$ in hand, the values of a_{UK} and a_{JP} are obtained from the value of a'_{JP}. Because the ratio a is derived as a function of π as shown in Appendix C, the values of π_{UK} and π_{JP} are computed from the values of a_{UK} and a_{JP} respectively.

Next, consider the value of $z_{0,\text{JP}}$. Transformed output $y_t/(z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{(\theta-1)\alpha}{1-\alpha}})$ becomes constant and independent of π and z_0 in the steady state as shown in Appendix C. Hence, the ratio of output in Japan to that in the U.K. in the prewar period is given by

$$\frac{y_{\text{JP}}}{y_{\text{UK}}} = \left(\frac{z_{0,\text{JP}}}{z_{0,\text{UK}}}\right)^{\frac{1}{1-\alpha}} \left(\frac{a_{\text{JP}}}{a_{\text{UK}}}\right)^{\frac{\alpha(\theta-1)}{1-\alpha}}, \tag{24}$$

where $z_{0,\text{UK}} = 1$ from normalization. With $a_{\text{UK}}/a_{\text{JP}}$ in hand, equation (24) gives the value of $z_{0,\text{JP}}$.

We solve the model's non-linear system of equations by using a function-iteration method. Appendix D describes details of the solution method.

3.2 Parameterization

The unit of time is a year. The subjective discount factor is set at $\beta = 0.97$. The growth rates of exogenous neutral technology γ and the frontier of unadopted ideas γ_z are jointly set to match the growth rate of per-capita output for the U.K. economy in the period of 1890-2000. In doing so, the contribution of the IST progress to the growth rate of per-capita output is assumed to be 0.6 following Greenwood, Hercowitz, and Krusell (1997).[6] The capital share and the capital depreciation rate are set at $\alpha = 0.36$ and $\delta = 0.089$ respectively, following Hayashi and Prescott (2002). While $\alpha = 0.36$ is based on the Japanese data on national account, α could be higher if unmeasured investment is taken into account, as argued by Parente and Prescott (2000) among others. In view of this possibility, we use an alternative higher value of $\alpha = 0.5$ as in Ngai (2004) for our quantitative analyses. The markup is set at $\theta = 1.2$. Based on Mansfield (1989) who report a median time to adoption of 8 years in the postwar period for Japan, parameter λ_0 in (12) is set to match the probability of technology adoption of 12.5 percent in the steady state in which the barriers to technology adoption are reduced. Finally, the elasticity

[6] The use of the contribution calculated by Greenwood, Hercowitz, and Krusell has to do with our concern that our dataset may underestimate the rate of IST progress. Our dataset are mainly based on PWT in the postwar period and exhibit a low rate of a decrease in the relative price for the U.S., compared with previous studies such as Greenwood, Hercowitz, and Krusell who use quality-adjusted prices of investment. This observation implies that our dataset may underestimate the rate of IST progress.

of technology adoption ω is set at 0.6 to roughly match the rate of the convergence of the relative price of investment in Japan after 1950. Table 1 summarizes the parameter values.

3.3 Main findings

We simulate the parameterized models for Japan and the U.K. by following the strategy presented in Section 3.1. Figure 2 plots the developments of per-capita output in Panel (a) and the ratio of the relative price of investment in Panel (b), both of which are generated by the simulation in the case of $\alpha = 0.36$. In the prewar period both the Japanese economy (thick solid line) and the U.K. economy (thick dashed line) are on a balanced-growth path by assumptions, and per-capita output in Japan remains about one-third of that in the U.K. In 1945 an unexpected capital destruction, which is calibrated to match the data of per-capita output in 1945, hits the Japanese economy so that the per-capita output plummets. At the same time, the barriers to technology adoption are reduced from $\pi_{\mathrm{JP}} = 7.2$ to $\pi'_{\mathrm{JP}} = 1$. The per-capita output recovers quickly and rises beyond a counterfactual path (thick dotted line) in which the barriers remain intact. Meanwhile, the ratio of the relative price of investment in Japan to that in the U.K. starts declining after the war, reflecting an increase in IST resulting from an increase in technology adoption. Technology adoption increases because the reduction in the barriers makes the return of adoption investment higher and thereby increases the technology adoption investment. The simulated ratio of the relative price of investment, denoted by "baseline," well captures the actual development of the corresponding data as shown in Panel(b). These results suggest an important role of technology adoption in explaining the transitory dynamics in the observed ratio of the relative price. In 2000, the simulated per-capita output in Japan becomes about one-half of that in the U.K. Hence, the reduction in the barriers to technology adoption explains about a quarter $(= 1 - (1 - 1/2) / (1 - 1/3))$ of the catch up after the war. In other words, the high degree of barriers to technology adoption explains about a quarter of the prewar gap regarding per-capita output between Japan and the U.K.

The fact that the model successfully replicates the decline in the relative price of investment in the postwar period implies that the measured TFP, which is calculated under the assumption of no IST progress, increases in the postwar period. Figure 3 plots the measured TFP under such an assumption for the model, the model without the reduction in the barriers, and data for non-primary sectors.[7] The model captures to some extent the rapid increase in the measured TFP in the postwar period. In addition, the model captures a slowdown in the measured TFP after the middle of the 1970s as the catch-up regarding the IST progress comes to an end in the same period in the model.

To accommodate the view that there could be unmeasured investment as argued by Parente and Prescott (2000) among others, we simulate the model with the capital share set at $\alpha = 0.5$. Figure 4 plots simulated results for the same variables as in the previous simulation with $\alpha = 0.36$. An increase in the capital share from 0.36 to 0.5 makes two major differences. First, in 2000 the per-capita output in Japan becomes greater than in the previous case and increases to about two-third of that in the U.K. Thus, the reduction in the barriers now explains about a half $(= 1 - (1 - 2/3) / (1 - 1/3))$ of the catch up after the war, much greater than a quarter in the previous case. To understand this effect, combining equations (23) and (24) yields:

$$\frac{y'_{\mathrm{JP}}}{y_{\mathrm{UK}}} = \left(\frac{z_{0,\mathrm{JP}}}{z_{0,\mathrm{UK}}}\right)^{\frac{1}{1-\alpha}} \left(\frac{p_{I,\mathrm{UK}}}{p'_{I,\mathrm{JP}}}\right)^{\frac{\alpha}{1-\alpha}}, \tag{25}$$

where $y'_{\mathrm{JP}}/y_{\mathrm{UK}}$ is the per-capita output in Japan relative to the U.K. in a balanced growth path after the removal of the barriers. Equation (25) implies that the effect of

[7] In Figure 3 the data for non-primary sectors but not all sectors are used to exclude the effect of a structural change regarding primary sectors including an agricultural sector. Still, the measured TFP for all sectos presented by Hayashi and Prescott (2008) shows a development similar to the one in Figure 3: a steady growth in the prewar period and a rapid increase in the postwar period. Appendix A describes the details of the data on the measured TFP for non-primary sectors.

the relative-price term, $p_{I,\mathrm{UK}}/p'_{I,\mathrm{JP}}$, becomes greater as the capital share α increases. An increase in the capital stock induced by a drop in the relative price has a greater effect on output as the capital share increases. Second, the convergence rates of the per-capita output and the relative price of investment become slower than in the previous case. A higher value of the capital share lowers the marginal product of capital, given the level of capital, and makes the speed of capital accumulation slower.

