Do Not Quote without the Authors' Permission

Quantity or Quality: The Impact of Labor-Saving Innovation on US and Japanese Growth Rates, 1960–2004

*By Ryuzo Sato[a] and Tamaki Morita[b]**

March 2007

[a] New York University and the University of Tokyo
[b] National Graduate Institute for Policy Studies (GRIPS), Japan

[*] Corresponding author. Tamaki Morita, National Graduate Institute for Policy Studies
7-22-1 Roppongi, Minato-ku, Tokyo 106-8677, Japan. E-mail address: morita@grips.ac.jp

Do Not Quote without the Authors' Permission

Quantity or Quality: The Impact of Labor-Saving Innovation on US and Japanese Growth Rates, 1960–2004

By Ryuzo Sato[a] *and Tamaki Morita*[b*]

March 2007

JEL Classification: O33, O47, O57

Keywords: Technical Change, Labor-Saving Innovation, Productivity

Abstract

This article deals with both theoretical and empirical analyses of the post-war period (1960–2004) for the United States and Japan. We investigated three factors contributing to growth: the growth rates of capital, labor, and labor-saving innovation. It is shown that in Japan, the growth rate of the labor force has been much less important than its quality improvement—i.e., labor-saving technical change—while in the US, the growth rate of labor and population has contributed more than their quality improvement. The policy implication here is Japan's declining population can be compensated for by additional quality improvement of the existing labor force.

[a] New York University and the University of Tokyo

[b] National Graduate Institute for Policy Studies (GRIPS), Japan

[*] Corresponding author. Tamaki Morita, National Graduate Institute for Policy Studies 7-22-1 Roppongi, Minato-ku, Tokyo 106-8677, Japan. E-mail address: morita@grips.ac.jp

Contents

I. Introduction

1. Japan's economic growth after the Second World War was miraculous. Hundreds of economic studies have been done to analyze the high performance of the economy. Recently, however, attention has turned to worrisome expectations for the future: Will Japan's population decline put an end to the country's macroeconomic growth?

The United States also experienced a high growth rate after the Second World War. President Kennedy's policies in the 1950's supported economic growth through innovation. The high growth was also backed by capital accumulation and population growth. However, recent rapid population growth coming from the influx of immigrants to the United States has been followed by much ambivalence toward population growth; many worry about problems that may come from lack of assimilation and overpopulation.

There is no economic or popular consensus on whether population growth is good or bad for long-run economic growth. This paper compares and contrasts the economies of Japan and the United States after the 1960's using traditional or basic growth models. The elements of the analysis are GDP, capital, labor, and total factor productivity (TFP). This last element is comparable to the index of Hicks-neutral economic progress, which explains the total efficiency of capital and labor.

The novel contribution of this paper, accruing from those of Sato and Ramachandran (1987) and Sato (1970), is that we analyze not only how the TFP has increased or decreased, but also analyze separately the efficiency of capital and the efficiency of labor. The result of this analysis will allow us to make a policy proposal that in order to raise TFP growth, we have to consider how and how much the efficiency of either or both of capital and labor must be increased. Merely knowing TFP is generally considered sufficient for economic analysis. However, our comparison of the two countries will show that because each country's composition of TFP is fundamentally different, knowing only total efficiency does not suffice.

In order to analyze the efficiency of capital and labor, we need to know the production function or the elasticity of (factor) substitution, which is the summary index of production function. In general terms, elasticity of substitution is a technology index. As Sato and Beckmann (1968) and Rose (1968) discovered, elasticity of substitution plays a critical role in the analysis of the efficiency of each input factor. Our growth analysis uses the concept of elasticity of substitution and applies the concept to the data of the two countries.

2. In this paper we contrast the difference in the economic structures of Japan and the United States (US) by comparing the rate of factor-augmenting technical progress. Our investigation reveals that whether or not the capital and labor are efficiently used has a strong impact on economic growth.

Following the theoretical explanation in Section II, we conduct in Section III the estimations of the growth rate of biased technical change using both countries' macro data from 1960 to 2004. The data are then divided into two periods—Period I (1960–1989) and Period II (1990–2004)—because the analysis of Period II is particularly useful in highlighting the characteristics of each economy. Period II for Japan includes the "lost decade," the period of long-lasting stagnation after the burst of the asset price bubble[1], while the same period of time for the US is often described as the "new economy," whose rapid growth was driven by newly developed industries such as IT and biotechnology.

In Subsection III-1, we determine that we can apply the model of factor-augmenting (biased) technical change to the Japanese and US economies. We find this by testing to confirm that the production functions in both countries are not Cobb-Douglas, and the technical progress in both countries is not Hicks-neutral. In Subsection III-2, we estimate the production functions with biased technical change. During the estimation process, we compare the 44 years' performance of each economy. The simulation results using the estimated production functions are shown in the next subsection. In Subsection III-4, we

[1] Many scholars and economists have attempted to analyze Japan's lost decade using TFP. Recognized contributions include an industry-level research of TFP by Fukao and Kwon (2006) and a TFP analysis focusing on information technology by Jorgenson and Motohashi (2005).

figure out how the roles of biased technical change differed in the two economies. The estimation results explain how Japan's high growth was sustained by the efficiency of labor. Subsection III-5 shows that Japan responded to external shocks such as oil crises more flexibly than the US did. Then, in Subsection III-6, we present another way to contrast the two countries by applying the stability condition theoretically explained in subsection II-3. We found that although the economic growth in the US may have been at the steady state, the growth in Japan has not yet neared the steady state.

It turned out that broadly defined innovation has been and will be the engine of the growth of the Japanese economy. Japan does not have to be pessimistic about the declining birth rate because value-added of labor can compensate for the decline.

II. A Model of Biased (Labor-Saving) Technical Change

3. Consider an aggregative economy where at each year t, one output ($Y(t)$) is produced by two factor inputs, capital ($K(t)$) and labor ($L(t)$), under the neo-classical constant returns to scale technology. Production of $Y(t)$ depends also on the general technical change ($T(t)$). Then the production function takes the form,

$$Y(t) = F\left[K(t), L(t), T(t)\right] \qquad [1]$$

where F satisfies the usual regularity conditions.

For the purpose of empirical analysis, it is convenient to study a special case of equation [1], where technical change is of the factor-augmenting type (or Sato-Beckman-Rose neutral type)[2]. Thus, equation [1] takes the form

$$Y(t) = F\left[A(t)K(t), B(t)L(t)\right] = F\left[\bar{K}(t), \bar{L}(t)\right], \qquad [2]$$

where $A(t)$ and $B(t)$ are efficiencies of capital and labor respectively; and $\bar{K}(t) = A(t)K(t)$ and $\bar{L}(t) = B(t)L(t)$ or the effective capital and the effective labor. Notice that $T(t)$ in equation [1] is divided up into $A(t)$ and $B(t)$ in [2]. Thus when $A(t) \equiv B(t) \equiv T(t)$, equation

[2] See Sato and Beckman (1968) and Rose (1968) for the condition for the factor-augmenting technical change.

[2] is reduced to the case of Hicks-neutral technical change, while when $A(t) \equiv 1 \neq B(t) \equiv T(t)$, it is reduced to the Harrod-neutral type and when $A(t) \equiv T(t) \neq B(t) \equiv 1$ it is reduced to the Solow-Ranis-Fei type. Because equation [1] is a linear homogeneous production function, under the Hicks-neutral case equation [2] can be rewritten as,

$$Y(t) = T(t)F\left[K(t), L(t)\right]; \qquad [3]$$

under the Harrod-neutral case as

$$Y(t) = F\left[K(t),\ T(t)L(t)\right] = F\left[K(t), \bar{L}(t)\right],\ T(t) = B(t); \qquad [4]$$

and under the Solow-Ranis-Fei neutral case as

$$Y(t) = F\left[T(t)K(t),\ L(t)\right] = F\left[\bar{K}(t), L(t)\right],\ T(t) = A(t). \qquad [5]$$

II-1. Importance of the Elasticity of Factor Substitution

4. There are three reasons that the elasticity of substitution $\sigma(t)$ plays a crucial role in the analysis of the factor-augmenting type of technical progress.

The first reason comes from the underlying invariance or neutrality theorem.[3] The factor-augmenting (biased) type of technical change [2] is theoretically justified by an invariant condition. That is to say, equation [2] is a result of derivation of the production function under the invariant condition that "inventions are neutral in the sense that the elasticity of substitution $\sigma(t)$ remains unchanged (or invariant) before and after inventions as long as the relative income shares of factor inputs, $\alpha(t)$ for capital and $\beta(t)$ = 1-$\alpha(t)$ for labor, are unaffected or vice versa".

This is a direct contrast to the case of "Hicks-neutral," where the invariance condition does not depend on the elasticity of the substitution concept. The Hicks-neutral case is the result of the invariance (or neutrality) condition that "inventions are neutral in the sense that the relative income shares are not affected before and after inventions as long as the capital-labor ratio remains constant."

[3] See Sato and Beckman (1968) for the invariant conditions for various types of production functions.

The second reason why the elasticity of substitution $\sigma(t)$ plays a crucial role in the analysis of the factor-augmenting type of technical progress is that once $\sigma(t)$ is known, one can derive (or integrate) the underlying production function *F*.

If one attempts to estimate *A*(*t*) and *B*(*t*) using empirical data, one will confront the situation where the elasticity of factor substitution $\sigma(t)$ must be predetermined. This is because the efficiencies of capital and labor, *A*(*t*) and *B*(*t*), are estimable only from the equations

$$\frac{\dot{A}(t)}{A(t)} = \frac{\sigma(t)\dfrac{\dot{r}(t)}{r(t)} - \left(\dfrac{\dot{Y}(t)}{Y(t)} - \dfrac{\dot{K}(t)}{K(t)}\right)}{\sigma(t)-1} \qquad [6]$$

and

$$\frac{\dot{B}(t)}{B(t)} = \frac{\sigma(t)\dfrac{\dot{w}(t)}{w(t)} - \left(\dfrac{\dot{Y}(t)}{Y(t)} - \dfrac{\dot{L}(t)}{L(t)}\right)}{\sigma(t)-1}, \qquad [7]$$

where dot = Newton's time derivative, *r*(*t*) = return to capital, and *w*(*t*) = wage rate of labor.[4]

Where $\sigma(t)$ is known, the elasticity of substitution $\sigma(t)$ can be looked at as a second order (non-linear) differential equation whose solution is the production function. The relationship between $\sigma(t)$ and *F* is shown by the solution,

$$y = A(t)\, f(C(t)x) = A(t)\exp\int^{C(t)x} G(\mu)\,\partial\log\mu\,, \qquad \text{([36] in Appendix)}$$

where $y = Y/K$ and $x = 1/k = L/K$, $\mu = C(t)\,v$

so that

$$Y(t) = F\left[A(t)K(t),\, B(t)L(t)\right] = F\left[\bar{K}(t),\, \bar{L}(t)\right].^{5} \qquad [8]$$

Thus, once $\sigma(t)$ is known, one can derive $F\left[A(t)K(t),\, B(t)L(t)\right]$ using equations [6], [7], and [8] simultaneously. In Section III, we do this using the US and Japanese data.

5. The third reason why the elasticity of substitution $\sigma(t)$ plays a crucial role is that technical change can be classified as biased (or non-neutral) in the sense of Hicks (at the

---

[4] These equations are derived in Sato (1970).

[5] In Appendix VI-1, we show the process to obtain equation [8], which originated with Sato and Beckman (1968).

constant $K(t)/L(t)$) using the relative shares of capital and labor, $\dot{A}/A$, $\dot{B}/B$, and $\sigma(t)$.

As Sato (1970) shows, if we define marginal rate of substitution ω as $\omega = r/w$ and k = K/L, we get

$$\frac{\dot{\omega}}{\omega} = \frac{\dot{r}}{r} - \frac{\dot{w}}{w} = \left(\frac{\dot{A}}{A} - \frac{\dot{B}}{B}\right)\left(1 - \frac{1}{\sigma}\right) - \frac{1}{\sigma}\frac{\dot{k}}{k}. \qquad [9]$$

Using equation [9], one can classify various cases as modeled in Hicks (1966). He defines "labor-saving" inventions as those whose initial effects are to increase the ratio of the marginal product of capital to that of labor (at constant capital-labor ratio). Such inventions increase the marginal product of capital more than they increase the marginal product of labor, thus raising the relative share of capital and reducing the relative share of labor. We classify technical change into several cases, as summarized below.

(1) Labor-saving:

(a) When the elasticity of substitution is less than unity, $\sigma(t) < 1$, and the efficiency of labor increases faster than that of capital, i.e., $\dot{B}/B > \dot{A}/A$ at the constant capital-labor ratio, technical change is labor-saving.

