A Model of Technology Transfer in Japan's Rapid Economic Growth Period

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Abstract

Why did the Japanese economy stagnate before World War II, how did it achieve rapid economic growth after the war, and why did it stagnate again after the 1970s? To answer these questions, I developed a two-country trade model with technology transfer, where firms in the two countries compete in a Bertrand fashion, where firms in a developed country (the U.S.) transfer technology to firms in a developing country (Japan) if it is profitable to do so, and where the technology transfer is the engine of economic growth. In this model, among multiple equilibria, the equilibrium with low labor cost in Japan was chosen during the rapid growth period. As a result, the firms in the developed country transferred technology to the firms in the developing country, resulting in rapid growth. However, during the other periods, the equilibrium with high labor cost in Japan was chosen, which caused stagnation. The model is quantitatively consistent with the per capita GDP relative to the U.S., the purchasing power parity-exchange rate ratio, and to some degree, the swings in labor share of postwar Japan.

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1 Introduction

The Japanese economy experienced rapid economic growth between the end of the World War II and the early 1970s. During this period, real per capita GDP grew at a rate of over 10% (see Figure 1). The following questions arise from this fact: Why did the Japanese economy stagnate before World War II, how did it achieve rapid economic growth after the war, and why did it stagnate again after the 1970s?

One possible and leading explanation is technology adoption (Peck and Tamura, 1976; Goto, 1993): rapid growth occurred because the Japanese firms imported and adopted superior foreign technologies in the postwar period, led to the increase in productivity and output.

However, this explanation raises further questions: For example, if technology adoption was the reason for rapid growth after the war, why did not Japan adopt more technologies and achieve rapid growth before the war? If prewar Japan had achieved rapid growth by technology adoption, the rewards would have been tremendous. Therefore, to analyze the more fundamental reasons for the rapid growth, we have to consider why economic agents did not adopt better technologies; that is, we have to consider the incentives of agents.

Parente and Prescott (2000) propose such a model. In their model, prewar Japan could not adopt technologies because vested interests prevented such adoption. Postwar Japan could adopt technologies because then these vested interests disappeared. However, again after the 1970s, Japan could not adopt technologies well because the vested interests partially reemerged.

Parente and Prescott (2000) assume that without the vested interests, Japanese firms could freely adopt better foreign technologies. In their model, constraints are on the agents' incentives in Japan. However, better technologies are not available if the firms in developed countries (which I refer to as U.S. firms) keep their technologies (or know-how) secret or restrict the use of their technologies. Therefore, constraints can also be on the agents' incentives in the U.S.

On the basis of this observation, this paper develops a two-country (the U.S. and Japan) trade model in which constraints are on the incentives of agents in the U.S.: i.e., technology transfer occurs only if a U.S. firm allows the transfer (license) of its technology to a Japanese firm.

In the model, firms in the two countries compete in a Bertrand fashion. A licenser U.S. firm benefits from licensing technology by obtaining a licensing fee. However, when the licenser U.S. firm licenses and transfers technology, the licensee (a Japanese firm) becomes a competitor and decreases the U.S. firm's profit. In the model, only if the benefit (licensing fee) outweighs the cost (profit loss), does the U.S. firm licenses the technology.

In this model, two kinds of equilibria exist. In one equilibrium, the labor cost of Japan relative to that of the U.S. is low. Because the profit of Japanese firms and, as a result, the licensing fee are high, licensing occurs (so does technology transfer). In another equilibrium, the relative labor cost of Japan is high. Because the profit of Japanese firms and licensing fee are low, licensing does not occur (neither does technology transfer).

The intuition of multiple equilibria is as follows. Suppose that Japan's wage and labor cost are low and the U.S. wage and labor cost are high. Then, for the Japanese firms, the prices they face are high because the competitor's labor cost, i.e., the labor cost in the U.S., is high. Because of the high price, the Japanese firms can sell a small volume of goods at a high profit, and hence, not many workers are needed for producing the goods. As a result, Japan can produce a broad range of goods and thus, comparatively less advantageous goods. Because the relative wage rate of the countries is determined by the relative productivity of the comparatively least advantageous goods in each country, Japan's wage rate becomes low. Thus, the equilibrium in which Japan's wage and labor cost are low exists. Conversely, there exists another equilibrium in which Japan's wage and labor cost are high.

Using this model, I interpret Japan's rapid growth in the following way. In the prewar period, the economy was in an equilibrium where Japan's relative labor cost was high. After the war, the economy *unexpectedly* shifted to another equilibrium where Japan's relative labor cost was low, possibly owing to the undervaluation of the yen under the Breton-Woods system. After the 1970s, the rapid growth stopped because the economy *unexpectedly* shifted back to the equilibrium where Japan's relative labor cost was high, possibly owing to the end of the Breton-Woods system.

Further, I investigate the quantitative performance of this model. I find that the model is quantitatively consistent with the per capita GDP of Japan relative to the U.S., the purchasing power parity-exchange rate ratio between Japan and the U.S., and postwar Japan's labor share.

Several papers argue that the undervaluation of the currency, low labor cost, and technology transfer are associated with economic development. First, Rodrik (2008) empirically shows that the undervaluation of the currency stimulates economic growth. Rajan (2010) argues that Japan achieved export-led growth by the undervalued currency. Second, Ohkawa and Rosovsky (1973) argue that low labor cost is one of the reasons for Japan's rapid growth. Yoshikawa (1994) points out that Japan's labor share increased considerably after the rapid growth period. Finally, as mentioned above, Peck and Tamura (1976) and Goto (1993) argue that technology adoption was the reason for Japan's rapid growth. This paper shows that undervaluation of the currency, low labor cost, and technology transfer are closely connected phenomena that contributed to the rapid growth in Japan.

In this paper, technology transfer is performed through licensing. Yang and Maskus (2001), Tanaka et al. (2007), and Ghosh and Saha (2008), among others, have developed models of economic growth with licensing. This paper's model is based on the framework laid in these papers.

Recently, the Japanese economy was quantitatively analyzed using neoclassical growth models. The literature shows the rapid increase in total factor productivity (TFP) can account for salient features of the rapid growth (Parente and Prescott, 1994; Chen et al., 2006; Otsu, 2009; Esteban-Pretel and Yasuyuki, 2009; among others). If TFP was the reason for the rapid growth, then Why did Japan's TFP stagnate before World War II, how did it rapidly increase after the war, and why did it stagnate again after the 1970s? Hayashi and Prescott (2008) develop a quantitative neoclassical growth model to explain the prewar stagnation and the postwar growth. However, as noted in their paper, their model does not explain why Japan's manufacturing TFP rapidly increased after World War II. This paper presents a hypothesis for these questions by developing a quantitative model.

The rest of the paper is organized as follows. Section 2 reviews some facts supporting the hypothesis that during the rapid growth period, the yen was undervalued because of low labor cost in Japan. Motivated by these facts, Section 3 introduces the basic version of the model and explains the basic intuition of the model. Section 4 extends the basic model so that it is comparable with the data. Using the extended model, Section 5 conducts a quantitative exercise and compares the simulated results of the model with the data. Section 6 concludes the paper.

2 The Undervaluation of the Yen

Rodrik (2008; 2010) argues that the undervaluation of a currency is important for growth, even if the Balassa-Samuelson (hereafter BS) effect is taken into account. Here, on the basis of facts, I argue that this claim also applies to Japan's rapid growth and that the yen was undervalued because of low labor cost in Japan.

2.1 The purchasing power parity-exchange rate ratio

Figure 2 plots the ratio of the purchasing power parity (PPP) and exchange rate (hereafter PPP/e) between Japan and the U.S. It shows that during the rapid growth period, the exchange rate of the yen was undervalued as compared with PPP. Specifically, during the rapid growth till the 1960s, the exchange rate was 1\$ = 360¥ whereas PPP was around 1\$ = 150¥. However, because non-tradable goods in developing countries are cheaper, the currency of a developing country is undervalued. This is known as the BS hypothesis or BS effect. According to the BS hypothesis, the undervaluation is a natural phenomenon. In what follows, I argue that even if we subtract the BS effect, the yen was undervalued. Before doing this, I review the BS hypothesis.

2.2 The BS hypothesis

The BS hypothesis assumes that there are competitive tradable and non-tradable goods sectors in each of two countries, the U.S. and Japan. The productivity level of non-tradable goods (e.g., hair cutting and taxi services) is the same across countries whereas that of tradable goods is higher in the U.S. than in Japan. In addition, I assume that the production technology is the constant-returns-to-scale and that labor is the only production input. Labor is mobile across sectors in the same country but is immobile across countries.

Under the assumptions, because one worker in the U.S. can produce more tradables than one worker in Japan the wage rate in the U.S. should be higher than that in Japan so that the unit cost and thus, price of tradables equate across the countries. Then, because one worker in each country produces the same amount of non-tradables and the labor cost in the U.S. is higher, the price of the non-tradables in the U.S. should be higher.

Suppose that PPP is constructed as the ratio of the geometric average of tradables and non-tradables in each country and the exchange rate as the ratio of tradables. Let p_T^C, p_N^C, w^C, and A_T^C be the prices of tradables and non-tradables, the wage rate, and the productivity level of tradables in country C, respectively. Then, under these assumptions, the PPP/e between Japan and the U.S. becomes as follows:[1]

$$\text{PPP}/e = \left(\frac{p_T^J}{p_T^U}\right)^{\eta}\left(\frac{p_N^J}{p_N^U}\right)^{1-\eta} \Big/ \left(\frac{p_T^J}{p_T^U}\right) = \left(\frac{w^J}{w^U}\right)^{1-\eta} = \left(\frac{A_T^J}{A_T^U}\right)^{1-\eta} < 1, \qquad (1)$$

where the superscripts U and J refer to the U.S. and Japan and η is the share of tradables. I here assume that η is the same for both countries. The equation shows that PPP/e becomes less than 1. According to the hypothesis, the undervaluation of the yen is a natural phenomenon.

2.3 The undervaluation of the yen

Using the framework, I argue that even after taking the BS effect into account, the yen was undervalued. To show this, I rewrite the above equation in the growth form as follows:

$$\widehat{\text{PPP}/e} = (1-\eta)(\hat{A}_T^J - \hat{A}_T^U),$$

where I express the growth rate by $\hat{}$. According to the equation, the growth rate of PPP/e is higher when the growth rate of Japanese productivity is high

[1] The equation is obtained because $p_T^U = p_T^J$ and $p_N^C = w^C/A_N$, where A_N is the productivity level of non-tradables and is the same across the countries.

and thus, under standard settings, the growth rate of the Japanese per capita income is higher. Did this relation hold in the postwar Japanese data?

Figure 3 plots the natural logarithm of PPP/e. The slope is the growth rate of PPP/e, $\widehat{\text{PPP}/e}$. The slope becomes steeper just after the rapid growth, where the productivity convergence ends (see the solid black lines in the figure). The increase in PPP/e just after the rapid growth cannot be explained by the BS hypothesis at least in the simple form. This means that compared with today's PPP/e, the yen was undervalued during the rapid growth period, even after taking into account the BS effect.

2.4 One possible explanation: low labor cost

What was the reason for the increase in PPP/e just after the rapid growth? Here, I argue that the answer is low labor cost in Japan during the rapid growth period. By rewriting (1), the following relation also holds:

$$\widehat{\text{PPP}/e} = (1-\eta)(\hat{w^J} - \hat{w^U}).$$

One interpretation of Figure 3 is that just after the rapid growth, w^J rapidly increased but A_T^J (and per capita income y^J under standard settings) did not. If so, the labor income share $w^J/y^J = w^J L^J/Y^J$ would increase.

