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Depopulation and importance of agriculture in Japan: implications from the overlapping generations and general equilibrium growth accounting model

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We investigate the effects of demographic change on agriculture and nonagriculture in Japan while considering capital accumulation and total population and labour. 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 nonagricultural inputs and outputs. Our simulation analyses show that demographic change greatly influenced agriculture and nonagriculture through capital accumulation although the influences of total population and labour 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 nonagriculture and an increase of the importance of agriculture.

I. Introduction

This study investigates the effects of demographic change on industrial structure in Japan considering capital accumulation, labour force, and total population. Simulation analyses using Growth Rate Multipliers (GRMs) and an Overlapping Generations (OLGs) model indicate a rapid demographic change after World War II; for example, decreased fertility and increased adult longevity stimulated capital accumulation, which increased the importance of nonagriculture.

After World War II, Japan experienced a remarkable demographic transition. At the beginning of the twentieth century, both fertility and mortality were high; however, mortality (especially adult mortality) declined rapidly. Subsequently, fertility began to decline. Fertility declined rapidly in the 1960s and 1970s, and is low today. Moreover, the population started to decline in 2005, and it is expected that it will continue to decline in the future. The effects of depopulation on the economy are controversial. A decrease in population can increase per capita income if other conditions do not change, however, it may decrease the labour force and the possibility of innovation. High life expectancy in Japan, also a characteristic of the country, is the highest in the world. Higher life expectancy may encourage 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) stated that the relationship between population and agriculture is important. Extensive research has attempted to explain economic development in relation to agriculture using a dual economy model.[1] The dual economy model assumes two sectors: the agricultural and the nonagricultural sectors. The agricultural sector is traditional, self-sufficient, and characterized by low productivity. The nonagricultural sector is modern, profitable, and highly productive. According to the dual economy model, it is necessary to have a technical change in agriculture at the onset of economic development, to move labour and capital into the nonagricultural sector.

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[1] For example, Lewis (1954), Ranis and Fei (1961), Jorgenson (1961), Kelley *et al*. (1972).

Yamaguchi's (1972, 1973, 1982, 2001) dual economy model was noteworthy in that it distinguished between changes in population and labour force. The author established a general equilibrium growth accounting model. In this study, we developed a new model that can capture the agricultural and nonagricultural distortion problems based on Temple (2005) and Hayashi and Prescott (2008).

The model analyses the effects of eight exogenous variables, including agricultural and nonagricultural technologies, total population, total labour, aggregate capital stock, land, demand shifter of agricultural products, and wage gap between the agricultural and nonagricultural sectors, on eight endogenous variables, including agricultural and nonagricultural outputs, labour and capital, relative prices of agricultural and nonagricultural products, and per capita income.

It is also important to consider the working and saving behaviour of people when we discuss the effects of demographics on 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 the working-age population increases. This stage is called the 'first demographic dividend.' Bloom and Williamson (1998), Bloom *et al*. (2000), and Kelley and Schmidt (2001, 2005) found that changes in age structure result in changes in the labour force, thus significantly contributing to economic growth. Demographic changes also influence saving behaviour. According to the lifecycle hypothesis, individuals save when they are young and employed and spend their savings after retirement (Modigliani and Brumberg, 1954; Tobin, 1967). Changes in the young dependency ratio could alter age-earning and consumption profiles. In particular, a higher young dependency ratio 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 (Lee *et al*., 2001; Kinugasa and Mason, 2007; Mason and Kinugasa, 2008). Capital accumulation significantly contributes to economic growth. In many developed countries, including Japan, the first demographic dividend has already disappeared. Declining growth of the labour force can suppress economic growth. On the other hand, the second demographic dividend could still continue in developed countries in the future. The life expectancies of old people are gradually increasing and many developed countries may still have opportunities for economic development. (Mason, 2007; Ogawa, 2007; Mason and Kinugasa, 2008).

The research discussed above does not analyse the effects of demographic change on industrialization in terms of capital accumulation. Kinugasa and Yamaguchi (2008) combined the OLG model of Kinugasa and Mason (2007) and the general equilibrium growth accounting model of Yamaguchi (1982, 2001). Kinugasa and Yamaguchi analysed the effects of changes in the number of children and adult longevity on capital accumulation, and examined how capital, which is influenced by the demographic change, affects agricultural and nonagricultural inputs and outputs. Their simulation analysis with Japanese data showed that a rapid decline in the number of children and an increase in adult longevity stimulated capital accumulation, which increased the importance of nonagriculture from the 1960s to 1990s. In this research, we develop the analyses of Kinugasa and Yamaguchi (2008) in the following four points and investigate the effects of demographic change on agriculture and nonagriculture from a broader perspective. First, we consider the effects of demographic change on per capita income and industrial structure, in terms of labour force and total population, as well as capital accumulation. Second, we estimate the effects of demographic change not only in the past and the present but also in the future. Third, we use the model that can consider the distortion problem as stated above. Fourth, we consider domestic capital and capital depreciation, which the research of Kinugasa and Yamaguchi (2008) did not consider.

