Demographic Dividends, Depopulation, and Importance of Agriculture in Japan:

the Past, the Present, and the Future

Tomoko Kinugasa*

Associate Professor

Graduate School of Economics, Kobe University

2-1, Rokkodai-cho, Nada-ku Kobe, 657-8501, Japan

Tel/Fax: +81-78-803-6805

Email: kinugasa@econ.kobe-u.ac.jp

and

Mitoshi Yamaguchi

Emeritus Professor

Graduate School of Economics, Kobe University

* Corresponding author.

Demographic Dividends, Depopulation, and Importance of Agriculture in Japan:

the Past, the Present, and the Future

Abstract

We investigate the effects of demographic change on agriculture and non-agriculture in Japan while considering capital accumulation and total population and labor. Combining the overlapping generations model with the three generations and general equilibrium growth accounting models, we simulate the effect of demographic change on agricultural and non-agricultural inputs and outputs. Our simulation analyses show that demographic change greatly influenced agriculture and non-agriculture through capital accumulation although the influences of total population and labor were not negligible. Remarkable demographic dividends like the decline of young dependents and increase of adult longevity greatly influenced capital accumulation in Japan in the 1950s to the 1990s, which decreased the importance of agriculture. In the future, aggregate capital in Japan will presumably decrease due to a decline of the working age population, which may result in the disappearance of the advantages of non-agriculture and an increase of the importance of agriculture.

JEL Classifications: J10, O11, Q10

1. Introduction

This research investigates the effects of demographic change on industrial structure in Japan considering capital accumulation, labor force, and total population. Simulation analyses using growth rate multipliers and overlapping generations model indicate rapid demographic change after World War II, for example, decreased fertility and increased adult longevity induced capital accumulation, which increased the importance of non-agriculture.

After World War II, Japan experienced a remarkable demographic transition. At the beginning of the 20th century, both fertility and mortality were high. But, after the War, mortality—especially adult mortality—declined rapidly. Subsequently, fertility began to decline. Fertility declined rapidly in the 1960s and 1970s, and now is low. Moreover, the population started to decline in 2005, and it is expected that the population will continue to decline in the future. The effects of depopulation on the economy are controversial. A decrease of population can increase income per capita if other conditions do not change, but it may decrease the labor force and the possibility of innovation. High life expectancy is also a characteristic of Japan, and is the highest in the world. Higher life expectancy may induce capital accumulation, which is considered a positive aspect of population aging.

Consideration of agriculture is essential when we discuss the development of a country. Agriculture is fundamental to human activity. Malthus (1798) wrote that the relationship between population and agriculture is important. Extensive research has tried to explain economic development in relation to agriculture using a dual economy model.[1] The dual economy model assumes two industrial sectors—agricultural sector and non-agricultural sector. The agricultural sector is traditional, self-sufficient,

---

[1] For example, Lewis (1954), Ranis and Fei (1956), Jorgenson (1961), Kelley, Williamson, and Cheetham (1972).

and characterized by low productivity. The non-agricultural sector is modern, profitable, and highly productive. According to the dual economy model, it is necessary to have technical change in agriculture at the onset of economic development to push labor and capital into the non-agricultural sector.

Yamaguchi's (1982, 2001) dual economy model is noteworthy in that it distinguishes between changes in population and labor force. The author established a general equilibrium growth accounting model. The model analyzes the effects of eight exogenous variables—including agricultural and non-agricultural technologies, total population, total labor, aggregate capital stock, land, demand shifter of agricultural products, and wage gap between agricultural and non-agricultural sectors—on eight endogenous variables—including agricultural non-agricultural outputs, labor and capital, relative prices of agricultural and non-agricultural products, and income per capita.

It is also important to consider people's working and saving behaviors when we discuss how demographics affect economic growth. A considerable volume of research has attempted to examine the economic implications of demographic transition. During a demographic transition, the young dependency rate decreases while the share of working-age population increases. This stage is called the "first demographic dividend." Bloom and Williamson (1998), Bloom, Canning, and Malaney (2000), and Kelley and Schmidt (2001, 2005) found that changes in age structure accordingly change the labor force, thus greatly contributing to economic growth. Demographic change also influences saving behavior. According to the life-cycle hypothesis, individuals save when they are young and employed and spend their savings after retirement (Modigliani and Brumberg (1957), Tobin (1967)). Changes in young dependency could alter age-earning and consumption profiles. In particular, a higher young dependency can result in increased consumption at a younger age (Mason (1981, 1987), Higgins and Williamson (1997)).

The concept of the "second demographic dividend" has also been attracting the attention of population economists. Increased adult longevity can increase the savings of prime-age adults, resulting in capital accumulation (Kinugasa and Mason (2007), Lee, Mason, and Millier (2001), Mason and Kinugasa (2008)). Capital accumulation contributes significantly to economic growth. In many developed countries including Japan, the first demographic dividend has already disappeared. Declining growth of the labor force can suppress economic growth. On the other hand, the second demographic dividend could still continue in developed countries into the future. The life expectancies of old people is slowly increasing and many developed countries may still have opportunities for economic development. (Mason (2007), Mason and Kinugasa (2008), Ogawa (2007)).

The research discussed above does not analyze the effects of demographic change on industrialization in terms of capital accumulation. Kinugasa and Yamaguchi (2008) combined the overlapping generations model of Kinugasa and Mason (2007) and the general equilibrium growth accounting model of Yamaguchi (1982, 2001). Kinugasa and Yamaguchi analyzed the effects of changes in the number of children and adult longevity on capital accumulation, and examined how capital, which is influenced by demographic change, affects agricultural and non-agricultural inputs and outputs. Their simulation analysis with Japanese data showed that a rapid decline of the number of children and an increase of adult longevity stimulated capital accumulation, which increased the importance of non-agriculture from the 1960s to 1990s.

In this research, we develop the analyses of Kinugasa and Yamaguchi (2008) and investigate the effects of demographic change on agriculture and non-agriculture from a broader perspective. We consider the effects of demographic change on income per capita and industrial structure in terms of labor force and total population, as well as capital accumulation. Besides, we estimate the effects of demographic change not only in the past and the present but also in the future.

Our findings regarding the relationships among demographic change, capital accumulation, and importance of agriculture are summarized by the flowcharts in Figure 1. In this figure, a broad arrowhead means the effect is strong, a thin arrowhead means the effect is weak, and dashed arrowhead indicates the effect appears after a while. Figure 1(a) presents the relationship from the 1950s to 1990s. Japan experienced a rapid decline of the number of children and a rapid increase of adult longevity during the period, which induced capital accumulation. During the period, the labor force increased rapidly because the working-age population increased, and this also induced capital accumulation. According to results from growth rate multipliers, accumulated capital induced industrialization, that is, it decreased the importance of agriculture. The analysis using growth rate multipliers also indicates that an increase labor force decreased the importance of agriculture and increased income per capita. Increased income per capita also increased capital accumulation according to the overlapping generations model, which decreased the importance of agriculture further. From the 1950s to 1990s, population growth rate was also high, which increased the importance of agriculture.

Figure 1 (b) describes the outlook for Japan. It is expected that the number of children will decrease and adult longevity will increase slowly, which will induce capital accumulation, and as a result increase the importance of non-agriculture slightly. A decline of the labor force will decrease capital accumulation to a large extent according to our overlapping generations model, which will make agriculture more important. The general equilibrium growth accounting model implies that a decrease of the labor force will directly increase the importance of agriculture. The model also indicates that a decrease of capital accumulation caused by a decrease of the labor force will decrease income per capita, and this will decrease capital accumulation further. Population will continue to decrease in Japan in the future, and this may increase the importance of non-agriculture according to Malthus's law, but this effect will not be large. To sum up, in Japan, the importance of agriculture will increase in the future considering the demographic situation.

The remainder of this paper is organized as follows. The general equilibrium growth accounting model established by Yamaguchi (1982, 2001) is introduced in Section 2. Section 2 also describes how total population, labor, and capital influence endogenous variables such as agricultural and non-agricultural outputs and inputs. Section 3 describes the overlapping generations model, which considers three generations, and explains the effects of demographic change—such as changes in present and past fertility and adult longevity—on capital accumulation. Moreover, the influence of present and past fertility and adult longevity on aggregate capital is also examined in this section. Based on the models described in Sections 2 and 3, and using Japanese data, we simulate the effects of demographic change on agricultural and non-agricultural outputs and inputs in Section 4. Section 5 presents the conclusion of this research.

2. Growth Accounting General Equilibrium Model

This section introduces the growth accounting general equilibrium model of Yamaguchi (1982, 2001).[2] The authors considered a two-sector economy consisting of agricultural and non-agricultural sectors and established a general equilibrium growth accounting model.[3] Further, they calculated the effects of eight exogenous variables on eight endogenous variables.[4] Each effect is referred to as a

---

[2] See also Yamaguchi and Binswanger (1975) and Yamaguchi and Kennedy (1984a, 1984b).

[3] This model is further explained in Appendix 1.

[4] The exogenous variables are agricultural technical growth (T_A), non-agricultural technical growth (T_M), population (Q), total labor force (L), aggregate capital (K), land (B), demand shifter of agricultural

"growth rate multiplier" (GRM), which reflects the percentage increase of an endogenous variable due to a 1% increase of a certain exogenous variable. GRMs are expressed by aligning endogenous and exogenous variables; for example, Y_AK[5] is the effect of a 1% increase of aggregate capital on agricultural output. Yamaguchi and colleagues also calculated the contributions of exogenous variables to endogenous variables by multiplying the GRMs and the growth rates of the exogenous variables.

Table 1 presents the GRMs with respect to capital, labor, and population. Table 1 shows that aggregate capital (K) has the following effects on the endogenous variables.[6] An increase of aggregate capital increases both agricultural and non-agricultural outputs. An increase of aggregate capital has a greater effect on non-agricultural output than on agricultural output, ($Y_MK > Y_AK > 0$). An increase of aggregate capital has a positive effect on both agricultural and non-agricultural capital, and its effect on non-agricultural capital is greater than that on agricultural capital, ($K_MK > K_AK > 0$). An increase of aggregate capital decreases agricultural labor, but increases non-agricultural labor ($L_AK < 0$, $L_MK > 0$). These findings imply that capital accumulation induces growth in both agricultural and non-agricultural sectors; however, it has a greater positive effect on non-agricultural growth. Therefore, capital accumulation is likely to accelerate industrialization. Moreover, an increase of aggregate capital increases income per capita. ($EK>0$)

---

products (a), and wage gap between agricultural and non-agricultural sectors. The endogenous variables are agricultural output (Y_A), non-agricultural output (Y_M), agricultural labor (L_A), non-agricultural labor (L_M), agricultural capital (K_A), non-agricultural capital (K_M), relative prices of agricultural goods and non-agricultural products (P), and income (E). Here, aggregate capital is considered to be domestic capital.