3.4 Timing of the removal of the barriers

The simulations conducted thus far assumed that the barriers to technology adoption was reduced in 1945 when the WWII ended. This timing, however, could be slightly early in light of historical evidence that major changes in policy and institution occurred in the 1950s as discussed in the next section. To address this timing issue, the same simulation but with the removal of the barriers in 1950 instead of 1945 is conducted for the model with $\alpha = 0.36$. Figure 5 plots the development of simulated per-capita output in Japan for this simulation (thick dotted line). The output recovers sharply just after the war and the recovery slows down some what around 1950 when the barriers are reduced, which is not consistent with the data. What causes this slowdown in the recovery is the income effect of the removal of the barriers. The elimination of the barriers increases the level of IST and future income, which works to increase current consumption and decreases current investment. This effect is less pronounced in the former simulation in which the barriers are reduced in 1945 because the marginal product of capital is quite high due to the destruction of capital in 1945.

One way to address this slowdown in the output growth in the simulation is to introduce the subsistence level of consumption as in Christiano (1989). With the subsistence level of consumption, $\bar{c}$, the periodic utility function is given by $\log\left(c_t - \bar{c}A^*_{t-1}\right)$. Figure 5 plots the simulated per-capita output in Japan for the modified model (thick solid line) in which $\bar{c}$ is set to forty-five percent of the steady state consumption.[8] With the subsistence level of consumption, the speed of capital accumulation becomes slower after the war and the marginal product of capital remains higher around 1950 than in the case of no subsistence level of consumption. As a result, there appears no slowdown in the output growth around 1950, more or less consistent with the data.

4 What were barriers to technology adoption?

The previous section showed within the framework of the two-sector neo-classical growth model that the existence of barriers to technology adoption explained about one-fourth of a gap in per-capita GDP between Japan and the U.K. in the prewar period and that a reduction of the barriers explained about one-fourth of a catch-up attained in the postwar growth miracle as well as the transitional dynamics of the relative price of investment. In the model the barriers, π, lowered the probability of technology adoption given the amount of technology adoption investment according to equation (12). Then, concretely, what were barriers to technology adoption? What prevented potential technology adoption in the prewar period and what promoted actual technology adoption in the postwar period?

In this section we address these questions from historical perspective. We point out three factors that potentially played a role as barriers to technology adoption that made difficult or costly to adopt technology in the prewar period relative to the postwar period: (i) low capability for absorbing technology; (ii) economic and political instability between Japan and foreign countries; (iii) less-competitive environment.

To summarize our argument in advance, in the prewar period workers' capability for absorbing and making use of advanced technology was likely to be lower than in the

[8] In 1944, many consumption goods were rationed in Japan and the per-capita consumption was about fifty percent of that in 1937-1938, the period just before the war started. This observation suggests that the subsistence level of consumption is lower than but possiblely close to fifty percent.

postwar period. This low capability must have been an obstacle for adopting advanced technology. Although the capability appeared to increase during the WWII, economic and political instability between Japan and foreign countries due to a series of wars and military incidents since 1931 must have blocked technology adoption from the foreign countries. In addition, due to a less-competitive environment and a vested interest, Zaibatsu companies –Japanese comglomerates– were likely to discourage new entries, investment, and technology adoption of their subsidiaries. These three factors played a role of barriers to technology adoption in the prewar period, which were greatly mitigated in the postwar period.

4.1 Low capability for absorbing technology

Capability for absorbing new technology indicates the degree of skill and knowledge of workers that allow them to learn, manage, and put new technology to practical use in a given period of time. Low capability would cause unsuccessful adoption of advanced technology and restrict adoptable technology to mediocre technology. Hence low capability corresponds to a high value of π in the model, i.e., barriers to technology adoption.

We argue that the capability had been low until the beginning of WWII and increased sharply during and after the war. The number of new graduates with engineering majors from university per year –one potential measure of the capability– did not exceed 5,000 (70 per a million population) as shown in Figure 6. In the pre-WWII period slow spread of modern science, indicated by the low numbers of graduates, made it difficult for Japan to develop industries that require advanced technology, so that the initial industrialization was concentrated to light indutries.[9] In addition, technology adoption depended on the capability as the adopted technology was not necessarily advanced but many of adopted technology featured intermediate technology between old and advanced technology[10],

[9] Minami (2002), p.83.

[10] Makino (1996), p.197.

indicating that technology adoption was restrained by low capability.

In 1945, however, the measure of the capability –the number of new graduates with enginnering majors from university– increased sharply to 12,125 (168 per a million population), more than doubled of those in the pre-WWII period. Accordingly, the total number of unversity graduates with engineering majors –not a flow but a stock of these university graduates– doubled from 41,080 (601 per a million population) in 1934 to 89,500 (1,146 per a million population) in 1947.[11] These increases were driven by wartime demand for manufacturing products that called for an increase in the number of engineers, which led the government to expand the size of engineering department and newly establish universities with engineering department.[12] In the postwar period the number of new graduates continued increasing as shown in Figure 6.

An expansion of high education institutions with engineering majors during the wartime increased capability for absorbing technology in the postwar period. Under the new education system that started in 1949 universities with engineering department were re-established in success to high education institutions expanded in the wartime.[13] The increase in capability, induced by an expansion of high education institutions in the wartime, led to an efficient use of adopted technology and innovations driven by investment in R&D and education in the postwar period.[14]

4.2 Economic and political instability

In spite of the increase in the capability during the WWII, it did not lead to an increase in technology adoption at the same period because the war made international transactions extremely difficult. In view of this fact, we argue that the second factor of barriers to

[11] The data sources of the number of university graduates and the total population are Sawai (2012b), pp.113 and Statistics Bureau, Ministry of Internal Affairs and Communications (2007) respectively.

[12] Sawai (2012a), pp.172-173.

[13] Sawai (2012a), p.173.

[14] Goto (1993), p.292.

technology adoption is economic and political instability between Japan and foreign countries.

In the prewar period, although the government established a foundation for introducing foreign capital around 1899 as explained in Appendix B, a series of subsequent wars and military events such as World War I (1914–1918), Manchurian Incident (1931), Second Sino-Japanese War (1937–1945), and World War II (1939–1945) negatively affected technology adoption. In this regard, the share of the number of foreigners who registered patents in Japan[15] dropped in the period of 1914–1918, affected by World War I, and decreased after 1931, reflecting the deterioration of the relationship between Japan and the U.S. and the U.K. In particular, the share dropped sharply from 18% in 1941 to 8.1% in 1942 following the Japan's declaration of war against the U.S. in December 1941.

In the postwar period, stabilized world economic and political situation invigorated foreign trades on technology in addition to goods and services, supported by the activity of International Monetary Funds and General Agreement on Tariffs and Trade.[16]

4.3 Less-competitive environment

In the model presented in the previous section each technology-adoption firm is assumed to be competitive and is able to make a choice in a frictionless manner. If the firm was owned by a mega company that could distort the decision making of the firm due to a lack of competition and a vested interest within the company, such a distortion could be represented by a constraint on technology-adoption investment $i_{a,t}$: $i_{a,t} \leq \bar{i}_{a,t}$., where $\bar{i}_{a,t}$ is the upper bound set by its owner company. In the model that has no such a constraint, the distortion caused the potential binding constraint would be represented by a high value of π as a reduced form. We call this factor that causes the high value of π as a less-competitive environemnt to reflect the background that it is the owner company

[15] The data source is Japan Patent Office (1984), p.587.

[16] Goto (1993), p.252.

with a lack of competition that lie behind such a high value of π.