Our findings regarding the relationships between demographic change, capital accumulation, and importance of agriculture are summarized by the flowcharts presented in Fig. 1.[2] In this figure, a broad arrowhead indicates that the effect is strong, a thin arrowhead indicates that the effect is weak, and a dashed arrowhead indicates that the effect appears after a while. Fig. 1(a) presents the relationship from the 1950s to 1990s. According to our OLG model, Japan experienced a rapid decline in the number of children and a rapid increase in adult longevity during the period, which stimulated capital accumulation. Moreover, the labour force increased rapidly because the working-age population increased, and this also stimulated capital accumulation. According to the results from the GRMs of the general equilibrium growth accounting model, capital accumulation stimulated industrialization; that is, it decreased the importance of agriculture.[3] The analysis using GRMs also indicates that an increase in labour force decreased the importance of agriculture and increased per capita income. Increased per capita income also increased capital accumulation according to the OLG model, which further decreased the importance of agriculture according to the general equilibrium growth accounting model. From the 1950s to 1990s, the population growth rate was also high, which increased the importance of agriculture according to the general equilibrium growth accounting model.

Fig. 1(b) describes the outlook for Japan. It is expected that the number of children will decrease and adult longevity will increase gradually, which will encourage capital accumulation and, as a result, increase the importance of nonagriculture slightly. According to our OLG model, a decline in the labour force will decrease capital accumulation to a large extent, which will make agriculture more important. The general equilibrium growth accounting model implies that a decrease in the labour force will directly increase the importance of agriculture. The model also indicates that a decrease in capital accumulation caused by a decrease in the labour force will decrease per capita income, and this will further decrease capital accumulation. The population will continue to decrease in Japan in the future, and this may increase the importance of nonagriculture according to Malthus's law as indicated in the general equilibrium growth accounting model. However, this effect will not be large. To sum up, in Japan, the importance of agriculture will increase in the future considering the demographic situation.

[2] In our theory, we do not consider linkage of demographic variables and treat different demographic variables, such as an increase in labour force, a decrease in the number of children/an increase in adult longevity, and an increase in population independently, because to consider these connections in theory would over-complicate the discussion. However, we use real data for three demographic variables, and the interrelationship between these demographic variables is incorporated in the simulation analysis; we would like to deal with these issues in future research.

[3] Henceforth, the importance of agriculture (nonagriculture) implies the relative importance of agriculture (nonagriculture) with respect to nonagriculture (agriculture).