(b) When $\sigma(t)$ is greater than unity, $\sigma(t) > 1$, and $\dot{A}/A > \dot{B}/B$ at the constant capital-labor ratio, technical change is labor-saving.

(2) Capital-saving:

When $\sigma(t) < 1$, $\dot{A}/A > \dot{B}/B$ or $\sigma(t) > 1$, and $\dot{B}/B > \dot{A}/A$ at $K(t)/L(t)$ = constant, technical change is capital-saving.

(3) Hicks-neutral:

When $\dot{A}/A \equiv \dot{B}/B$ under $K(t)/L(t)$ = constant, technical change is Hicks-neutral, regardless of whether $\sigma(t)$ is greater than (or less than) unity.

(4) When $\sigma(t)$ =1, or the Cobb-Douglas case, any factor-augmenting type will appear as the Hicks-neutral case. That is to say, one can not differentiate $A(t)$ and $B(t)$.

We will present in Section III that both the Japanese and US economies' technical progress since 1960 can be categorized into labor-saving technical progress.

II-2. Why Do We Need Biased Technical Change?

(1) Theoretical inequality vs. empirical identity

6. For the factor-augmenting type of production function [2], the growth rate of Y may be expressed as

$$\begin{aligned}\frac{\dot{Y}(t)}{Y(t)} &= \frac{\partial F(t)}{\partial \bar{K}(t)}\frac{\bar{K}(t)}{Y(t)}\left(\frac{\dot{\bar{K}}(t)}{\bar{K}(t)}\right)+\frac{\partial F(t)}{\partial \bar{L}(t)}\frac{\bar{L}(t)}{Y(t)}\left(\frac{\dot{\bar{L}}(t)}{\bar{L}(t)}\right) \\ &= \frac{\partial F(t)}{\partial K(t)}\frac{K(t)}{Y(t)}\left(\frac{\dot{A}(t)}{A(t)}+\frac{\dot{K}(t)}{K(t)}\right)+\frac{\partial F(t)}{\partial L(t)}\frac{L(t)}{Y(t)}\left(\frac{\dot{B}(t)}{B(t)}+\frac{\dot{L}(t)}{L(t)}\right),\end{aligned} \qquad [10]$$

where

$$\frac{\partial F(t)}{\partial K(t)}\frac{K(t)}{Y(t)} = \text{the relative income share of capital} = \alpha\left(\bar{k}(t)\right),$$

$$\frac{\partial F(t)}{\partial L(t)}\frac{L(t)}{Y(t)} = \text{the relative income share of labor} = \beta\left(\bar{k}(t)\right), \text{ and}$$

$$\alpha\left(\bar{k}(t)\right)+\beta\left(\bar{k}(t)\right)=1, \text{ and } \bar{k}(t)=\frac{\bar{K}(t)}{\bar{L}(t)}=\frac{A(t)K(t)}{B(t)L(t)}.$$

To highlight the difference between the Hicks-neutral case and the general factor-augmenting (biased) case, we may denote the relative shares of capital and labor as: $\alpha^B\left(\bar{k}(t)\right)$ and $\beta^B\left(\bar{k}(t)\right)$ for the general factor-augmenting type, and $\alpha^N\left(k(t)\right)$ and $\beta^N\left(k(t)\right)$ for the Hicks-neutral case.

Using these definitions, equation [10] may be written as:

$$\frac{\dot{Y}(t)}{Y(t)} = \alpha^B\left(\bar{k}(t)\right)\frac{\dot{A}(t)}{A(t)}+\beta^B\left(\bar{k}(t)\right)\frac{\dot{B}(t)}{B(t)}+\alpha^B\left(\bar{k}(t)\right)\frac{\dot{K}(t)}{K(t)}+\beta^B\left(\bar{k}(t)\right)\frac{\dot{L}(t)}{L(t)} \qquad [10']$$

for the factor-augmenting type, and

$$\frac{\dot{Y}(t)}{Y(t)} = \frac{\dot{T}(t)}{T(t)}+\alpha^N\left(k(t)\right)\frac{\dot{K}(t)}{K(t)}+\beta^N\left(k(t)\right)\frac{\dot{L}(t)}{L(t)} \qquad [10'']$$

for the Hicks-neutral case, where $A(t) \equiv B(t) \equiv T(t)$ and $Y(t)=T(t)F\left[K(t), L(t)\right]$.

For any given value of $\dot{Y}(t)/Y(t)$, we have

$$\alpha^B\left(\bar{k}(t)\right)\frac{\dot{A}(t)}{A(t)}+\beta^B\left(\bar{k}(t)\right)\frac{\dot{B}(t)}{B(t)}=\frac{\dot{Y}(t)}{Y(t)}-\left(\alpha^B\left(\bar{k}(t)\right)\frac{\dot{K}(t)}{K(t)}+\beta^B\left(\bar{k}(t)\right)\frac{\dot{L}(t)}{L(t)}\right) \quad [11]$$

and

$$\frac{\dot{T}(t)}{T(t)}=\frac{\dot{Y}(t)}{Y(t)}-\left(\alpha^N\left(k(t)\right)\frac{\dot{K}(t)}{K(t)}+\beta^N\left(k(t)\right)\frac{\dot{L}(t)}{L(t)}\right). \quad [12]$$

Unless $A(t) \equiv B(t) \equiv T(t)$, we have $\alpha^B\left(\bar{k}(t)\right)\neq\alpha^N\left(k(t)\right)$ and $\beta^B\left(\bar{k}(t)\right)\neq\beta^N\left(k(t)\right)$. Hence we have "*theoretical inequality*" between equations [11] and [12].

7. Equations [11] and [12] are also linked by an important statistical (or empirical) identity. We have no *a priori* knowledge about the existence and magnitudes of $A(t)$ and $B(t)$. This means that we have no *a priori* knowledge about whether or not capital's income share (also labor's income share) is affected by $A(t)$ and $B(t)$. In other words, we cannot identify *a priori* whether the observed share of capital α is α^N or α^B, and whether that of β is β^N or β^B .

In working with the empirical estimation of $\dot{T}(t)/T(t)$ using the Solow-Kendrick method (equation [12]), one may be, in effect, estimating equation [11]. Thus equations [11] and [12] may coincide with each other. Hence, the estimated value of $\dot{T}(t)/T(t)$, $\left.\dot{T}(t)/T(t)\right|_{\text{estimated}}$ by equation [11] must be identical with the estimated value of the weighted sum of $\dot{A}(t)/A(t)$ and $\dot{B}(t)/B(t)$, weights given by the relative income shares, which are affected by $A(t)$ and $B(t)$, or by $\bar{k}(t)=A(t)K(t)/B(t)L(t)$. Hence,

$$\left.\frac{\dot{T}(t)}{T(t)}\right|_{\text{estimated}}\equiv\alpha^B\left(\bar{k}(t)\right)\frac{\dot{A}(t)}{A(t)}+\beta^B\left(\bar{k}(t)\right)\frac{\dot{B}(t)}{B(t)}. \quad [13]$$

We shall call equation [13] the "*empirical identity*." This states that the percentage change of the estimated Hicks-neutral technical change factor or TFP is always equal to the weighted sum of the percentage changes of the biased technical change factors, where the weights are given by their observed relative income shares.

(2) More than total productivity

8. One might argue that as long as we know $\dot{T}(t)/T(t)$, we do not have to be bothered with the relative efficiencies of capital and labor, $\dot{A}/A$ and $\dot{B}/B$. Nevertheless, the

relative efficiencies are exactly the point. There may be an infinitely large number of different combinations between $\dot{A}/A$ and $\dot{B}/B$ that satisfy equation [12]. For example, $\dot{A}/A$ can and may be negative, while $\dot{B}/B$ may be positive and large, so that $\dot{T}(t)/T(t)$ can still be positive. (See Subsection III-4 for the Japanese estimate.)

A negative $\dot{A}/A$ value has a profound implication in terms of R&D or innovation policy. This is the reason why we need the analysis of biased technical change. Estimating only TFP does not give the full story behind the country's economic performance and productivity growth.

II-3. Equilibrium Growth and Stability under Biased Technical Change

9. In this subsection, succeeding the theoretical framework of Sato (2006), we present the equilibrium growth rate and stability condition for the economy with biased technical change.

Let $Y(t) = F\left[K(t), L(t)\right]$ be the production function before technical change. To distinguish the production function after the factor-augmenting type of technical change from the production function before the technical change, we may denote the function as $\bar{Y}(t)$ so that

$$\bar{Y}(t) = F\left[\bar{K}(t), \bar{L}(t)\right], \qquad [2'']$$

where $\bar{K}(t) = A(t)K(t)$, $\bar{L}(t) = B(t)L(t)$, and $\bar{Y}(t)$ is output after technical change. This equation can be viewed as the production function after K has been transformed to $\bar{K}$ and L to $\bar{L}$. To begin with the simplest case, it may be assumed that labor and its efficiency factor are both exogenously given as

$$\frac{\dot{\bar{L}}}{\bar{L}} = \frac{\frac{d}{dt}(BL)}{BL} = \frac{\dot{B}}{B} + \frac{\dot{L}}{L} = b + n = \lambda > 0, \qquad [14]$$

where b = the growth rate of labor-augmenting technical change and n = the growth rate of labor.

Assume $\dot{\bar{K}}$ is endogenously determined by

$$\dot{\bar{K}} = \tfrac{d}{dt}(AK) = s\bar{Y}, \quad 1 > s > 0$$

where s is a fraction of output (or income) $\bar{Y}$ used to create additional effective capital.

If we define output by effective capital as $\bar{y} = \bar{Y}/\bar{K} = \bar{Y}/AK$, then by dividing $\dot{\bar{K}}$ by $\bar{K}$, and using $\dot{\bar{K}} = s\bar{Y}$, we get

$$\frac{\dot{\bar{K}}}{\bar{K}} = \frac{s\bar{Y}}{\bar{K}} = \frac{s\bar{Y}}{AK} = s\bar{y} . \qquad [15]$$

Using the capital-labor ratio in efficiency units

$$\bar{k}(t) = \frac{\bar{K}(t)}{\bar{L}(t)} = \frac{A(t)K(t)}{B(t)L(t)},$$

we may write

$$\begin{aligned} \frac{\dot{\bar{k}}}{\bar{k}} &= \frac{\dot{\bar{K}}}{\bar{K}} - \frac{\dot{\bar{L}}}{\bar{L}} = \frac{s\bar{Y}}{\bar{K}} - \lambda \\ &= sF\left(1, \frac{\bar{L}}{\bar{K}}\right) - \lambda = sF\left(1, \frac{1}{\bar{k}}\right) - \lambda = sf\left(\frac{1}{\bar{k}}\right) - \lambda . \end{aligned} \qquad [16]$$

A growth path with factor-augmenting technical change is stable if

$$\frac{d\left(\frac{\dot{\bar{k}}}{\bar{k}}\right)}{\bar{k}} = s\frac{df}{d\bar{k}} = -s\frac{df}{d\left(\frac{1}{\bar{k}}\right)}\bar{k}^2 < 0 . \qquad [17]$$

Because $df/d\left(1/\bar{k}\right)$ (= the marginal product of effective labor) is always positive, the above is always satisfied. Thus, a balanced path is stable under the endogenous factor-augmenting type of technical change.

Whenever $\dot{\bar{k}}/\bar{k}$ is positive, $\bar{k}$ must be increasing, whereas whenever $\dot{\bar{k}}/\bar{k}$ is negative, $\bar{k}$ must be decreasing. When $\bar{k} = \bar{k}^*$, $\dot{\bar{k}}/\bar{k} = 0$, which implies that *sf* must be exactly equal to λ. At $\bar{k} = \bar{k}^*$, the growth rate of effective capital is identical to the growth rate of effective labor, i.e., $\dot{\bar{K}}/\bar{K} = \dot{\bar{L}}/\bar{L}$.

10. This stability condition can also be applied when the efficiency improvement of labor depends on the amount of expenditure devoted to education and training. Then equation [14] must be modified to

$$\frac{\dot{\bar{L}}}{\bar{L}} = \frac{\frac{d}{dt}(BL)}{BL} = \frac{\dot{B}}{B} + \frac{\dot{L}}{L} = s_B\frac{\bar{Y}}{\bar{L}} + n .$$

Labor efficiency now depends on the amount of money spent for improvement purposes. It is determined by a fraction (s_B) of income per labor measured in its efficiency unit. With this endogeneity assumption, equation [16] must be changed to

$$\begin{aligned}\frac{\dot{\bar{k}}}{\bar{k}} &= \frac{\dot{\bar{K}}}{\bar{K}} - \frac{\dot{\bar{L}}}{\bar{L}} = \frac{s\bar{Y}}{\bar{K}} - \frac{s_B\bar{Y}}{\bar{L}} - n \\ &= sF\left(1, \frac{1}{\bar{k}}\right) - s_B F\left(\bar{k}, 1\right) - n \quad \text{, where}\end{aligned}$$

$1 > s + s_B > 0$.