[5] Definitions of variables are summarized in Appendix Table 1.

[6] These findings are valid for the entire period of the analysis except 1945. Japan was at war in 1945; hence, this year can be considered an exceptional situation.

Growth of labor force can also increase the importance of non-agriculture. Growth of total labor increases agricultural and non-agricultural output and labor, but increases non-agricultural output and labor more than the corresponding agricultural output and labor. ($Y_ML > Y_AL > 0$, $L_ML > L_AL > 0$). An increase of the labor force increases non-agricultural capital, but decreases agricultural capital. ($K_AL < 0$, $K_ML > 0$). It is also confirmed that an increase of the labor force increases income per capita. ($EL>0$)

Malthus's law holds for the effects of population growth on endogenous variables. An increase of population increases agricultural inputs and outputs and decreases non-agricultural inputs and outputs ($Y_AQ>0$, $Y_MQ<0$, $K_AQ>0$, $K_MQ<0$, $L_AQ>0$, $L_MQ<0$). An increase of population decreases income per capita ($EQ<0$).

To sum up, increases of capital and labor decrease the importance of agriculture and increase the importance of non-agriculture. An increase of population increases the importance of agriculture. Aggregate capital and labor affects income per capita positively, and total population affects income per capita negatively.

3. Overlapping Generations Model and Capital Accumulation

3.1 Consumer's Utility Optimization

This section presents an overlapping model established by Kinugasa and Yamaguchi (2008) in order to gauge the effects of demographic change on capital accumulation. The model takes into account the existence of different generations at the same time. It is assumed that there are three generations—children, prime-age adults, and elderly. Child age, prime age, and old age are set at age zero, one, and two, respectively. Children are considered to be dependent and not employed. Prime-age adults take care of children, work, and save in order to consume in their old age. The elderly are retired and spend the savings they accumulate in their prime age.[7] Not all children survive to prime age and not all prime-age adults survive after retirement.

The prime-age adults at time t decide present consumption for themselves and their children, and their consumption in the future maximizes the following utility function.

$$V_t = \lambda_1 \frac{c_{1,t}^{1-\theta}}{1-\theta} + \frac{\lambda_2 q_t}{1+\rho} \frac{c_{2,t+1}^{1-\theta}}{1-\theta} + \kappa n_t^{1-\varepsilon} \lambda_0 \frac{c_{0,t}^{1-\theta}}{1-\theta}, \quad (1)$$

where $c_{1,t}$, $c_{2,t+1}$, and $c_{0,t}$ represent the consumption of prime-age adults, elderly, and dependent children, respectively. q_t is the survival rate of prime-age adults until old age and is used as a measure of adult longevity. Prime-age adults decide $c_{1,t}$, $c_{2,t+1}$, and $c_{0,t}$. The parameter κ implies the rate at which parents discount the utility of children, and it is assumed that $0 \le \kappa \le 1$. It is also assumed that $\varepsilon > 0$, so that marginal utility with respect to the number of children declines according to the number of children. The parameters λ_0, λ_1, and λ_2 are the relative importance of consumption for children, prime-age, and post-retirement, respectively. ρ is the discount rate, that is, the rate of time preference. The intertemporal elasticity of substitution is given by $(1/\theta)$. [8]

Prime-age adults work and obtain wage income $A_t w_t$ per unit of labor, of which A_t is the level of technology and w_t is the wage per effective worker. Prime-age adults are endowed with one unit of time. Raising one child takes up ν units of time, and prime-age adults with n children work for $(1 - \nu n)$ units of time. Prime-age adults allocate their earnings to their own consumption, to that of their children, and to saving. The budget constraint of prime-age adults is given by: $c_{1,t} + n_t c_{0,t} + s_{1,t} = A_t w_t (1 - \nu n_t)$,

---

[7] For simplicity, it is assumed that there are neither bequests nor transfers from children to parents.

[8] If $(1/\theta) > 1$, an increase of the interest rate will increase saving by prime-age adults; however, if $(1/\theta) < 1$, the increase of the interest rate will have the opposite effect on saving. In this research, we assume that $(1/\theta) > 1$.

where $s_{1,t}$ represents saving by prime-age adults. After retirement, the elderly consume the proceeds of their savings. Thus, the budget constraint of the elderly is described as:[9] $c_{2,t+1} = (1 + r_{t+1}) s_{1,t} / q_t$. According to the budget constraints of the prime-age adults and the elderly, the lifetime budget constraint faced by prime-age adults is derived as follows:

$$w_t A_t (1 - \nu n_t) = c_{1,t} + n_t c_{0,t} + \frac{q_t}{1 + r_{t+1}} c_{2,t+1}. \qquad (2)$$

Consumers determine their children's consumption and their own consumption in prime-age and after retirement, thus maximizing life utility as given in equation (1) under the lifetime budget constraint given in equation(2).

Saving by prime-age adults is also calculated according to these results, as follows:

$$s_{1,t} = \frac{q_t \left(\frac{\lambda_2}{\lambda_1(1+\rho)}\right)^{\frac{1}{\theta}} (1 + r_{t+1})^{\frac{1-\theta}{\theta}} (1 - \nu n_t) A_t w_t}{1 + \left(\frac{\kappa\lambda_0}{\lambda_1}\right)^{\frac{1}{\theta}} n_t^{\frac{\theta-\varepsilon}{\theta}} + q_t \left(\frac{\lambda_2}{\lambda_1(1+\rho)}\right)^{\frac{1}{\theta}} (1 + r_{t+1})^{\frac{1-\theta}{\theta}}} \qquad (3)$$

In equation (3), $\partial s_{1,t} / \partial q_t > 0$; hence, the savings of prime-age adults increase along with an increase of the adult survival rate. Evidently, if consumers are aware of the fact that they will live longer, they are more likely to have higher savings in preparation for old age. Equation (3) also implies $\partial s_{1,t} / \partial n_t < 0$ if $\theta > \varepsilon$. Saving by prime-age adults decreases with an increase in the number of children as long as $\theta > \varepsilon$. Moreover, expenditure on children correspondingly increases with an increase in the number of children,

---

[9] We assume the availability of insurance against longevity risk. An annuity is purchased at the onset of prime-age if insurance companies are risk neutral and annuity markets are perfect. The rate of return for the surviving elderly is $((1+r_{t+1})/q_t)$, where r_{t+1} represents the riskless interest rate on saving. The return with regard to annuities is $((1+r_{t+1})/q_t)$. Returns of insurance are higher than the regular norm; therefore, individuals restrict their saving to insurance. After retirement, the elderly consume the proceeds of their savings. See Yaari (1965) and Blanchard (1985) for a detailed explanation.

while the wage income of prime-age adults decreases because raising children requires the expenditure of time. Therefore, higher fertility decreases saving by prime-age adults.

3.2 The Effects of Demographic Change on Capital Accumulation

This subsection discusses how demographic change influences capital accumulation. Appendix 2 details how aggregate capital is determined. The aggregate capital at t+1, W_{t+1}, is given by:

$$W_{t+1} = K_{t+1} + F_{t+1} = s_{1,t} N_{1,t}, \tag{4}$$

where K is domestic capital and F is foreign capital. From equation (4), the total savings of prime-age adults at time t formulates the aggregate capital in the next period.[10] Higher savings of prime-age adults result in higher capital accumulation. In this context, the number of prime-age adults at t is expressed as $N_{1,t} = p_t N_{0,t-1} = p_t n_{t-1} N_{1,t-1}$, where p_t is the survival rate of children. Therefore, equation (4) can be rewritten as: $W_{t+1} = s_{1,t} p_t n_{t-1} N_{1,t-1}$. Let us assume that the ratio of domestic capital to aggregate capital, d_t, is exogenous, and domestic capital at time t is given by: $K_{t+1} = d_{t+1} W_{t+1}$. Then, the following equation is obtained:

$$K_{t+1} = d_{t+1} s_{1,t} p_t n_{t-1} N_{1,t-1}. \tag{5}$$

From the simulation analysis, we can ascertain the effects of demographic change on the growth rate of domestic capital. The growth rate of domestic capital $\dot{K}_t$ is defined as follows:

$$\dot{K}_t = \frac{K_t - K_{t-1}}{K_{t-1}}. \tag{6}$$

According to equations (5) and (6), an increase of adult longevity at t does not influence the growth rate of

---

[10] In this scenario, the economy's aggregate capital *stock* at t is equal to the *flow* of savings at t – 1. This occurs because the model has only one period of working life and wealth is not accumulated across generations.

domestic capital. In addition, the effect of an increase of adult longevity at time t on the growth rate of domestic capital at time t+1 is given by: $\frac{\partial \dot{K}_{t+1}}{\partial q_t} = \frac{d_{t+1}(\partial s_{1,t} / \partial q_t) p_t n_{t-1} N_{1,t-1}}{K_t} > 0$. This indicates that an increase of adult longevity at t increases the growth rate of domestic capital at time t+1 due to an increase of the savings of prime age adults at t.[11]

The number of children at time t does not influence the growth rate of capital at time t. The effect of an increase of the number of children at t on the growth rate of capital at t+1 is: $\frac{\partial \dot{K}_{t+1}}{\partial n_t} = \frac{d_{t+1} \partial s_{1,t} / \partial n_t}{K_t} < 0$. The number of children at time t decreases domestic capital at t+1. If the number of children increases at t, prime-age adults save less during the same period; thus, less capital is accumulated at time t+1.

The effect of the number of children at t on the growth of capital at t+2 is given by: $\frac{\partial \dot{K}_{t+2}}{\partial n_t} = \frac{d_{t+1} s_{1,t} p_t N_{1,t} - d_{t+1}(\partial s_{1,t} / \partial n_t) p_t n_{t-1} N_{1,t-1}}{K_{t+1}^2} > 0$. The number of children at time t increases the number of prime-age adults who can accumulate capital at t+1, which results in higher capital accumulation at t+2. Also, less capital is accumulated at t+1, which gives rise to a higher growth rate of capital at time t+2. Therefore, the growth rate of aggregate capital increases at t+2 if fertility increases at t. Evidently, an increase of fertility prevents capital accumulation in the short run. However, once children become older, the increase of the prime-age population stimulates capital accumulation.