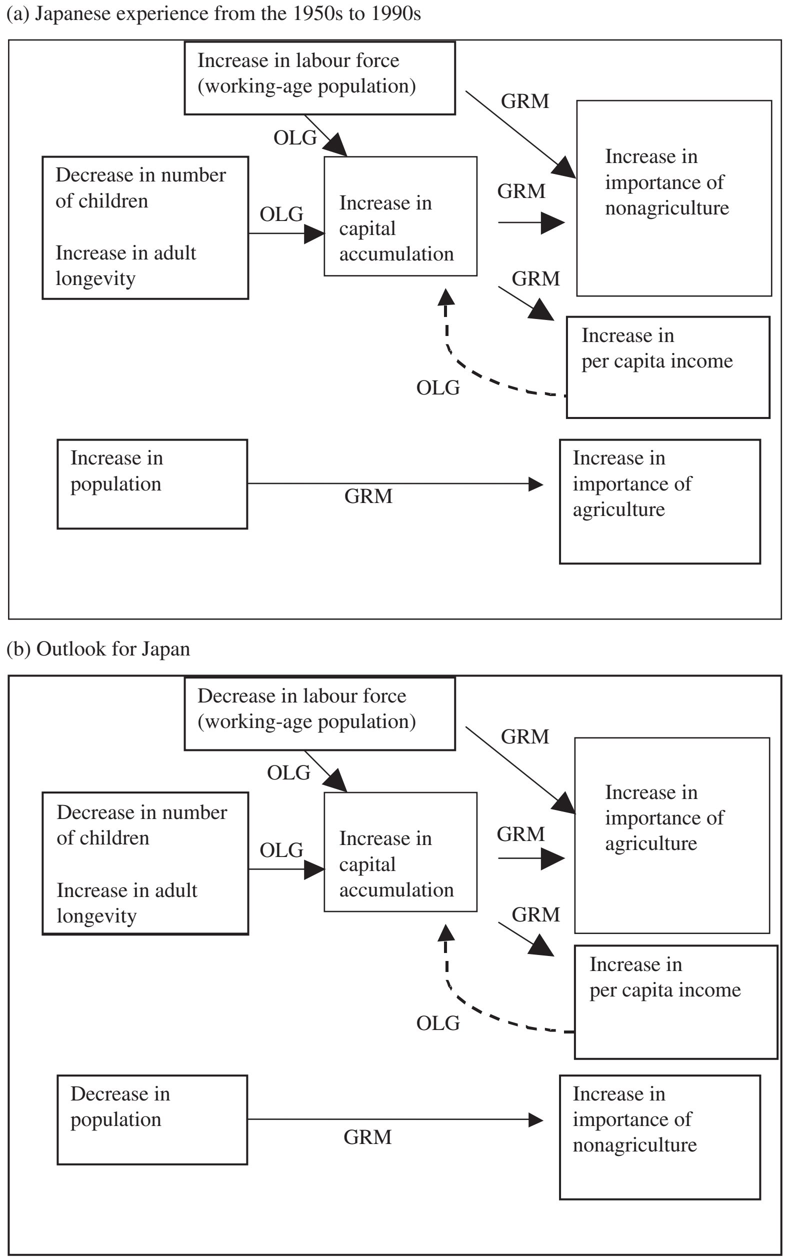

Fig. 1. Outline of relationships between demographic change, capital accumulation, and importance of agriculture.
Note: 'OLG' indicates the Overlapping Generations model. 'GRM' indicates the Growth Rate Multiplier in general equilibrium growth accounting model.

The remainder of this article is organized as follows: The general equilibrium growth accounting model established by Yamaguchi (1982, 2001) is introduced in Section II. Section II also describes how total population, labour, and capital influence endogenous variables such as agricultural and nonagricultural outputs and inputs. Section III describes the OLG 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, this section also examines the influence of present and past fertility and adult longevity on aggregate capital. Based on the models described in Sections II and III, and using Japanese data, we simulate the effects of demographic change on agricultural and nonagricultural outputs and inputs in Section IV.[4] Section V presents the conclusion.

[4] Our model combines two different kinds of models. Therefore, the models might not be entirely consistent. An OLG model is used to calculate the growth rate of aggregate capital. Although simulated growth in aggregate capital is obtained in the discrete OLG model, we multiply the simulated growth rate of capital based on the discrete OLG model with a growth rate multiplier of the continuous general equilibrium growth accounting model. However, the model's implication would not be remarkably influenced given the inconsistency. Moreover, our OLG model with three periods is a necessary assumption in the discussion on the effects of various demographic variables, such as the number of children and adult and child mortality, on the economy.

II. General Equilibrium Growth Accounting Model

The Computable General Equilibrium (hereafter CGE) model has prevailed since 1975. However, Ezaki (1984) evaluated that Yamaguchi (1969, 1972, 1973, 1982) made the bridge (i.e. Yamaguchi is the first person who applied the theoretical general equilibrium growth model to CGE model in the world) to the present CGE model. More accurately, Kelley *et al.* (1972) and Kelley and Williamson (1971, 1974) also began to build the bridge to the present CGE model in the early 1970s. Kelley and Williamson (1971) published a CGE model similar to the present CGE model. However, although the Yamaguchi model is a CGE model, this is also a general equilibrium growth accounting model with endogenous variables precisely coinciding with actual values. In this sense, Yamaguchi models are also growth accounting models and are completely different from Kelley and Williamson and other present CGE models.

Since the beginning of the 1970s, Yamaguchi (1973) evaluated the Kelley–Williamson model very highly. However, he criticized the following three points of their works. First, the Stone-Geary model is the ideal model for a demand system and is used in many recent studies, including Kelley–Williamson works. However, not enough research exists for this model to adopt the rigorous sectoral differences of parameters between agriculture and nonagriculture. Second, population and labour were treated as a single variable in their model. Yamaguchi greatly criticized their treatment. Although it took a long time to consider Yamaguchi's criticism, Bloom and Williamson (1998) finally recognized this importance and used labour and population independently. Mason (2005, 2007) and Mason and Kinugasa (2008) found the first and second dividend by treating labour and population independently. These are very important findings in population studies.

Recent researches on economic development, which must be considered in our study, are in the following three areas. The first area is the agricultural-nonagricultural distortion problem. Hayashi and Prescott (2008) consider that the labour barrier existed because the pre-war patriarchy forced the son designated as the heir to remain in agriculture. Moreover, Temple (2005) pointed out the problem of distortion, i.e. output losses associated with factor misallocation and aggregate growth in the presence of factor market distortion. Therefore, we considered the problem of distortion and assume imperfect competition in both labour and capital markets (m_1, m_2, m_3, m_4, N_w, and N_r in our model described in Appendix 1 and Table A1).