Letting $F\left(1,\ 1/\bar{k}\right) = f\left(1/\bar{k}\right)$ and $F\left(\bar{k}, 1\right) = g\left(\bar{k}\right)$, the above becomes

$$\frac{\dot{\bar{k}}}{\bar{k}} = sf\left(\frac{1}{\bar{k}}\right) - s_B g\left(\bar{k}\right) - n.$$

The stability condition is satisfied if

$$\frac{d\left(\frac{\dot{\bar{k}}}{\bar{k}}\right)}{\bar{k}} = s\frac{df}{d\bar{k}} - s_B\frac{dg}{d\bar{k}} < 0. \qquad [18]$$

The first term $s \cdot df/d\bar{k}$ is negative (see equation [17]). The second term is always positive because $dg/d\bar{k}$ is the marginal product of effective capital. Hence equation [18] is automatically satisfied. Introducing endogenous labor-augmentation makes the system more stable.

11. To apply the balanced growth condition to the actual data, we rearrange equation [11] as

$$\begin{aligned}\frac{\dot{\bar{Y}}}{\bar{Y}} &= \alpha\left(\frac{\dot{A}}{A} + \frac{\dot{K}}{K}\right) + \beta\left(\frac{\dot{B}}{B} + \frac{\dot{L}}{L}\right) \\ &= \alpha\frac{\dot{\bar{K}}}{\bar{K}} + \beta\frac{\dot{\bar{L}}}{\bar{L}}.\end{aligned} \qquad [19]$$

At steady-state $\bar{k} = \bar{k}^*$, $\left(\dot{\bar{K}}/\bar{K}\right)^* = \left(\dot{\bar{L}}/\bar{L}\right)^*$ holds. Because $\alpha + \beta = 1$, if we put $\left(\dot{\bar{K}}/\bar{K}\right)^* = \left(\dot{\bar{L}}/\bar{L}\right)^* = G^*$, equation [19] becomes

$$\left(\frac{\dot{\bar{Y}}}{\bar{Y}}\right)^* = \alpha\left(\frac{\dot{\bar{K}}}{\bar{K}}\right)^* + \beta\left(\frac{\dot{\bar{L}}}{\bar{L}}\right)^* = \alpha G^* + \beta G^* = G^*,$$

such that

$$\left(\frac{\dot{\bar{Y}}}{\bar{Y}}\right)^* = \left(\frac{\dot{\bar{K}}}{\bar{K}}\right)^* = \left(\frac{\dot{\bar{L}}}{\bar{L}}\right)^* = G^* \quad [20]$$

is the condition for the stable growth. In Subsection III-6, we examine the economies of Japan and the United States to see whether they satisfy this condition.

III. Applications to the US and Japanese Data

III-1. Tests of Non-Unity of σ

12. Before we conduct the estimation of biased technical progress, we must ensure that the production functions are not Cobb-Douglas. If the function is Cobb-Douglas, there is no way to separate *A* and *B*. Also, we have to determine whether technical progress is Hicks-neutral. If it is so, *A* should always be equal to *B*, which means we have no need to estimate the biased technical growth.

To determine whether the production functions are Cobb-Douglas, we first use test 1: average elasticity of substitution method. We then apply test 2: the Hicks-neutrality test to examine the fitness of the data of both countries.

(1) Test 1: Average elasticity of substitution method

13. This is a test introduced by Sato (1970: 192-193) to identify whether the production function of each country is Cobb-Douglas type. Define $z = Y/L$, $x = L/K$ and $R(z/w)$ to be equal to the ratio of $\dot{z}/z$ to $\dot{w}/w$, then from equation [7], we get

$$R\left(\frac{z}{w}\right) = \frac{\sigma}{1+(\sigma-1)\dfrac{\dot{B}/B}{\dot{z}/z}}. \quad [21]$$

Also, define $R(y/r)$ as the ratio of $\dot{y}/y$ to $\dot{r}/r$, and $R(x/\omega)$ as the ratio of $\dot{x}/x$ to $\dot{\omega}/\omega$. Then,

$$R\left(\frac{y}{r}\right)=\frac{\sigma}{1+(\sigma-1)\dfrac{\dot{A}/A}{\dot{y}/y}}$$ [22]

$$R\left(\frac{x}{\omega}\right)=\frac{\sigma}{1+\dfrac{(\sigma-1)\left(\dot{A}/A-\dot{B}/B\right)}{\dot{x}/x}}.$$ [23]

If $\sigma = 1$, then $R(z/w)$, $R(y/r)$, and $R(x/\omega)$ should be, on the average, the same and equal to unity, regardless of whether or not A and B are the same. That is,

$$\bar{R}\left(\frac{z}{w}\right)=\bar{R}\left(\frac{y}{r}\right)=\bar{R}\left(\frac{x}{\omega}\right)=1,$$ [24]

where the upper-bar indicates the average value of R's. Therefore, equation [24] may be used as a test of the Cobb-Douglas function.

The average values calculated are presented in Table 1.

In both countries' cases, the three variables are very different from one another and equation [24] does not hold. Therefore, we can conclude σ is not unity, which means that the production functions of both countries are not Cobb-Douglas.

Table 1. Average Elasticity of Substitution Method Results

	Japan	United States
$\bar{R}(z/w)$	1.0366 (0.9358)	0.7178 (1.6730)
$\bar{R}(y/r)$	0.6831 (0.8642)	0.5133 (1.4028)
$\bar{R}(x/\omega)$	0.6445 (0.9227)	0.4687 (2.4109)

Notes: Standard Deviation is in parenthesis. In the US case, extreme 4 data are excluded from $R(z/w)$, 1 and 2 data are excluded from $R(y/r)$ and $R(x/\omega)$ respectively.

(2) Test 2: Test of Hicks-neutrality

14. Next we determine whether the technical progress is Hicks-neutral. When technical progress is biased, the following fundamental equations hold[6].

[6] See Sato (1970: 183) for the discussion on these fundamental relations.

$$\frac{\dot{w}}{w}=\frac{\dot{B}}{B}-\frac{\alpha}{\sigma}\left(\frac{\dot{B}}{B}-\frac{\dot{A}}{A}-\frac{\dot{k}}{k}\right) \qquad [25]$$

$$\frac{\dot{r}}{r}=\frac{\dot{A}}{A}+\frac{\beta}{\sigma}\left(\frac{\dot{B}}{B}-\frac{\dot{A}}{A}-\frac{\dot{k}}{k}\right), \qquad [26]$$

where $k = 1/x = K/L$.

When technical progress is Hicks-neutral, equations must satisfy the two equations below:

$$\frac{\dot{w}}{w}=\frac{\dot{T}}{T}+\frac{\alpha}{\sigma}\frac{\dot{k}}{k} \qquad [25']$$

$$\frac{\dot{r}}{r}=\frac{\dot{T}}{T}-\frac{\beta}{\sigma}\frac{\dot{k}}{k}, \qquad [26']$$

where $\dot{T}/T=\dot{A}/A=\dot{B}/B$. In this case the two regressional estimates of $\dot{T}/T$, which are between $\dot{w}/w$ and $\dot{k}/k$, and between $\dot{r}/r$ and $\dot{k}/k$, should be equal. Results are in Table 2.

Table 2. The Hicks-Neutrality Test Results

	Japan	United States
Average $\dot{T}/T$	2.10%	1.06%
α	0.2934	0.3133
β	0.7066	0.6867
Regression Results	$\frac{\dot{w}}{w}=-0.0086\quad+0.7938\frac{\dot{k}}{k}$ (–2.7401) (20.9474) R^2=0.9126 Estimated $\dot{T}/T$ = −0.86% Estimated σ = 0.3696	$\frac{\dot{w}}{w}=0.0139\quad+0.0970\frac{\dot{k}}{k}$ (5.0320) (0.9332) R^2=0.0203 Estimated $\dot{T}/T$ = 1.39% Estimated σ = 3.2343
	$\frac{\dot{r}}{r}=0.0019\quad-0.4658\frac{\dot{k}}{k}$ (0.1312) (–2.6095) R^2=0.1395 Estimated $\dot{T}/T$ = 0.19% Estimated σ = 1.5170	$\frac{\dot{r}}{r}=0.0218\quad-1.1324\frac{\dot{k}}{k}$ (3.3915) (–4.6888) R^2=0.3436 Estimated $\dot{T}/T$ = 2.18% Estimated σ = 0.6064

In both countries' cases, the coefficients of determinations are very low, except for Japan's $\dot{w}/w$; $\dot{T}/T$ obtained from the two equations for each country are very different. Thus, these results suggest that technical progress is nonneutral. We are now ready to estimate production functions with biased technical change.

III-2. Estimates of Production Functions

15. We take four steps in the estimation of the production functions with biased technical change for Japan and the United States. We should note here that there are always inevitable limitations in the application of the theory. In our case, all the theoretical equations are time continuous, while actual data are discrete (in our case, annual). Thus, we should approximate the derivatives by the difference. To do so, for a year *t*, we substitute the growth rate $\dot{Y}(t)/Y(t)$ for $\Delta Y(t)/Y(t) = \left(Y(t+1) - Y(t)\right)/Y(t)$. In the remainder of this paper, we continue to use the derivatives even in the application, for the sake of simplicity.

(1) Estimation of Hicks-neutral technical progress

As discussed in Section II, we need to know the elasticity of substitution, σ(t), in advance of estimating the growth rate of biased technical progress $\dot{A}/A$ and $\dot{B}/B$. For the purpose of finding out the elasticity, we first derive Solow-Kendrick TFP for each country.

The production function with Hicks-neutral technical progress should take the form of equation [3]. As we have observed, with the share of capital $\alpha(t) = r(t)K(t) / Y(t)$ and that of labor $\beta(t) = w(t)L(t) / Y(t)$, the growth rate of *Y* is expressed as

$$\frac{\dot{Y}(t)}{Y(t)} = \frac{\dot{T}(t)}{T(t)} + \alpha(t)\frac{\dot{K}(t)}{K(t)} + \beta(t)\frac{\dot{L}(t)}{L(t)}. \qquad [27]$$

If we further define $z = Y/L, \quad k = K/L$, so that $\dot{z}/z = \dot{Y}/Y - \dot{L}/L$ $\dot{k}/k = \dot{K}/K - \dot{L}/L$, then, by rearranging equation [27], we get

$$\frac{\dot{T}(t)}{T(t)} = \frac{\dot{z}(t)}{z(t)} - \alpha(t)\frac{\dot{k}(t)}{k(t)}. \qquad [28]$$

With the data divided by time period into Period I (1960–1989) and Period II (1990–2004), the period averages of observed relative share of factor inputs used in equation [28] are shown in Table 3. The period averages of estimated $\dot{T}(t)/T(t)$ are shown in Table 4, together with other variables. The period averages for the period

t = [0, S] are calculated as $\left(\dot{T}/T\right)_{AVG} = \left(1/S\right)\sum_{t=0}^{S}\left(\dot{T}(t)/T(t)\right)$.

Table 3. Average Relative Share of Input Factors

	Japan			United States		
	1960-2004	1960-1989	1990-2004	**1960-2004**	1960-1989	1990-2004
Average Relative Share of Capita α	**29.34%**	31.60%	24.82%	**31.33%**	30.80%	32.39%
Average Relative Share of Labor β	**70.66%**	68.40%	75.17%	**68.67%**	69.20%	67.61%
Total	**100%**	100%	100%	**100%**	100%	100%

Table 4. Growth Rate of Hicks-Neutral Technical Change and Other Factors

	Japan			United States		
	1960-2004	1960-1989	1990-2004	**1960-2004**	1960-1989	1990-2004
Growth Rate of Output $\dot{Y}/Y$	**4.65%**	6.35%	1.03%	**3.08%**	3.05%	3.13%
Growth Rate of Hicks Neutral Technical Change $\dot{T}/T$	**2.13%**	2.91%	0.45%	**1.07%**	0.90%	1.43%
Growth Rate of Capital $\dot{K}/K$	**7.32%**	9.25%	3.18%	**3.31%**	3.58%	2.72%
Growth Rate of Labor $\dot{L}/L$	**0.28%**	0.56%	-0.31%	**1.39%**	1.49%	1.19%
Growth Rate of Output Per Labor $\dot{z}/z$	**4.35%**	5.76%	1.34%	**1.66%**	1.54%	1.92%

16. Given these results, we take a bird's eye view to compare the performance over 44 years of the economies of Japan and the US. From 1960 through 2004, the average annual growth rate $\dot{Y}/Y$ for Japan was 4.65%, while that for the US was 3.08%. In the same period, the labor increased only 0.28% per annum in Japan, while it increased 1.39% in the US.