Our main argument is that the presence of Zaibatsu in the pre-WWII period contributed to a less-competitive environment and played a role of barriers to technology adoption. Technology adoption in the prewar period was mainly conducted by Zaibatsu companies and their subsidiaries.[17] In this sense, Zaibatsu companies, which had large amount of capital, led technology adoption.[18] Still, the Zaibatsu-specific corporate governance could have blocked potential adoption of new technology. A Zaibatsu holding company was owned by Zaibatsu family who were capitalists and partners of unlimited liability. The holding company managed the financial activity of its subsidiaries by owning them in a closed manner so that the shares of the subsidiaries were not open to public. The investment behavior of subsidiaries were monitored strictly by its holding company and investment by subsidiaries was in principle funded only by the net worth of the holding and subsidiaries, which lasted until the 1920s.[19] While Zaibatsu companies contributed to industrialization by providing their subsidiaries long-term funds by means of their internal funds, they had an aspect of making conservative decisions regarding new entries and investment of their subsidiaries.[20] Morikawa (1978) points out that in the process of heavy and chemical industrialization in the 1910s and 1920s some major Zaibatsu companies were conservative and behind emerging companies with less capital for three reasons: (i) slow decision making and low dynamism due to a large size of Zaibatsu; (ii) the influence of Zaibatsu family whose priority lies in preserving the family's assets; (iii) difficulty in reconciling differences of opinion among subsidiaries that run diversified operations.[21]

[17] Ohkawa and Rosovsky (1973), p.258.

[18] For example, Udagawa (2005) agues that the positive significance of the presence of Zaibatsu in the Japanese management history is that Zaibatsu became risk takers in modernized industry and contributed to the Japan's economic development (p.53).

[19] Teranishi (2007), p.66.

[20] Miyajima (2004), pp.178–189.

[21] Morikawa (1978), pp.187–193. Morikawa (1980), pp.168–202 discusses more details of conservative features of Zaibatsu.

In the postwar period the resolution of Zaibatsu and the division of companies[22] as a part of economy democratization policy stimulated competition among firms, which marked a necessary condition for the subsequent high growth.[23] For example, in the steel industry, Japan Iron & Steel[24] was divided into two firms, Yawata Iron & Steel and Fuji Iron & Steel, which stimulated the investment in the industry.[25] In the paper-manufacturing industry, former Oji Paper was divided into three firms, which initiated the competition of investment. Also, the reorganization of the electricity industry cut an access to power plants by one electric company to the others and led to an increase in investment. In this way, the resolution of Zaibatsu and the decentralization of firms destroyed an old regime of industries and initiated the competition of investment in the process of the economic recovery.[26]

The intense market competition in the postwar period contributed to an increase in technology adoption.[27] In this regard, according to the survey on technology adoption under Foreign Capital Act, conducted by the Ministry of International Trade and Industry in 1961, main reasons behind firms' decisions to adopt foreign technology include enhancing domestic and international competitiveness, saving the cost of research, and

[22] In the resolution of Zaibatsu that started in 1946, 83 companies were designated as the mother company of Zaibatsu and 21 companies out of them were actually split apart. In addition, in 1947 Excessive Economic Power Deconcentration Law was enacted and 11 companies that had large presence in each industry were divided.

[23] Minami (2002), pp.101–102. Still, the effects of the resolution of Zaibatsu is controversial. For example, Miwa (1993), pp.109-130 casts doubt on the view of Minami.

[24] Japan Iron & Steel was establised in 1934 as a joint company of the state owned Yawata Iron Factory and private companies.

[25] Japan Iron & Steel was a nationa-policy-oriented company that the government owned more than a half of its shares, so that it was not a competitor to private companies. After the division of Japan Iron & Steel after the war, however, the resulting two companies became a pure competitor to other private companies including Kawasaki Steel which entered overall production of iron and steel in a sense of danger about fierce competition. This entry triggered additional entries to overall production by other three companies, and as a result the six companies competed severely. The source of this footnote is Yonekura (1992), pp.100–103.

[26] Kosai (1989), pp.306-307.

[27] Goto (1993), p.289.

starting up firms.[28]

5 Conclusion

In this paper we built a two-sector dynamic model with endogenous technology adoption and quantify the effect of barriers to technology adoption on the Japanese prewar stagnation and the post war growth miracle. In doing so we used data on the relative price of investment and identified the degree of the barriers in the model. The existence of the barriers explained about one-fourth of a gap in per-capita GDP between Japan and the U.K. in the prewar period. Similarly, a reduction in the barriers explained about one-fourth of the catch-up attained in the postwar period. In addition, the model successfully replicated the observed transitional dynamic of the relative price of investment. We reinforced the model result by arguing from historical perspective that the sources of barriers to technology adoption were low capability for absorbing technology, world economic and political instability, and less competitive environment.

We would like to conclude with some caveats on our main results. First, the quantitative results depend on the data on the relative price of investment that could involve measurement errors. Such errors are likely to increase as the data go back to the past from 1950, the oldest benchmark year when additional data are collected in constructing purchasing power parities over consumption and investment. Second, the barriers to technology adoption in the model are somewhat reduced-form of the three sources we argued from historical perspective, especially capability for aborbing technology and less competitive environment. Richer micro foundations are required for providing a tight relationship between theory and historical evidence.

[28] The Ministry of International Trade and Industry (1962), Source Materials, p.91.

Appendix

A Data

Relative price of investment: The relative price of investment is defined as the ratio of the price of consumption to the price of investment. For both Japan and the U.K. in the postwar period from 1950 to 2000, the data source is Penn World Table 7.1.

For the data in the prewar period from 1890 to 1940, we construct connected series of the prices of consumption and investment by using the inflation rates of the prices. For Japan, the data source of the price of investment is the index of investment good prices excluding the prices of residential buildings in Table 7 of Ohkawa, Shinohara, and Umemura (1967b). The data source of the price of consumption is the price index of consumption good prices in Table 8–9 of Ohkawa, Shinohara, and Umemura (1967a). To connect the postwar series with the prewar series, we use the linkage scales presented on p.72 of Ohkawa, Shinohara, and Umemura (1967b) and p.389 of Ohkawa, Shinohara, and Meissner (1979) for the prices of investment and consumption respectively.

For the U.K. in the prewar period, we follow Collins and Williamson (2001). The data source of the price of investment are Feinstein and Pollard (1988), pp.470–471 for those from 1890 to 1920 and Feinstein (1972), Table 61 for those from 1920 to 1950. The data source of the price of consumption is Feinstein (1972), Table 61.

Total factor productivity: We calculate the TFP in non-primary sectors in Japan by $A = Y/(K^{\alpha}N^{1-\alpha})$, where Y is the real output, K is the real capital stock, and N is total hours worked in non-primary sectors. The data source of N is Hayashi and Prescott (2008) and N is given by the total number of employees times the average hours worked in non-agricultural sectors. Both Y and K are constructed by their nominal counterparts divided by the price of consumption. The data source of the nominal output is Cabinet Office (2001) for the period of 1955–1998 and Ohkawa, Shinohara, and Umemura (1974), table 9 for the period of 1890–1940. The data source of the price of consumption is the same as that explained above for the relative price of investment. For the nominal capital in the period of 1890–1940, it is constructed by summing up five types of capital stock in non-primary sectors: producers' durable equipment, public works, electric utilities, railroads, and non-residential buildings. The nominal capital is constructed from the real capital presented in Table 5 of Ohkawa, Shinohara, and Umemura (1966) and deflators in Table 7 of Ohkawa, Shinohara, and Umemura (1967b). For the nominal capital in the period of 1955–1998, it is not available so that we calculate it as the total nominal capital stock multiplied by the ratio of the nominal gross capital stock in non-agricultural sectors to the total gross capital stock, where the data source is Cabinet Office (2001).

Number of technology adoption: In the pre-WWII period no official statistics regarding technology adoption is available. Still, according to the survey conducted by the Agency of Industrial Science and Technology, the number of contracts of technology adoption that existed in 1941 was 231.