The second area is the reconfirmation that agriculture is the centre of development (Gollin *et al.*, 2002), although this conclusion may be reversed when we consider the international situation (Matsuyama, 1992). In other words, two opposing opinions for agriculture exist. Gollin *et al.* (2002) believe that agriculture is very important and must occupy the central topic of development. On the other hand, Matsuyama, for example, opposes this thinking with respect to international trade. As the third area, Temple (2005) evaluates that the two-sector model is still important in the research of development. Therefore, we use the two-sector model in this study.

Laitner (2000) (on page 546) suggest that while an unusual thrift may lead to a high income level (as shown in Solow's framework), causality can run the other way: a higher standard of living can lead to a higher measured savings rate. In our study, we calculate how population, labour, and capital stock influence income levels and sectoral outputs through savings.

In this study, we explain the extension of the growth accounting general equilibrium model (as stated above, we assume imperfect competition, i.e. the distortion problem in our model here) of Yamaguchi (1982, 2001).[5] The authors considered a two-sector economy consisting of agricultural and nonagricultural sectors and established a general equilibrium growth accounting model.[6] Further, they calculated the effects of eight exogenous variables on eight endogenous variables.[7] Each effect is referred to as a GRM, which reflects the percentage increase of an endogenous variable given a 1% increase in a certain exogenous variable. GRMs are expressed by aligning endogenous and exogenous variables; for example, Y_AK is the effect of a 1% increase in 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, labour, and population. This table shows that aggregate capital (K) has the following effects on the endogenous variables.[8] An increase in aggregate capital increases both agricultural and nonagricultural outputs; however, it has a larger effect on nonagricultural output than on agricultural output, ($Y_MK > Y_AK > 0$). Moreover, an increase in aggregate capital has a positive effect on both agricultural and nonagricultural capital, and its effect on nonagricultural capital is larger than that on agricultural capital, ($K_MK > K_AK > 0$). An increase in aggregate capital decreases agricultural labour, but increases nonagricultural labour ($L_AK < 0, L_MK > 0$). These findings imply that capital accumulation induces growth in both agricultural and nonagricultural sectors; however, it has a greater positive effect on nonagricultural growth. Therefore, capital accumulation is likely to accelerate industrialization. Moreover, an increase in aggregate capital increases per capita income ($EK > 0$).

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

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

To sum up, increases in capital and labour decrease the importance of agriculture and increase the importance of nonagriculture.

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

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

[7] The exogenous variables are agricultural technical growth (T_A), nonagricultural technical growth (T_M), population (Q), total labour force (L), aggregate capital (K), land (B), demand shifter of agricultural products (a), and wage gap between the agricultural and nonagricultural sectors (m_W). The endogenous variables are agricultural output (Y_A), nonagricultural output (Y_M), agricultural labour (L_A), nonagricultural labour (L_M), agricultural capital (K_A), nonagricultural capital (K_M), relative prices of agricultural goods and nonagricultural products (P), and income (E). Here, aggregate capital refers to domestic capital.

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

Table 1. GRMs for aggregate capital, labour, 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 from columns Y_AK to EK are adopted from Yamaguchi (1982, 2001). New values from columns Y_AL to EQ are estimated by using the data of Yamada and Hayami (1972), Minami and Ono (1978), Ohkawa (1972), and Ohkawa and Shinohara (1979).

Table 2. Equations with respect to the OLG model

$V_t = \lambda_1 \frac{c_{1,t}^{1-\theta}}{1-\theta} + \frac{\lambda_2 q_t}{1+\rho}\frac{c_{2,t+1}^{1-\theta}}{1-\theta} + \kappa n_t^{1-\varepsilon}\lambda_0 \frac{c_{0,t}^{1-\theta}}{1-\theta}$	(1)
$w_t A_t(1-\nu n_t) = c_{1,t} + n_t c_{0,t} + \frac{q_t}{1+r_{t+1}} c_{2,t+1}$	(2)
$s_{1,t} = \frac{q_t(\lambda_2/(\lambda_1(1+\rho)))^{1/\theta}(1+r_{t+1})^{1/\theta-1}(1-\nu n_t)A_t w_t}{1+(\kappa\lambda_0/\lambda_1)^{1/\theta} n_t^{1-\varepsilon/\theta} + q_t(\lambda_2/(\lambda_1(1+\rho)))^{1/\theta}(1+r_{t+1})^{1/\theta-1}}$	(3)
$W_{t+1} = K_{t+1} + F_{t+1} = s_{1,t} N_{1,t}$	(4)
$K_{t+1} = d_{t+1} s_{1,t} p_t n_{t-1} N_{1,t-1}$	(5)
$\dot{K}_t = \frac{K_t - K_{t-1}}{K_{t-1}}$	(6)

An increase in the population increases the importance of agriculture. Aggregate capital and labour positively affect per capita income, and total population negatively affects per capita income.