Figure 4 plots the labor shares of postwar Japan. The labor income shares increased just after the rapid growth period ended, which supports the interpretation that PPP/e was low during the rapid growth period because of the low labor cost in Japan.

I argue that the rapid growth was associated with low labor cost. If so, the prewar labor share should also be higher. To check this claim, Table 1 lists the prewar (1932) and postwar (1957) labor share of manufacturing. The table shows that the former is actually higher than the latter.

In summary, the facts suggest that the rapid growth was associated with low labor cost. In what follows, I develop a model that is consistent with this finding.

3 The Basic Model

In this section, on the basis of the finding in the previous section, I develop a simple model in which technology transfer and rapid growth are associated with low labor cost. In the next section, I extend the basic model and conduct quantitative analysis.

3.1 Environment

Here, I develop a Bertrand competition version of the Dornbusch et al. (1977) model. The model has two countries (the U.S. U and Japan J) that trade goods. There is a Cobb-Douglas aggregate production function, which consists of a continuum of tradable goods between $[0, 1]$:

$$X = X^U + X^J = \exp\left\{\int_0^1 \ln x_i di\right\}.$$

The households in each country receive a utility by consuming the aggregate tradable goods X^C ($C \in \{U, J\}$)). I normalize the price of X to be 1.

There is a Japanese and U.S. firm in each disaggregated goods sector producing x_i. They compete in a Bertrand fashion. There is only one production factor in the economy: labor. Labor is mobile across sectors in the same country but is immobile across the two countries. I assume that in the basic model of this section, labor supply L_x^C is exogenous.

3.2 Production technology

The firm's production function is as follows:

$$x_i^C = A_i^C \ell_i^C, \quad C \in \{U, J\},$$

where A_i^C and ℓ_i^C are the productivity and labor input of the firm in country C. All the U.S. firms have A^U technology, i.e., $A_i^U = A^U$ (here, I slightly abuse notations). The Japanese firms in $[0, \alpha]$ have $A^J (< A^U)$, whereas the remaining firms (firms in $(\alpha, 1]$) have A^U. I do not consider technology transfer for a while and let the technology cutoff α be given.

3.3 Construction of equilibria

In this model, firms in comparatively advantageous sectors produce goods. Thus, U.S. firms tend to produce in a sector in which $A_i^U/A_i^J = A^U/A^J$, and Japanese firms tend to produce in a sector in which $A_i^U/A_i^J = 1$ (see Figure 5).

There are multiple equilibria in this model. Let θ be the production cutoff, which is endogenous in the model, where the goods in $[0, \theta]$ are produced by the U.S. firms and the goods in $(\theta, 1]$ are produced by the Japanese firms. Then, in an equilibrium (referred to as Equilibrium 1), where θ is less than α, some goods (goods in $(\theta, \alpha]$) for which the Japanese firms have inferior technology A^J are produced by the Japanese firms. In another equilibrium (referred to as Equilibrium 2), where θ is more than α, some goods (goods in $(\alpha, \theta]$) for which the Japanese firms have advanced technology A^U are produced by the U.S. firms. In what follows, I show that these two equilibria exist.

3.3.1 Equilibrium 1 ($\theta < \alpha$)

Here, I construct Equilibrium 1 where $\theta < \alpha$. In Equilibrium 1, goods in $[0, \theta]$ are produced by the U.S. firms, goods in $(\theta, \alpha]$ are produced by the Japanese firms with A^J technology, and goods in $(\alpha, 1]$ are produced by the Japanese firms with A^U technology.

Due to the Bertrand competition, the U.S. firms set their price at $p_i^U = w^J/A^J$. Their unit cost is $\mathsf{uc}_i^U = w^U/A^U$. On the other hand, the Japanese firms in $(\theta, \alpha]$ set their price at $p_1^J = w^U/A^U$. (I denote the Japanese firm in $(\theta, \alpha]$ by ${}_1^J$ and the Japanese firm in $(\alpha, 1]$ by ${}_2^J$.) Their unit cost is $\mathsf{uc}_1^J = w^J/A^J$. Because $p_i^C \geq \mathsf{uc}_i^C$ holds,

$$\frac{w^U}{w^J} = \frac{A^U}{A^J}.$$

Using the above relation, I obtain θ in the equilibrium. Since the production function of the aggregated goods X is Cobb-Douglas, the following relation holds:

$$p_i^U x_i^U = \frac{w^J}{A^J} A^U \ell_i^U = X.$$

By arranging this,

$$\ell_i^U = \frac{1}{w^J} \frac{A^J}{A^U} X.$$

Using the property and the labor market clearing condition,

$$L_x^U = \int_0^\theta \ell_i^U \, di = \theta \frac{1}{w^J} \frac{A^J}{A^U} X. \tag{2}$$

Next, I obtain a property similar to (2) for Japan. Rearranging the Cobb-

Douglas property,

$$p_1^J x_1^J = \frac{w^U}{A^U} A^J \ell_1^J = X, \;\; p_2^J x_2^J = \frac{w^U}{A^U} A^U \ell_2^J = X,$$

I obtain the following relations:

$$\ell_1^J = \frac{1}{w^U} \frac{A^U}{A^J} X, \;\; \ell_2^J = \frac{1}{w^U} X.$$

Using these properties and the labor market clearing condition,

$$L_x^J = \int_\theta^1 \ell_i^J di = (\alpha - \theta) \frac{1}{w^U} \frac{A^U}{A^J} X + (1 - \alpha) \frac{1}{w^U} X. \tag{3}$$

Using (2) and (3), I finally obtain θ in Equilibrium 1:

$$\theta = \frac{\frac{L_x^U}{L_x^J}}{1 + \frac{A^U}{A^J} \frac{L_x^U}{L_x^J}} \left[\left(\frac{A^U}{A^J} - 1 \right) \alpha + 1 \right]. \tag{4}$$

Using (4), I verify under what condition the assumption of Equilibrium 1, i.e., $\theta < \alpha$, is true. Figure 6 plots (4). Figure 6 shows that if

$$\alpha \geq \frac{1}{1 + \frac{L_x^J}{L_x^U}}, \tag{5}$$

θ is less than α; i.e., Equilibrium 1 exists.

3.3.2 Equilibrium 2 ($\theta > \alpha$)

Here, I construct Equilibrium 2 where $\theta > \alpha$. In Equilibrium 2, goods in $[0, \alpha]$ and $(\alpha, \theta]$ are produced by the U.S. firms, and goods in $(\theta, 1]$ are produced by the Japanese firms with A^U technology. Note that for the goods in $(\alpha, \theta]$, the U.S. firms compete with the Japanese firms that have the same level of advanced technologies.

Due to the Bertrand competition, the U.S. firms in $(\alpha, \theta]$ set their price at $p_2^U = w^J/A^U$. (I denote the U.S. firm in $[0, \alpha]$ by ${}_1^U$ and the U.S. firm in $(\alpha, \theta]$ by ${}_2^U$.) Their unit cost is $\mathsf{uc}_2^U = w^U/A^U$. The Japanese firms set their price at $p_i^J = w^U/A^U$. Their unit cost is $\mathsf{uc}_i^J = w^J/A^U$. Because $p_i^C \geq \mathsf{uc}_i^C$,

$$w \equiv w^U = w^J.$$

Using the above relation, as in Equilibrium 1, I obtain θ in this equilibrium. Rearranging the Cobb-Douglas property,

$$p_1^U x_1^U = \frac{w}{A^J} A^U \ell_1^U = X, \;\; p_2^U x_2^U = \frac{w}{A^U} A^U \ell_2^U = X,$$

I obtain the following relations:

$$\ell_1^U = \frac{1}{w}\frac{A^J}{A^U} X, \;\; \Longrightarrow \ell_2^U = \frac{1}{w} X.$$

Using these properties and the labor market clearing condition,

$$L_x^U = \int_0^\theta \ell_i^U di = \alpha \frac{1}{w}\frac{A^J}{A^U} X + (\theta - \alpha)\frac{1}{w} X. \tag{6}$$

Next, I obtain a property similar to (2) for Japan. Rearranging the Cobb-Douglas property,

$$p_i^J x_i^J = \frac{w}{A^U} A^U \ell_i^J = X,$$

I obtain the following relation:

$$\ell_i^J = \frac{1}{w} X.$$

Using the property and the labor market clearing condition:

$$L_x^J = \int_\theta^1 \ell_i^J di = (1-\theta)\frac{1}{w}X. \tag{7}$$

Using (6) and (7), I finally obtain θ in Equilibrium 2:

$$\theta = \frac{1}{1+\frac{L_x^U}{L_x^J}}\left[\left(1-\frac{A^J}{A^U}\right)\alpha + \frac{L_x^U}{L_x^J}\right]. \tag{8}$$

Using (8), I verify under what condition the assumption of Equilibrium 2, i.e., $\theta > \alpha$, is true. Figure 7 plots (8). Figure 7 shows that if

$$\alpha \leq \frac{1}{1+\frac{A^J}{A^U}\frac{L_x^J}{L_x^U}}, \tag{9}$$

θ is more than α; i.e., Equilibrium 2 exists.

3.4 Existence of multiple equilibria

(5) and (9) indicate that multiple equilibria exist if

$$\underbrace{\frac{1}{1+\frac{L_x^J}{L_x^U}}}_{\text{Lower bound of Eq. 1}} \leq \alpha \leq \underbrace{\frac{1}{1+\frac{A^J}{A^U}\frac{L_x^J}{L_x^U}}}_{\text{Upper bound of Eq. 2}}.$$

When α is more than the upper bound of the above equation, only Equilibrium 1 exists. On the other hand, when α is less than the lower bound, only Equilibrium 2 exists. I only consider the situation where multiple equilibria exist; i.e., α is located between the bounds.

The intuition of why multiple equilibria exist is as follows. In Equilibrium 1, when w^U/w^J is high, due to the Bertrand assumption, the price that the Japanese (U.S.) firms face is low (high). Then, due to the Cobb-Douglas assumption, the Japanese firms can sell a small volume of goods at a high profit, whereas the U.S. firms have to sell a large volume of goods at zero profit. This means that unlike the U.S. firms, the Japanese firms do not require many workers to produce goods As a result, because the labor supply is fixed in each country, the Japanese firms can produce the comparatively less advantageous goods (i.e., $(\theta, 1]$ is large), whereas the U.S. firms can produce only the comparatively most advantageous goods (i.e., $[0, \theta]$ is small). Then, because the wage ratio is determined by the relative productivity of the marginal goods (which are the comparatively least advantageous goods in each country), w^U/w^J is high. Opposite effects yield in Equilibrium 2.

3.5 Technology transfer

I introduce technology transfer to the model. I make the following assumptions (they are similar to Ghosh and Saha, 2008). First, a U.S. firm can transfer its technology to a Japanese firm in the same sector. Second, the U.S. firm agrees to transfer the technology if the profit it can obtain after the technology transfer, including the licensing fees obtained from the licensee Japanese firm, is larger than the profit it now obtains. The licensing fees are a part of the licensee's profit. Third, after the technology transfer, the technology level of the Japanese firm equals that of the U.S. firm, i.e., $A_i^J = A^U$.