---

[11] The effects of adult longevity at t on growth of capital at time t + 1 are given as $\frac{\partial \dot{K}_{t+2}}{\partial q_t} = \frac{-d_{t+1}(\partial s_{1,t} / \partial q_t) p_t n_{t-1} K_{t+2}}{K_{t+1}^2} < 0$. An increase of adult longevity at t decreases the growth of capital at t + 2 because of the increase of the denominator. This circumstance and $\partial \dot{K}_{t+1} / \partial q_t > 0$ indicate that a continuing rapid increase of adult longevity increases the speed of capital accumulation.

Our theory implies that stylized demographic changes such as declining fertility and mortality either increase or decrease the growth of aggregate capital stock; therefore, a detailed simulation analysis would be beneficial. In the next section, we set the values for the parameters to simulate the influence of demographic change on capital accumulation in Japan.

4. Simulation Analysis Using Japanese Data

In this section, we estimate the effects of demographic change on capital and agricultural and non-agricultural inputs and output in the past, present, and future. The simulation method is detailed in Appendix 3. First, the growth of aggregate capital is simulated using data on number of children per adult and adult and child longevities based on the overlapping generations model in Section 3. Next, the sums of contributions of simulated aggregate capital, population, and labor to agricultural and non-agricultural inputs and outputs are calculated.

Figure 2 shows graphs of demographic variables such as number of children per adult, child survival index, and adult survival index, [12] growths of population and labor from 1890 to 2025. Number of children per adult increased moderately from 1980 to 1935, and began to decline rapidly in 1965. Number of children declined rapidly from 1965 to 1980. Since the 1990s, the number of children per adult has been decreasing slowly, and it is expected to continue to decrease in the future. The child survival index did not change greatly before World War II and increased greatly in 1950. Since then, Japan's child survival has been close to 100% and high child survival is expected to continue in Japan. A significant increase of the adult survival index was not seen until around 1950. Adult longevity increased rapidly from the 1950s to 1990s. Since 1990, it has still been increasing and is projected to continue to increase slowly in the future.

[12] Appendix 2 describes how to calculate child and adult survival indices.

From Figure 2(b), labor force growth was much less than population growth mainly because of a high fertility rate. After World War II, the growth rate of the labor force increased sharply and was greater than population growth rate from 1950 to 1995.[13] Japan had a high cyclical population growth rate from 1890 to 1970. Since 1970, population growth has slowed, becoming negative around 2005. Growth rates of population and labor force are projected to continue decreasing in the future. Also, it is expected that the labor force growth rate will be less than the population growth rate until 2020.[14] The period in which labor force growth was greater than population growth may be the period in which Japan benefitted from the "first demographic dividend" as mentioned in Section 1. It is probable that Japan had a great opportunity to use the first demographic dividend during the high economic growth period after the war. However, the first dividend has not been effective since 2000.

Figure 3 presents simulated and real growth of capital. In the simulation analysis, the growth rate of domestic aggregate capital ($\dot{K}_t$) is calculated from our overlapping generations model. In the analysis, we consider capital depreciation.[15] Simulated capital growth weaved in and out from 1900 to 1940, and was much lower than in subsequent years. From 1950 to 1985, simulated growth of capital is quite high. It is simulated that capital growth has been decreasing since 1970, became almost zero in 2005, and will continue to decrease in the future. Simulated growth of capital is much higher than real growth, especially

---

[13] Growth rates of labor force and population in the 1970s were exceptional. Population growth rate increased mainly because of increased fertility rate during the second baby boom, and the growth of the labor force declined mostly because of an increase of unemployment during the second oil crisis.

[14] According to the data, the growth of the labor force is higher than that of population in 2025, probably because the death rate of first baby-boomers born from 1947 to 1950 will become high.

[15] The research of Kinugasa and Yamaguchi (2008) did not consider domestic capital and capital depreciation. A detailed explanation is given in Appendix 3.

from 1955 to 1980. It may be speculated that the simulation result does not reflect the actual situation well. However, the pattern of simulated capital growth change from 1955 to 1970 is similar to that of real capital growth. One reason that simulated capital growth is much higher than real growth could be because we do not consider intergenerational transfer. Japan has had a traditional intergenerational transfer system: it is expected for children to take care of their aging parents, and many of the older generation live with their children. Our theory based on the life cycle model could not explain past changes of capital in Japan well. Nowadays, traditional intergenerational transfer is disappearing, and individuals are becoming more responsible for their own consumption when they age, therefore, the life cycle model could be more applicable. Simulated capital growth in the future might approach real capital growth in the future.

Figure 4 presents the simulation results for the effects of demographic change on agricultural and non-agricultural outputs and inputs considering changes of labor, total population, and capital accumulation. The effects of demographic change on agricultural inputs and outputs are calculated as the sum of the products of GRM and growth rate of related exogenous variables. For example, the contribution of demographic change to agricultural output is calculated as: $Y_A K \cdot \dot{\hat{K}} + Y_A L \cdot \dot{L} + Y_A Q \cdot \dot{Q}$, and the contribution of demographic change to non-agricultural capital is calculated as: $K_M K \cdot \dot{\hat{K}} + K_M L \cdot \dot{L} + K_M Q \cdot \dot{Q}$ where $\dot{\hat{K}}$ is the simulated growth of domestic capital. The results are graphed in Figure 4(a). We also calculate the contribution of demographic change to agricultural and non-agricultural inputs and outputs when we do not think of the effects of demographic change on aggregate capital and only consider the effects of growths of population and labor. In this case, the contribution of demographic changes on agricultural output is: $Y_A L \cdot \dot{L} + Y_A Q \cdot \dot{Q}$, and the contribution of demographic changes to non-agricultural capital is : $K_M L \cdot \dot{L} + K_M Q \cdot \dot{Q}$. The results are presented in Figure 4(b).

Figure 4 (a) shows that demographic change contributed significantly to increases of both agricultural and non-agricultural capital. The contribution of demographic change to non-agricultural capital was a little more than that to agricultural capital until 1955, and it was much more than that to agricultural capital from 1960 to 1970. Demographic change influenced agricultural and non-agricultural output positively from 1890 to 2000, and the effect of demographic change on non-agricultural output was much larger than that on agricultural output from 1930 to 1985. It seems that demographic characteristics in Japan had a small effect on agricultural and non-agricultural labor compared to outputs and capital in both sectors throughout the period, but increased both agricultural and non-agricultural labor from 1900 to 1950.[16] From 1955 to 1980, demographic change is simulated to decrease agricultural labor and increase non-agricultural labor. And, from 1985 to 1995 it is simulated to increase both agricultural and non-agricultural labor, but to increase non-agricultural labor more than agricultural labor. From 2005 onward, the simulated contribution of demographic change to agricultural labor is negative. From 2010 onward, the simulated contribution to non-agricultural labor is negative. Throughout the period from 1905 to 1995, the simulated effect of demographic change on non-agricultural labor was greater than agricultural labor with the exception of 1945. After 2005, demographic change is simulated to decrease non-agricultural labor more than agricultural labor. On the whole, Figure 4(a) implies that demographic change increased the importance of non-agriculture before around 2000. Since the beginning of the 21st century, demographics have influenced and will continue to influence both agriculture and non-agriculture negatively in terms of output, labor, and capital. It is expected that the importance of agriculture will increase relative to non-agriculture in the future because demographic characteristics will influence

[16] In 1910, the effect of demographic change on agricultural capital was negative, which was exceptional.

non-agriculture more negatively than agriculture.

Figure 4(b) graphs the contribution of demographic change to agricultural and non-agricultural inputs and outputs when we do not think about the effect of demographic change on aggregate capital and only consider the effects of growths of population and labor. The scale of the vertical axis in Figure 4(b) is much smaller than that in Figure 4(a), so the effect of demographic changes on agriculture and non-agriculture is much smaller when we ignore its effect on aggregate capital. From 1905 to 2000, demographic changes are simulated to increase agricultural and non-agricultural outputs, but the simulated contribution of demographic changes to agricultural output is greater than that to non-agricultural output from 1905 to 1950. From 1955 to 1965, and from 1980 to 1995, demographic changes are simulated to contribute to the growth of non-agricultural output more than agricultural output. From 1970 to 1975, Japan experienced a second baby boom, and the population growth rate was higher than the growth rate of the labor force. During that period, growths of population and labor influenced agriculture more favorably than non-agriculture. In 2000, the simulated effect of demographic change on agricultural output is still positive and the simulated effect on non-agricultural effect is negative. In 2005 and 2010, the simulated effects of demographic change on both agricultural and non-agricultural outputs are negative, but the effect on non-agricultural output is more negative than that on agriculture, mainly because the growth of the labor force declines more than population growth. After 2010, the effect of demographic change on agricultural output is more negative than that on non-agricultural output. Population growth is expected to decline more than the growth of the labor force, and Malthus's law may become dominant. The population consuming food will decrease and agriculture will decline more than non-agriculture. The simulated effect of demographic change on agricultural capital is positive in 2000 and 2005, while the effect on non-agriculture is negative during the same time. Demographic change is simulated to influence agricultural capital negatively and non-agricultural capital positively after 2010. According to Table 1, depopulation tends to decrease agricultural capital and increase non-agricultural capital, and the decline of labor force growth tends to increase agricultural labor and decrease agricultural capital. It seems that depopulation will have a stronger effect on agricultural and non-agricultural capital than the decrease of the labor force. Depopulation and decrease of the labor force are simulated to decrease both agricultural and non-agricultural labor after 2005 and decrease agricultural labor more than non-agricultural labor after 2010.

Figure 4(b) implies that demographic change contributed to agriculture more favorably than agriculture before 2000, mainly because of an increase of population. According to Malthus's law, an increase of population increases agricultural outputs and inputs because more food is required to feed a larger population. The result of Figure 4(b) is different from that of Figure 4(a) and may not be consistent with the fact that Japan experienced remarkable industrialization after World War II. Therefore, it would be important to consider the effect of demographic change on capital accumulation when we discuss the effect of demographic change on industrial structure. On the other hand, capital accumulation induced by demographic changes was not the only factor that brought about industrialization after World War II. Technical changes in agriculture and non-agriculture sectors influenced industrial structure remarkably. In this paper, we do not go into detail about technical change, but it would be important to discuss it in future research.