III. Demographic Change and Capital Accumulation in the OLG Model

This section presents an OLG model to investigate the effects of demographic change on capital accumulation. Table 2 presents key equations in our OLG model. Our model is similar to Kinugasa and Yamaguchi (2008), although it considers international capital flow. The OLG model considers the existence of different generations at the same time. We assume 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 and work, and save to consume in their old age. The elderly are retired and spend the savings they accumulate in their prime-age years.[9] Not all children survive to prime-age and not all prime-age adults survive after retirement.

The utility function of a prime-age adult is expressed in Equation 1 of Table 2. Prime-age adults at time t decide on their present consumption for themselves and their children, and their consumption in the future maximizes the lifetime utility as shown in Equation 1 of Table 2. In the equation, $c_{1,t}$, $c_{2,t+1}$, and $c_{0,t}$ represent the consumption of prime-age adults, the elderly, and the 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 $0 \leq \kappa \leq 1$. It is also assumed that $\varepsilon > 0$, so that the 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 reflect 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 $(1/\theta)$.[10]

Prime-age adults obtain wage income $A_t w_t$ per unit of labour, where A_t is the level of technology and w_t is the wage per effective worker. The total time available for a prime-age adult is one unit. ν units of time need to be spent to nurture one child, and prime-age adults with n children work for (1-νn) units of time. They allocate their earnings to their own consumption, to that of their children, and to savings. Therefore, their budget constraint is given by: $c_{1,t} + n_t c_{0,t} + s_{1,t} = A_t w_t(1-\nu n_t)$, where $s_{1,t}$ represents savings by prime-age adults. After retirement, the elderly consume the proceeds from their savings. Thus, the budget constraint of the elderly is:[11] $c_{2,t+1} = (1+r_{t+1})s_{1,t}/q_t$. According to the budget constraints of prime-age adults and the elderly, the lifetime budget constraint faced by prime-age adults is derived as shown in Equation 2 of Table 2. Consumers determine their children's consumption and their own consumption in prime-age and post-retirement, thus maximizing life utility as given in Equation 1 under the lifetime budget constraint given in Equation 2.

Savings by prime-age adults is calculated as shown in Equation 3 in Table 2 based on the utility maximization problem. In Equation 3, $\partial s_{1,t}/\partial q_t > 0$ holds, and the savings of prime-age adults increase if the adult survival rate increases. Intuitively, if consumers are aware 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 $\theta > \varepsilon$. Savings 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, while the wage income of prime-age adults decreases because raising children requires the expenditure of time. Therefore, higher fertility decreases savings by prime-age adults.

Based on the individual utility maximization problem, aggregate capital is determined as detailed in Appendix 2. The aggregate capital at $t+1$, W_{t+1}, is given by Equation 4 in Table 2, where K is the domestic capital and F is the foreign capital. From Equation 4,

[9] For simplicity, we assume that there are neither bequests nor transfers from children to parents.

[10] In this research, we assume that $(1/\theta) > 1$. An increase in the interest rate will increase savings by prime-age adult s if $(1/\theta) > 1$. On the other hand, an increase in the interest rate will decrease savings by prime-age adults if $(1/\theta) < 1$.

[11] In this model, availability of insurance against longevity risk is assumed. A consumer purchases an annuity at the beginning of age 2 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} is the riskless interest rate on savings. The return with regard to annuities is $((1+r_{t+1})/q_t)$. Since returns on insurance are higher than on regular notes, individuals restrict their savings to insurance. After retirement, the elderly consume the proceeds of their savings. See Yaari (1965) and Blanchard (1985) for details.

the total savings of prime-age adults at time t formulates the aggregate capital in the next period.[12] Higher savings of prime-age adults result in higher capital accumulation. In this context, the number of prime-age adults at time 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 $W_{t+1} = s_{1,t} p_t n_{t-1} N_{1,t-1}$. We 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, we obtain Equation 5 as shown in Table 2.

The growth rate of domestic capital $\dot{K}_t$ is defined as shown in Equation 6 of Table 2. According to Equations 5 and 6, the effect of an increase in adult longevity at time t on the growth rate of domestic capital at time $t+1$ is given by $\partial \dot{K}_{t+1}/\partial q_t = d_{t+1}(\partial s_{1,t}/\partial q_t) p_t n_{t-1} N_{1,t-1}/K_t > 0$. This indicates that an increase in adult longevity at time t increases the growth rate of domestic capital at time $t+1$ given an increase in the savings of prime-age adults at time t.[13] In this model, an increase in adult longevity at time t does not influence the growth rate of domestic capital at the same time.

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

The influence of the number of children at time t on the growth rate of capital at time $t+2$ is expressed as $\partial \dot{K}_{t+2}/\partial n_t = (d_{t+1} s_{1,t} p_t N_{1,t} - d_{t+1}(\partial s_{1,t}/\partial n_t) p_t n_{t-1} N_{1,t-1})/K_{t+1}^2 > 0$. The number of children at time t increases the number of prime-age adults who can accumulate wealth at time $t+1$, which results in a higher capital growth at time $t+2$. Moreover, less capital is accumulated at time $t+1$, which gives rise to a higher growth rate of capital at time $t+2$. Therefore, the growth rate of aggregate capital increases at time $t+2$ if fertility increases at time t. To sum up, an increase in fertility prevents capital accumulation in the short run. As children grow, the increase in the prime-age population stimulates capital accumulation.