When $A_i^J = A^U$, the profit of the U.S. firm that competes with the Japanese firm is zero in both equilibria. Then, the condition that a U.S. firm transfers technology can be written as follows:

$$\mu\pi_i^J > \pi_i^U, \text{ or } \left(1 - \frac{c_i^J}{p_i^J}\right) p_i^J x_i^J > \left(1 - \frac{c_i^U}{p_i^U}\right) p_i^U x_i^U,$$

where $\mu\pi_i^J$ is a fraction of profit at each period that the licenser can obtain as licensing fees after technology transfer, and π_i^U is the profit the licenser obtains before technology transfer.

In Equilibrium 1, $\pi_i^J > \pi_i^U = 0$, and in Equilibrium 2, $\pi_i^U > \pi_i^J = 0$. Thus, in Equilibrium 1, a U.S. firm has an incentive to transfer technology, and in Equilibrium 2, a U.S. firm does not have an incentive to do so.

I further assume that in Equilibrium 1, where the transfer condition is satisfied, in each period, a certain number of Japanese firms from the highest i adopt new technologies; i.e., in each period, α decreases by a certain amount. Here, I assume that the lower bound of α exists and is $1/(1 + L_x^J/L_x^U)$, which is the lower bound of Equilibrium 1. Then, until α hits the lower bound, since θ also decreases, the Japanese income increases.

Since the transfer condition above is a static one, one might think that under a dynamic setting the transfer condition would change. However, I assume that the agents in the economy expect the equilibrium in which the economy is in now to continue forever. Then, the transfer condition under a dynamic setting coincides with the static one above.

3.6 The model's interpretation of the rapid growth

Using the model, I interpret Japan's rapid growth as follows. Prewar Japan was in Equilibrium 2. With no technology transfer, the Japanese economy stagnated. After World War II, the equilibrium *unexpectedly* switched to Equilibrium 1, technologies were transferred to Japan, and the Japanese income, which is proportional to $(\theta, 1]$, increased. After the 1970s, before the per capita GDP of Japan fully converged to that of the U.S., the equilibrium again *unexpectedly* switched to Equilibrium 2. Consequently, technology transfer stopped, and the Japanese economy stagnated again. Further, the yen-dollar rate appreciated for w^U/w^J to decrease.

This model with the above interpretation is qualitatively consistent with the finding of Imbs and Wacziarg (2003). They find that as countries develop, their economies become less specialized and more diversified (i.e., they produce a broader range of goods), but after a certain point of development, they begin to specialize (they produce a narrower range of goods). In my model, in the prewar period, $(\theta, 1]$ is narrow; i.e., the Japanese firms produce only a narrow range of goods. However, after World War II, when the economy switched to Equilibrium 1, due to technology transfer, $(\theta, 1]$ becomes broader; i.e., the Japanese firms produce a broader range of goods. After the 1970s, the economy again switched to Equilibrium 2 and $(\theta, 1]$ decreases; i.e., the Japanese firms produce a narrower range of goods than when the economy is in Equilibrium 1 with the same α (for this, see the location of $\theta_{Eq.1}$ and $\theta_{Eq.2}$ in Figure 5).

4 The Extended Model

In this section, I extend the basic model in the previous section so that it is comparable with the data. I introduce (1) non-tradable goods, (2) multiple inputs for tradable goods, (3) competition within domestic firms, (4) the assumption that the U.S. licenser firm commits to stop production after technology transfer, and (5) the externality of technology transfer. In what follows, I explain these features in greater detail.

4.1 Non-tradable goods

In the basic model, non-tradable goods do not exist. However, in order to argue the BS effect and compare the model's PPP/e to that of the data, non-tradable goods are required. I therefore introduce non-tradable goods.

I introduce the following risk-neutral preference as the utilities of households in each country:[2]

$$u^C(c_{Nt}^C, c_{Tt}^C) = \begin{cases} c_{Nt}^C & \text{if } c_{Nt}^C < \bar{c_N} \\ c_{Tt}^C + \bar{c_N} & \text{otherwise,} \end{cases}$$

where c_{Nt}^C and c_{Tt}^C are non-tradable and tradable consumption at date t. This specification is similar to Eswaran and Kotwal (1993) and Gollin et al. (2007) (however, note that in their models, c_N corresponds to agricultural goods). In what follows, I drop the time subscript t for brevity.

The production function of non-tradable goods is:

$$L^C c_N^C = L_N^C,$$

where L^C is the population and $L^C c_N^C$ is the total demand for non-tradables in each country. I assume $\bar{c_N} = 1 - \eta$ $(0 < \eta < 1)$. Then,

$$L^C c_N^C = L_N^C = (1-\eta)L^C. \tag{10}$$

4.2 Tradable goods

In the basic model, there is no capital. However, to explain changes in the labor income share, it is necessary to introduce capital-like inputs. Here, I introduce the intermediate inputs and use them in the simulation as a kind of capital input, as in Parente and Prescott (1999).

I modify the production function of tradable goods in the basic model as follows:

$$\hat{x}_i^C = A_i^C \tilde{x}_i^{C\rho} \ell_i^{C^{1-\rho}}, \quad \hat{x}_i^C \equiv x_i^C + \tilde{x}_i^C. \tag{11}$$

[2]By assuming the risk-neutral preference, I abstract from international borrowings and lendings.

Thus, each tradable good is produced from labor and this tradable good.

By solving the cost-minimization of a firm, the production function can be rewritten as follows:

$$x_i^C = \tilde{A}_i^C \ell_i^C, \tag{12}$$

where $\tilde{A}_i^C \equiv (\delta A_i^C)^{1/(1-\rho)}$ and $\delta \equiv \rho^\rho (1-\rho)^{1-\rho}$.

As in the basic model, I assume the following tradable production function

$$X = \exp\left\{\int_0^1 \ln x_i di\right\}. \tag{13}$$

The market condition of labor inputs for tradable goods is as follows:

$$L_x^C = \int_0^1 \ell_i^C di. \tag{14}$$

As in the basic model, I normalize the price of X to be 1.

4.3 Competition between domestic firms

In the basic model, competition exists only between firms in different countries. However, some might argue that in many cases, firms compete with those in the same country. For example, General Motors competes with Ford.

To accommodate this, I introduce a competitor in the same country. In addition to the U.S. and Japanese firms in the basic model (referred to as U.S. and Japanese leader firms), there is also a U.S. follower firm and a Japanese follower firm. The follower firms have inferior technology. Specifically, the U.S. follower firm has $\sigma\tilde{A}^U$ technology, and the Japanese follower firm has $\sigma\tilde{A}^J$ technology. I assume that only the U.S. leader firms can transfer technology.

4.4 Licenser's commitment after transfer

In the basic model, even after transferring its technology, the U.S. licenser firm sets the competitive Bertrand price as $w^u/\tilde{A}^U$. However, it is more profitable for the licenser firm to commit not to produce, because when the licenser firm does not produce, the Japanese licensee firm can obtain higher profits, which results in higher licensing fees.

To capture this, I assume that for the sector $i > \alpha$, the U.S. leader (licenser) firm stops producing. Then, the best technology of the U.S. firms in $(\alpha, 1]$ is $\sigma\tilde{A}^U$.

4.5 Externality of technology transfer

In the basic model, I assume that after technology transfer, the Japanese firm instantaneously acquires A^U technology. However, in reality, (1) firms gradually acquire technological know-how, and (2) the know-how of a technology is acquired when the know-how of other technology is acquired. For example, by acquiring the know-how of the motherboard production, one can acquire some knowledge about CPU production and vice versa.

For the first point, I modify the assumption on technology transfer as follows: After technology transfer, the technology of a Japanese firm becomes

$$\tilde{A}^{J'} = \min\{\gamma\tilde{A}^J, \tilde{A}^U\}, \qquad (15)$$

where $\gamma > 1$. Under the assumption on the lower bound of α mentioned later, $\gamma\tilde{A}^J < \tilde{A}^U$ holds. I assume that the best technology of Japanese firms in $(\alpha, 1]$ is $\tilde{A}^{J'}$.

To capture the second point, I impose the following assumption: the externality of technology transfer. By technology transfer, overall $\tilde{A}^J$ and $\tilde{A}^{J'}$

increase according to

$$\tilde{A}^J = g(\alpha) = \min\{\left(A\frac{L_x^U}{L_x^J}\frac{1-\alpha}{\alpha}\right)\tilde{A}^U, \tilde{A}^U\}, \tag{16}$$

where A is a constant. Under (27) and the assumption on the lower bound of α mentioned later, $\left(A\frac{L_x^U}{L_x^J}\frac{1-\alpha}{\alpha}\right) < 1$ holds. Then, as α decreases, $\tilde{A}^J$ increases.

The externality assumption (16) is easier to interpret when $\theta = \alpha$, $\tilde{A}^{J'} = \gamma\tilde{A}^J$, and $\tilde{A}^J = \left(A\frac{L_x^U}{L_x^J}\frac{1-\alpha}{\alpha}\right)\tilde{A}^U$. Then,

$$\frac{\tilde{A}^U}{\tilde{A}^J} = \frac{1}{A}\frac{\alpha}{1-\alpha}\frac{L_x^J}{L_x^U} = \frac{1}{A}\frac{X^U/L_x^U}{X^J/L_x^J}.$$

Thus, the assumption basically says that the technology level of a country is proportional to the income level of the tradables.[3]

This assumption is needed to guarantee multiple equilibria. Without the externality assumption, when competition between the firms in the same country is fierce, i.e., σ is close to 1, multiple equilibria disappear.

4.6 Preliminary for solving the model

Under the setup, the productivities of the firms with the best technologies in each country are

$$A_i^U = \tilde{A}^U, \quad A_i^J = \tilde{A}^J, \quad \text{for } i \in [0, \alpha], \tag{17}$$

$$A_i^U = \sigma\tilde{A}^U, \quad A_i^J = \tilde{A}^{J'}, \quad \text{for } i \in (\alpha, 1]. \tag{18}$$

[3]Note that since $\tilde{A}^U/\tilde{A}^J$ is the TFP difference for the goods that Japan does not produce, it is not the TFP difference actually measured. To be comparable with measured data, we might use $\sigma\tilde{A}^U/\tilde{A}^{J'}$, the TFP difference for the goods that Japan actually produces.