In the post-WWII period the average number of technology adoption is 230 per year in the 1950s, within which about 100 items are approved by Foreign Capital Act that deals with items whose contract duration or payment duration exceeds a year.

For comparison of number of technology adoption between the prewar and postwar periods, existing number of technology adoption in 1960 is estimated as follows. According to Ministry of International Trade and Industry (1962), Source Materials, p.13, technology-adoption contracts made in the period of 1950–1961 are categorized into the length of contract duration. By using this data and the annual data on the number of technology-adoption contracts under Foreign Capital Act[29], the number of contracts with duration over 1 year in 1960 is estimated to be 1,170. Those with duration less than 1 year is estimated by the average value in the fiscal year of 1959 and 1960, which is 243. Summing up the two values yields the estimated number of contracts of technology

[29] The data source is Science and Technology Agency (1965), p.153.

adoption in 1960 of 1,413.

To summarize, the number of contracts of technology adoption is 231 in 1941 while it is estimated to be 1,413 in 1960.

B Overview of Technology Adoption in Japan

In Section 4 we argue that barriers to technology adoption existed in the pre-WWII period in Japan, which restrained technology adoption and thus kept the level of technology low relative to the U.K. and other advanced countries. The literature on history of Japanese technology adoption, however, is not as clear-cut as our argument. The literature points out an active role of technology adoption in enhancing economic growth in both prewar and postwar periods[30] but provides little comparison of technology adoption between the two periods. While our argument is more or less consistent with the literature, it sheds light on the comparison of technology adoption between the two periods. In the following we provide an overview of technology adoption in Japan from the Meiji Restoration of 1868 to 1950, which serves as the background of our argument in Section 4.

Since the Meiji Restoration Japan had modernized, industrialized, and developed rapidly by means of technology adoption from the U.S. and European countries.[31] In the late 19th century Japan actively adopted technology by employing foreign engineers who could teach how to use advanced technology, sending Japanese engineers to abroad for acquiring skills, and importing capital goods that were embedded with advanced technology.[32]

Yet the Japanese government had kept its stance of restraining foreign capital while

[30] See Goto (1993) p.277 for the postwar period and Saito (1979) p.627 and p.630 for the prewar period. Peck and Tamura (1976) p.527 points out that the role of technology adoption in raising productivity is not limited to the postwar period but applies to the prewar period.

[31] Saito (1979) p.652.

[32] Uchida (1990), pp.265–285.

actively introducing foreign technology. Behind such a conflicting stance lied painful experiences of the attempt by foreigners to introduce foreign capital and control Takashima coal mine –the biggest coal mine– and Mitsui-gumi –the biggest financial institution– in the 1870s. Subsequently, the government legislated against foreign capital in mining industries by enacting Nippon Koho (Japan Mining Act) in 1873 and prohibited foreign stockholders in banking industries by revising National Bank Act in 1876.[33]

The year of 1899 marked a shift of policies toward foreign capital from exclusion to introduction. In 1899 the treaties with foreign countries was revised[34] and Japan acquired jurisdiction over foreigners in Japan. Consequently, foreign direct investment in Japan was made possible in principle.[35] In addition, the treaty revision necessitated protection of foreigners' industrial property so that Japan participated in Union for the Protection of Industrial Property in 1899.[36] Moreover, in response to an increase in demand for introducing foreign capital in accordance with rapid industrialization following Sino-Japanese War of 1894-1895, the government revised commercial law in 1899 and allowed foreigners to hold shares and exercise management participation rights.[37] The set of legislation led to a shift in Japanese foreign capital policy from exclusion to introduction.[38] In fact, subsequent years after 1899 observed technology adoption by means of technology assistance contracts with foreign large companies, which included foreign companies' acquisition of domestic companies' shares. In particular, in the electric-machinery industry, Nippon Electric was established in 1899 as the first foreign company by Western Electric that contributed 54% of equity, and technical cooperation contracts were made between the two companies. In 1905 and 1907 General Electric acquired 51% and 23% of equity of Tokyo Electric and Shibaura Manufacturing and made technical cooperation

[33] Ishii (2015), pp.34-35.

[34] The revision of the treaties was signed in the period of 1894–1897 and implemented in 1899.

[35] Ishii (2015), p.38.

[36] Suzuki (2000), p.223.

[37] Miyazaki (1965), p.23.

[38] Shinomiya (1994), p.40.

contracts with the two companies respectively.

In spite of the shift to introducing foreign capital in 1899, there were movements to encourage the use of domestic products, which were likely to restrain foreign capital and technology adoption. Against the backdrop of continued current account deficit and resulting limited amount of foreign currencies, the government encouraged the purchase of domestic products. In particular, the Ministry of Agriculture and Commerce advocated a movement to promote the use of domestic products in 1914.[39] This movement weakened during World War I but strengthened after the war as Japan run high current account deficit. In 1930 the cabinet decided a movement to encourage the use of domestic products – those produced by companies with the share of Japanese stock holders of 51% or more – to promote a recovery from the Great Depression.[40] Importantly, domestic products in the movement excluded those produced by using foreign patents.[41] These movements worked to stimulate domestic activity in R&D while restraining technology adoption from abroad.

In 1931 the Manchurian Incident broke out and the government positive stance toward foreign capital was transformed into the negative stance that regulated and excluded foreign capital.[42] Technology adoption was suspended in the subsequent period of wars and the period of turbulence after the WWII.

After the WWII in face of deterioration in domestic capital the government regarded the introduction of foreign funds and technology as essential to achieve technological development and rationalization of firms and industries, and thereby enhancing technology adoption became one of the most important economic policies.[43] Indeed, the Ashida Cabinet (March 1948–October 1948) established "an economic recovery under-

[39] Ministry of International Trade and Industry (1985), p.132.

[40] Japan Patent Office (1984), p.416.

[41] Japan Patent Office (1984), p.416.

[42] Shinomiya (1994), p.64.

[43] Ministry of International Trade and Industry (1972), p.237.

pinned by foreign capital and a recovery of foreign credit" as its primary objective, and the following series of Yoshida Cabinets (October 1948–February 1954) grappled with the introduction of foreign capital as one of its most important challenges.[44]

In the period of just after the WWII the Japanese economy was unstable as it suffered from the damage to the supply side and resulting high inflation. In 1949 the Dodge Line – contractionary fiscal and monetary policies – brought an end to the high inflation and a fixed exchange rate was set up, laying an economic foundation for introducing foreign capital. Accordingly, the government introduced legislation for foreign capital: it enacted "Foreign Exchange and Foreign Trade Control Act" and "Foreign Capital Act" in 1949 and 1950 respectively. While the former act heavily regulated foreign trades and payments in view of current account deficit and limited foreign currencies, the latter act aimed to enhance adoption of superior technology from abroad by allocating limited foreign currencies to important technology adoption. Once technology adoption was approved under Foreign Capital Act, the remittance in exchange for technology adoption was conducted without another approval.[45]

C Equilibrium Conditions and Steady State

C.1 Equilibrium conditions

The fifteen equilibrium conditions, (1), (2), (6), (7), (9), (11), and (13)-(21), can be arranged and transformed into eight equations. Equations (1), (2), (6) and (7) imply

$$\frac{k_{c,t-1}}{n_{c,t}} = \frac{k_{I,t-1}}{n_{I,t}} = \frac{\alpha}{1-\alpha}\frac{w_t}{r_t}.$$

The identical capital-labor ratio implies $mc_{I,t} = 1$ from (1) and (6) and also leads to the following identity: $k_{c,t-1}/n_{c,t} = k_{I,t-1}/n_{I,t} = k_{t-1}$. Then, the six equations, (1), (2), (6),

[44] Asai (2001) p.97.