The Japanese economy grew much faster with a much lower growth rate of labor. From Table 5, we can learn that in Japan, the relative contribution of labor $\left(\beta \cdot \left(\dot{L}/L\right)\right)/\left(\dot{Y}/Y\right)$ was just 4.30% of total GDP growth. Although it turned negative in Period II, this downturn may have been caused not by population decline but by the lack of effective demand. In lieu of labor contribution, the increase of capital $\dot{K}/K$ and technical progress $\dot{T}/T$ supported high economic growth. Capital contributed as much as 46.14% to the GDP growth, and technical progress contributed nearly as much (45.76%). Actually, Japan's capital increase (annually 7.32%) was more than twice that of the US (annually 3.31%). The rate of Hicks-neutral technical change was 2.13% per annum, also nearly double that of the US (1.07%). We found that the engines of Japanese economic growth were booming capital investment and properly combined technical progress of capital and labor.

Table 5. Relative Contributions to Economic Growth by Technical Change and Factor Inputs

	Japan			United States		
	1960-2004	1960-1989	1990-2004	**1960-2004**	1960-1989	1990-2004
$\frac{\dot{T}}{T} \Big/ \frac{\dot{Y}}{Y}$	45.76%	45.87%	44.30%	34.80%	29.58%	45.69%
$\left(\alpha \frac{\dot{K}}{K}\right) \Big/ \frac{\dot{Y}}{Y}$	46.14%	46.05%	76.90%	33.65%	36.11%	28.15%
$\left(\beta \frac{\dot{L}}{L}\right) \Big/ \frac{\dot{Y}}{Y}$	4.30%	6.03%	-22.60%	31.09%	33.73%	25.71%
Statistical Adjustment	3.80%	2.05%	1.41%	0.46%	0.58%	0.45%
Total	**100%**	100%	100%	**100%**	100%	100%

Notes: To apply actual data to the theory, we have to approximate differentiation by difference. Thus the weighted sum of the increase of each factor is not equal to the growth rate. We show the discrepancy as "Statistical Adjustment"

These results indicate that the source of Japan's economic growth was quality improvement—rather than quantity increase—of population and labor force. In contrast, the source of economic growth for the US was quantity increase—rather than quality improvement—of population and labor force. The growth rate of output per unit of labor $\dot{z}/z$ was only four-tenths that of Japan (Table 1). The US economic growth was sustained by technical progress and the increase of the labor force.

We should note that in the United States, the relative contributions to economic growth of technical progress, capital increase, and labor increase are balanced. The contribution rates are 34.8%, 33.65% and 31.09%, respectively. Discussion on this balanced growth appears in Subsection III-6. In a country blessed with abundant land and natural resources, population increase played a major role in the US economic growth. Population increase made economic expansion possible without much improvement in the efficiency of factors.

(2) Deriving average elasticity of substitution σ^N

17. Next, we estimate average elasticity of substitution under the assumption of Hicks-neutral technical progress, σ^N.

For a year t, σ^N is estimated using

$$\sigma^N(t) = \frac{d\left(\dfrac{K(t)}{L(t)}\right) \Big/ \dfrac{K(t)}{L(t)}}{d\left(\dfrac{w(t)}{r(t)}\right) \Big/ \left(\dfrac{w(t)}{r(t)}\right)} = \frac{\dfrac{\dot{K}(t)}{K(t)} - \dfrac{\dot{L}(t)}{L(t)}}{\dfrac{\dot{w}(t)}{w(t)} - \dfrac{\dot{r}(t)}{r(t)}}.$$

The average elasticity of substitution for the period [0, S] is calculated as

$$\sigma^N_{AVG} = \frac{1}{S}\sum_{t=0}^{S} \sigma^N(t). \qquad [29]$$

Some of the σ_t^N s give extraordinarily high or negative values. Since σ in developed countries are known to range $0 < \sigma < 1$, we excluded negatives and those over one from the summation in equation [29].

The estimated σ^N for Japan from 1960 to 2004 is 0.57. In Period I only it is 0.63, and in Period II only it is 0.50. For the United States, the average elasticity of substitution for these periods is 0.46, 0.51, and 0.38, respectively. The results are also appear later in Table 6 (Subsection III-3).

(3) Estimation of CES functions with Hicks-neutral technical change

18. Since we discovered production functions in both countries are not Cobb-Douglas type and there are no trends of σ correlating with the values k or time t, we assume the constant elasticity of substitution (CES) production function and identify how σ^N fits the actual data. Before we directly estimate the production function with factor-augmenting (biased) technical change, we estimate the function with Hicks-neutral technical change in order to make a comparison.

With Hicks-neutral technical change, the function should take the form of

$$Y^N(t) = T(t)\left[\alpha K(t)^{-\rho^N} + \beta L(t)^{-\rho^N}\right]^{-1/\rho^N}, \qquad [30]$$

where $\sigma^N = 1/(1+\rho^N)$. $T(t)$ is assumed to grow at a constant rate during a period, which is given as the average of each $\dot{T}(t)/T(t)$ estimated in . We also assume Cobb-Douglas α and β are constant throughout the period, and we apply period averages of observed α and β.

(4) Estimation of CES functions with factor-augmenting technical change

We are now ready to estimate the CES function with factor-augmenting (biased) technical change. We substitute the estimates of elasticity σ^N into equations [6] and [7] to derive $\dot{A}/A$ and $\dot{B}/B$. Theoretically, the elasticity of substitution of factor-augmenting technical change has to be stated as equation [31] because when technical progress is nonneutral, the value of the elasticity itself is influenced by the efficiencies of capital and labor.[7] We thus have the following equation:

$$\sigma^B = \frac{d\left(\frac{AK}{BL}\right) \Big/ \frac{AK}{BL}}{d\left(\frac{\partial F/\partial BL}{\partial F/\partial AK}\right) \Big/ \frac{\partial F/\partial BL}{\partial F/\partial AK}} . \qquad [31]$$

In view of the fact that we cannot observe σ^B directly, we use σ^N instead. As presented in Appendix (VI-3), in the simulation of $Y^B(t)$, variational changes of σ around σ^N do not give significant deviation to their results. Thus, σ^N qualifies to be the proxy of σ^B.

Then, the CES function takes the form of

$$Y^B(t) = \left[\alpha\left(A(t)K(t)\right)^{-\rho^N} + \beta\left(B(t)L(t)\right)^{-\rho^N}\right]^{-1/\rho^N} . \qquad [32]$$

Estimated $Y^B(t)$ summarizes our model. It represents both the form of the production function and the biasedness of technical change.

In this way, we will obtain two series, Y^N and Y^B.

[7] See Sato (1970) for detailed discussion on the elasticity of substitution of factor-augmenting technical change.

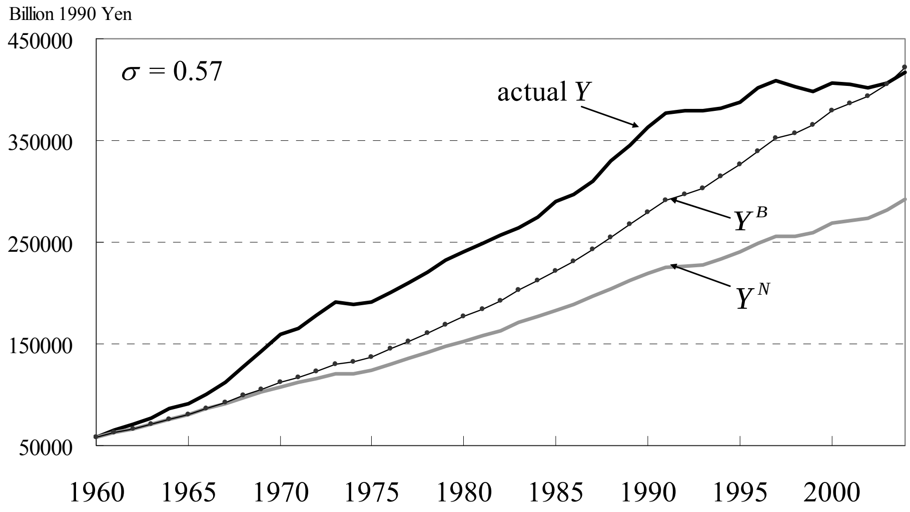
III-3. Simulation Results

19. Equipped with average σ^N , $\dot{A}/A$, and $\dot{B}/B$ (shown in Table 6 in Subsection III-4), we estimated Y^N and Y^B . CES production functions with Hicks-neutral technical change Y^N are plotted with thick gray lines in Figures 1 and 2. As our tests have suggested, the technical progress in both countries may not be Hicks-neutral. Hence, Y^N deviates far from actual *Y*. Hicks-neutral technical change assumes the rate of the efficiency of capital and labor changing at equal rates, which is not true for Japan and the US.

As for the estimated CES production functions with biased technical change Y^B, shown by thin lines with markers in Figures 1 and 2, they all fit much better than do Y^N. This supports our view that the economies of Japan and the United States both experienced biased technical growth. Also, it suggests that estimation of TFP does not suffice to diagnose the economic performance and to prescribe any policy for either of these countries.

Figure 1. Estimated Output of Japan

Panel 1. 1960–2004



Panel 2. 1960–1989 and 1990–2004

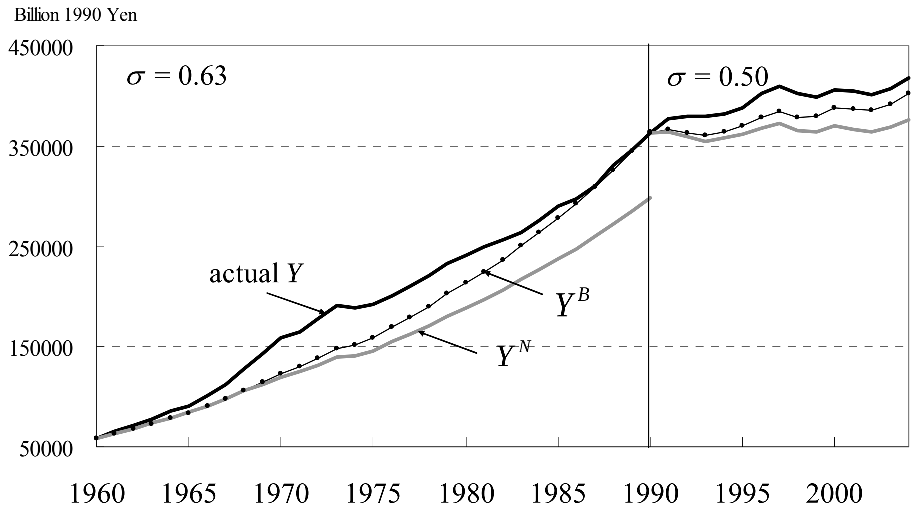
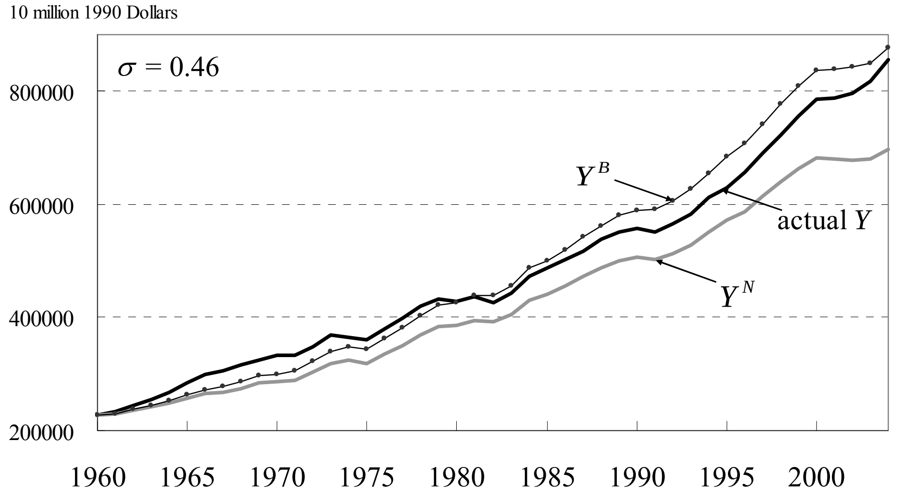
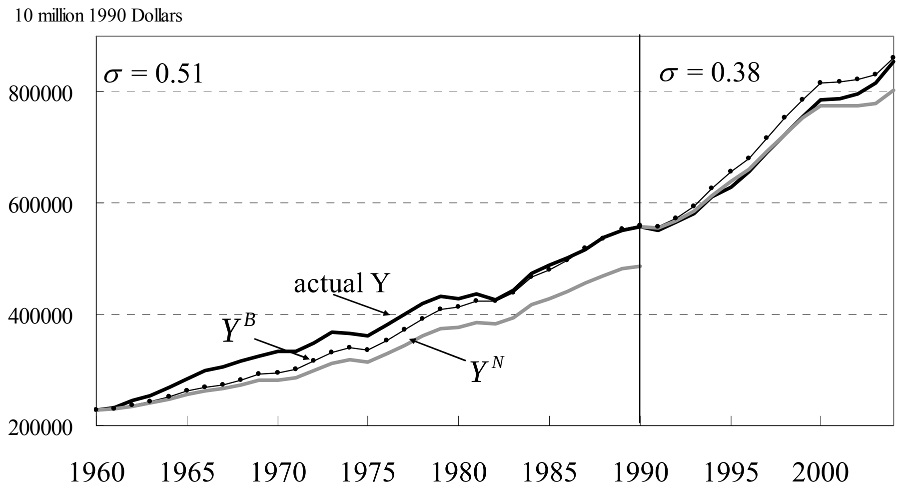