The prices these firms face are

$$p_i^U = \min\{\frac{w^J}{\tilde{A}^J}, \frac{w^U}{\sigma \tilde{A}^U}\}, \quad p_i^J = \min\{\frac{w^U}{\tilde{A}^U}, \frac{w^J}{\sigma \tilde{A}^J}\}, \quad \text{for } i \in [0, \alpha], \tag{19}$$

$$p_i^U = \min\{\frac{w^J}{\tilde{A}^{J'}}, \frac{w^U}{\sigma \tilde{A}^U}\}, \quad p_i^J = \min\{\frac{w^U}{\sigma \tilde{A}^U}, \frac{w^J}{\sigma \tilde{A}^J}\}, \quad \text{for } i \in (\alpha, 1]. \tag{20}$$

4.7 Multiple equilibria

In the same way as in the basic model, I construct Equilibrium 1 in the extended model, where some Japanese leader firms with $\tilde{A}^J$ produce ($\theta < \alpha$). (The details of the derivations are in Appendix A.) In Equilibrium 1,

$$\frac{w^U}{w^J} = \frac{\tilde{A}^U}{\tilde{A}^J}, \tag{21}$$

$$\theta = \frac{\frac{L_x^U}{L_x^J}}{1 + \frac{\tilde{A}^U}{\tilde{A}^J}\frac{L_x^U}{L_x^J}} \left[\left(\frac{\tilde{A}^U}{\tilde{A}^J} - \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} \right) \alpha + \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} \right]. \tag{22}$$

This equilibrium exists if

$$\alpha \geq \frac{1}{1 + \frac{\tilde{A}^{J'}}{\sigma \tilde{A}^U}\frac{L_x^J}{L_x^U}}. \tag{23}$$

Next, I construct Equilibrium 2, where some U.S. follower firms competing with Japanese leader firms with $\tilde{A}^{J'}$ produce ($\theta > \alpha$). In Equilibrium 2,

$$\frac{w^U}{w^J} = \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}}, \tag{24}$$

$$\theta = \frac{1}{1 + \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}}\frac{L_x^U}{L_x^J}} \left[(1 - \sigma)\, \alpha + \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}}\frac{L_x^U}{L_x^J} \right]. \tag{25}$$

This equilibrium exists if

$$\alpha \leq \frac{1}{1 + \frac{\tilde{A}^{J'}}{\tilde{A}^U}\frac{L_x^J}{L_x^U}}. \tag{26}$$

By manipulating (16), (23), and (26), I obtain the condition under which multiple equilibria exist when $\tilde{A}^{J'} = \gamma \tilde{A}^J$ and $\tilde{A}^J = \left(A \frac{L_x^U}{L_x^J} \frac{1-\alpha}{\alpha} \right) \tilde{A}^U$:

$$\underbrace{\frac{\sigma}{\gamma}}_{\text{Lower bound of Eq. 1}} \leq A \leq \underbrace{\frac{1}{\gamma}}_{\text{Upper bound of Eq. 2}} \tag{27}$$

If $A > 1/\gamma$, only Equilibrium 1 exists. If $A < \sigma/\gamma$, only Equilibrium 2 exits. I assume that (27) holds and rewrite A as follows:

$$A \equiv \omega \frac{\sigma}{\gamma} + (1 - \omega) \frac{1}{\gamma},$$

where $0 < \omega < 1$.

4.8 U.S. firm's decision of technology transfer

The settings for the U.S. firm's decision of technology transfer are the same as in the basic model: if $\mu \pi_i^J > \pi_i^U$, the U.S. firm transfers its technology. In Equilibrium 1, $\pi_i^J > \pi_i^U = 0$, and in Equilibrium 2, $\pi_i^U > \pi_i^J = 0$. Thus, in Equilibrium 1, a U.S. firm always has an incentive to transfer the technology, and in Equilibrium 2, a U.S. firm never has an incentive to transfer the technology.

In the extended model, I specify the details of technology transfer for the quantitative exercise. I assume that in Equilibrium 1, where the transfer condition is satisfied, in each period, a certain number of Japanese firms Δ_α from the highest i adopt new technologies: i.e., α_t shifts from period t to $t+1$ by:

$$\alpha_{t+1} - \alpha_t = -\Delta_\alpha. \tag{28}$$

I assume that the lower bound of α exists and is $1/(1 + (1/\sigma)(L^J/L^U))$, which is the lower bound of (23) when $\tilde{A}^{J'} = \tilde{A}^U$.

In each period, the Japanese firms to which the U.S. technologies are transferred pay fees f_i^J to the U.S. firms:

$$f_i^J = \mu \pi_i^J \quad \text{for } i \in (\alpha_t, \alpha_{\text{Prewar}}],$$

where α_{Prewar} is α at the prewar period (For simplicity, I assume that in the prewar period, the Japanese firms do not pay licensing fees). I assume the U.S. firms are owned by domestic households and f_i^J go to the U.S. households.

Then, the market conditions for tradables become:

$$L^U c_T^U = \theta X + F^J, \tag{29}$$

$$L^J c_T^J = (1-\theta) X - F^J, \tag{30}$$

where $F^J \equiv (\alpha_{\text{Prewar}} - \alpha_t) f_{it}^J$.

4.9 Computing the equilibria

This section explains how the extended model is computed. First, I set the initial technology level α_{Prewar}, a sequence of the U.S. technology levels $\{\tilde{A}_t^U\}$, and the exogenous labor supply L^C as exogenous variables. Then, in each period, other variables are computed as follows.

1. c_{Nt}^C and L_{xt}^C are obtained using (10).
2. Given α_t, $\tilde{A}_{it}^C$ is determined by (15)–(18).
3. The equilibrium (Equilibrium 1 or Equilibrium 2) in which the economy is in at this period is chosen (in the model, shifts between the equilibria are unexpected to the agents).
4. Given the equilibrium and the above variables,
   w_t^U / w_t^J and θ_t are computed using (21) and (22) in Equilibrium 1 and (24) and (25) in Equilibrium 2.

5. Given which equilibrium is computed and the above variables,

   w_t^C is computed using $x_{it}^C = X/p_{it}^C$, (13), (19), and (20).

   ℓ_{it}^C (as well as x_{it}^C and X_t^C) is computed using $\ell_{it}^C = X/(p_{it}^C \tilde{A}_{it}^C)$, (14), (19), and (20).

6. Given the above variables, F_t^J is computed using $F_t^J = (\alpha_{\text{Prewar}} - \alpha_t)\mu\pi_i^J$, where $\pi_{it}^J = ((1-\theta_t)X_t - w_t^J L_{xt}^J)/(1-\alpha_t)$.

7. Given the above variables, c_{Tt}^C is computed by (29) and (30).

8. α_{t+1} is determined by (28).

(For details of the variables in 5 and 6, see Appendix A.)

5 Quantitative Findings

In this section, I calibrate the parameters of the model and use the extended model to see whether it can replicate the changes in the per capita GDP relative to the U.S., PPP/e, and labor share of postwar Japan.

5.1 Simulation scenario

I consider the following scenario. First I define each period as one year and rapid growth period as 16 years from 1955 to 1971. I define the years in the model before the rapid growth period as the prewar period. I assume that during the prewar period, the economy is in Equilibrium 2 and that $\alpha_{\text{Prewar}} = \alpha_{1955}$. During the rapid growth period, I assume that the economy is in Equilibrium 1 and that during these years, α_t shifts (decreases) in each period. I define the years after 1971 as the post-1971 period. I assume that during the post-1971 period, the economy is in Equilibrium 2 and that $\alpha_{\text{Post 1971}} = \alpha_{1971}$. I assume that when the equilibrium of the economy switches, it occurs *unexpectedly.*

5.2 Calibration

The parameters of the model are reported in Table 2. The values for L^U and L^J are selected to be roughly consistent with the population ratio of the U.S. and Japan. ρ, the share of intermediate input in tradable production, is 0.5, which is comparable with Parente and Prescott (2000). σ, the inverse of the markup rate, is set to 0.7, which roughly corresponds to the lower bound in Bernard et al. (2003).[4]

η, the expenditure share of tradable goods in consumption, which is also the expenditure share of industrial goods in consumption in my model, is set on the basis of the values of the industrial sector share in the literature. In Parente and Prescott (1999), they set the share of the industrial sector, which corresponds to the tradable sector in my model, for developed countries to be 0.84 and the share of the agricultural and services sectors, which correspond to the non-tradables in my model, to be 0.16. In Greenwood et al. (1997) and Ngai and Samaniego (2009), in which investment-specific technological change accounts for a major part of postwar U.S. growth, the share of capital goods is around 1/3. As an intermediate value, I set η to 0.5.

I choose γ, the productivity improvement after technology transfer to be 2 on the basis of the argument in Parente and Prescott (1999).[5] As in Parente and Prescott (1999), the results do not depend on the absolute value of $\tilde{A}^U$. Thus, $\tilde{A}^U$ is set to 1. I set ω to 0.5, because if ω is close to 0 or 1, the existence of multiple equilibria is dubious.

The rest of the parameters are chosen to roughly match the simulated results with the data. I set μ, the share of licensing fees, over the profit so that the relative per capita GDP does not change much around the end of the rapid

[4] In their model, the lower bound of the inverse of the markup rate is $(3.79-1)/3.79 \simeq 0.736$.

[5] They argue, "it is not uncommon for the next technological innovation to be between two and three times more productive than the current technology... (p. 1228)"

growth period. If μ is close to 0, the relative per capita GDP decreases sharply after 1971. However, if μ is close to 1, the relative per capita GDP shoots up after 1971. To be consistent with the data, μ should be around 0.5. $\alpha_{1955}(=\alpha_{\text{Prewar}})$ and α_{1970} are chosen so that the relative per capita GDP of 1955 and 1970 in the model match those in the data. Finally, given α_{1955} and α_{1970}, Δ_α is pinned down.

5.3 Construction of artificial data

Here, I describe the construction of the per capita GDP of Japan relative to the U.S., PPP/e, and Japan's labor share in the model.

I follow the Penn World Table (PWT, Heston et al., 2009) to construct per capita relative GDP and PPP/e (details of the construction are in Appendix B). Following PWT, I define nominal GDP (PGDP), nominal consumption (PC), and nominal investment (PI) as follows:

$$\begin{aligned} \text{PGDP}^C &\equiv \text{PC}^C + \text{PI}^C, \\ \text{PC}^C &\equiv w^C c_N^C L^C + c_T^C L^C, \\ \text{PI}^C &\equiv \int \mathsf{uc}_i^C \tilde{x}_i^C \, di. \end{aligned}$$

Note that the price level of the tradable goods is normalized to be 1 and that under the setting (11), PI^C is calculated as follows:

$$\text{PI}^C = \frac{\rho}{1-\rho} w^C L_x^C.$$

Using them for both countries and the Geary-Khamis method, I construct the relative per capita GDP and PPP/e.

I calculate Japan's labor share as follows:

$$\text{Japan's labor share} = \frac{w^J L^J}{\text{PC}^J + \text{PI}^J + F^J}.$$

To calculate the labor share, I include F^J to be consistent with the labor share data that I use (Hayashi and Prescott (2002) data).

5.4 Simulation results

Figure 8 plots the simulation result of the per capita GDP of Japan relative to the U.S., together with the actual data. Note that before 1955, I only plot the simulation result. The model replicates the rapid growth. However, it does not explain the so-called "stable growth" between the end of the rapid growth period and the end of the bubble economy in the late 1980s.

Figure 9 plots the simulation result and data of the PPP/e. As with the relative per capita GDP, the model fits the data well, especially during the rapid growth period, and roughly captures the surge in PPP/e at the end of the rapid growth period. However, the model cannot replicate the surge in PPP/e around 1995.

In the simulated model, the relative wage rate as well as the unit cost of the tradable goods determines the PPP/e. In the standard BS model discussed in Section 2, only the relative wage rate determines PPP/e. This mechanism works in the simulated model, where at the end of the rapid growth period, w^J/w^U jumps from 0.31 to 0.88. In addition, in the simulated model, the ratio of the average unit cost of Japan and the U.S., $\mathsf{uc}^J/\mathsf{uc}^U$, jumps from 0.52 to 1.41, because the labor cost of the Japanese firms increases. The unit cost is also important to explain the surge in PPP/e in my model.

Finally, Figure 10 plots the simulation result and data of Japan's labor share. The model qualitatively traces the movement in labor share. However, quantitatively, the model predicts too much decline for the rapid growth period (in percentage points, the decline predicted by the model is twice as great). One interpretation of the disparity between the model and the data is that in the postwar Japanese corporative system, some of the rents (profits) are distributed among workers.