Figure 4(c) shows the simulated contribution of demographic change to income per capita in cases for which the effects of demographic change on domestic capital are considered and not considered. This figure implies that capital accumulation induced by demographic change contributed greatly to economic growth in the late 20th century. If demographic change did not influence capital accumulation at all, there would not be high economic growth after World War II; High population growth could influence income per capita negatively even though the high growth rate of the labor force encouraged economic growth. Figure 4 (c) indicates that economic growth will be negative according to the demographic situation in Japan mainly because of a decrease of capital growth, although depopulation may increase income per capita in the future if we do not think about the effect of demographic change on capital accumulation.

Here, we attempt to calculate changes in the importance of agriculture based on the simulation results in Figure 4. Let us define changes in the importance of agriculture in terms of output (capital, labor) as a contribution of demographic change to agricultural output (capital, labor) minus that to non-agricultural output (capital, labor). If the simulated change in the importance of agriculture is positive, it means that demographic change is simulated to influence agriculture more favorably than non-agriculture. Figure 5 presents the results. The importance of agriculture in Figure 5 (a) is calculated from Figure 4 (a). Simulated changes in the importance of agriculture in terms of output had been negative until 2000 with one exception in 2000. The importance of agriculture in terms of capital and labor had been decreasing until 2000 with a few exceptions. It seems that demographic changes influenced the importance of agriculture in terms of output much more seriously than in terms of capital or labor. From 1955 to 1985, when simulated domestic capital was quite high as shown in Figure 2, the importance of agriculture decreased greatly in terms of output and input. Figure 5(a) shows that changes in the importance of agriculture in terms of both output and input became positive in 2005, and will continue to be positive in the future. This implies that agriculture may become increasingly important in the near future.

Figure 5(b) is calculated from the results in Figure 4(b). If we do not consider the effect of demographic change on capital accumulation, demographic change such as changes of population and labor influence the importance of agriculture in terms of capital or labor more than that in terms of output. Changes of population and labor increased the importance of agriculture until 1950. From 1955 to 1965, demographic change influenced non-agriculture more advantageously than agriculture in terms of output, while it influenced agriculture more favorably than non-agriculture with regard to capital and labor in 1960 and 1965. In 1970, the importance of agriculture increased with respect to all three aspects. Demographic change decreased the importance of agriculture in terms of output from 1975 to 1995 and in terms of capital and labor from 1985 to 1995. In 2000, the importance of agriculture in terms of output increased, and it is expected to increase in 2005, 2010, and 2015, but decrease in 2020 and 2025. If we do not think about the effects of demographic change on capital accumulation, demographic change will not increase the importance of agriculture in the near future. In 2020 and thereafter, population growth will be lower than the growth of the labor force, so the importance of agriculture will decrease according to Malthus's theorem.

5. Conclusion

The effects of demographic change on agriculture and non-agriculture have been discussed using Malthus's model. However, the effects are not researched enough in terms of capital accumulation. Many recent studies on economic development have focused on growth theory, and do not consider agriculture and non-agriculture. However, it is important to discuss the interaction between agriculture and non-agriculture when we discuss development because agriculture produces food, which is essential for life through all ages. The research of Kinugasa and Yamaguchi (2008) took capital accumulation into account and analyzed the effects of demographic changes on agriculture and non-agriculture, however, they did not consider the effects of population and labor, and they researched only past effects. This research considers capital accumulation, total labor, and population, and analyzes the effects of demographic changes on agriculture and non-agriculture in the past, the present, and the future. Our research confirms that it is important to consider capital accumulation when discussing the effects of demographic change on agriculture and non-agriculture; our simulation results differ significantly when we do not consider the effects of demographic change on capital accumulation.

Our simulation analyses indicate that demographic changes can greatly influence capital accumulation and the importance of agriculture. A decrease of the number of children and an increase of adult longevity induced capital accumulation, promoted economic growth, and increased the importance of non-agriculture to a significant extent from the middle of the 20th century until around 2000. Japan took advantage of first and second demographic dividends in the second half of the 20th century. First and second demographic dividends may have contributed to industrialization and decreased the importance of agriculture. Now, Japan is experiencing depopulation although the second demographic dividend is still continuing. The decline of population growth may increase the importance of non-agriculture with a decline of demand for food. However, more importantly, a decline of labor force growth and a decline of capital accumulation caused by the decline of labor force growth will decrease the importance of non-agriculture more than agriculture. Therefore, the importance of non-agriculture will not continue and the relative importance of agriculture may increase in the near future.

This research does not consider the effects of demographic changes on technical change. However, demographic changes could greatly influence technical change as Yamaguchi (1982, 2001) indicated. Analyzing this issue is an important subject for future research. Moreover, this research assumed only a life-cycle model, whereas we need to consider intergenerational transfer. Traditional intergenerational transfer whereby children take care of their parents when they age has been common in Japan. Nowadays, the social security system is playing an important role in intergenerational transfer. The difficulty in analyzing intergenerational transfer is that it is not easy to obtain reliable data, however, it would be important to take intergenerational transfer into account in the future.

References

Bloom, D. E. and J. G. Williamson (1998) "Demographic Transitions and Economic Miracles in Emerging Asia", World *Bank Economic Review*, Vol. 12, No. 3, pp.419–455.

Higgins, M. (1994) *The Demographic Determinants of Savings, Investment and International Capital Flows*. Ph.D. Dissertation, Department of Economics, Harvard University

Higgins, M. and J. Williamson (1997) "Age Structure Dynamics in Asia and Dependence on Foreign Capital.", *Population and Development Review*, Vol. 23, No.2, pp.261-293.

Japan. Cabinet Office (2004) *Shoshika Shakai Hakusho Heisei 16nen-ban (Whitepaper on Birthrate-Declining Society 2004,* Gyosei.

Japan. Health and Welfare Statistics Association, *Seimeihyo* (*Life Table)*, various years.

Japan. National Institute of Population and Social Security Research, "Danjo Nenrei Kakusai-betsu Jinko: Shussho Chui (Shibo Chui) Suikei (Population by Age and Sex: Medium-variant Fertility and Mortality" http://www.ipss.go.jp/pp-newest/j/newest03/02_syosai/01/Mm1-9.xls, (December 22, 2007).

———— , "Danjo Nenrei-betsu Shorai Seimei Hyo: Chui Katei (Estimated Life Table by Age and Sex: Medium Variance", http://www.ipss.go.jp/syoushika/tohkei/suikei07/houkoku/katei/11-6-1.xls, (December 22, 2007).

Japan. Ministry of Internal Affairs and Communications, Statistics Bureau and the Director-General for Policy Planning (Statistical Standards), Statistical Research and Training Institute, "Capital Finance Accounts - 93SNA (1980--2002, F.Y.1980--2002)", http://www.stat.go.jp/data/chouki/zuhyou/03-27.xls, (May 6, 2008).

———, "Closing Stocks, Capital Transactions and Reconciliations of Assets and Liabilities for the

Nation - 68SNA (1969--1998)", http://www.stat.go.jp/data/chouki/zuhyou/03-14-b.xls, (May 6, 2008).

Japan. Statistic Bureau and Statistic Research and Tranining Institute (2006) "Historical Statistics of Japan", http://www.stat.go.jp/data/chouki/02.htm, (November 25, 2006).

———, *Japan Statistical Yearbook*, various years.

Jorgenson, D.W. (1961) "The Development of a Dual Economy", *Economic Journal* Vol.71, pp.686-698.

Kelley, A.C., and R. M. Schmidt (2001) "Economic and Demographic Change: A Synthesis of Models, Findings, and Perspectives", in B.,Nancy, A. C. Kelley, and S. Sinding, eds., *Population Matters: Demographic Change, Economic Growth, and Poverty in the Developing World*, New York: Oxford University Press, pp. 67‐105.

——— (2005) "Evolution of Recent Economic-Demographic Modeling: A Synthesis", *Journal of Population Economics*, Vol.18, No.2, pp.275-300.

Kelley, A.C., J.G. Williamson, and R.J. Cheetham (1972) *Dualistic Economic Development Theory and History*, Chicago, University of Chicago Press.

Kinugasa, T. and A. Mason (2007) "Why Countries Become Wealthy: The Effects of Adult Longevity on Saving", *World Development*, Vol.35, No.1, pp.1-23.

Kinugasa, T. and M. Yamaguchi (2008) "The Effect of Demographic Change on Industrial Structure: A Study Using the Overlapping Generations and General Equilibrium Growth Accounting Models", *Journal of Population Studies*, Vol. 42, pp.21–40.

Lee, R., A. Mason, and T. Miller (2001) "Saving, Wealth, and the Demographic Transition in East Asia", Mason, A. (ed.) *Population Change and Economic Development in East Asia: Challenges Met, Opportunities Seized.* Stanford: Stanford University Press.

Lewis, A.W. (1954) "Economic Development with Unlimited Supplies of Labor", *Manchester School of Economics and Social Studies*, Vol.20.

Malthus, Thomas (1798) An Essay on the Principle of Population with Introduction by Philip Appleman. Norton.

Mason, A. (1981) "An Extension of the Life-Cycle Model and its Application to Population Growth and Aggregate Saving", *East-West Population Institute Working Paper* No.4, Honolulu.

——— (1987) "National Saving Rates and Population Growth: A New Model and New Evidence", in Johnson, D.G. and R.D. Lee, eds., P*opulation Growth and Economic Development: Issues and Evidence. Social Demography series,* Madison, Wis.: University Wisconsin Press, pp.523-60.

——— (2007) "Demographic Dividends: The Past, the Present, and the Future" in A. Mason and M. Yamaguchi, eds, P*opulation Change, Labor Markets and Sustainable Growth: Towards a New Economic Paradigm*, Elsevier Press.

——— and T. Kinugasa (2008) "East Asian Development: Two Demographic Dividends", *Journal of Asian Economics*, Vol. 19 No. 5-6, pp.389-400.

Modigliani, F. and R. Brumberg (1954) "Utility Analysis and the Consumption Function: An Interpretation of Cross Section Data", in K. Kurihara, ed., *Post Keynesian Economics*, New Brunswick, N. J.: Rutgers University Press.

Ogawa, N. (2007) "Population aging and economic growth: the role of two demographic dividends in Japan", in F. Coulmas, H. Conrad, A. Schad-Seifert, and G. Vogt, eds., *The Demographic Challenge: A Handbook About Japan*, Brill Academic Pub.

Ohkawa K., and M. Shinohara, eds. (1979) *Patterns of Japanese Economic Development: A Quantitive Appraisal*, New Haven and London, Yale University Press.