Figure 2. Estimated Output of the United States

Panel 1. 1960–2004



Panel 2. 1960–1989 and 1990–2004



III-4. Biased Technical Change of Japan and the United States

20. As our neutrality tests and simulation results suggested, the estimation with neutral technical change lacks the ability to explain the actual economic growth. Conversely, the factor-augmenting (biased) technical change explains further the characteristics of each economy. Once we know the growth rate of efficiency of each factor ($\dot{A}/A$ and $\dot{B}/B$), we are able to more adequately tailor policies to raise the total efficiency ($\dot{T}/T$).

Tables 6 and 7 summarize the average growth of efficiency of factors. Both countries' σ is less than one, and $\dot{A}/A$ is smaller than $\dot{B}/B$ in all periods. According to the definition in Subsection II-1, both countries experienced labor-saving technical progress.

In Japan, labor-saving technical progress helped the economic growth despite labor itself declining. Japan's labor-saving technical progress offset the low labor increase. The growth rate of labor efficiency $\dot{B}/B$ in Japan for 44 years was annually 3.86%, a figure more than double that of the US (1.74%). This labor efficiency sustained Japan's high growth. The Japanese economy developed without depending too much on its population growth.

Another fact revealed in the analysis on biased technical change is that Japan experienced over investment. As implied in the economic conservation law[8], overly rapid capital accumulation lowers the efficiency of capital. This mainly happened in Period I, when the growth rate of capital was as high as 9.25%. As we will argue in Subsection III-6, the income/capital ratio in Japan was much higher than it needed to be to ensure Japan's stable growth.

21. Now we focus on Period II (1990–2004), which includes the Japan's lost decade and the United States' new economy. As is well known, the growth rate of US surpassed that of Japan in Period II. In Japan, the growth rate of GDP, labor, and labor efficiency all declined in Period II compared to the rates in Period I. The growth rate of labor efficiency slowed to 1.01% from 5.11% in Period I. This 4.1 percentage point decline was much

[8] The income-capital conservation law is summarized in Sato (1985).

larger than that of labor (a decline of 0.87 points, to -0.31 % from 0.56%.)

Capital efficiency continuously decreased during 1960–2004, although in Period II it showed a scant 0.27 point improvement to -1.36% from -1.63%. This fact indicates that Japan's lost decade suffered from over investment and consecutive accumulation of bad loans. To raise total productivity, Japan needs to turn the capital efficiency toward the positive, as was done in the US, and it needs to raise labor efficiency to a greater extent.

In the United States, capital efficiency turned moderately positive in Period II to 0.08% from -0.59%. Capital efficiency growth is very close to zero, so we can assume Harrod-neutral growth for the US economy.

The idea of biased technical change itself is not new, but not many applications have been done so far. Our findings revealed that analyzing only TFP or Hicks-neutral technical change is not sufficient as a basis for evaluating the economic performance of Japan and the United States.

Table 6. Growth Rate of Biased Technical Change

	Japan			United States		
	1960-2004	1960-1989	1990-2004	**1960-2004**	1960-1989	1990-2004
Growth Rate of Hicks Neutral Technical Change $\dot{T}/T$	**2.13%**	2.91%	0.45%	**1.07%**	0.90%	1.43%
Estimated Elastisity of Substitution σ^N_{AVG}	**0.57**	0.63	0.50	**0.46**	0.51	0.38
Growth Rate of Capital Efficiency $\dot{A}/A$	**- 1.61%**	-1.63%	-1.36%	**-0.41%**	-0.59%	0.08%
Growth Rate of Labor Efficiency $\dot{B}/B$	**3.86%**	5.11%	1.01%	**1.74%**	1.56%	1.97%

Table 7. Relative Contributions of Hicks-Neutral Technical Change by Biased Technical Change

	Japan			United States		
	1960-2004	1960-1989	1990-2004	**1960-2004**	1960-1989	1990-2004
$\left(\alpha \frac{\dot{A}}{A}\right) \Big/ \frac{\dot{T}}{T}$	-22.18%	-17.67%	-74.09%	-11.96%	-20.18%	1.86%
$\left(\beta \frac{\dot{B}}{B}\right) \Big/ \frac{\dot{T}}{T}$	128.14%	119.97%	167.09%	111.44%	119.80%	92.95%
Statistical Adjustment	-5.95%	-2.30%	7.00%	0.52%	0.38%	5.19%
Total	**100%**	100%	100%	**100%**	100%	100%

III-5. Contrast in Response to Oil Crises

22. In this subsection, we contrast the economic response of the two countries toward external shocks, i.e., the two oil crises in 1973 and 1979. If it were not for deflationary pressures in Japan and the US, the recent hike in oil price would have caused another crisis. Looking ahead, due to complex international relationships around the Middle Eastern countries and policy changes in oil-producing South American countries, the worldwide crude oil supply could face shortages at any time. It is worth examining the response toward past price shocks.

The two oil crises affected both countries. We assume the time-lags of the shocks were the same to both countries, and compare the total data (with the oil crisis periods included) to the data with those years excluded (the years during lagged shocks are chosen as 1974–75 and 1980–82.) By this comparison, we can see how the two countries responded to the shocks in different ways. Table 8 lists the technical progress in each year with the averages for all years and for those excluding 1974–75 and 1980–82. Table 9 shows the average growth rates of other factors, also excluding those periods.

The Japanese response toward oil crises was superior to that of the United States. Especially in 1974 and 1975, Japan's growth rates of capital efficiency were considerably positive, which means that Japan overcame the price pressures by substituting capital for energy. Energy saving measures were developed quickly enough in Japan, an energy-scarce country. This did not happen in the United States, an energy-abundant country, where both factor efficiencies declined after the crises.

Table 8. Technical Progress with and without Oil Crises

	Japan			United States		
σ^N_{AVG}	0.57			0.46		
Rates of Technical Change	$\dot{A}/A$	$\dot{B}/B$	$\dot{T}/T$	$\dot{A}/A$	$\dot{B}/B$	$\dot{T}/T$
Average	-1.61%	3.86%	2.13%	-0.41%	1.74%	1.07%
Average excluding 1974-75,1980-82	-1.97%	4.39%	2.34%	0.10%	1.94%	1.36%
1961	-4.80%	14.24%	7.07%	-0.91%	3.18%	1.90%
1962	-0.16%	5.89%	3.81%	1.29%	4.20%	3.29%
1963	-0.75%	4.75%	3.02%	0.89%	2.60%	2.06%
1964	-1.31%	12.22%	7.45%	1.32%	4.09%	3.21%
1965	0.82%	1.77%	1.62%	0.48%	3.54%	2.56%
1966	-3.06%	9.32%	5.11%	1.46%	4.03%	3.22%
1967	-7.19%	13.13%	5.99%	-0.44%	1.27%	0.74%
1968	-6.42%	15.32%	7.28%	1.20%	1.79%	1.64%
1969	-2.26%	13.44%	7.49%	1.91%	-1.51%	-0.41%
1970	-5.21%	12.19%	5.33%	-5.10%	4.79%	1.75%
1971	-2.33%	0.80%	-0.12%	-0.56%	-1.49%	-1.17%
1972	-2.78%	8.01%	4.19%	0.98%	1.05%	1.03%
1973	0.99%	4.40%	3.29%	2.37%	1.49%	1.76%
1974*	5.44%	-6.00%	-1.43%	-3.23%	-2.15%	-2.48%
1975*	3.65%	-1.53%	0.31%	-8.57%	3.90%	0.11%
1976	-0.14%	1.46%	1.16%	0.87%	1.91%	1.60%
1977	1.70%	2.05%	2.02%	0.08%	1.62%	1.16%
1978	-6.75%	5.84%	2.29%	0.46%	1.52%	1.19%
1979	-7.82%	6.33%	2.29%	-1.12%	-0.23%	-0.51%
1980*	-5.50%	4.01%	1.26%	-3.22%	-0.46%	-1.33%
1981*	3.59%	0.15%	1.25%	-3.21%	1.28%	-0.11%
1982*	-1.35%	2.08%	1.02%	-3.74%	-1.62%	-2.29%
1983	0.62%	-0.82%	-0.29%	-3.01%	3.80%	1.75%
1984	-1.74%	4.30%	2.50%	1.97%	1.80%	1.85%
1985	-9.77%	7.88%	2.90%	-0.54%	1.94%	1.14%
1986	-2.76%	2.01%	0.52%	-0.22%	0.78%	0.46%
1987	-0.57%	2.37%	1.54%	1.08%	-0.02%	0.33%
1988	-0.99%	6.48%	4.14%	1.54%	1.89%	1.78%
1989	0.96%	2.44%	1.98%	-1.48%	1.43%	0.51%
1990	0.76%	2.74%	2.36%	0.13%	0.42%	0.34%
1991	2.74%	2.15%	2.28%	-2.63%	0.41%	-0.57%
1992	-2.04%	1.69%	0.82%	0.16%	2.04%	1.46%
1993	2.24%	-0.73%	0.19%	-0.34%	1.35%	0.82%
1994	1.48%	-0.93%	-0.27%	-1.19%	3.57%	2.09%
1995	0.94%	0.02%	0.27%	0.04%	0.19%	0.14%
1996	-4.28%	3.81%	1.82%	-1.34%	4.06%	2.27%
1997	-0.13%	0.86%	0.62%	0.85%	2.21%	1.75%
1998	-1.18%	-0.18%	-0.41%	4.15%	0.09%	1.49%
1999	-0.45%	-1.03%	-0.88%	2.18%	1.43%	1.69%
2000	0.95%	0.17%	0.36%	3.31%	1.01%	1.81%
2001	2.25%	-0.35%	0.30%	-2.14%	1.63%	0.41%
2002	-3.28%	0.73%	-0.19%	-1.58%	2.78%	1.38%
2003	-1.24%	1.14%	0.60%	-1.36%	4.45%	2.57%
2004	-13.71%	5.30%	0.86%	-0.80%	4.45%	2.73%

Notes: The $\dot{A}/A$ and $\dot{B}/B$ presented here are calculated from the σ^N for each country. We have also calculated the $\dot{A}/A$ and $\dot{B}/B$ from various values of σ. Interested readers may get the results upon request.