5.5 What if the rapid growth continued?

According to the model, the rapid growth stopped, in 1972 because the economy switched from Equilibrium 1 to Equilibrium 2. Then, could the rapid growth continue if the economy remained in Equilibrium 1 for a few more years? To answer this question, I perform two types of counterfactual simulations in this section. In the first ("counterfactual 1"), until 1980, the economy was in Equilibrium 1, and in 1980, it *unexpectedly* switched to Equilibrium 2. I choose 1980 as the switching year for two reasons. First, the growth trend shows that around 1980, the relative per capita GDP converges to 1. Second, I impose the lower bound of α_t to be $1/(1 + (1/\sigma)(L^J/L^U))$ in Section 4.8, and the economy hits the lower bound of α_t in 1983 if it continues to be in Equilibrium 1.

In the second counterfactual simulation ("counterfactual 2"), the economy continues to be in Equilibrium 1. In the simulation, as is noted above, since the economy hits the lower bound of α_t in 1983, I assume that α_t decreases until 1983, and thereafter, $\alpha_t = \alpha_{1983}$.

The results of the counterfactual simulation are shown in Figures 11 and 12. The counterfactual simulations show that if the rapid growth continued till 1980 or 1983, PPP/e continued to be low and the per capita GDP of Japan reached (in "counterfactual 1," it slightly surpassed) the U.S. level. The final relative per capita income level of "counterfactual 2" is lower than that of "counterfactual 1" because in the latter, licensing fees are paid to the U.S. firms.

6 Conclusion

In this paper, I propose a model of technology transfer to understand the cause of Japan's rapid economic growth. In the model, there are multiple equilibria. In one equilibrium, Japan's labor cost is low and the profits of the Japanese firms are high. In another equilibrium, Japan's labor cost is low and so are the profits. The paper's interpretation of Japan's rapid economic growth is that during the rapid growth period, the former equilibrium was chosen and the U.S. firms transferred their technology because it was more profitable. Technology transfer was the driving force of the rapid growth. Before and after the rapid growth period, the latter equilibrium was chosen. During these periods, the economy stagnated because technologies were not transferred. This model is quantitatively consistent with the per capita GDP of Japan relative to the U.S., the PPP-exchange rate ratio between Japan and the U.S., and postwar Japan's labor share.

A Derivations of the Extended Model

In the appendix, I derive the properties of Equilibrium 1 and Equilibrium 2 used in Sections 4.7 and 4.9.

A.1 Equilibrium 1 ($\theta < \alpha$)

Here, I construct an equilibrium where some Japanese leader firms with $\tilde{A}^J$ produce ($\theta < \alpha$).

Due to the Bertrand competition, the U.S. leader firms in $[0, \theta]$ set their price at $p_i^U = \min\{\frac{w^J}{\tilde{A}^J}, \frac{w^U}{\sigma \tilde{A}^U}\}$. Their unit cost is $\mathsf{uc}_i^U = \frac{w^U}{\tilde{A}^U}$. On the other hand, the Japanese leader firms in $(\theta, \alpha]$ set their price at $p_1^J = \min\{\frac{w^U}{\tilde{A}^U}, \frac{w^J}{\sigma \tilde{A}^J}\}$. Their unit cost is $\mathsf{uc}_1^J = \frac{w^J}{\tilde{A}^J}$. (Note that as in the basic model, I denote the Japanese firm in $(\theta, \alpha]$ by ${}_1^J$ and the Japanese firm in $(\alpha, 1]$ by ${}_2^J$.) Because $p_i^C \geq \mathsf{uc}_i^C$, from the above relations, I obtain (21):

$$\frac{w^U}{w^J} = \frac{\tilde{A}^U}{\tilde{A}^J}.$$

Then, $p_i^U = \dfrac{w^J}{\tilde{A}^J}$, and $p_1^J = \dfrac{w^U}{\tilde{A}^U}$.

The Japanese leader firms in $(\alpha, 1]$ set their price at $p_2^J = \min\{\dfrac{w^U}{\sigma \tilde{A}^U}, \dfrac{w^J}{\sigma \tilde{A}^J}\} = \dfrac{w^U}{\sigma \tilde{A}^U}(= \dfrac{w^J}{\sigma \tilde{A}^J})$. Their unit cost is $\mathsf{uc}_2^J = \dfrac{w^J}{\tilde{A}^{J'}}$.

Then, for the U.S. firms,

$$p_i^U x_i^U = \frac{w^J}{\tilde{A}^J} \tilde{A}^U \ell_i^U = X \Longrightarrow \ell_i^U = \frac{1}{w^J} \frac{\tilde{A}^J}{\tilde{A}^U} X.$$

Using the property,

$$L_x^U = \int_0^\theta \ell_i^U di = \theta \frac{1}{w^J} \frac{\tilde{A}^J}{\tilde{A}^U} X. \tag{31}$$

On the other hand, for the Japanese firms,

$$p_1^J x_1^J = \frac{w^U}{\tilde{A}^U} \tilde{A}^J \ell_1^J = X \Longrightarrow \ell_1^J = \frac{1}{w^U} \frac{\tilde{A}^U}{\tilde{A}^J} X \quad \text{for } i \in (\theta, \alpha],$$
$$p_2^J x_2^J = \frac{w^U}{\sigma \tilde{A}^U} \tilde{A}^{J'} \ell_2^J = X \Longrightarrow \ell_2^J = \frac{1}{w^U} \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} X \quad \text{for } i \in (\alpha, 1].$$

Then,

$$L_x^J = \int_\theta^1 \ell_i^J di = (\alpha - \theta) \frac{1}{w^U} \frac{\tilde{A}^U}{\tilde{A}^J} X + (1 - \alpha) \frac{1}{w^U} \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} X. \tag{32}$$

Using (31) and (32), I obtain (22):

$$\theta = \frac{\frac{L_x^U}{L_x^J}}{1 + \frac{\tilde{A}^U}{\tilde{A}^J}\frac{L_x^U}{L_x^J}} \left[\left(\frac{\tilde{A}^U}{\tilde{A}^J} - \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} \right) \alpha + \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} \right].$$

From the equation, I obtain the condition that Equilibrium 1 exists, (23):

$$\alpha \geq \frac{1}{1 + \frac{\tilde{A}^{J'}}{\sigma \tilde{A}^U}\frac{L_x^J}{L_x^U}}.$$

Next, I explain the details of the derivations of procedures 4 and 5 in Section 4.9, when the economy is in Equilibrium 1. I first derive w^C, ℓ_i^C, x_i^C, and X^C. Substituting $x_i^U = X/(w^J/\tilde{A}^J), x_1^J = X/(w^U/\tilde{A}^U)$, and $x_2^J = X/(w^U/(\sigma \tilde{A}^U))$ into (13), I obtain

$$w^U = \sigma^{1-\alpha}\tilde{A}^U, \quad w^J = \sigma^{1-\alpha}\tilde{A}^J.$$

Substituting (31) into $\ell_i^U = X/((w^J/\tilde{A}^J)\tilde{A}^U)$ and (32) into $\ell_1^J = X/((w^U/\tilde{A}^U)\tilde{A}^J)$ and $\ell_2^J = X/((w^U/(\sigma\tilde{A}^U))\tilde{A}^{J'})$, I obtain

$$\ell_i^U = \frac{L_x^U}{\theta}, \quad \ell_1^J = \frac{L_x^J}{(\alpha - \theta) + (1-\alpha)\sigma\frac{\tilde{A}^J}{\tilde{A}^{J'}}}, \quad \ell_2^J = \frac{\sigma\frac{\tilde{A}^J}{\tilde{A}^{J'}}L_x^J}{(\alpha - \theta) + (1-\alpha)\sigma\frac{\tilde{A}^J}{\tilde{A}^{J'}}}.$$

Substituting these relations into $x_i^U = \tilde{A}^U\ell_i^U$, $x_1^J = \tilde{A}^J\ell_1^J$, and $x_2^J = \tilde{A}^{J'}\ell_2^J$, I obtain x_i^C. X is computed from x_i^C using (13). Finally, I derive π_i^J and F^J. The total profit of the Japanese firms is $(1-\theta)X - w^J L_x^J$. Since the Japanese firms in $(\alpha_t, 1]$ earn the same level of profit π_2^J at t, the total Japanese profit is written as $(1-\alpha_t)\pi_2^J$. By rearranging the relations, I obtain π_i^J. Among the Japanese firms that earn profit, the firms in $(\alpha_t, \alpha_{\text{Prewar}}]$ pay licensing fees. Thus, the total licensing fee F^J is $(\alpha_{\text{Prewar}} - \alpha_t)\pi_i^J$.

A.2 Equilibrium 2 ($\theta > \alpha$)

I construct an equilibrium where some U.S. follower firms competing with the Japanese leader firms with $\tilde{A}^{J'}$ produce ($\theta > \alpha$).[6]

Due to the Bertrand competition, the U.S. follower firms in $(\alpha, \theta]$ set their price at $p_2^U = \min\{\frac{w^J}{\tilde{A}^{J'}}, \frac{w^U}{\sigma\tilde{A}^U}\}$. Their unit cost is $\mathsf{uc}_2^U = \frac{w^U}{\sigma\tilde{A}^U}$. (Note that as in the basic model, I denote the U.S. firm in $[0, \alpha]$ by ${}_1^U$ and the U.S. firm in $(\alpha, \theta]$ by ${}_2^U$.) The Japanese leader firms in $(\theta, 1]$ set their price at $p_i^J = \min\{\frac{w^U}{\sigma\tilde{A}^U}, \frac{w^J}{\sigma\tilde{A}^J}\}$. Their unit cost is $\mathsf{uc}_i^J = \frac{w^J}{\tilde{A}^{J'}}$. Because $p_i^C \geq \mathsf{uc}_i^C$, from the above relations, I obtain (24):

$$\frac{w^U}{w^J} = \frac{\sigma\tilde{A}^U}{\tilde{A}^{J'}}.$$

Then, $p_2^U = \frac{w^J}{\tilde{A}^{J'}}$, and $p_i^J = \frac{w^U}{\sigma\tilde{A}^U}$.

U.S. leader firms in $[0, \alpha]$ set their price at $p_1^U = \min\{\frac{w^U}{\sigma\tilde{A}^U}, \frac{w^J}{\tilde{A}^J}\} = \frac{w^U}{\sigma\tilde{A}^U}$. Their unit cost is $\mathsf{uc}_2^U = \frac{w^U}{\tilde{A}^U}$.

Then, for the U.S. firms,

$$p_1^U x_1^U = \frac{w^U}{\sigma\tilde{A}^U}\tilde{A}^U \ell_1^U = X \Longrightarrow \ell_1^U = \frac{\sigma}{w^U} X \text{ for } i \in [0, \alpha],$$
$$p_2^U x_2^U = \frac{w^J}{\tilde{A}^{J'}}\sigma\tilde{A}^U \ell_2^U = X \Longrightarrow \ell_2^U = \frac{1}{w^J}\frac{\tilde{A}^{J'}}{\sigma\tilde{A}^U} X \quad \text{for } i \in (\alpha, \theta].$$

Using the property,

$$L_x^U = \int_0^\theta \ell_i^U \, di = \alpha\frac{\sigma}{w^U} X + (\theta - \alpha)\frac{1}{w^J}\frac{\tilde{A}^{J'}}{\sigma\tilde{A}^U} X. \tag{33}$$

[6] Due to the assumption in Section 4.4, the U.S. leader firms in $(\alpha, 1]$ do not produce.