[45] Yoshida (1967), p.74; Ministry of International Trade and Industry (1972), pp.236–239; Ministry of Finance (1976), pp.105–106.

(7), (9), (11), are arranged into the following four equations

$$
\begin{aligned}
r_t &= z_t \alpha k_{t-1}^{\alpha-1}, &(26)\\
w_t &= z_t (1-\alpha) k_{t-1}^{\alpha}, &(27)\\
p_{I,t} &= \frac{\theta}{A_{t-1}^{\theta-1}}, &(28)\\
V_t &= (\theta-1) A_{t-1}^{-1} z_t k_{t-1}^{\alpha} n_{I,t} + m_{t,t+1} V_{t+1}. &(29)
\end{aligned}
$$

Equations (16) and (17) are written as

$$
\begin{aligned}
1 &= m_{t,t+1} \left[\frac{A_{t-1}^{\theta-1}}{\theta} z_{t+1} \alpha k_t^{\alpha-1} + \frac{A_{t-1}^{\theta-1}}{A_t^{\theta-1}} (1-\delta) \right], &(30)\\
k_t &= (1-\delta) k_{t-1} + A_{t-1}^{\theta-1} z_t k_{t-1}^{\alpha} n_{I,t}, &(31)
\end{aligned}
$$

Equations (18) and (21) is written as

$$
z_t k_{t-1}^{\alpha} (1 - n_{I,t}) = c_t + (Z_{t-1} - A_{t-1}) i_{a,t}, \qquad (32)
$$

$$
y_t = [1 + (\theta-1) n_{I,t}] z_t k_{t-1}^{\alpha}. \qquad (33)
$$

Now a system of equations for this model economy consist of eight equations (13)-(15), (29)-(33) with the following eight unknowns $\{k_t, n_{I,t}, V_t, A_t, J_t, i_{a,t}, y_t, c_t\}$. The return on capital r_t, the wage w_t, and the relative price of investment $p_{I,t}$ are given by (26), (27), and (28) respectively.

C.2 Transformed equilibrium conditions

We stationarize variables in the system of equations, (13)-(15), (29)-(33), as

$$
\begin{aligned}
\hat{k}_{t-1} &\equiv \frac{k_{t-1}}{z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{\theta-1}{1-\alpha}}}, \hat{y}_t \equiv \frac{y_t}{z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{(\theta-1)\alpha}{1-\alpha}}}, \hat{c}_t \equiv \frac{c_t}{z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{(\theta-1)\alpha}{1-\alpha}}}, a_t \equiv \frac{A_t}{Z_t},\\
\hat{V}_t &\equiv \frac{V_t A_{t-1}}{z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{(\theta-1)\alpha}{1-\alpha}}}, \hat{J}_t \equiv \frac{J_t A_{t-1}}{z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{(\theta-1)\alpha}{1-\alpha}}}, \hat{\imath}_{a,t} \equiv \frac{i_{a,t} A_{t-1}}{z_t^{\frac{1}{1-\alpha}} A_{t-1}^{\frac{(\theta-1)\alpha}{1-\alpha}}}, \gamma_{A,t} \equiv \frac{A_t}{A_{t-1}}
\end{aligned}
$$

The transformed system of equation for this economy consists of nine equations

$$a_t\gamma_{z,t} = a_{t-1} + \lambda_t (1 - a_{t-1}), \tag{34}$$

$$\hat{J}_t = -\hat{\imath}_{a,t} + m_{t,t+1}\gamma_{t+1}^{\frac{1}{1-\alpha}}\gamma_{A,t}^{\frac{\alpha(\theta-1)}{1-\alpha}-1}\left[\lambda_t\hat{V}_{t+1} + (1-\lambda_t)\hat{J}_{t+1}\right], \tag{35}$$

$$1 = \frac{\lambda_0\omega}{\pi}\hat{\imath}_{a,t}^{\omega-1}m_{t,t+1}\gamma_{t+1}^{\frac{1}{1-\alpha}}\gamma_{A,t}^{\frac{\alpha(\theta-1)}{1-\alpha}-1}\left(\hat{V}_{t+1} - \hat{J}_{t+1}\right), \tag{36}$$

$$\hat{V}_t = (\theta-1)\hat{k}_{t-1}^{\alpha}n_{I,t} + m_{t,t+1}\gamma_{t+1}^{\frac{1}{1-\alpha}}\gamma_{A,t}^{\frac{\alpha(\theta-1)}{1-\alpha}-1}\hat{V}_{t+1}, \tag{37}$$

$$\hat{k}_t\gamma_{t+1}^{\frac{1}{1-\alpha}}\gamma_{A,t}^{\frac{\theta-1}{1-\alpha}} = (1-\delta)\hat{k}_{t-1} + \hat{k}_{t-1}^{\alpha}n_{I,t}, \tag{38}$$

$$1 = m_{t,t+1}\gamma_{t+1}^{\frac{1}{1-\alpha}}\left[\frac{\alpha}{\theta}\left(\hat{k}_t\gamma_{A,t}^{\frac{\theta-1}{1-\alpha}}\right)^{\alpha-1} + \gamma_{A,t}^{-(\theta-1)}(1-\delta)\right], \tag{39}$$

$$\hat{k}_{t-1}^{\alpha}(1-n_{I,t}) = \hat{c}_t + \left(\frac{1}{a_{t-1}} - 1\right)\hat{\imath}_{a,t}, \tag{40}$$

$$\hat{y}_t = [1 + (\theta-1)n_{I,t}]\hat{k}_{t-1}^{\alpha}, \tag{41}$$

$$\gamma_{A,t} = \frac{a_t}{a_{t-1}}\gamma_{z,t}, \tag{42}$$

where

$$m_{t,t+1} = \beta\frac{\hat{c}_t}{\hat{c}_{t+1}}\left(\gamma_{t+1}^{\frac{1}{1-\alpha}}\gamma_{A,t}^{\frac{\theta-1}{1-\alpha}}\right)^{-1},$$

$$\lambda_t = \frac{\lambda_0}{\pi}\hat{\imath}_{a,t}^{\omega},$$

with nine unknowns $\left\{\hat{k}_t, n_{I,t}, \hat{V}_t, a_t, \hat{J}_t, \hat{\imath}_{a,t}, \hat{y}_t, \hat{c}_t, \gamma_{A,t}\right\}$. The growth rates, γ_t and $\gamma_{z,t}$, are exogenous.

C.3 Steady state

Equation (42) implies that the growth rate of A_t becomes equal to the growth rate of Z_t:

$$\gamma_A = \gamma_z.$$

Equation (39) pins down the capital as

$$\hat{k} = \gamma_z^{-\frac{\theta-1}{1-\alpha}} \left\{ \frac{\alpha}{\theta} \left[\frac{\gamma_z^{\frac{\sigma(\theta-1)}{1-\alpha}} \gamma^{\frac{\sigma-1}{1-\alpha}}}{\beta} - \gamma_z^{-(\theta-1)} (1-\delta) \right]^{-1} \right\}^{\frac{1}{1-\alpha}}.$$

From equation (38), the labor in the investment-good sector is given by

$$n_I = \left(\gamma^{\frac{1}{1-\alpha}} \gamma_z^{\frac{\theta-1}{1-\alpha}} - 1 + \delta \right) \hat{k}^{1-\alpha}.$$

From equation (41), the output is given by

$$\hat{y} = [1 + (\theta - 1) n_I] \hat{k}^{\alpha}.$$

Note that the output $\hat{y}$ is independent of π and z_0. From equation (37), the value of an adopted idea is given by

$$\hat{V} = \frac{(\theta-1) \hat{k}^{\alpha} n_I}{1 - \beta \gamma^{\frac{1-\sigma}{1-\alpha}} \gamma_z^{-\frac{(\sigma-\alpha)(\theta-1)}{1-\alpha} - 1}}.$$