Ohkawa K., M. Shinohara, and M. Umemura, eds. (1966), Choki Keizai Tokei (Long-Term Economic Statistics of Japan), Toyo Keizai Shimposha.

Ranis, G. and J. Fei (1961) "A Theory of Economic Development", *American Economic Review*, Vol.51, No.4, pp. 533-565.

Tobin, J. (1967) "Life Cycle Savings and Balanced Growth", in W. Fellner ed., *Ten Economic Studies in the Transition of Irving Fisher*. New York: Wiley, pp. 231-256.

Yaari, M. (1965) "Uncertain Lifetime, Life Insurance, and the Theory of the Consumer", *The Review of Economic Studies*, Vol.32, No.2, pp.137-50.

Yamaguchi, M. (1982) "The Source of Japanese Economic Eevelopment: 1880–1970", *Economic Studies Quarterly* Vol.33, No.2, pp.126–146.

——— (2001) *Jinko Seicho to Keizai Hatten: Shoshi-korei-ka to Jinko Bakuhatsu no Kyozon (Population Growth and Economic Development),* Yuhikaku.

——— and H. P. Binswanger (1975) "The Role of Sectoral Technical Change in Development: Japan, 1880–1965", *American Journal of Agricultural Economics* Vol.57, No.2, pp. 269–78.

——— and G. Kennedy (1984a) "Contribution of Population Growth to Per Capita Income and Sectoral Output Growth in Japan, 1880–1970", *Developing Economies* Vol.22, No.3, pp.237–63.

——— and ——— (1984b) "A Graphic Model of The Effects of Sectoral Technical Change: The Case of Japan, 1880–1970" , *Canadian Journal of Agricultural Economics*,Vol.32, No.1, pp.71–92.

Appendix 1 Outline of General Equilibrium Growth Accounting Model

The general equilibrium growth accounting model formulated by Yamaguchi (1982, 2001) and his colleagues is described by the following 12 equations.[17]

$$Y_A = aQP^{\eta}E^{\zeta} \text{ : Agricultural demand function.} \quad (A.1)$$

$$Y_A = T_A L_A{}^{\alpha} K_A{}^{\beta} B^{1-\alpha-\beta} \text{ : Agricultural production function.} \quad (A.2)$$

$$Y_M = T_M L_M{}^{\gamma} K_M{}^{\delta} \text{ : Non-agricultural production function.} \quad (A.3)$$

$$L = L_A + L_M \text{ : Sectoral allocation of labor.} \quad (A.4)$$

$$K = K_A + K_M \text{ : Sectoral allocation of capital.} \quad (A.5)$$

$$w_A = \alpha P_A (Y_A / L_A) \text{ : Wage = Value marginal product of labor.} \quad (A.6)$$

$$w_M = \gamma P_M (Y_M / L_M) \text{ : Wage = Value marginal product of labor.} \quad (A.7)$$

$$r_A = \beta P_A (Y_A / K_A) \text{ : Interest rate = Value marginal product of capital.} \quad (A.8)$$

$$r_M = \delta P_M (Y_M / K_M) \text{ : Interest rate = Value marginal product of capital.} \quad (A.9)$$

$$w_A = m_w w_M \text{ : Wage gap in the two sectors.} \quad (A.10)$$

$$r_A = r_M \text{ : Interest rate in the two sectors.} \quad (A.11)$$

$$P'QE = P_A Y_A + P_M Y_M \text{ : Identical equation for income.} \quad (A.12)$$

The subscript A represents the agricultural sector and the subscript M represents the non-agricultural (or manufacturing) sector. The exogenous variables are agricultural technical growth (T_A), non-agricultural technical growth (T_M), population (Q), total labor force (L), aggregate capital (K), land (B), demand shifter

[17] Yamaguchi (1982, 2001) conceived of his model as including a degree of competitiveness between the agricultural and non-agricultural sectors.

of agricultural products (a), and the wage gap between the agricultural and non-agricultural sectors (m_W). The endogenous variables are agricultural output (Y_A), non-agricultural output (Y_M), agricultural labor (L_A), non-agricultural labor (L_M), agricultural capital (K_A), non-agricultural capital (K_M), relative prices of agricultural and non-agricultural products (P), and income (E).[18]

From equations (A.1) to (A.12) in the above model, the eight abovementioned endogenous variables and agricultural wage (w_A), non-agricultural wage (w_M), agricultural interest rate (r_A), and non-agricultural interest rate (r_M) are endogenous. From equations (A.6) to (A.11), w_A, w_M, r_A, and r_M are cancelled out and the following two equations are derived:

$$\begin{aligned} m_w &= P(\alpha Y_A L_M)/(\gamma Y_M L_A) \\ 1 &= P(\beta Y_A K_M)/(\delta Y_M K_A). \end{aligned}$$

From these equations, we obtain the following:

$$\begin{aligned} m_w &= (\alpha\delta K_A L_M)/(\gamma\beta K_M L_A) \\ P &= [(\alpha\delta)^{\delta}\gamma T_M m_w{}^{\gamma}]/[(\delta\beta)^{\delta}\alpha T_A L_A{}^{\alpha-\gamma} K_A{}^{\beta-\delta} B^{1-\alpha-\beta}]. \end{aligned} \tag{A.13}$$

The static model with 12 equations (from equations (A.1) to (A.12)) can be converted into a dynamic model with eight equations by taking the logarithm of both sides of each equation and differentiating with respect to time t as follows:

$$\begin{aligned} \dot{Y}_A &= \dot{a} + \dot{Q} + \eta\dot{P} + \zeta\dot{E} \\ \dot{Y}_A &= \dot{T}_A + \alpha\dot{L}_A + \beta\dot{K}_A + (1-\alpha-\beta)\dot{B} \\ \dot{Y}_M &= \dot{T}_M + \gamma\dot{L}_M + \delta\dot{K}_M \\ \dot{L} &= l_A\dot{L}_A + l_M\dot{L}_M \\ \dot{K} &= k_A\dot{K}_A + k_M\dot{K}_M \\ \dot{m}_w &= \dot{K}_A - \dot{K}_M + \dot{L}_M - \dot{L}_A \\ \dot{P} &= \dot{T}_M - \dot{T}_A + (\gamma-\alpha)\dot{L}_A + (\delta-\beta)\dot{K}_A - (1-\alpha-\beta)\dot{B} + \lambda\dot{m}_w \\ \dot{Q} &= \chi\dot{Y}_A + (1-\chi)\dot{Y}_M - \dot{E}. \end{aligned} \tag{A.14}$$

A dot over a variable, such as $\dot{Y}_A$, denotes the growth rate. l_A represents the share of agricultural labor in total labor, l_M is the share of non-agricultural labor in total labor, k_A is the share of agricultural

[18] Appendix Table 1 gives the definitions of these parameters.

capital in aggregate capital, k_M is the share of non-agricultural capital in aggregate capital, and χ is the share of agricultural income in total income.

These equations can be expressed by a matrix as follows:

$$\underbrace{\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & -\eta & -\zeta \\ 1 & 0 & -\beta & 0 & -\alpha & 0 & 0 & 0 \\ 0 & 1 & 0 & -\delta & 0 & -\gamma & 0 & 0 \\ 0 & 0 & 0 & 0 & l_A & l_M & 0 & 0 \\ 0 & 0 & k_A & k_M & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & -1 & 1 & 0 & 0 \\ 0 & 0 & \beta-\delta & 0 & \alpha-\gamma & 0 & 1 & 0 \\ \chi & 1-\chi & 0 & 0 & 0 & 0 & 0 & -1 \end{pmatrix}}_{Z} \underbrace{\begin{pmatrix} \dot{Y}_A \\ \dot{Y}_M \\ \dot{K}_A \\ \dot{K}_M \\ \dot{L}_A \\ \dot{L}_M \\ \dot{P} \\ \dot{E} \end{pmatrix}}_{x} = \underbrace{\begin{pmatrix} \dot{a}+\dot{Q} \\ \dot{T}_A+(1-\alpha-\beta)\dot{B} \\ \dot{T}_M \\ \dot{L} \\ \dot{K} \\ \dot{m}_w \\ \dot{T}_M-\dot{T}_A-(1-\alpha-\beta)\dot{B}+\lambda\dot{m}_w \\ \dot{Q} \end{pmatrix}}_{b}. \quad (A.15)$$

The equation $Zx = b$ can also be represented as $x = Z^{-1}b$. Each component of the matrix of Z^{-1} is the growth rate multiplier (GRM). For example, the component of the 1st row and the 5th column of Z^{-1}, c_{15}, represents $\partial\dot{Y}_A / \partial\dot{K}$, which gives the percentage increase of agricultural output with a 1% increase of aggregate capital. The contribution of an exogenous variable to an endogenous variable is obtained by multiplying the GRM and the growth rate of the exogenous variable.

Appendix 2 Determinant of Aggregate Capital

Gross national saving at time t (S_t) is given by the change of aggregate asset plus depreciation,[19] that is, $S_t = (K_{t+1} + F_{t+1}) - (K_t + F_t) + \xi K_t$, where K is domestic assets, F is foreign assets, and ξ is the

[19] We assume a small open economy in order to keep the interest rate constant with the world interest rate. Perfect capital mobility is assumed in a small open economy, in which the domestic economy is able to borrow and lend in the international capital market at a given interest rate. Whether the economy is lending or borrowing capital is an important issue; however, we are merely concerned with the aggregate capital holdings of a country for the sake of simplicity.

depreciation rate. Net national saving $(S_t - \xi K_t)$ is equal to the aggregate national income minus total consumption; therefore,

$$(K_{t+1} + F_{t+1}) - (K_t + F_t) = w_t(1 - \nu n_t)A_t N_{1,t} + r_t(K_t + F_t) - (n_t c_{0,t} N_{0,t} + c_{1,t} N_{1,t} + c_{2,t} N_{2,t}), \tag{A.16}$$

where $N_{0,t}$ is the number of children; $N_{1,t}$, the number of prime-age adults; and $N_{2,t}$, the number of the elderly. From budget constraints of prime-age adults and the elderly and equation (A.16), we can obtain equation (4).

Appendix 3 Simulation Method and Descriptions of Parameters

The level and the growth of domestic capital are simulated according to the theory described in Section 3. Using the growth rate multiplier in Table 1 and the simulated growth rate of domestic capital, we calculate the contribution of demographic changes to agricultural and non-agricultural outputs and inputs. Contributions of simulated domestic capital to agricultural and non-agricultural outputs and inputs are calculated by multiplying simulated growth of domestic capital by GRM in Table 1.