According to the OLG model, a typical demographic transition such as declining fertility and mortality may either increase or decrease the growth of aggregate capital stock. Therefore, a detailed simulation analysis would be helpful to precisely investigate the effect of demographic change. In the next section, we set the values for the parameters to simulate the influence of demographic change on capital accumulation in Japan.

IV. Simulation Analysis using Japanese Data

In this section, we estimate the effects of demographic change on capital and agricultural and nonagricultural inputs and output in the past, present, and future. The simulation method is detailed in Appendix 3. First, growth in aggregate capital is simulated using data from the number of children per adult, and adult and child longevities based on the OLG model in Section III. Then, the sums of contributions of simulated aggregate capital, population, and labour to agricultural and nonagricultural inputs and outputs are calculated.[14]

Fig. 2 shows graphs of demographic variables such as the number of children per adult, the child survival index, and the adult survival index,[15] and growths in population and labour from 1890 to 2025. The number of children per adult increased moderately from 1890 to 1935, and began to decline rapidly in 1965. The number of children declined rapidly from 1965 to 1980. Since the 1990s, the number of children per adult has decreased gradually, and it is expected to decrease continuously in the future. The child survival index did not change significantly before the World War II and increased considerably in 1950. Since then, Japan's child survival index has been close to 100%, and this figure is expected to remain high in Japan. A significant increase in the adult survival index was not seen until around 1950. Adult longevity increased rapidly from the 1950s to 1990s. Since 1990, it has continued to increase and is estimated to increase gradually in the future.

From Fig. 2(b), labour force growth rate was much lower than the population growth rate, primarily because of a high fertility rate. After the World War II, the growth rate of the labour force increased sharply and was greater than the population growth rate from 1950 to 1995.[16] Japan had a high cyclical population growth rate from 1890 to 1970. Since 1970, the population growth has slowed, and became negative around 2005. Growth rates of the population and labour force are estimated to continuously decrease in the future. Furthermore, it is expected that the labour force growth rate will be lower than the population growth rate until 2020.[17] The period in which labour force growth was greater than the population growth may be the period in which Japan benefited from the 'first demographic dividend,' as mentioned in Section I. It is likely 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.

Fig. 3 presents the simulation results for the effects of demographic change on agricultural and nonagricultural outputs and inputs considering changes in labour, total population, and capi-

[12] Because the model assumes only one period of working life and wealth is not accumulated across generations, the economy's aggregate capital stock at time t is equal to the flow of savings at time $t-1$. This is a typical assumption in the OLG model with two or three generations as Higgins (1994) and Kinugasa and Mason (2007) did. This might be problematic; however, to overcome this problem, we need to set up an OLG model with many generations, which will over-complicate our model. The characteristic of our overlapping generations model is that it considers consumption for children and different survival rates for adults and children.

[13] We can calculate the effect of adult longevity at time t on growth of capital at time $t+1$ as: $\partial \dot{K}_{t+2}/\partial q_t = -d_{t+1}(\partial s_{1,t}/\partial q_t) p_t n_{t-1} K_{t+2}/K_{t+1}^2 < 0$. An increase in adult longevity at time t decreases the growth in capital at time $t+2$ because of the increase in the numerator. This and $\partial \dot{K}_{t+1}/\partial q_t > 0$ imply that a continuing increase of adult longevity increases the rate of capital accumulation.

[14] In this research, many variables such as demographic variables and land are assumed to be exogenous. We need further discussion regarding the determinants of these variables; however, our discussion would become over-complicated if we regard these variables endogenously.

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

[16] The labour force and population growth rates in the 1970s were exceptional. The population growth rate increased primarily because of an increased fertility rate during the second baby boom, and the growth in the labour force declined, primarily because of an increase in unemployment during the second oil crisis.

[17] According to the data, the growth of the labour 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.