With $\lambda = \frac{\lambda_0}{\pi} \hat{\imath}_a^{\omega}$ in mind, equation (35) is written as

$$\hat{J} = \hat{J}(\hat{\imath}_a) = \frac{-\hat{\imath}_a + \beta \gamma^{\frac{1-\sigma}{1-\alpha}} \gamma_z^{-\frac{(\sigma-\alpha)(\theta-1)}{1-\alpha} - 1} \frac{\lambda_0}{\pi} \hat{\imath}_a^{\omega} \hat{V}}{1 - \beta \gamma^{\frac{1-\sigma}{1-\alpha}} \gamma_z^{-\frac{(\sigma-\alpha)(\theta-1)}{1-\alpha} - 1} \left(1 - \frac{\lambda_0}{\pi} \hat{\imath}_a^{\omega}\right)}.$$

Substituting this equation into (36) yields

$$\hat{\imath}_a^{1-\omega} = \frac{\lambda_0 \omega}{\pi} \beta \gamma^{\frac{1-\sigma}{1-\alpha}} \gamma_z^{-\frac{(\sigma-\alpha)(\theta-1)}{1-\alpha} - 1} \left(\hat{V} - \hat{J}(\hat{\imath}_a) \right).$$

The technology adoption investment $\hat{\imath}_a$ is determined by solving this fixed point problem. From equation (34), the ratio of A_t to Z_t is given by

$$a = \frac{1}{\left(\frac{\gamma_z}{1-\delta_A} - 1 \right) \lambda^{-1} + 1}.$$

Thus, the ratio a a function of λ, which in turn is function of the degree of barriers to technology adoption π. Finally, the consumption is given by (40) as

$$\hat{c} = \hat{k}^{\alpha}(1 - n_I) - \left(\frac{1}{a} - 1\right)\hat{\imath}_a.$$

D Solution Method

The function-iteration method of Richter, Throckmorton, and Walker (2011) is adapted to solve the model.

1. Discretize states as $\hat{k}_{t-1} \in \hat{\mathbf{k}} \equiv \left\{\hat{k}^1, ..., \hat{k}^n\right\}$ and $a_{t-1} \in \mathbf{a} \equiv \{a^1, ..., a^m\}$.

2. Guess rules for $\hat{\imath}_{a,t} = \hat{\imath}_a(\hat{k}_{t-1,}a_{t-1})$, $\hat{c}_t = \hat{c}(\hat{k}_{t-1}, a_{t-1})$, $\hat{V}_t = \hat{V}(\hat{k}_{t-1}, a_{t-1})$, and $\hat{J}_t = \hat{J}(\hat{k}_{t-1}, a_{t-1})$ for $(\hat{k}_{t-1}, a_{t-1}) \in \hat{\mathbf{k}} \times \mathbf{a}$. In practice, initial rules are set to those derived from a linearized model.

3. For each state $(\hat{k}_{t-1}, a_{t-1}) \in \hat{\mathbf{k}} \times \mathbf{a}$, the probability of technology adoption is given as $\lambda_t = (\lambda_0/\pi)\, i^{\omega}_{a,t}$. The distance to the frontier a_t is given by (34) as

$$a_t = \frac{a_{t-1} + \lambda_t(1 - a_{t-1})}{\gamma_z}.$$

The growth rate of A_t is given by (42) as

$$\gamma_{A,t} = \frac{a_t}{a_{t-1}}\gamma_z.$$

A fraction of labor used in the investment-good sector $n_{I,t}$ is derived from (40) as

$$n_{I,t} = 1 - \hat{k}^{-\alpha}_{t-1}\left[\hat{c}_t + \left(\frac{1}{a_{t-1}} - 1\right)\hat{\imath}_{a,t}\right].$$

From (38) capital stock $\hat{k}_t$ is given as

$$\hat{k}_t = \frac{(1-\delta)\,\hat{k}_{t-1} + \hat{k}^{\alpha}_{t-1}n_{I,t}}{\gamma_{A,t}^{\frac{\theta-1}{1-\alpha}}}.$$

With a_t and $\hat{k}_t$ in hand, calculate $\hat{c}_{t+1} = \hat{c}(\hat{k}_t, a_t)$, $\hat{V}_{t+1} = \hat{V}(\hat{k}_t, a_t)$, and $\hat{J}_{t+1} = \hat{J}(\hat{k}_t, a_t)$ by using the guessed rules for $\hat{c}_t$, $\hat{V}_t$, and $\hat{J}_t$ respectively. Set $\hat{\imath}_{a,t}$, $\hat{c}_t$, $\hat{V}_t$, and $\hat{J}_t$ so as to satisfy (35), (36), (37), and (39):

$$\hat{J}_t = -\hat{\imath}_{a,t} + \frac{\beta \hat{c}_t}{\hat{c}_{t+1}} \gamma_c^{1-\sigma} \gamma_{A,t}^{\frac{(\alpha-\sigma)(\theta-1)}{1-\alpha}-1} \left[\lambda_t \hat{V}_{t+1} + (1-\lambda_t) \hat{J}_{t+1} \right],$$

$$1 = \frac{\lambda_0 \omega}{\pi} \hat{\imath}_{a,t}^{\omega-1} \frac{\beta \hat{c}_t}{\hat{c}_{t+1}} \gamma_c^{1-\sigma} \gamma_{A,t}^{\frac{(\alpha-\sigma)(\theta-1)}{1-\alpha}-1} \left(\hat{V}_{t+1} - \hat{J}_{t+1} \right),$$

$$\hat{V}_t = (\theta-1) \hat{k}_{t-1}^{\alpha} n_{I,t} + \frac{\beta \hat{c}_t}{\hat{c}_{t+1}} \gamma_c^{1-\sigma} \gamma_{A,t}^{\frac{(\alpha-\sigma)(\theta-1)}{1-\alpha}-1} \hat{V}_{t+1}$$

$$1 = \frac{\beta \hat{c}_t}{\hat{c}_{t+1}} \left(\gamma_c \gamma_{A,t}^{\frac{\theta-1}{1-\alpha}} \right)^{-\sigma} \gamma_c \left[\frac{\alpha}{\theta} \left(\hat{k}_t \gamma_{A,t}^{\frac{\theta-1}{1-\alpha}} \right)^{\alpha-1} + \gamma_{A,t}^{-(\theta-1)} (1-\delta) \right].$$

4. With new rules for $\hat{\imath}_{a,t}$, $\hat{c}_t$, $\hat{V}_t$, and $\hat{J}_t$ in hand, if a distance between the old rules and the new rules is small enough, stop. Else, go back to step 3 with the new rules.