Table 9. Average Growth Rates with and without Oil Crises

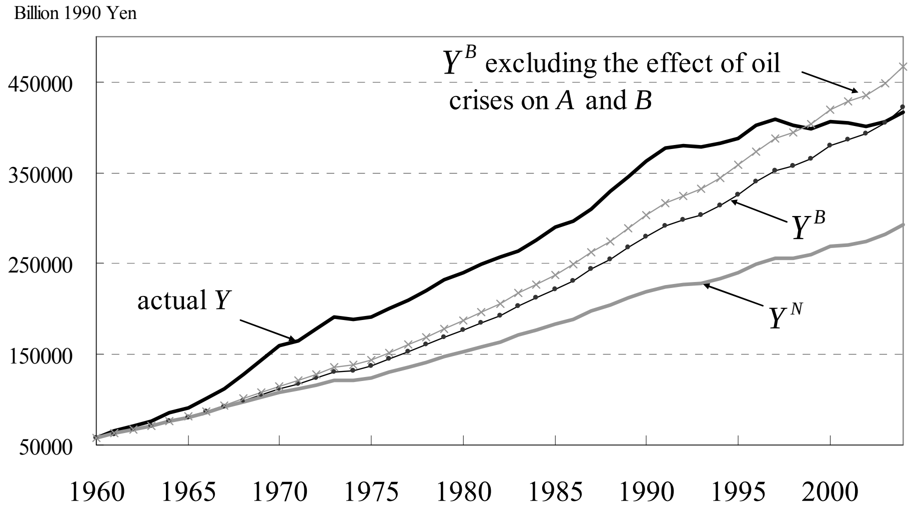
		Japan		United States	
		1960-2004	1960-2004 excl OS	1960-2004	1960-2004 excl OS
Growth Rate of Output	$\dot{Y}/Y$	4.65%	4.98%	3.08%	3.56%
Growth Rate of Hicks Neutral Technical Change	$\dot{T}/T$	2.13%	2.34%	1.07%	1.36%
Growth Rate of Capital	$\dot{K}/K$	7.32%	7.35%	3.31%	3.25%
Growth Rate of Labor	$\dot{L}/L$	0.28%	0.40%	1.39%	1.67%
Growth Rate of Output Per Labor	$\dot{z}/z$	4.35%	4.56%	1.66%	1.86%
Growth Rate of Capital Efficiency	$\dot{A}/A$	- 1.61%	-1.97%	-0.41%	0.10%
Growth Rate of Labor Efficiency	$\dot{B}/B$	3.86%	4.39%	1.74%	1.94%

Notes: The years excluded are 1974–75 and 1980–82.

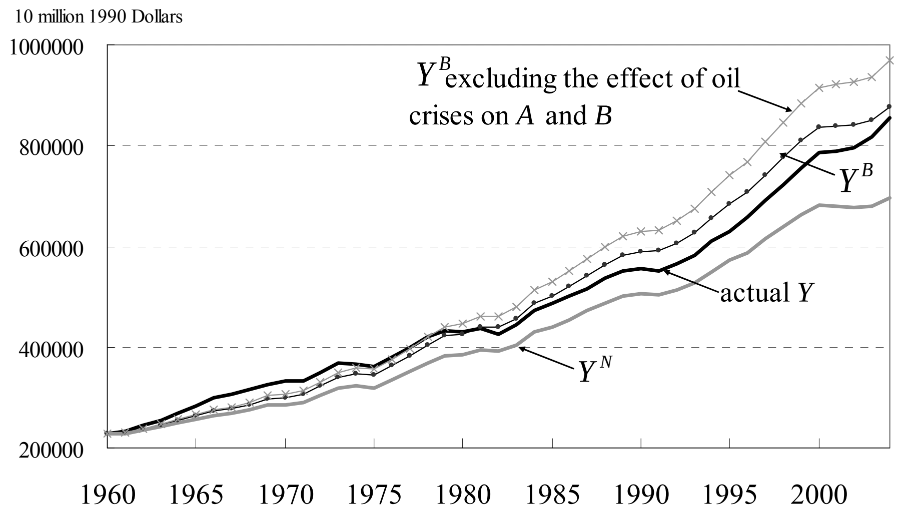
Needless to say, if the efficiency of factors had not dropped because of the crises, both economies would have grown faster. The estimation of the efficiencies without the effects of oil crises are plotted in Figure 3.

Figure 3. Performance Excluding the Effect of Oil Crises

Panel 1. Japan



Panel 2. United States



III-6. Economic Performance Revisited

23. In this subsection, we test the equilibrium condition derived in Subsection II-3 to determine each economy's performance.

For simplicity, we take three average growth rates, that of Period I (1960–1989), Period II (1990–2004) and the whole period (1960–2004), noted by i = 1, 2, and W, respectively.

From equations [15] and [19], we can derive following two equations.

$$\begin{cases} \left(\dfrac{\dot{\overline{Y}}}{\overline{Y}}\right)_i = \alpha_i s_i \overline{y}_i + \beta_i \left(\dfrac{\dot{\overline{L}}}{\overline{L}}\right)_i \\ \left(\dfrac{\dot{\overline{K}}}{\overline{K}}\right)_i = s_i \overline{y}_i \end{cases} \qquad \begin{cases} i = W: & 1960-2004 \\ i = 1: & 1960-1989 \\ i = 2: & 1990-2004 \end{cases}$$

In each period, there exists steady-state growth rate G_i^* that satisfies equation [20], and optimal output by effective capital $\overline{y}_i^* = \left(\overline{Y}/\overline{K}\right)_i^* = \left(\overline{Y}/AK\right)_i^*$ for each s_i.

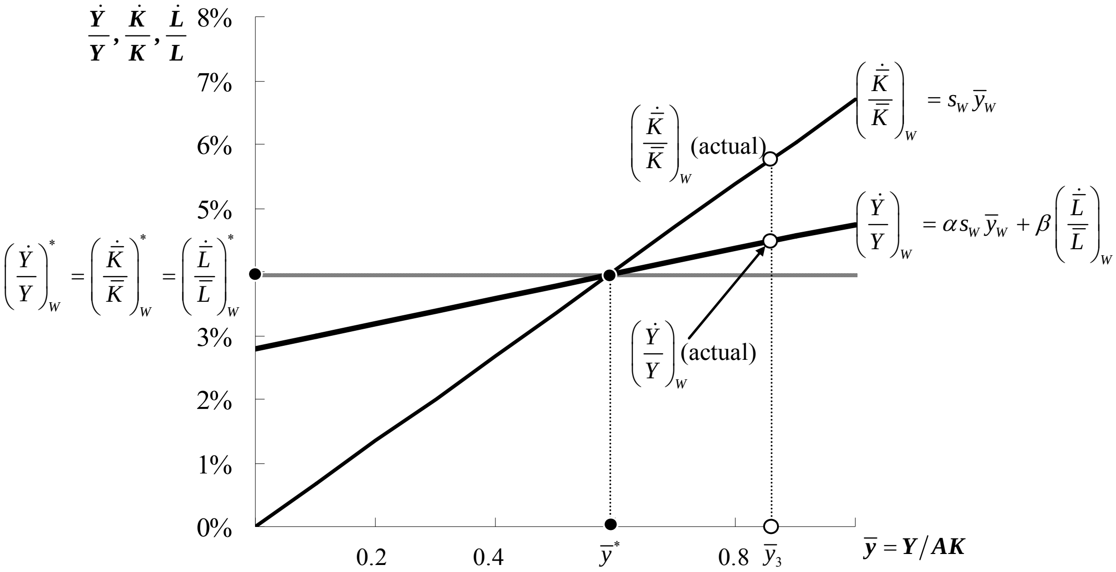
In Japan, $\overline{y}_i$ is much higher than $\overline{y}_i^*$. Japanese capital stock has grown very fast, but it was not utilized to increase the economy's total income (GDP). In Period I, especially before the first oil crisis in 1973, an extremely high rate of investment accumulated Japanese physical stock at a very rapid pace, which supported the country's miraculous economic growth. In Period II, the Japanese economic growth was still lower than the growth rate of effective capital, and had not reached its steady state (Figure 4, Panel 3.) We can find here that there was over investment that kept the return on investment very low.

As for the US, $\overline{y}_i$ is very close to $\overline{y}_i^*$ in every panel of Figure 5, and the actual output in period i was just below the optimal output by effective capital. The growth rate of effective capital and effective labor, and the economic growth rate were balanced in both Period I and Period II.

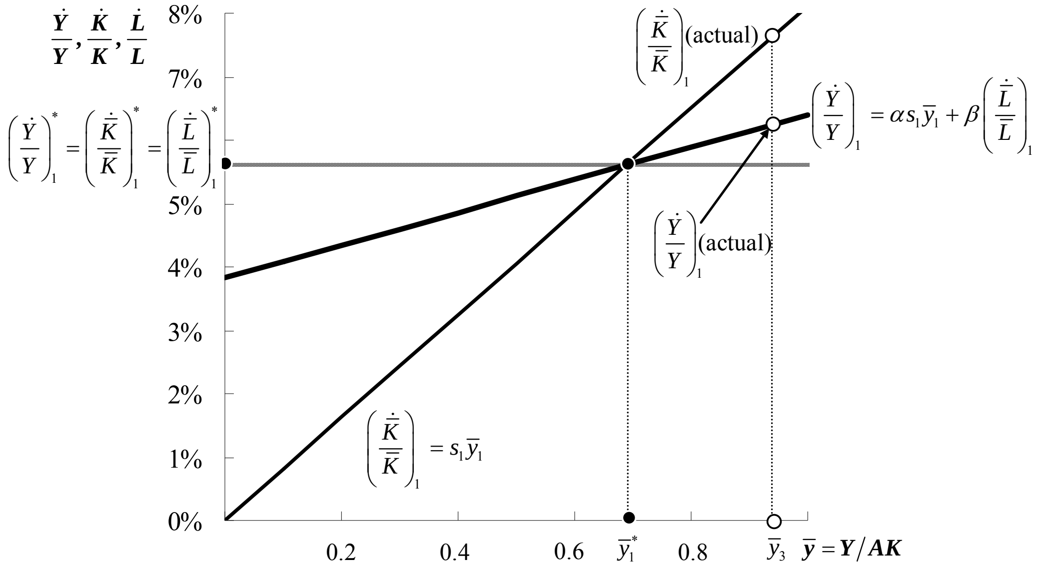
Figures 4 and 5 indicate that the US might already be at a steady-state growth rate, but Japan is not.

Figure 4. Output-Effective Capital Ratio (Japan)

Panel 1. 1960–2004



Panel 2. 1960–1989



Panel 3. 1990–2004

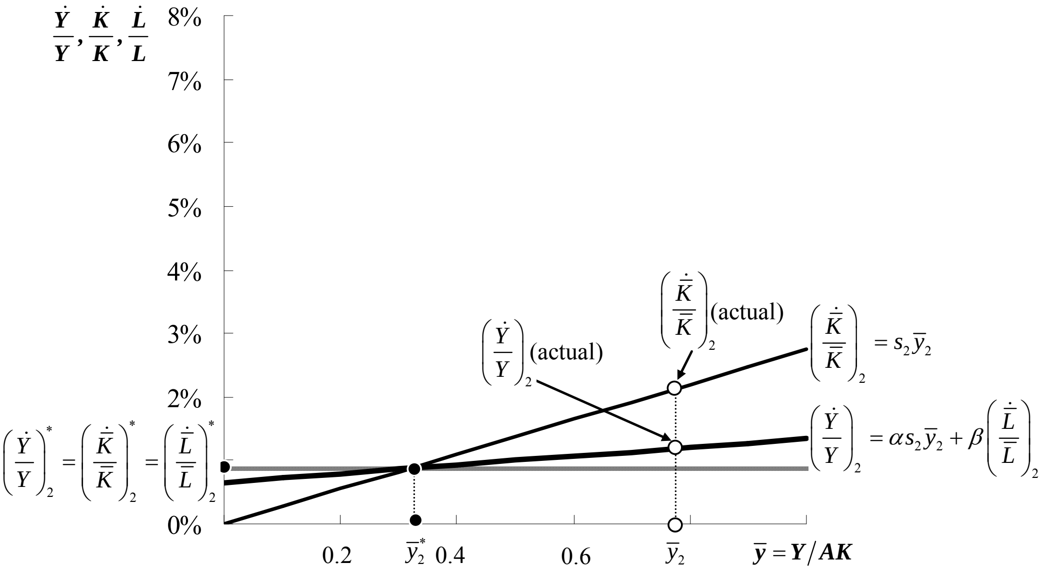
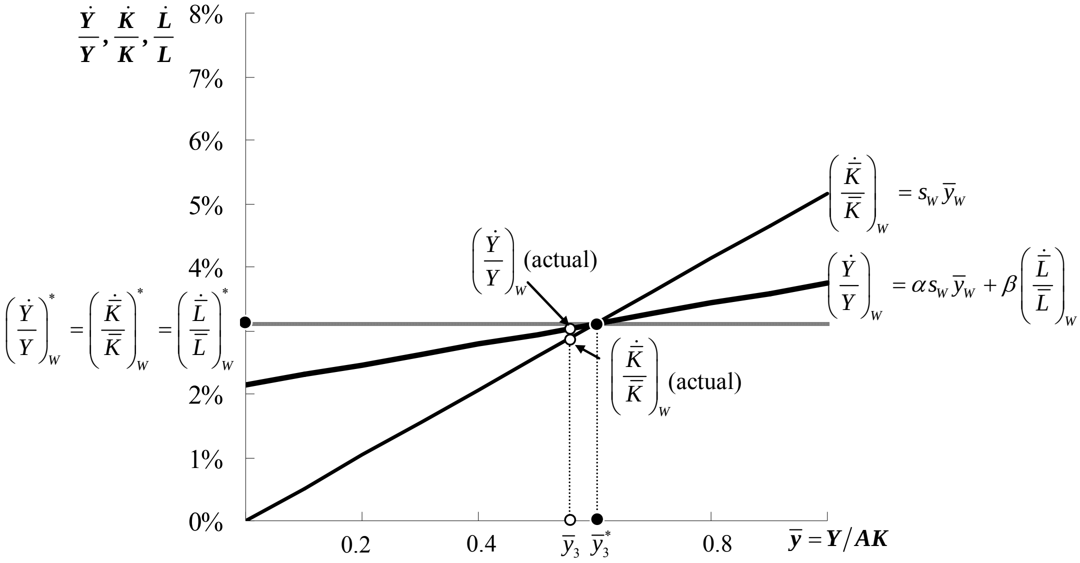
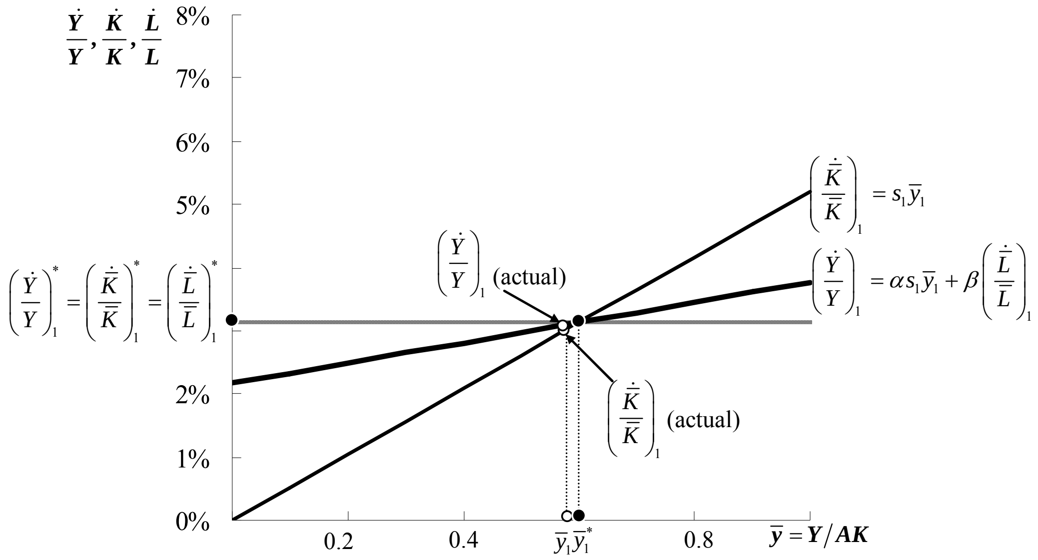