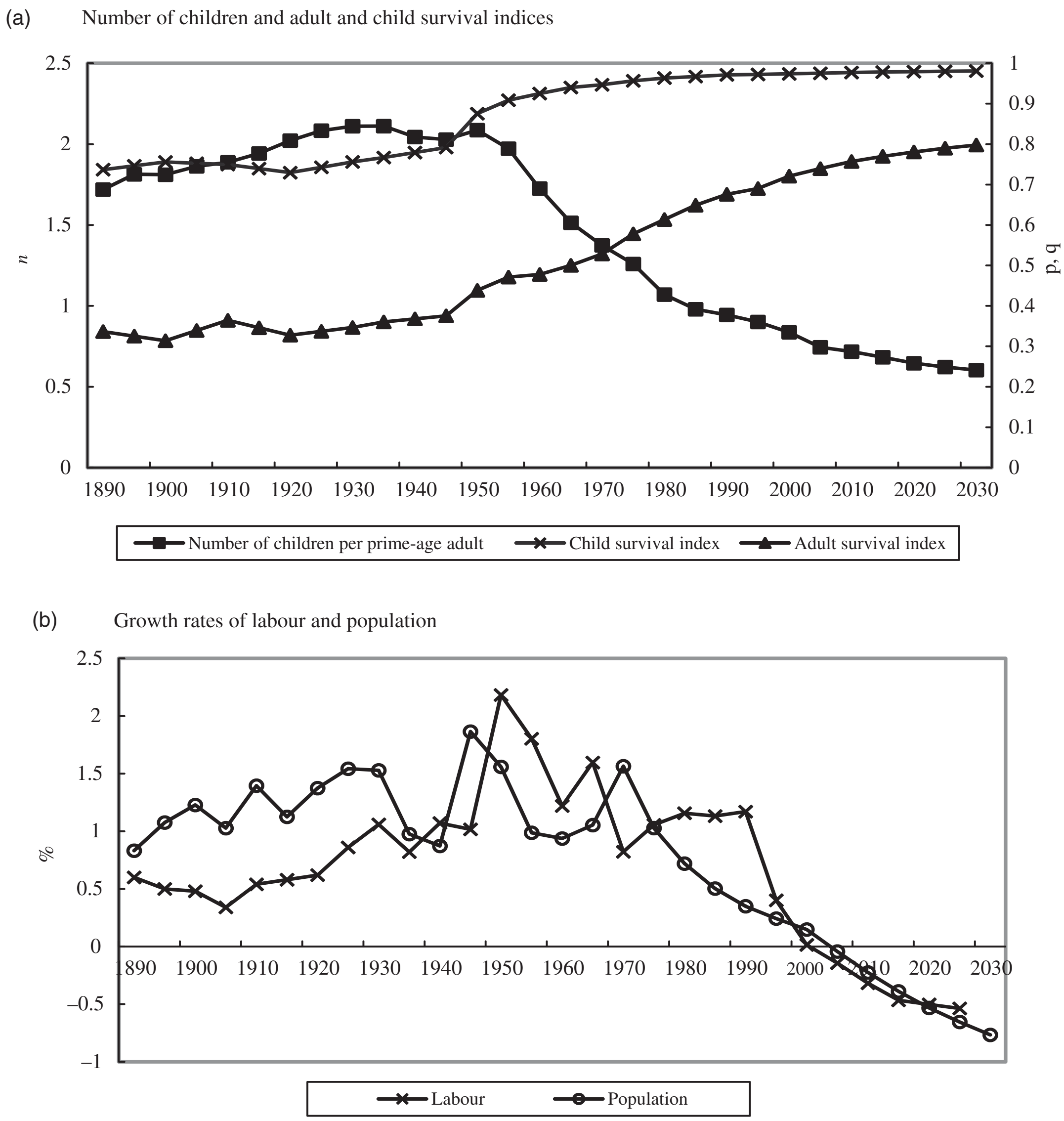

Fig. 2. Demographic changes in Japan

tal accumulation[18] (The data are taken from Yamada and Hayami (1972), Minami and Ono (1978), Ohkawa (1972), Ohkawa and Sinohara (1979), Ohkawa *et al*. (1966) and others). The effects of demographic change on agricultural inputs and outputs are calculated as the sum of the products of GRM and the 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 nonagricultural 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 in domestic capital based on our OLG model (Equation 6 in Table 2). The results are illustrated in Fig. 3(a). We also calculate the contribution of demographic change to agricultural and nonagricultural inputs and outputs when we do not consider the effects of demographic change on aggregate capital and only the effects of growths of population and labour are considered. 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 nonagricultural capital is $K_M L \cdot \dot{L} + K_M Q \cdot \dot{Q}$.[19] The results are presented in Fig. 3(b).

Fig. 3(a) shows that demographic change significantly contributed to increases in both agricultural and nonagricultural capital. The contribution of demographic change to nonagricultural capital was slightly more than the contribution to agricultural capital until 1955, and it was much more than the contribution to agricultural capital from 1960 to 1970. Demographic change positively influenced agricultural and nonagricultural output from 1890 to 2000, and the effect of demographic change on nonagricultural output was much larger than that on agricultural output from 1930 to 1985. Demographic characteristics in Japan seem to have had an insignificant effect on agricultural and nonagricultural labour compared with outputs and capital in both sectors throughout the period, but

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

[19] When we do not consider the effects of demographic change on aggregate capital, we do not use an OLG model. We calculate the contributions of demographic change to agricultural and nonagricultural output and input based only on GRM.