We simulate domestic capital in equation (5) and growth of domestic capital under the following assumptions. Each age bracket consists of 30 years. Children are from 0 to 29 years old, prime-age adults are from 30 to 59 years old, and the elderly are from 60 to 89 years old. Therefore, each period should also consist of 30 years. However, in equation (5), the capital in the next period is based on saving behavior 30 years previously, which is not a realistic assumption. Therefore, we assume one period consists of 5 years; that is, domestic capital is determined by the saving behavior of prime age adults 5 years previously. $\dot{K}$, growth rate of domestic capital per 1 year, is calculated every 5 years. We assume that the ratio of domestic capital to the aggregate capital, d_t, is the ratio of investment to saving. The data on investment and saving are from Maddison (1992) until 1980 and Japan, Ministry of Internal Affairs and

Communications, Statistics Bureau and the Director-General for Policy Planning (Statistical Standards), Statistical Research and Training Institute, Capital Finance Accounts - 93SNA (1980--2002, F.Y.1980--2002)", for 1981 and after. In this analysis, we consider capital depreciation assuming that capital is depreciated 5% a year, and 1 unit of capital becomes 0.77 unit in 5 years.

According to Higgins (1994), the values of the following parameters are assumed. The utility weights are assigned as follows: $\lambda_0 = 0.5$, $\lambda_1 = 1$, and $\lambda_2 = 0.9$, which implies that the consumption of children is 50%, while that of the elderly is 90% of the prime-age consumption. θ is determined to be such that the intertemporal elasticity of substitution ($1/\theta$) is 1.3. Under this value of θ, an increase of interest rate moderately increases saving by prime-age adults. κ is set at 0.53, so that the utility of children is discounted and is equivalent to 53% of prime-age adult's utility. ν is set at 0.1 so that 10% of working time is devoted to raise 1 child.

It is assumed that ε is 0.1; hence, the marginal utility of the number of children declines to a very small extent with a decline in the number of children. Wage (w) is set constant at 1. The technological level is assumed to be 1 in 1890 and its annual growth is assumed to be based on contributions of demographic change to income per capita. The interest rate (r) is set at 5% for 1 year; therefore, 1+r = 4.322 for 30 years. In this study, we use GRMs calculated in Table 1. Yamaguchi (1982, 2001) calculates these from 1880 to 1965, whereas we recalculate them from 1970 to 2000.

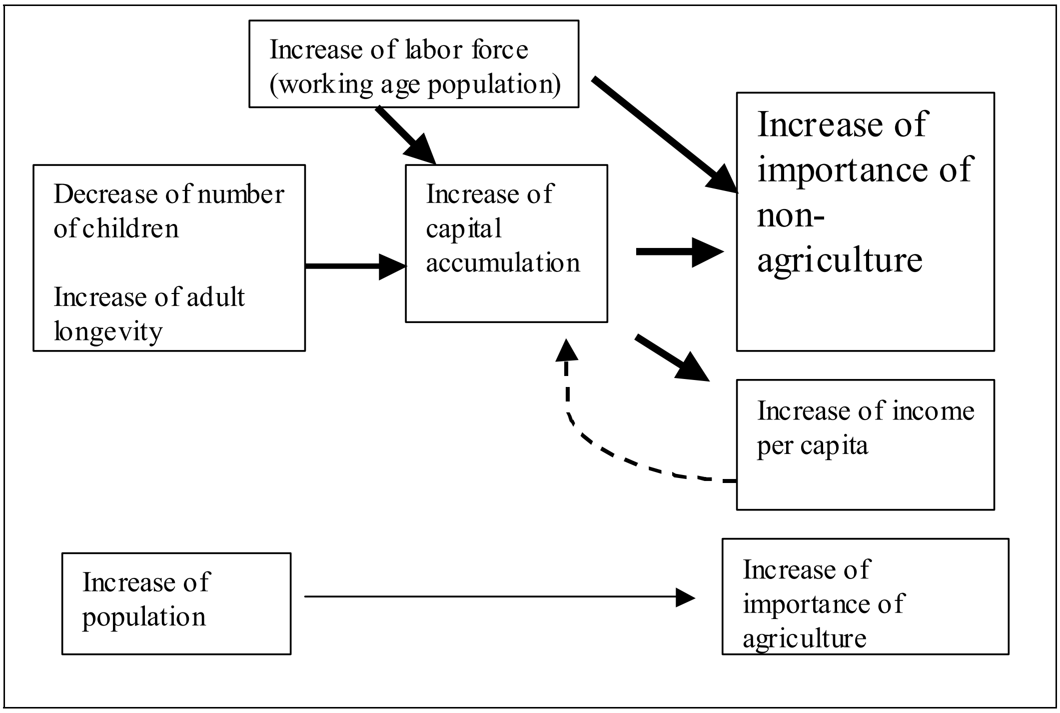
For the number of children per adult, we divide the population aged 0–29 by that aged 30–59. The data are obtained from the "Historical Statistics of Japan" from the Statistics Bureau and the Statistical Research and Training Institute in Japan (from 1890 to 2000) and from National Institute of Population and Social Security Research in Japan (from 2005 to 2025). Adult and child survival rates are calculated using the life table from the Health and Welfare Statistics Association in Japan (from 1890 to 2000) and estimated life table from National Institute of Population and Social Security Research in Japan (from 2005 to 2025). The adult survival index is defined as $\sum_{x=60}^{89} L_x / \sum_{x=30}^{59} L_x$, where L_x is number of years lived between the exact age x and the exact age $x+1$.[20] The child survival index is defined as $\sum_{x=30}^{59} L_x / \sum_{x=0}^{29} L_x$.

Data on population are obtained from *Japan Statistical Yearbook*. Data on labor force are obtained from Ohkawa and Shinohara eds. (1979) (from 1890 to 1950), "Historical Statistics of Japan" (from 1950 to 2000), and Cabinet Office in Japan (2004) (from 2005 to 2025) .

[20] Where data for the total population were unavailable, we used the mean of the adult (child) survival rates for males and females.

Figure 1 Outline of Relationships Among Demographic Change, Capital Accumulation, and Importance of Agriculture

(a) Japanese Experience from the 1950s to 1990s



(b) Outlook for Japan

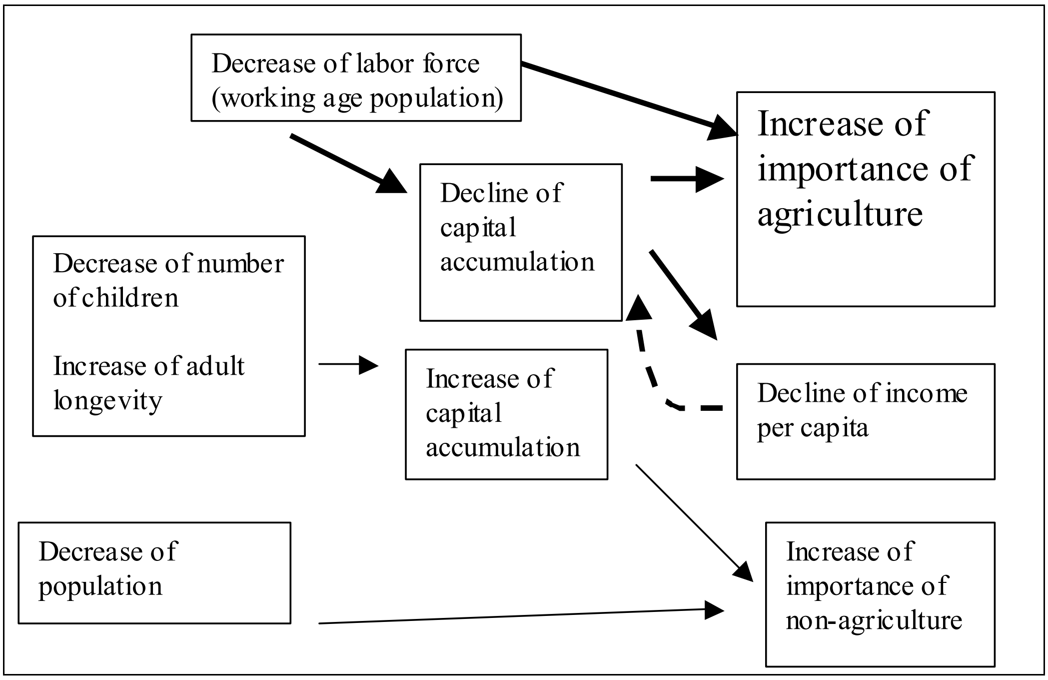
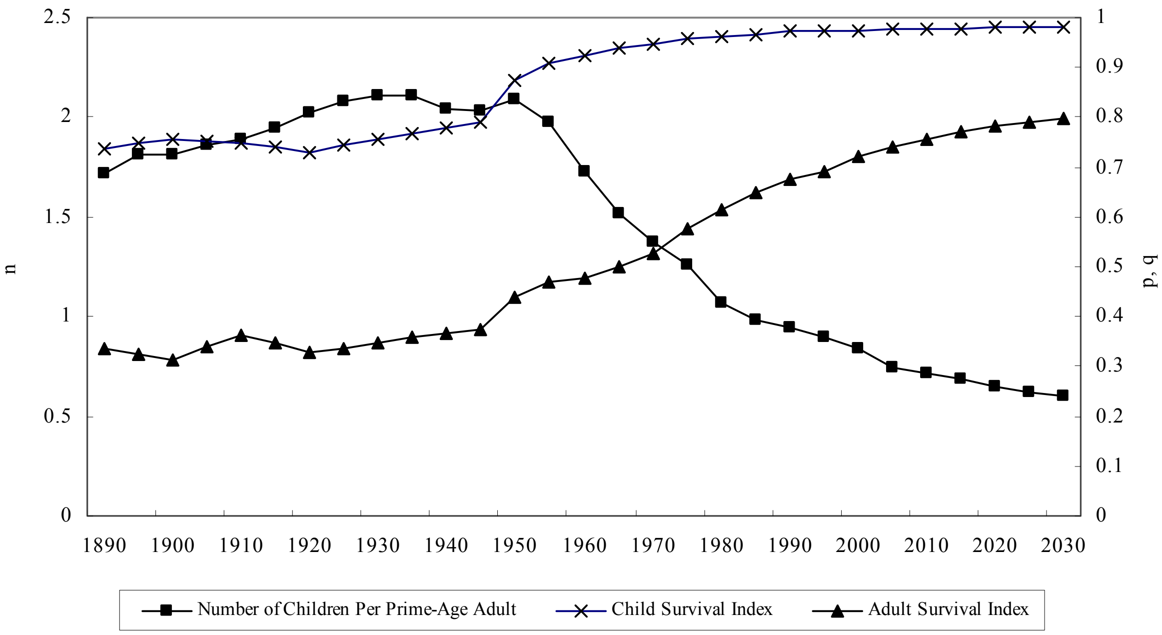