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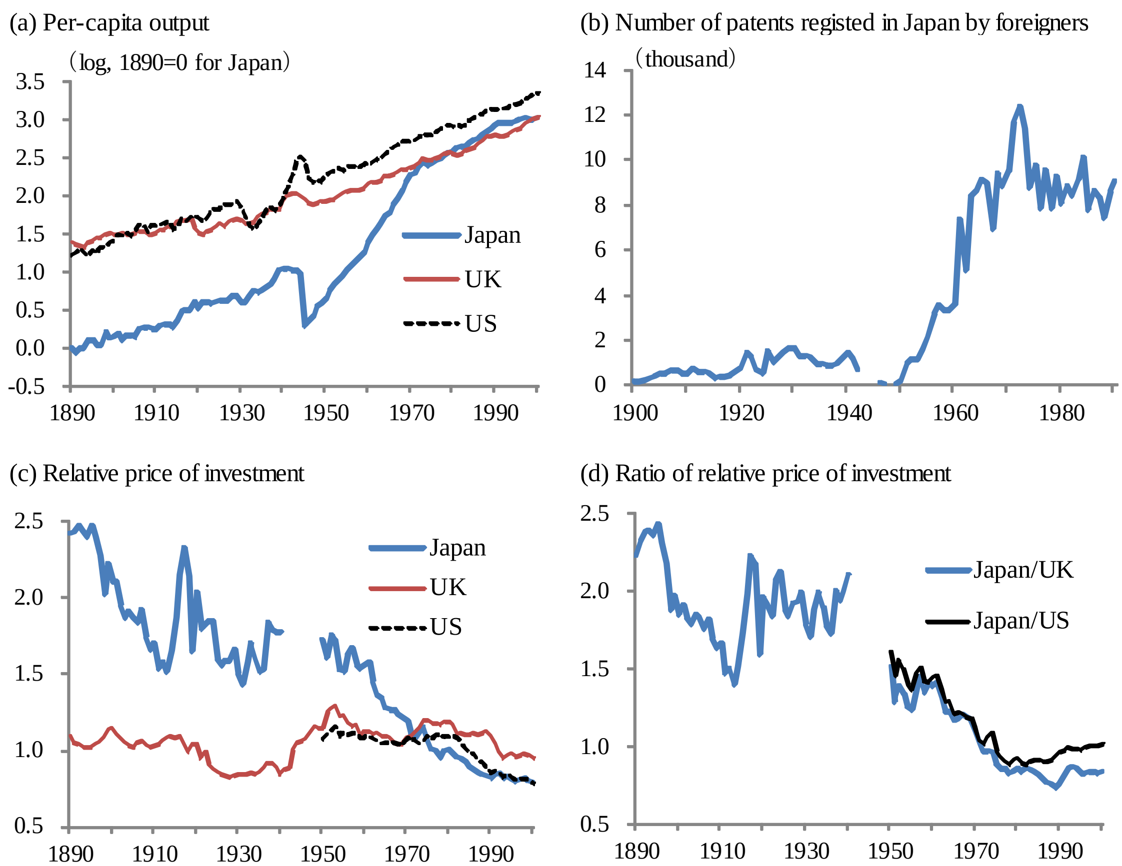
Table 1: Parameterization of the model.

Parameter	Description	Value
β	Subjective discount factor	0.97
α	Capital share	0.36 or 0.5
δ	Capital depreciation rate	0.089
θ	Gross markup	1.2
γ	Gross growth rate of neutral technology	1.0061
γ_z	Gross growth rate of the frontier of ideas	1.0463
λ	Adoption probability in the steady state in Japan after the war	0.125
ω	Elasticity of technology adoption	0.6

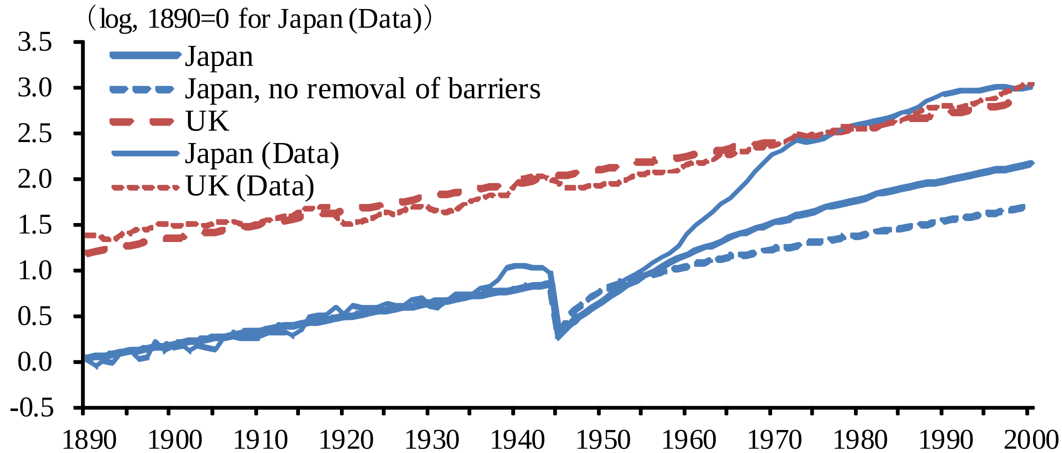
Figure 1: Japan's economic development since 1890



Notes: The data sources are Professor Angus Maddison's Database for Panel (a) and Japan Patent Office for Panel (b). For Panel (c) and (d), see Appendix A.

Figure 2: Simulation in the case of $\alpha = 0.36$

(a) Per-capita output



(b) Ratio of the relative price of investment: Japan/UK

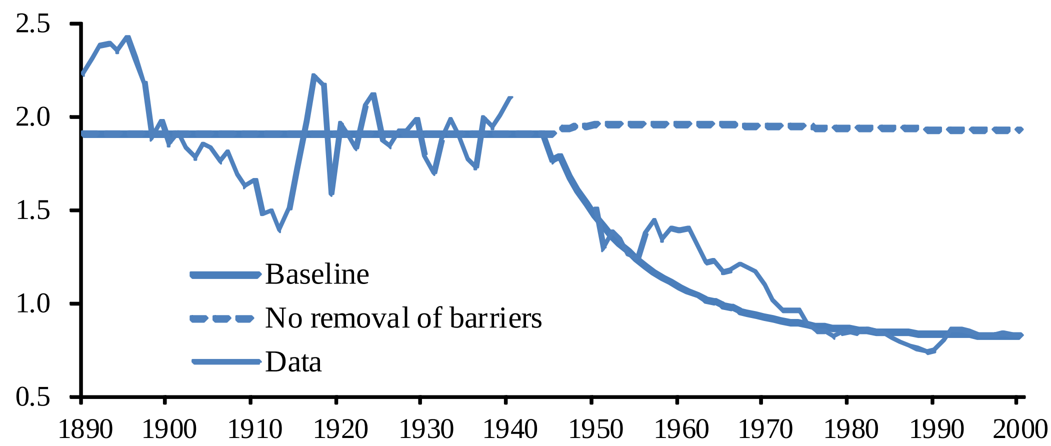
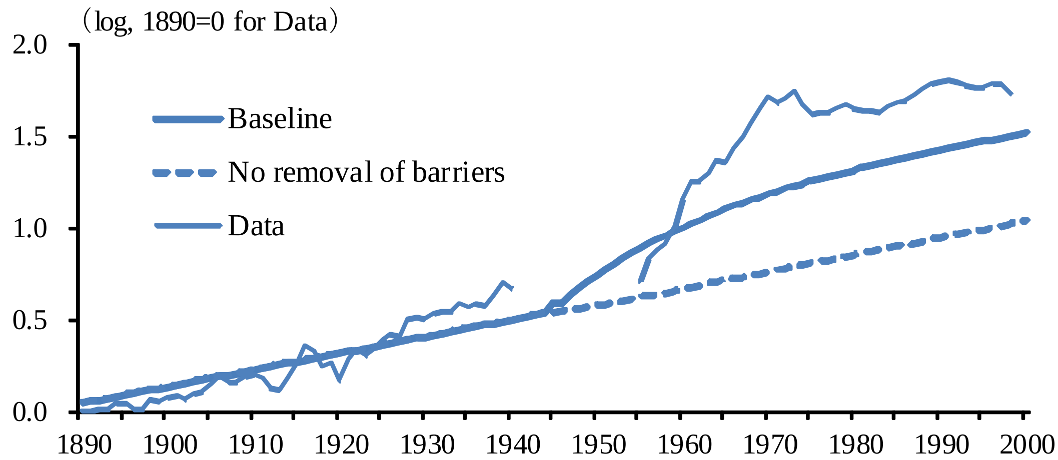