On the other hand, for the Japanese firms,

$$p_i^J x_i^J = \frac{w^U}{\sigma \tilde{A}^U} \tilde{A}^{J'} \ell_i^J = X \Longrightarrow \ell_i^J = \frac{1}{w^U} \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} X \quad \text{for } i \in (\theta, 1].$$

Similarly,

$$L_x^J = \int_\theta^1 \ell_i^J di = (1-\theta) \frac{1}{w^U} \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} X. \tag{34}$$

From (33) and (34), I obtain (25):

$$\theta = \frac{1}{1 + \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} \frac{L_x^U}{L_x^J}} \left[(1-\sigma)\,\alpha + \frac{\sigma \tilde{A}^U}{\tilde{A}^{J'}} \frac{L_x^U}{L_x^J} \right].$$

From the equation, I obtain the condition that Equilibrium 2 exists, (26):

$$\alpha \leq \frac{1}{1 + \frac{\tilde{A}^{J'}}{\tilde{A}^U} \frac{L_x^J}{L_x^U}}.$$

Next, I explain the details of the derivations of 4 in Section 4.9, when the economy is in Equilibrium 2. Substituting $x_1^U = X/(w^U/(\sigma \tilde{A}^U)), x_2^U = X/(w^J/\tilde{A}^{J'})$, and $x_i^J = X/(w^U/(\sigma \tilde{A}^U))$ into (13), I obtain

$$w^U = \sigma \tilde{A}^U, \quad w^J = \tilde{A}^{J'}.$$

Substituting (33) into $\ell_1^U = X/((w^U/(\sigma \tilde{A}^U))\tilde{A}^U)$ and $\ell_2^U = X/((w^J/\tilde{A}^{J'})\sigma \tilde{A}^U)$, and (34) into $\ell_i^J = X/((w^U/(\sigma \tilde{A}^U))\tilde{A}^{J'})$, I obtain

$$\ell_1^U = \frac{\sigma L_x^U}{\alpha\sigma + (\theta - \alpha)}, \quad \ell_2^U = \frac{L_x^U}{\alpha\sigma + (\theta - \alpha)}, \quad \ell_i^J = \frac{L_x^J}{1-\theta}.$$

Substituting these relations into $x_1^U = \tilde{A}^U \ell_1^U$, $x_2^U = \sigma \tilde{A}^U \ell_2^U$, and $x_i^J = \tilde{A}^{J'} \ell_i^J$, I obtain x_i^C. X is computed from x_i^C using (13).

B Construction of Relative Per Capita GDP and PPP/e

In the appendix, I describe the details of the construction of the per capita GDP of Japan relative to the U.S. and the PPP/e explained in Section 5.3.

I follow the Penn World Table (PWT, Heston et al., 2009) to construct the per capita relative GDP and PPP/e. The construction procedure is as follows:

1. As described in the text, following PWT, I define nominal GDP (PGDP), nominal consumption (PC), and nominal investment (PI) as follows:

$$\text{PGDP}^C \equiv \text{PC}^C + \text{PI}^C,$$
$$\text{PC}^C \equiv w^C c_N^C L^C + c_T^C L^C,$$
$$\text{PI}^C \equiv \int \mathsf{uc}_i^C \tilde{x}_i^C di.$$

   The PGDP in the model corresponds to the GDP in the exchange rate, because I normalize the price of tradables to be 1. Under the setting (11), PI^C is written as follows:

$$\text{PI}^C = \int \mathsf{uc}_i^C \tilde{x}_i^C di = \int \frac{\rho}{1-\rho} w^C \ell_i^C di = \frac{\rho}{1-\rho} w^C L_x^C.$$

   PI^C is calculated from the last expression of the equation.

2. I choose 1972 to be the base year.

3. Employing the Geary-Khamis method and using the prices for consumption (i.e., w^C and 1 for non-tradables and tradables) and investment (I use the geometric weighted average of uc_i^Cs as the price), I calculate the price levels for PC and PI for the base year.

4. For the other years, using the prices for consumption and investment, I

calculate the deflators for consumption and investment.

5. Using the deflators, the price levels for PC and PI for the base year are deflated to all the years.

6. Using PC, PI, and the price levels and employing the Geary-Khamis method, I calculate PPP (PPP/e) for all the years.

7. Using the PPP, I calculate the relative per capita GDP for all the years.

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Table 1: Prewar and postwar labor income shares of manufacturing

Prewar (1932)	Postwar (1957)
50%	34%

Note: Minami (2002) p. 220 and p. 223.

Table 2: Parameters

L^U and L^J	ρ	σ	η	γ	$\tilde{A}_t^U$
2 and 1	0.5	0.7	0.5	2	1
ω	μ	α_{1955}	α_{1971}	Δ_α	
0.5	0.5	0.93	0.73	$\frac{\alpha_{1971}-\alpha_{1955}}{1971-1955}$	

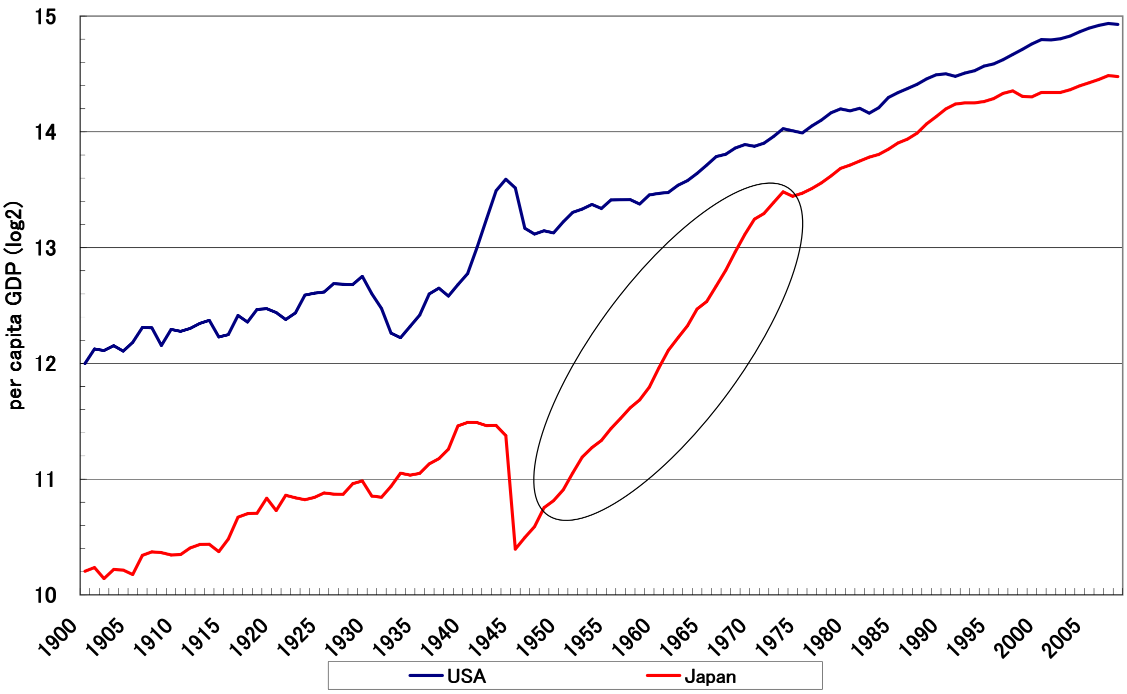

Figure 1: Per capita GDP of the U.S. and Japan

Note: Maddison (2010).

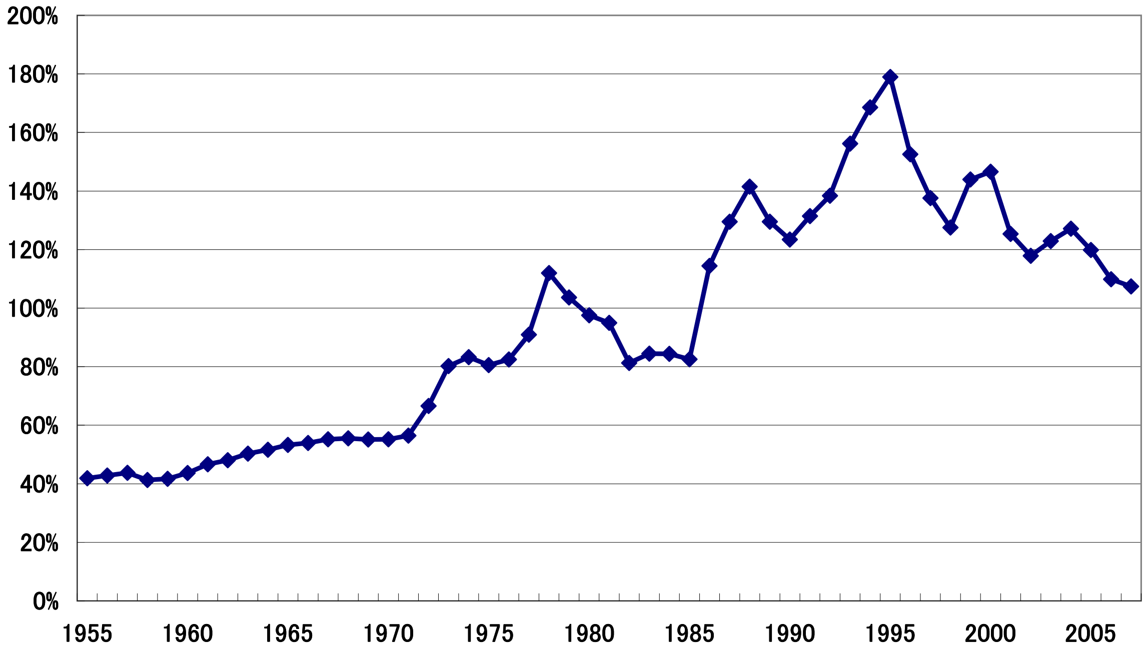

Figure 2: PPP-exchange rate ratio between Japan and the U.S.
Note: Heston et al. (2009).