Figure 2 Demographic Changes in Japan

(a) Number of Children and Adult and Child Survival Indices



(b) Growth Rates og Labor and Population

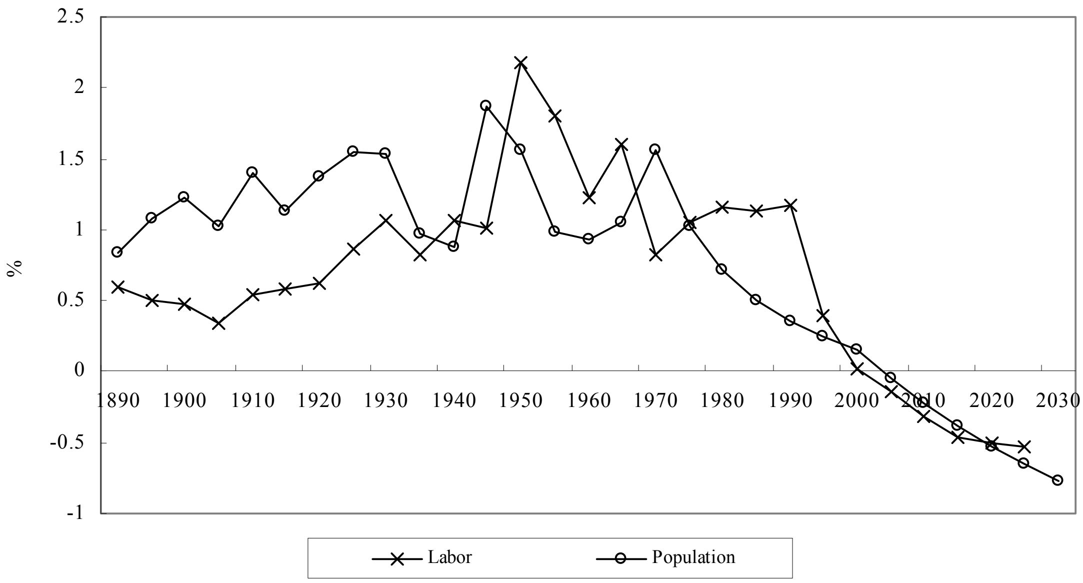
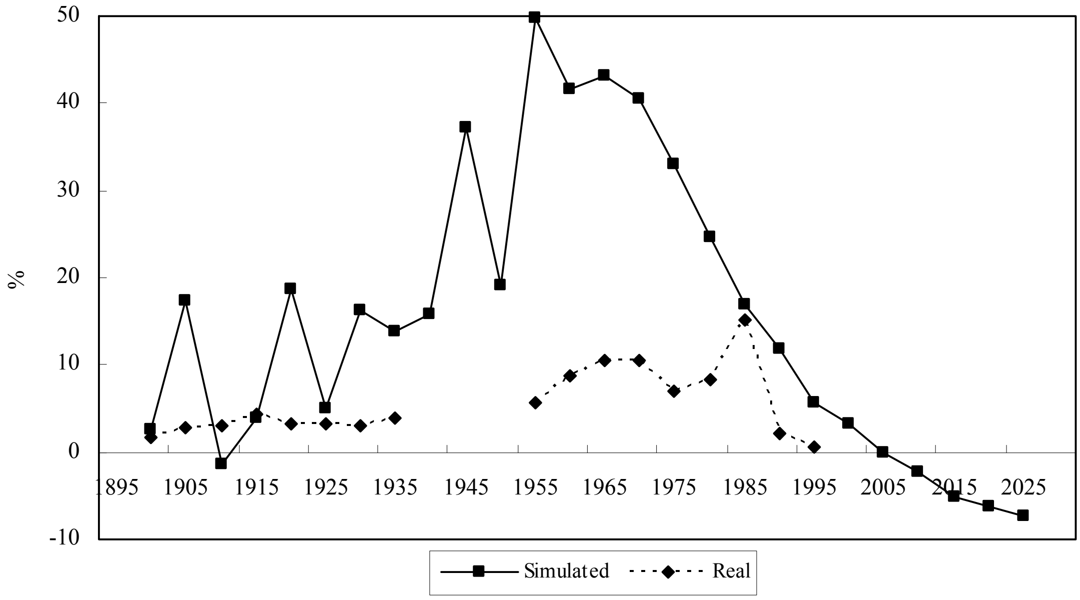


Figure 3 Simulated and Real Growth of Domestic Capital in Japan



Note: To calculate real growth of domestic capital, data on domestic capital are obtained from Ohkawa et al. eds. (1966) (before 1940), Ohkawa and Shinohara eds. (1979) (from 1954 to 1958), and Ministry of Internal Affairs and Communications, Statistics Bureau and the Director-General for Policy Planning (Statistical Standards), Statistical Research and Training Institute, Japan (from 1959 to 1998). Domestic capital is deflated by consumer price index.

Figure 4 Simulated Contributions of Demographic Changes to Agricultural and Non-agricultural Inputs and Outputs and Income Per Capita

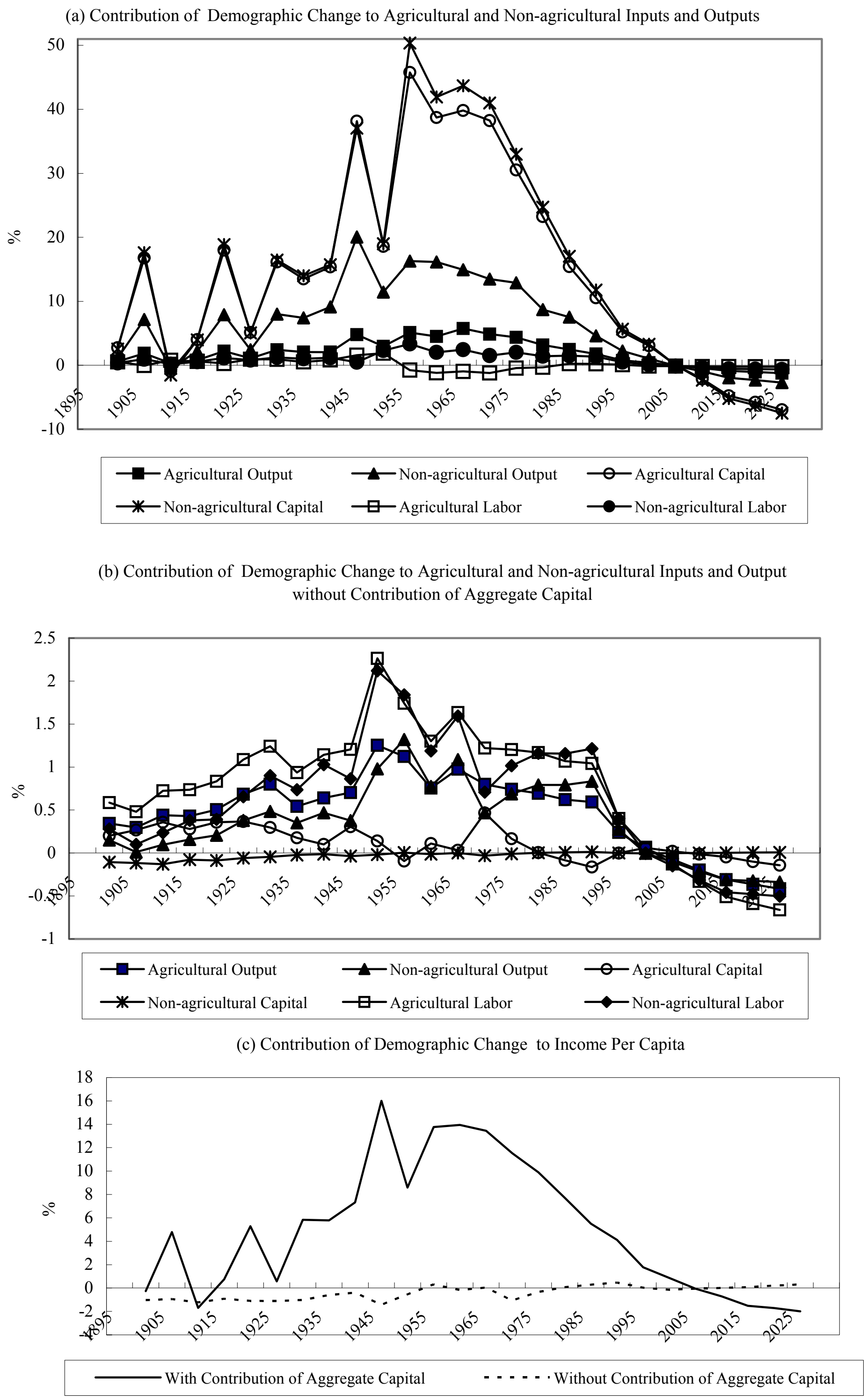
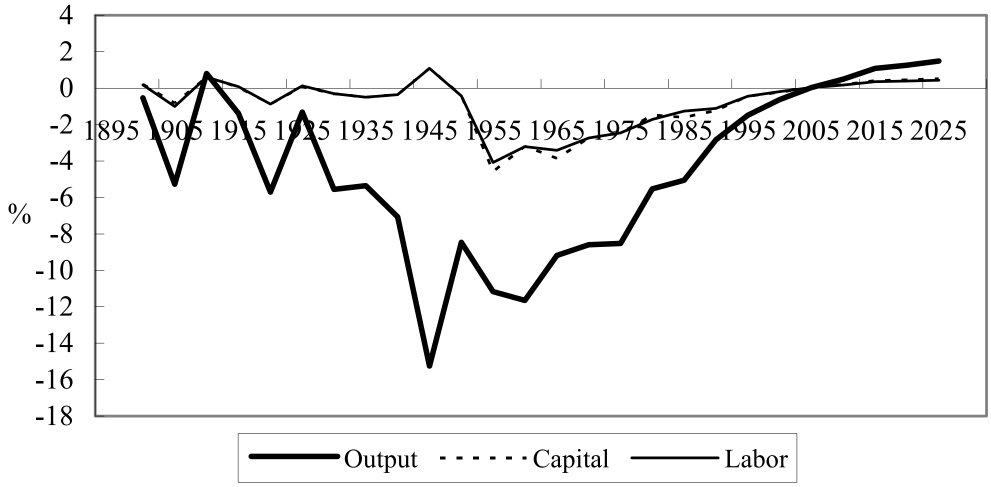