Figure 5. Output-Effective Capital Ratio (United States)

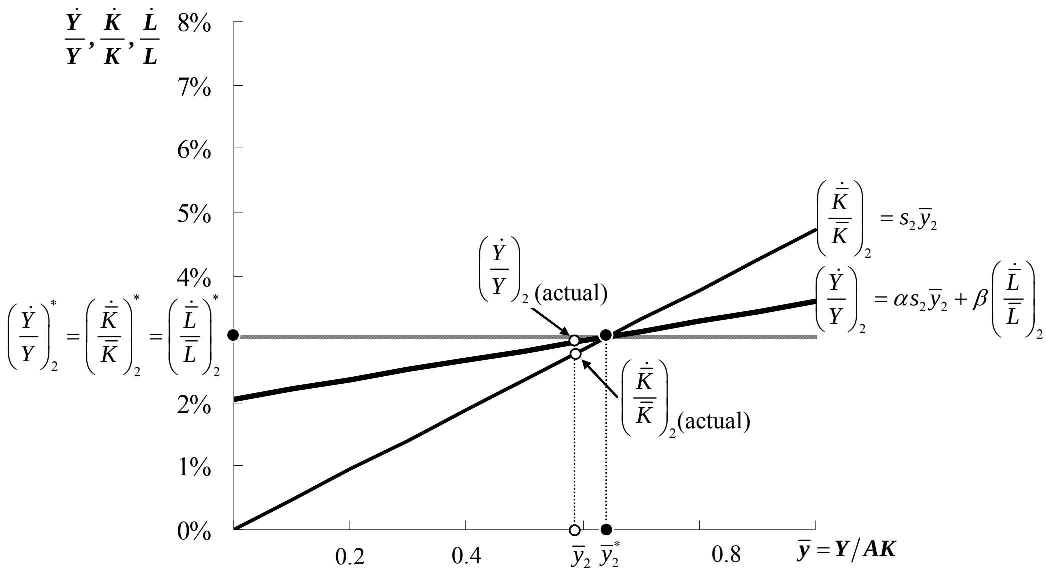
Panel 1. 1960–2004



Panel 2. 1960–1989



Panel 3. 1990–2004



IV. Conclusion

24. Population decline in Japan is becoming a major concern. The declining birth rate together with the increase of people reaching retirement age will surely reduce the size of the workforce. The Ministry of Health, Labour and Welfare estimated that the labor force would peak at 67.7 million in 2005 and decline to 63 million in 2025[9], which would mark a roughly 0.36% annual decline. The Japanese government believes that the expected demographic change will undermine the fundamentals of Japan's economy and society. Anticipating such a national crisis, the Basic Law on Measures for Society with Decreasing Birthrate was legislated[10].

As for the United States, the population has been steadily increasing. After recording 100 million in 1915, it doubled to 200 million in 1967. The year 1967 was during the prosperous Johnson presidency and people welcomed the number. Thirty-nine more years added another 100 million; the population amounted to 300 million in October 2006. Now, however, the mood regarding the growing population is not congratulatory. One reason is the foreseen environmental problems congestion might provoke. Another reason is the immigration issue—diverse views exist on the rising number of immigrants. The proportion of immigrants to the total population was just 4% in 1967, but it had increased to 12% by 2004. About half of the newly added 100 million members of the population were Hispanic, an ethnic group whose ratio now outweighs that of African Americans. The US Census Bureau estimates that the projected Hispanic population will reach 20% of the total US population by 2030[11]. Many worry about problems that may come from lack of assimilation.

25. In this paper we contrasted the difference of economic structure of Japan and the United States by comparing the rate of factor-augmenting technical progress. Our

---

[9] Cabinet Office, Government of Japan, *Shousika Shakai Hakusho* (White Paper on Declining Birth Rate Society) 2004, p. 77.
[10] Law No. 133 of July 30, 2003
[11] U.S. Census Beureau, 2004, "U.S. Interim Projections by Age, Sex, Race and Hispanic Origin," Table 1a.

investigation revealed that efficient utilization of capital and labor will affect economic growth. We suggested growth policies tailored for each economy.

After the theoretical explanations in Section II, we conducted the estimation using both countries' macro data. The data were taken from 1960 to 2004 and then divided into two periods: Period I (1960–1989) and Period II (1990–2004). Period II for Japan includes the lost decade, while that for the United States is often described as the new economy. The analysis on Period II was particularly effective in highlighting the characteristics of each economy.

26. In Subsection III-2, we compared the 44 years' performance of each economy. The Japanese economy grew much more strongly with much lower labor growth. The high economic growth was supported by the increase of capital and technical progress. We found that the engines of Japanese economic growth were booming capital investment and properly combined technical progress of capital efficiency and labor efficiency.

Concisely stated, the source of Japan's economic growth was quality improvement—rather than quantity increase—of population and labor force. In contrast, for the US, what supported its economic growth was quantity increase—rather than quality improvement—of population and labor force. The growth rate of GDP per unit of labor was only 38% of that of Japan. Economic growth in the US was sustained by technical progress and the increase of the labor force. In a country blessed with abundant land and natural resources, population increase played a major role in US economic growth. Population increase made economic expansion possible without much improvement in the efficiency of factors.

27. In Subsection III-4, the economic performance of each economy during the 44 years is further explained by factor-augmenting (biased) technical change, which divides the Hicks-neutral technical progress into the growth rates of capital efficiency and labor efficiency. The Japanese economy developed without depending too much on its population growth. We should note, however, negative capital efficiency indicates that

Japan accumulated capital too rapidly until it caused over investment. On the contrary, the US capital efficiency was around zero while labor efficiency grew only modestly.

Focusing on Period II (1990–2004), with the Japanese economy taking a downturn, the growth rate of the US economy surpassed that of the Japanese economy. In Japan, the growth rate of GDP, labor, and labor efficiency all declined compared to the rates in Period I. The decline of the growth rate of labor efficiency was sharper than that of labor itself. The capital efficiency was also decreasing. These facts indicate that Japan's lost decade suffered from the resulting over investment and bad loans. In contrast, the US capital efficiency turned positive in Period II.

28. Overall, we discovered that Japan's high growth in Period I was not so much due to the increase of the population, but to improved labor efficiency. Japan's stagnation, too, was not explained by the population decrease or shortage of effective demands, but by the slowdown of the improvement of labor efficiency.

Concerning the macro economy, labor decline itself has not been a cause of problems in Japan. More important was the fact that the burst of the bubble economy eroded firms' capacity to promote technical progress. Technical progress here does not necessarily mean either development of IT-related technology or introduction of brand-new, innovative technology.[12] In our context, technical progress includes all ingenuity that can be used to improve the efficiency of capital and labor.

Broadly defined innovation has been and will be the engine of the development and growth of the Japanese economy. Thus, Japan does not have to be pessimistic about the declining birth rate.[13] Value-added of labor can compensate for the decline in the workforce. Innovation can be brought about by policies that encourage people's motivations and expectations.

[12] Basu and Fernald (2002) examine that the aggregate Solow residual (TFP) qualifies to be an index of welfare change as long as the economic profits are small.

[13] However, Japan's social security system is in need of reform because it was originally designed with the premise that the country's population would continuously grow. We stress here that social security reform is a matter of great urgency.

V. References

Basic Law on Measures for Society with Decreasing Birthrate, Law No. 133 of July 30, 2003.

Basu; Susanto and John G. Fernald (2002), "Aggregate Productivity and Aggregate Technology," *European Economic Review*, Vol. 46, 963–991.

Cabinet Office, Government of Japan (2004), *Shousika Shakai Hakusho* (White Paper on Declining Birth Rate Society)

Fukao, Kyoji and Hyeog Ug Kwon (2006), "Why Did Japan's TFP Growth Slow Down in the Lost Decade? An Empirical Analysis Based on Firm-Level Data of Manufacturing Firms," *The Japanese Economic Review*, Vol. 57, No. 2, June, 195–228.

Hicks, John R. (1932, Second edition in 1963), *The Theory of Wages*, Macmillan.

Jorgenson, Dale W. and Kazuyuki Motohashi (2005), "Information Technology and the Japanese Economy," *NBER Working Paper*, No. 11801.

Rose, Hugh (1968), "The Condition for Factor-Augmenting Technical Change," *The Economic Journal*, Vol. 78, No. 312, pp. 966–971.

Sato, Ryuzo (1970), "The Estimation of Biased Technical Progress and the Production Function," *International Economic Review*, 11, 179–208. Reprinted in R. Sato, *Growth Theory and Technical Change*, *The Selected Essays of Ryuzo Sato*, Vol.1, Economists of the Twentieth Century Series, Edward Elgar Publishing, 1996, Chapter 12.

Sato, Ryuzo (1985), "The Invariance Principle and Income-Wealth Conservation Laws," *Journal of Econometrics* 30, 365–389. Reprinted in *Production, Stability and Dynamic Symmetry, The Selected Essays of Ryuzo Sato*, Vol.2, Economists of Twentieth Century Series, Edward Elgar Publishing, 1999, Ch. 18.

Sato, Ryuzo (2006), "The Stability of the Solow-Swan Model with Biased Technical Change" in R. Sato, *Biased Technical Change and Economic Conservation Laws*, Springer, Ch. 2.

Sato, R., and M. J. Beckmann (1968), "Neutral Inventions and Production Functions," *The Review of Economic Studies,* Vol. 35, No.1, 57–66. Reprinted in R. Sato, *Growth Theory and Technical Change*, *The Selected Essays of Ryuzo Sato*, Vol.1, Economists of the Twentieth Century Series, Edward Elgar Publishing, 1996, Chapter 11.

Sato, R., and R. Ramachandran (1987), "Factor Price Variation and The Hicksian Hypothesis: A Microeconomic Model," *Oxford Economic Papers*, 39, 343–356. Reprinted in R. Sato, *Growth Theory and Technical Change*, *The Selected Essays of Ryuzo Sato*, Vol.1, Economists of the Twentieth Century Series, Edward Elgar Publishing, 1996, Chapter 15.