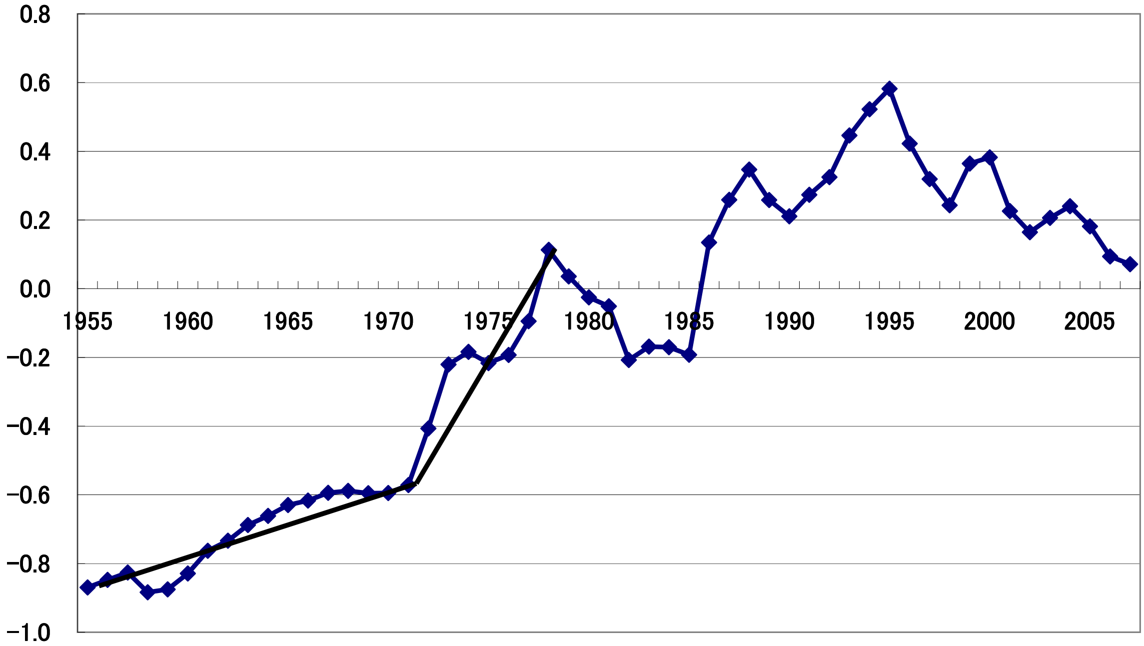

Figure 3: The natural logarithm of the PPP-exchange rate ratio between Japan and the U.S.

Note: Heston et al. (2009). The solid black lines are added.

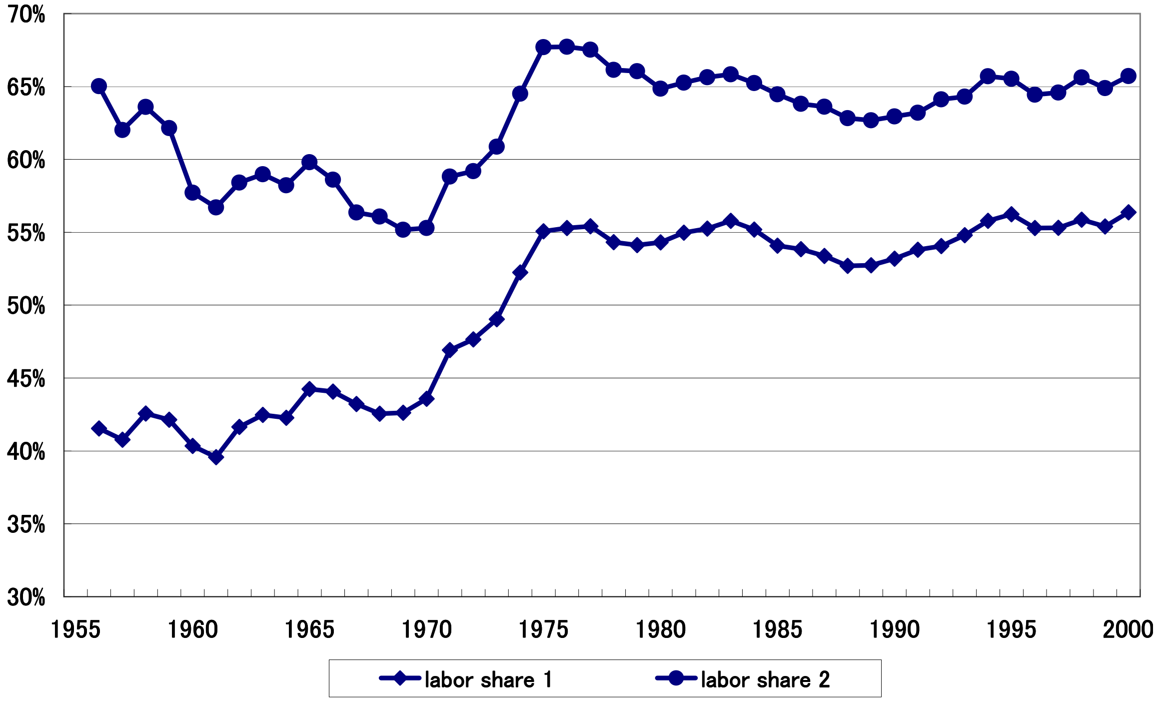

Figure 4: Japan's labor share

Note: Hayashi and Prescott (2002) data. "Labor share 1" is "Compensation of Employees"/"Total Output." "Labor share 2" is "Compensation of Employees"/("Total Output" − "Net Factor Payments" − "Indirect Taxes" − "Non-Housing Operating Surplus"), following Gollin (2002) and Bernanke and Gurkaynak (2002).

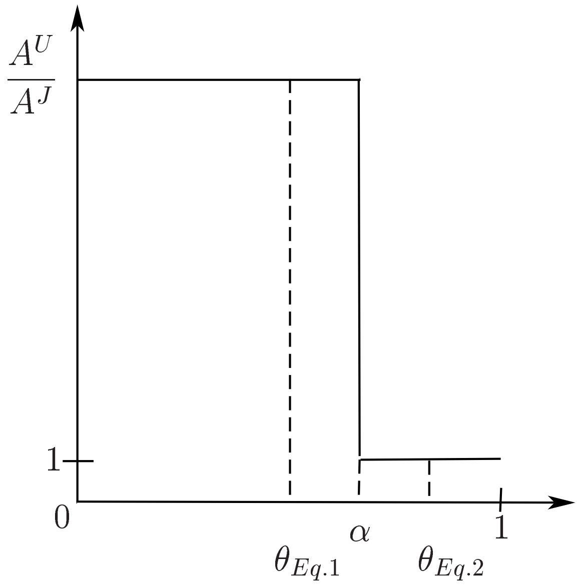

Figure 5: Productivity differences for the disaggregated goods in $[0, 1]$

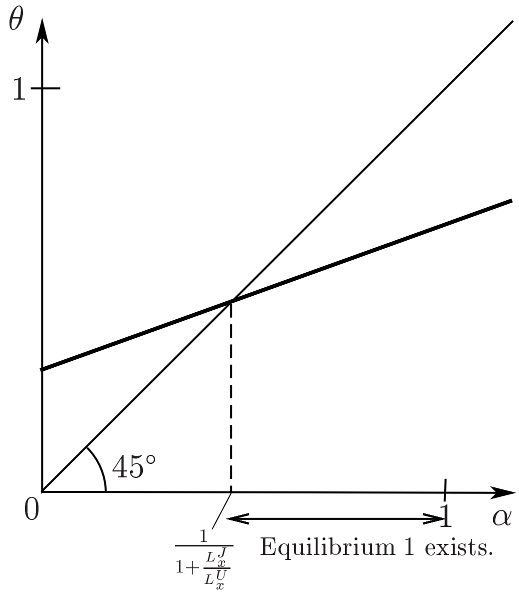

Figure 6: The region of α where Equilibrium 1 ($\theta < \alpha$) exists

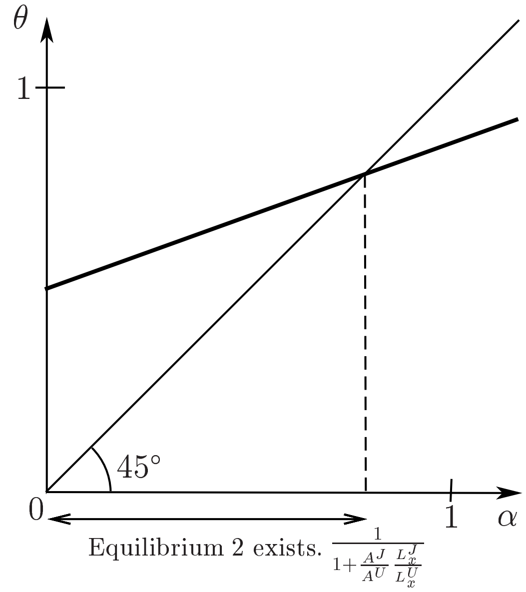

Figure 7: The region of α where Equilibrium 2 ($\theta > \alpha$) exists

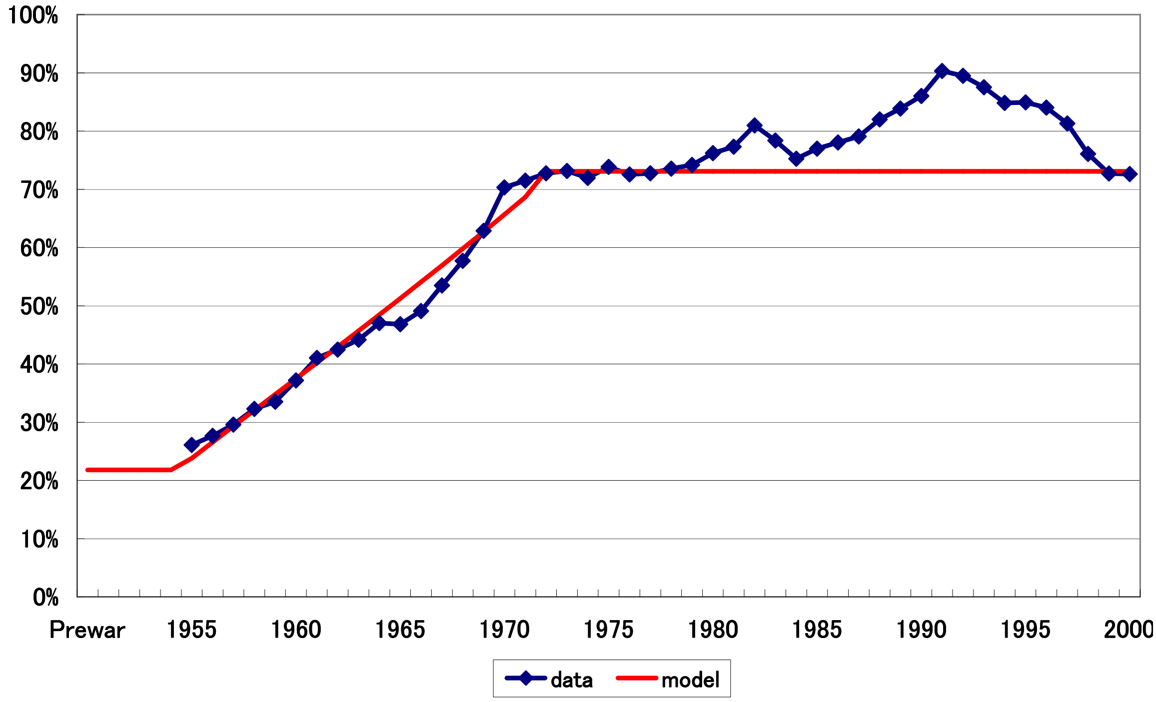

Figure 8: Simulation and data: per capita GDP of Japan relative to the U.S.
Note: Data from Heston et al. (2009).