Figure 5 Simulated Changes of Importance of Agriculture in Terms of Output, Capital, and Labor

(a) With the Effect of Demographic Change on Domestic Capital



(b) Without the Effect of Demographic Change on Domestic Capital

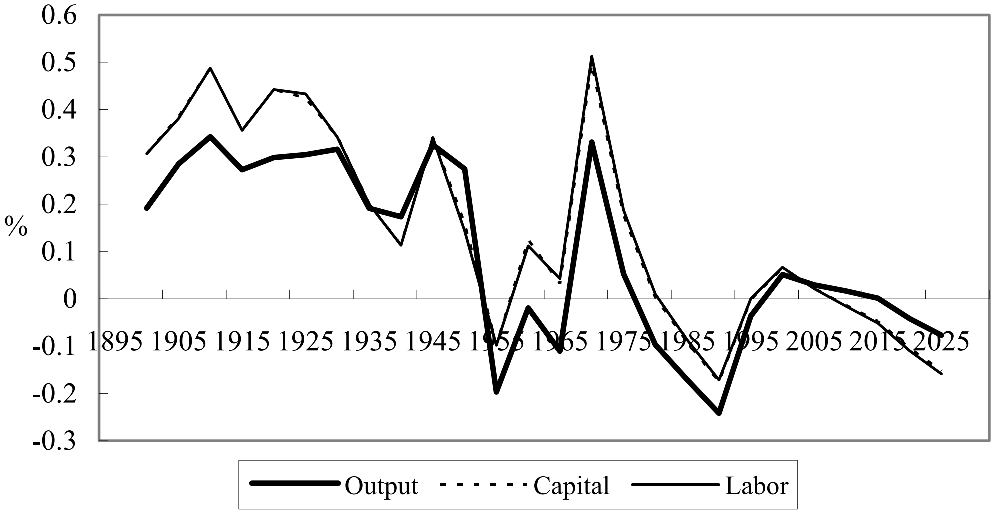


Table 1 Growth Rate Multipliers for Aggregate Capital, Labor, and Population

	Y_AK	Y_MK	K_AK	K_MK	L_AK	L_MK	EK	Y_AL	Y_ML	K_AL	K_ML	L_AL	L_ML	EL	Y_AQ	Y_MQ	K_AQ	K_MQ	L_AQ	L_MQ	EQ
1890	0.10	0.30	0.96	1.03	-0.02	0.05	0.22	0.48	0.88	-0.14	0.09	0.92	1.16	0.73	0.09	-0.22	0.22	-0.14	0.12	-0.25	-1.10
1895	0.10	0.33	0.96	1.02	-0.02	0.04	0.25	0.49	0.81	-0.12	0.07	0.93	1.13	0.71	0.08	-0.19	0.21	-0.12	0.11	-0.22	-1.10
1900	0.09	0.37	0.97	1.01	-0.02	0.03	0.29	0.51	0.75	-0.12	0.06	0.94	1.12	0.68	0.08	-0.17	0.21	-0.11	0.11	-0.21	-1.10
1905	0.09	0.41	0.95	1.02	-0.03	0.05	0.33	0.48	0.76	-0.18	0.08	0.90	1.17	0.69	0.13	-0.24	0.32	-0.14	0.17	-0.29	-1.15
1910	0.09	0.42	0.94	1.02	-0.03	0.05	0.34	0.48	0.75	-0.19	0.07	0.90	1.16	0.68	0.13	-0.22	0.33	-0.12	0.17	-0.28	-1.14
1915	0.09	0.51	0.94	1.02	-0.03	0.04	0.42	0.47	0.62	-0.18	0.06	0.90	1.14	0.59	0.14	-0.18	0.34	-0.10	0.19	-0.25	-1.11
1920	0.09	0.41	0.94	1.01	-0.03	0.04	0.34	0.46	0.71	-0.20	0.04	0.88	1.12	0.66	0.16	-0.17	0.35	-0.08	0.21	-0.22	-1.09
1925	0.08	0.40	0.94	1.01	-0.03	0.03	0.33	0.49	0.71	-0.22	0.04	0.87	1.12	0.66	0.17	-0.15	0.36	-0.06	0.22	-0.20	-1.08
1930	0.10	0.46	0.97	1.01	-0.02	0.02	0.42	0.51	0.63	-0.21	0.03	0.87	1.11	0.61	0.17	-0.12	0.34	-0.05	0.21	-0.18	-1.09
1935	0.11	0.51	0.96	1.01	-0.03	0.02	0.46	0.46	0.56	-0.20	0.02	0.88	1.10	0.55	0.17	-0.11	0.35	-0.04	0.22	-0.17	-1.07
1940	0.09	0.55	0.97	1.00	-0.02	0.01	0.49	0.46	0.51	-0.20	0.02	0.87	1.09	0.50	0.17	-0.09	0.36	-0.04	0.24	-0.16	-1.06
1945	0.11	0.53	1.02	1.00	0.01	-0.01	0.47	0.49	0.50	-0.14	0.02	0.91	1.07	0.50	0.11	-0.07	0.24	-0.03	0.15	-0.12	-1.04
1950	0.09	0.55	0.97	1.00	-0.02	0.01	0.48	0.46	0.52	-0.20	0.02	0.88	1.10	0.51	0.16	-0.10	0.37	-0.04	0.22	-0.18	-1.06
1955	0.08	0.30	0.92	1.01	-0.05	0.03	0.27	0.47	0.82	-0.32	0.03	0.78	1.13	0.77	0.28	-0.16	0.49	-0.05	0.34	-0.20	-1.09
1960	0.09	0.37	0.93	1.01	-0.06	0.02	0.34	0.42	0.72	-0.27	0.02	0.79	1.09	0.69	0.26	-0.11	0.47	-0.04	0.36	-0.15	-1.08
1965	0.11	0.32	0.92	1.01	-0.06	0.02	0.31	0.42	0.74	-0.27	0.02	0.78	1.07	0.72	0.29	-0.09	0.44	-0.03	0.37	-0.11	-1.06
1970	0.10	0.32	0.93	1.01	-0.06	0.02	0.31	0.42	0.74	-0.27	0.02	0.78	1.07	0.72	0.29	-0.09	0.44	-0.03	0.37	-0.11	-1.06
1975	0.11	0.37	0.92	1.00	-0.05	0.03	0.31	0.42	0.74	-0.27	0.02	0.78	1.07	0.72	0.29	-0.09	0.44	-0.03	0.37	-0.11	-1.06
1980	0.10	0.32	0.94	1.00	-0.06	0.01	0.31	0.42	0.73	-0.28	0.02	0.76	1.06	0.72	0.30	-0.08	0.46	-0.02	0.38	-0.09	-1.05
1985	0.11	0.40	0.92	1.01	-0.05	0.02	0.31	0.41	0.73	-0.28	0.01	0.76	1.06	0.73	0.30	-0.08	0.46	-0.02	0.38	-0.09	-1.05
1990	0.10	0.32	0.91	1.00	-0.07	0.01	0.31	0.41	0.72	-0.29	0.01	0.74	1.05	0.72	0.31	-0.07	0.47	-0.02	0.39	-0.08	-1.04
1995	0.09	0.35	0.93	1.01	-0.06	0.02	0.31	0.40	0.72	-0.29	0.01	0.75	1.05	0.70	0.31	-0.07	0.48	-0.01	0.39	-0.08	-1.04
2000	0.11	0.32	0.92	1.01	-0.06	0.02	0.31	0.40	0.74	-0.30	0.01	0.74	1.03	0.72	0.32	-0.07	0.48	-0.01	0.40	-0.07	-1.04

Note: The data are adopted from Yamaguchi (1982, 2001), and new values are estimated.

Appendix Table 1 Definitions of Variables and Parameters

Variables	Definitions	Parameters	Definitions
c_0	Consumption of children	λ_0	Relative importance of consumption in childhood
c_1	Consumption of prime-age adults	λ_1	Relative importance of consumption in prime age
c_2	Consumption of the elderly	λ_2	Relative importance of consumption in old age
n	Number of children per prime-age adult	κ	The rate at which parents discount the utility of children
q	Adult longevity (adult survival rate)	ε	(See the explanation in Section 3.)
s_1	Saving of prime age adults	ρ	Discount rate
A	The level of technology of the whole economy	θ	Reciprocal of intertemporal elasticity of substitution
w	Wage	ν	Time taken to raise one child
r	Interest rate	ξ	Depreciation rate
S	Gross national saving	η	Price elasticity of agricultural products
W	Aggregate capital	ζ	Income elasticity of agricultural products
K	Domestic capital	α	Share of agricultural labor in agricultural output
F	Foreign capital	β	Share of agricultural capital in agricultural output
N_0	Number of children	γ	Share of non-agricultural labor in non-agricultural output
N_1	Number of prime-age adults	δ	Share of non-agricultural capital in non-agricultural output
N_2	Number of the elderly	l_A	Share of agricultural labor in total labor
K	Aggregate capital	l_M	Share of non-agricultural labor in total labor
p	Child survival rate	k_A	Share of agricultural capital in total capital
Y_A	Agricultural output	k_M	Share of non-agricultural capital in total capital
Y_M	Non-agricultural output	χ	Share of agricultural income in total income
L_A	Agricultural labor		
L_M	Non-agricultural labor		
K_A	Agricultural capital		
K_M	Non-agricultural capital		
P	Relative prices of agricultural and non-agricultural products		
P'	Consumer price index		
E	Income per capita		
w_A	Agricultural wage		
w_M	Non-agricultural wage		
r_A	Agricultural interest rate		
r_M	Non-agricultural interest rate		
T_A	Agricultural technical growth		
T_M	Non-agricultural technical growth		
L	Total labor force		
B	Land		
a	Demand shifter of agricultural products		
m_w	Wage gap between agricultural and non-agricultural sectors		

Note: In Section 3, variables are expressed using subscripts of time. For example, $c_{0,t}$ is the consumption of children at time t.