Sato, R., R. Ramachandran, and Y. Kim (1999), "Estimation of Biased Technical Progress," in R. Sato ed., *Global Competition and Integration*, Kluwer Academic Publishers, 127–170. Reprinted in R. Sato, *Biased Technical Change and Economic Conservation Laws*, Springer, Ch. 5.

U.S. Census Bureau, U.S. Interim Projections by Age, Sex, Race, and Hispanic Origin; Available at: http://www.census.gov/ipc/www/usinterimproj/

VI. Appendix

VI-1. Theoretical Justification of Production Function with Biased Technical Change

Sato and Beckmann (1968) precisely provide the theoretical justification of this production function. They set general production function as $Y = F[K, L]$, which is homogeneous of degree one, then under the condition that factor shares are invariant as long as σ remains constant, i.e., σ is a function of β only,, they deduce the general production function which incorporates the above invariance condition.

Define $k = K/L$, $x = 1/k = L/K$, $y = Y/K$, then $y = f(x)$ and $Y = Kf(x)$.
In this case, marginal productivities are

$$F_K = \frac{\partial Y}{\partial K} = y - xy_x$$

and

$$F_L = \frac{\partial Y}{\partial L} = y_x .$$

The income share of labor is expressed as

$$\beta = \frac{xy_x}{y} .$$

Now we define marginal rate of substitution r/w as ω. Then,

$$MRS = \omega = \frac{r}{w} = \frac{F_K}{F_L} = \frac{y - xy_x}{y_x} .$$

In this case σ is

$$\sigma = \frac{d\left(\frac{L}{K}\right)\Big/\frac{L}{K}}{d\left(\frac{F_K}{F_L}\right)\Big/\frac{F_K}{F_L}} = \frac{dx/x}{d\omega/\omega},$$

and inverse of σ can be expressed as

$$\frac{1}{\sigma} = \frac{d\log\omega}{d\log x} . \qquad [33]$$

Since σ must be a function of β, we define the function ϕ as $(1/\sigma) = \phi(\beta)$. Therefore,

$$\frac{1}{\sigma}=\frac{\partial \log \omega}{\partial \log x}=\frac{\partial \log\left(\frac{y-xy_x}{y_x}\right)}{\partial \log x}=\phi\left(\frac{xy_x}{y}\right)=\phi(\beta)$$

$$\phi(\beta)=x\frac{\partial \log\left(x\left(\beta^{-1}-1\right)\right)}{\partial x}. \qquad [34]$$

Solving and integrating equation [34] makes

$$\frac{\partial x}{x}=\frac{\partial \beta}{\left(1-\phi(\beta)\right)\left(1-\beta\right)\beta}$$

$$\log x+\log C(t)=g(\beta)=\int \frac{\partial \beta}{\left(1-\phi(\beta)\right)\left(1-\beta\right)\beta}$$

$$C(t)x=e^{g(\beta)}=e^{\int \frac{\partial \beta}{(1-\phi(\beta))(1-\beta)\beta}}. \qquad [35]$$

Here, log$C(t)$ is the arbitrary constant arising from integrating $\partial x/x$, which measures the technical progress factor.

From equation [35], we can derive β as a function of $C(t)x$ as $\beta = xy_x/y = G\left(C(t)x\right)$. Arrange and integrate the above, so

$$\frac{x}{y}\cdot\frac{\partial y}{\partial x}=G\left(C(t)x\right)$$

$$\frac{\partial y}{y}=\frac{G\left(C(t)x\right)}{x}\partial x$$

$$\int\frac{\partial y}{y}=\int\frac{G\left(C(t)x\right)}{x}\partial x$$

$$\log y-\log A(t)=\log\int\frac{G\left(C(t)x\right)}{x}\partial x$$

$$y=A(t)\exp\int^{x}\frac{G\left(C(t)v\right)}{C(t)v}C(t)\partial v\ ,$$

where $A(t)$ is the arbitrary constant arising from integrating $\partial y/y$, which satisfies $C(t)$ = B(t)/A(t).

Substituting $C(t)v = \mu$, the above can be simplified as

$$y=A(t)\exp\int^{C(t)x}G\left(\mu\right)\partial \log \mu, \qquad [36]$$

where the integration is carried out at constant t,

$$y=A(t)f\left(C(t)x\right). \qquad [37]$$

From equation [37], we can derive the production function with the factor-augmenting type of technical progress.

$$\frac{Y}{K} = A(t)\, f\left(\frac{B(t)}{A(t)} \cdot \frac{L}{K}\right) = A(t) \cdot F\left[1, \quad \frac{B(t)}{A(t)} \cdot \frac{L}{K}\right]$$

$$Y = F\left[A(t)K,\, B(t)L\right]$$

In the economy in which σ is constant as long as β is constant, we are able to estimate *A* and *B*.

VI-2. Data

To complete the historical data, we take data of 1960–1990 from Sato, et al. (1999), which is derived from OECD statistics. After 1991, we adjusted the data for the relevant variables using different sources listed below.:

Japan

Y: Real Gross Domestic Products excluding Government Consumption
(SourceOECD National Accounts Database, OECD,
http://new.sourceoecd.org/vl=1563494/cl=22/nw=1/rpsv/home.htm).

K: Real Private Capital Stock
(Annual Report on Gross Capital Stock of Private Enterprises, Systems of National Accounts, Cabinet Office Homepage, Japan,
http://www.esri.cao.go.jp/jp/sna/toukei.html#s-kakuho)

L: Labor Force
(Labor Force Survey, SourceOECD Main Economic Indicators, OECD,
http://new.sourceoecd.org/vl=1563494/cl=22/nw=1/rpsv/home.htm)
multiplied by
Hours worked per worker
(Systems of National Accounts, Cabinet Office Homepage, Japan,
http://www.esri.cao.go.jp/jp/sna/toukei.html#s-kakuho)

w: Real Compensation of Employees (SourceOECD National Accounts Database, OECD, http://new.sourceoecd.org/vl=1563494/cl=22/nw=1/rpsv/home.htm)
divided by
labor force (L).

United States

Y: Real Gross Domestic Products of Private Sector
(National Income and Product Accounts Tables, Bureau of Economic Analysis, U.S. Department of Commerce, http://www.bea.gov/national/nipaweb/Index.asp).

K: Real Private Fixed Assets
(Fixed Asset Tables, Bureau of Economic Analysis, U.S. Department of Commerce, http://www.bea.gov/national/FA2004/SelectTable.asp#S6)

L: Total Hours Worked, Private
(National Income and Product Accounts Tables, Bureau of Economic Analysis, U.S. Department of Commerce, http://www.bea.gov/national/nipaweb/Index.asp)

w: Real Compensation of Employees (SourceOECD National Accounts Database, OECD, http://new.sourceoecd.org/vl=1563494/cl=22/nw=1/rpsv/home.htm)
divided by
labor force (L).

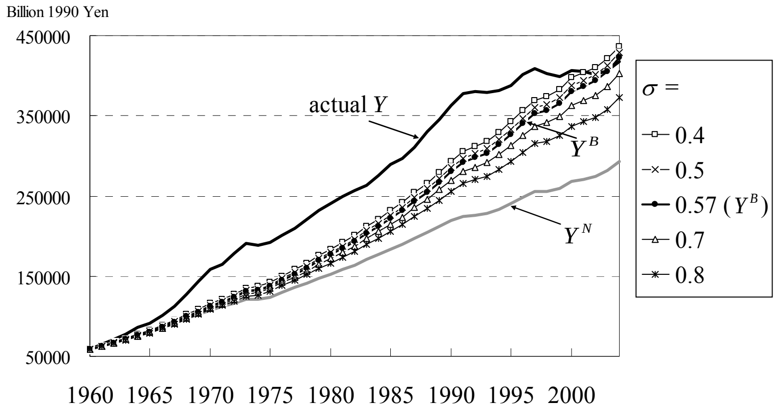
VI-3. Simulation Results for Different Values of σ

Because no methods exists for identifying the exact value of σ under the biased technical change (Impossibility Theorem, see Sato (1970)), we experimented with conducting simulation with different values of σ in the neighborhood of the value corresponding to the assumed case of Hicks-neutral type σ^N (Y^N).

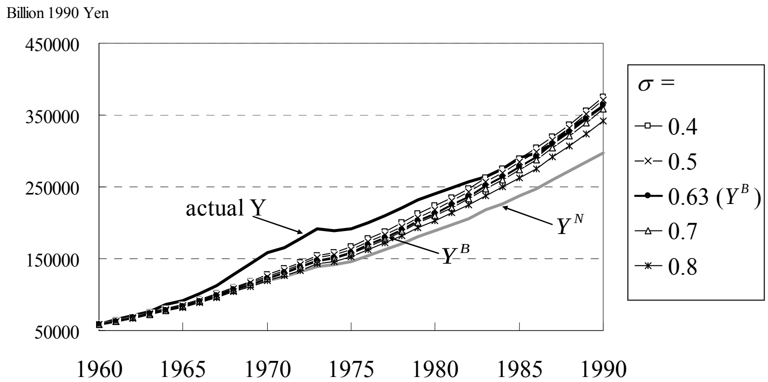
As shown in Figures 6 and 7, the results are encouraging in the sense that the variations of σ do not significantly affect the simulation path.

Figure 6 Simulation Path Using the σ around σ^N (Japan)

Panel 1 (1960–2004)



Panel 2 (1960–1989)



Panel 3 (1990–2004)

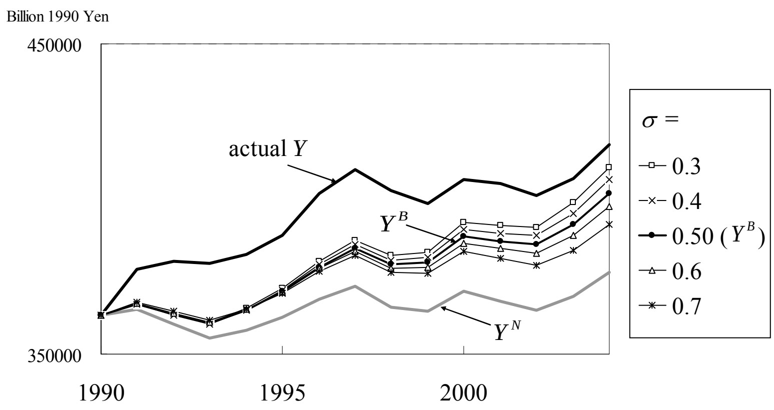
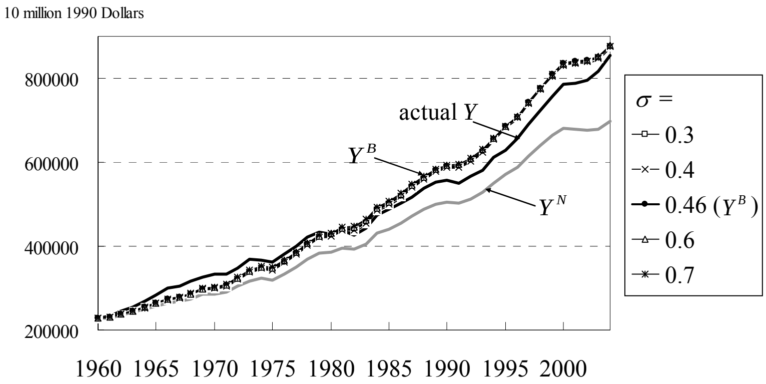
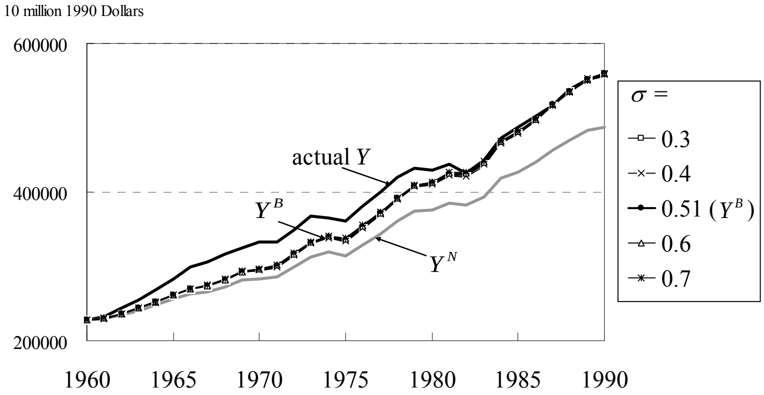


Figure 7 Simulation Path Using the σ around σ^N (United States)

Panel 1 (1960–2004)



Panel 2 (1960–1989)



Panel 3 (1990–2004)