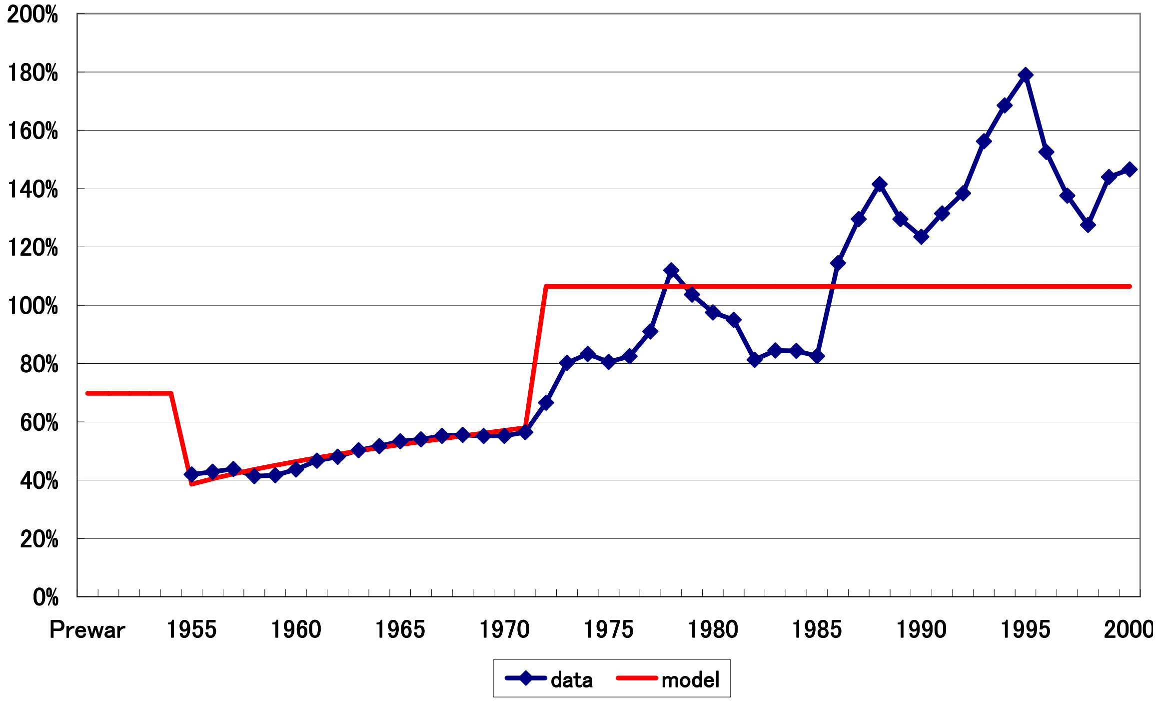

Figure 9: Simulation and data: PPP-exchange rate ratio between Japan and the U.S.

Note: Data from Heston et al. (2009).

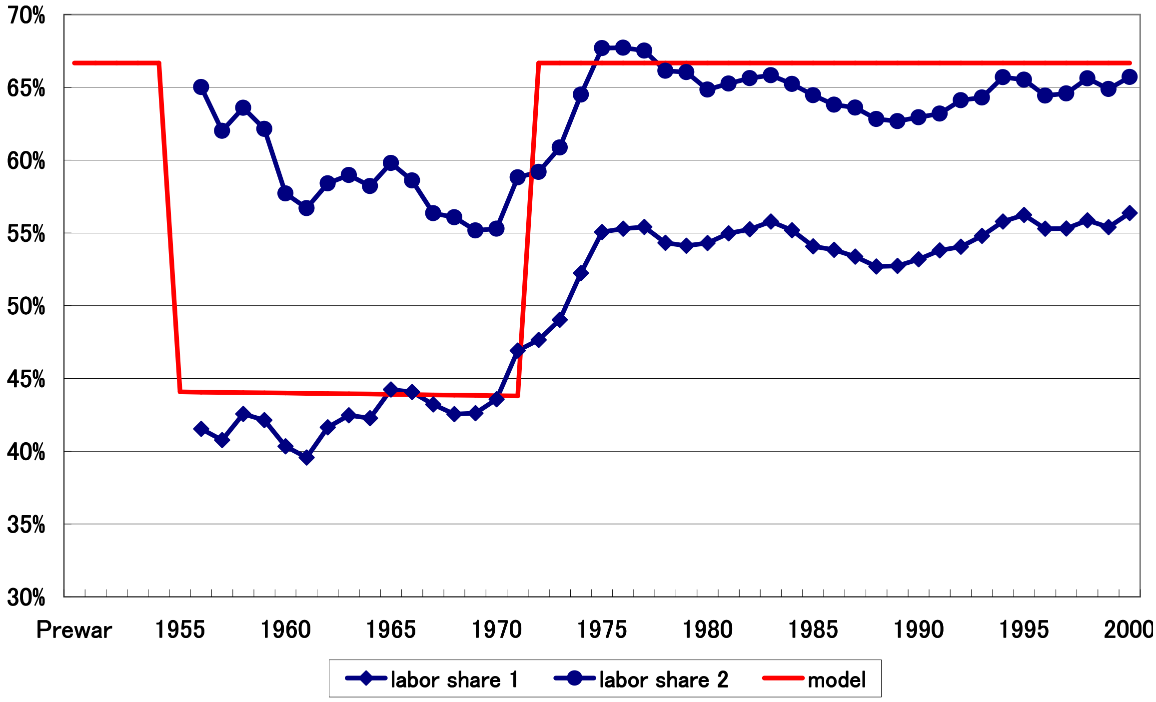

Figure 10: Simulation and data: Japan's labor share

Note: Data from Hayashi and Prescott (2002). For the definitions of labor share 1 and 2, see the note in Figure 4.

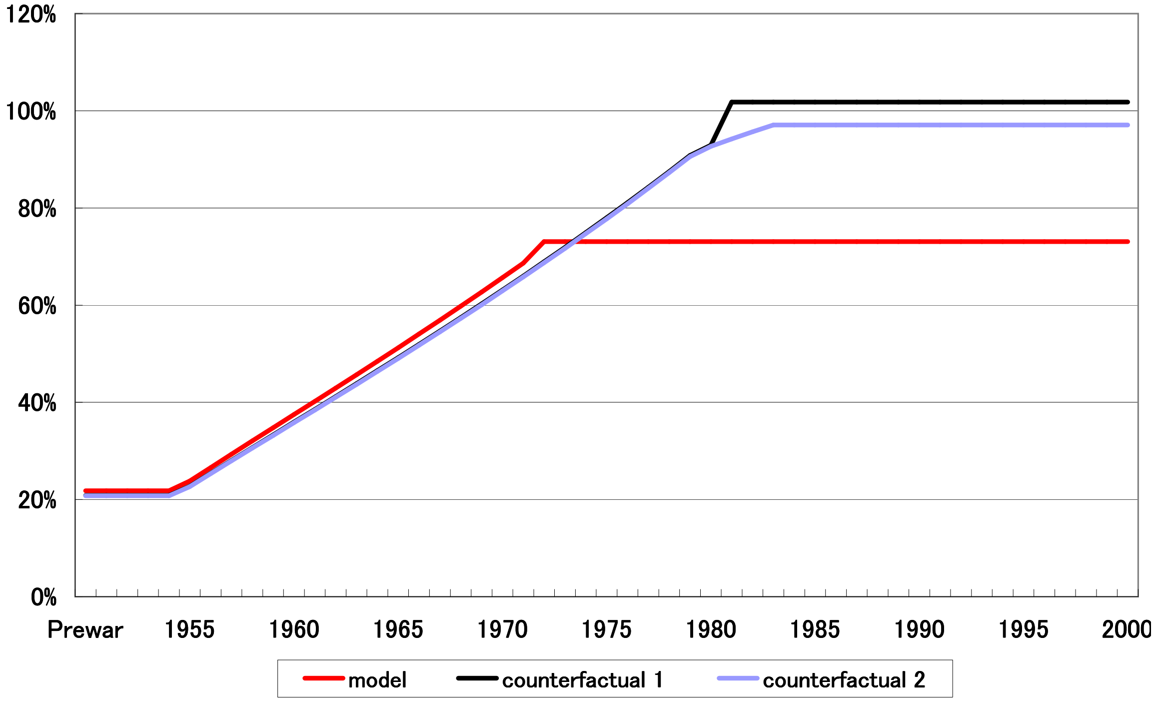

Figure 11: Counterfactual simulations: per capita GDP of Japan relative to the U.S.

Note: "Model" is the same as the simulation result in Figure 8. In "counterfactual 1," until 1980, the rapid growth continues (the economy is in Equilibrium 1), and in 1980, the growth suddenly stops (the economy *unexpectedly* switches to Equilibrium 2). In "counterfactual 2," until 1983, the rapid growth continues and after 1983, the growth stops (but the economy remains in Equilibrium 1).

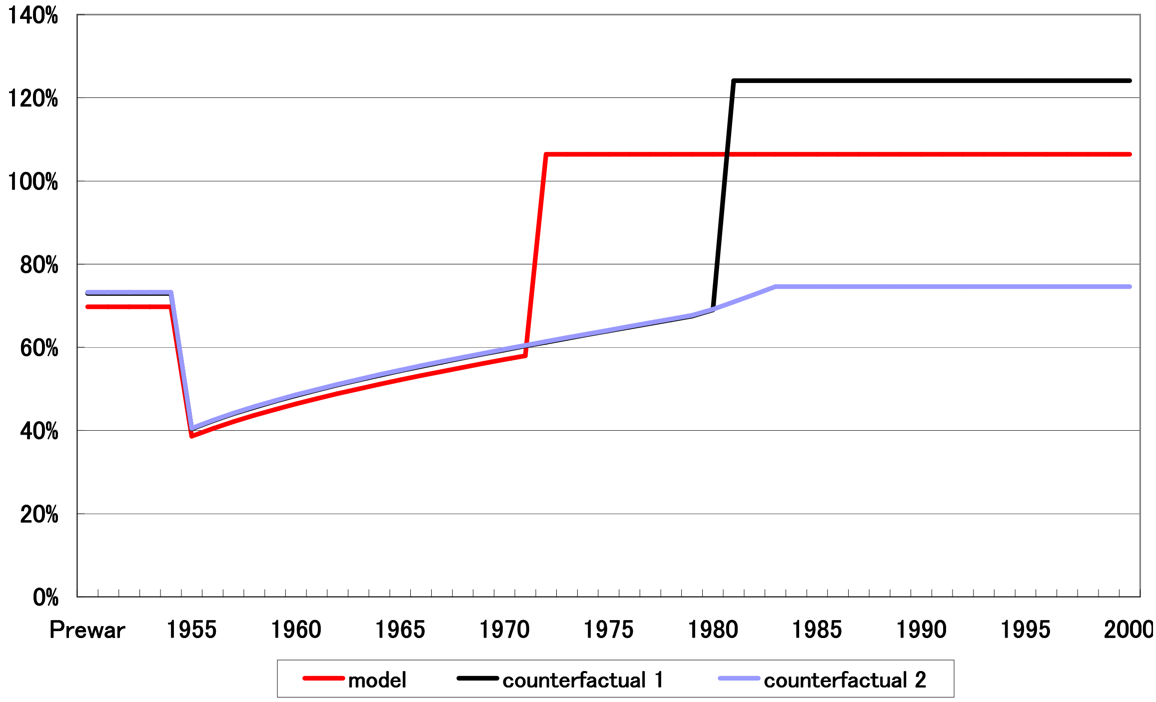

Figure 12: Counterfactual simulations: PPP-exchange rate ratio between Japan and the U.S.

Note: "Model" is the same as the simulation result in Figure 8. In "counterfactual 1," until 1980, the rapid growth continues (the economy is in Equilibrium 1), and in 1980, the growth suddenly stops (the economy *unexpectedly* switches to Equilibrium 2). In "counterfactual 2," until 1983, the rapid growth continues and after 1983, the growth stops (but the economy remains in Equilibrium 1).