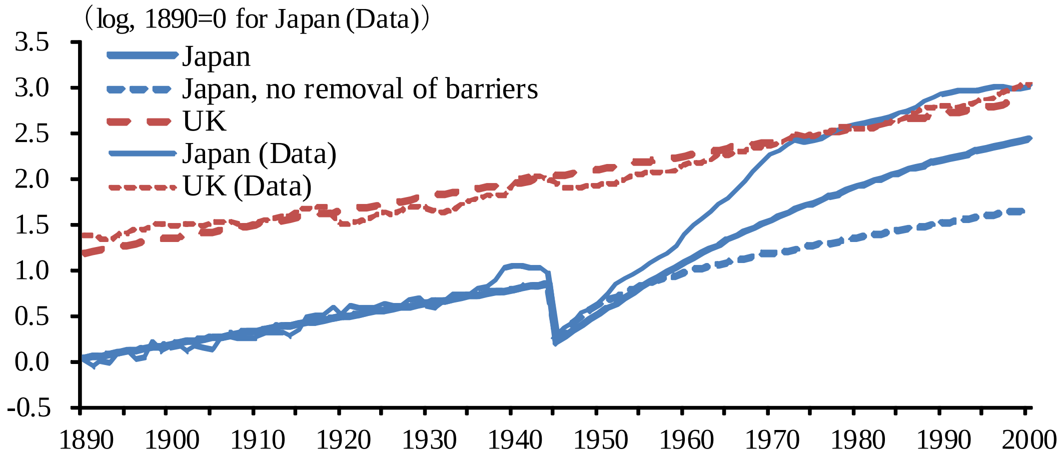
Figure 3: Measured TFP



Notes: The measured TFP is that of non-primary sectors. For the calculation and the data source, see Appendix A.

Figure 4: Simulation in the case of $\alpha = 0.5$

(a) Per-capita output



(b) Ratio of the relative price of investment: Japan/UK

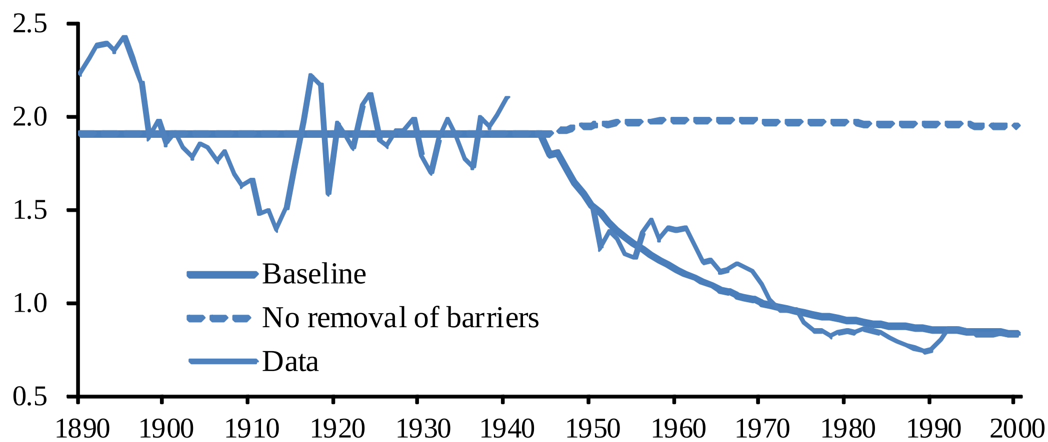


Figure 5: Simulation in the case of the removal of the barriers in 1950

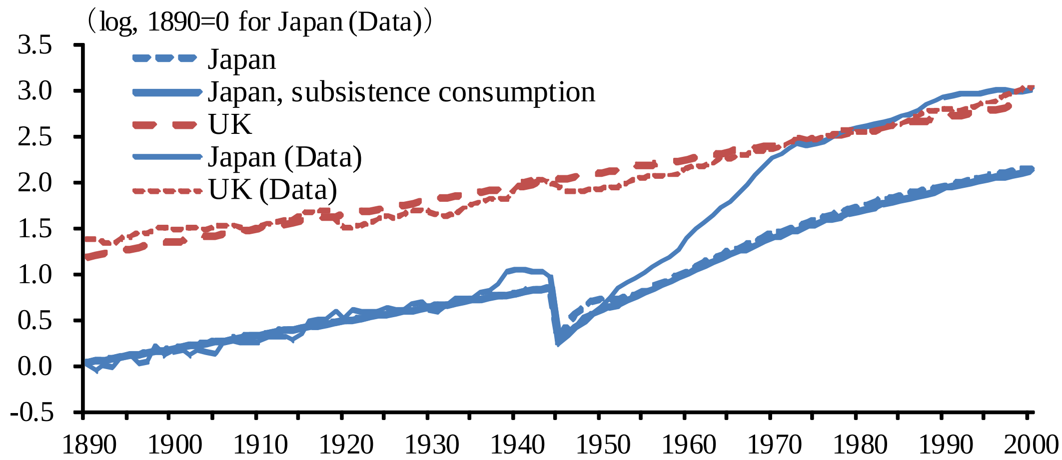
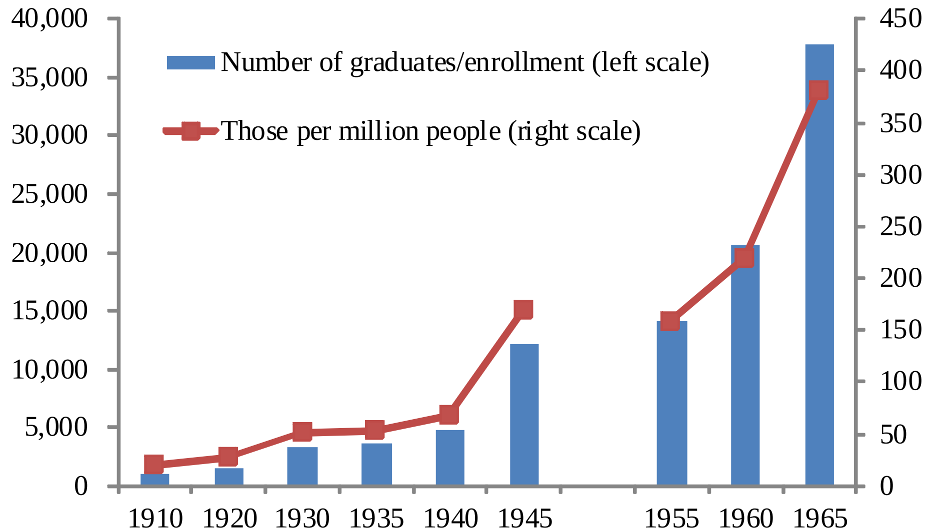


Figure 6: The number of university graduates/enrollment with engineering majors



Notes: The figures up to 1945 are the sum of graduates with enginerring majors from universities and those from engineering high schools. Studens of universities and high schools under the old system of equcation until 1947 roughly correspond to studends in the 3rd year or more and those in the 1st and 2nd years of universities under the current system of education respectively. The figures from 1955 correspond to university enrollment with engineering majors. The data sources are Sawai (2012a), p.172, Figure 10-2 for the number of graduates up to 1945, Statistics Bureau, Ministry of Internal Affairs and Communications (2007) for population, and School Basic Survey, Ministry of Education, Culture, Sports, Science and Technology for the number of enrollment after 1945.