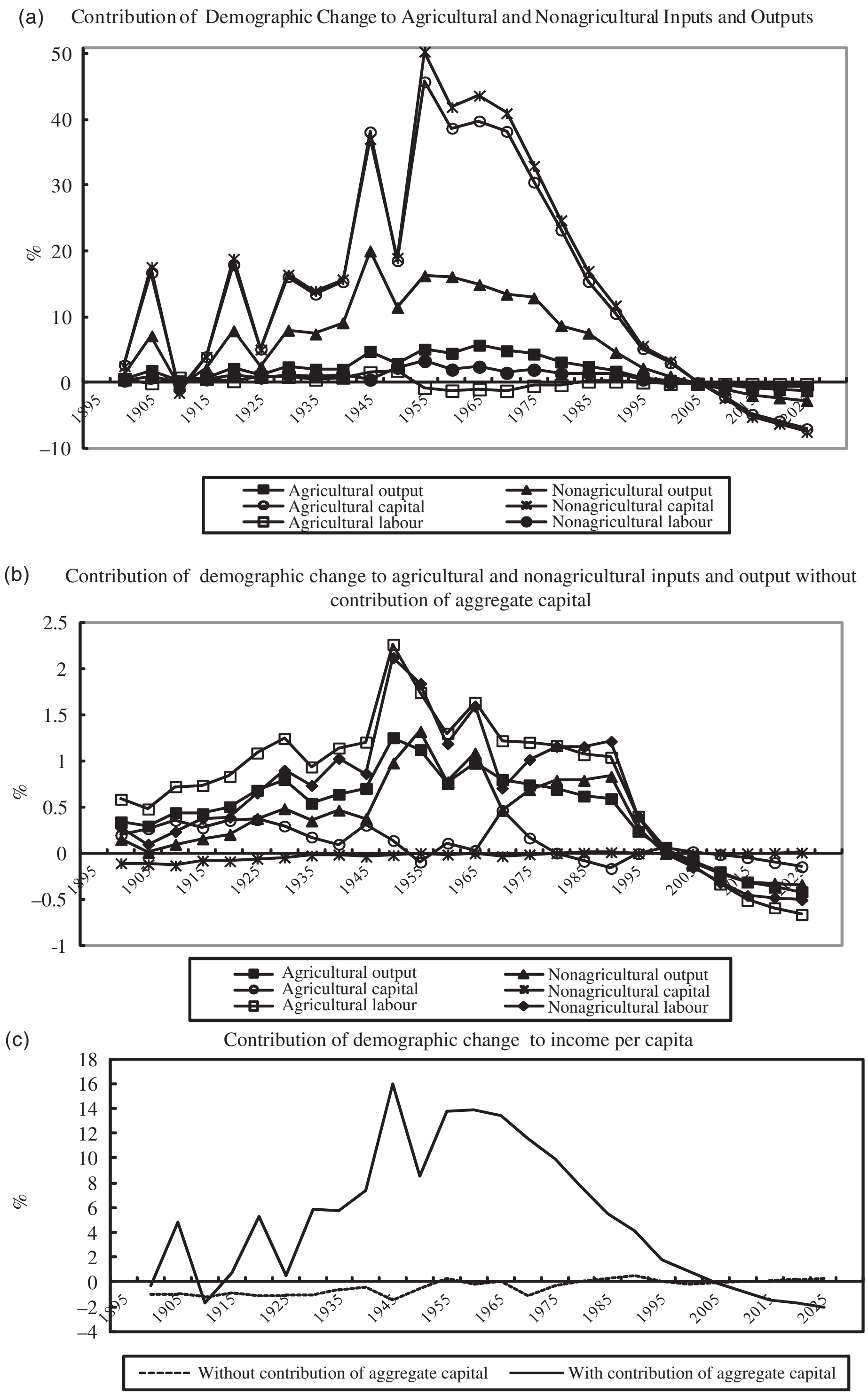

Fig. 3. Simulated contributions of demographic changes to agricultural and nonagricultural inputs and outputs and per capita income

increased both agricultural and nonagricultural labour from 1900 to 1950.[20] From 1955 to 1980, demographic change is simulated to decrease agricultural labour and increase nonagricultural labour, and from 1985 to 1995, it is simulated to increase both agricultural and nonagricultural labour, but simulated to increase nonagricultural labour more than agricultural labour. From 2005 onward, the simulated contribution of demographic change to agricultural labour is negative. From 2010 onward, the simulated contribution to nonagricultural labour is negative. Throughout the period from 1905 to 1995, the simulated effect of demographic change on nonagricultural labour was greater than agricultural labour, with the exception of 1945. After 2005, demographic change is simulated to decrease nonagricultural labour more than agricultural labour. On the whole, Fig. 4(a) implies that demographic change increased the importance

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

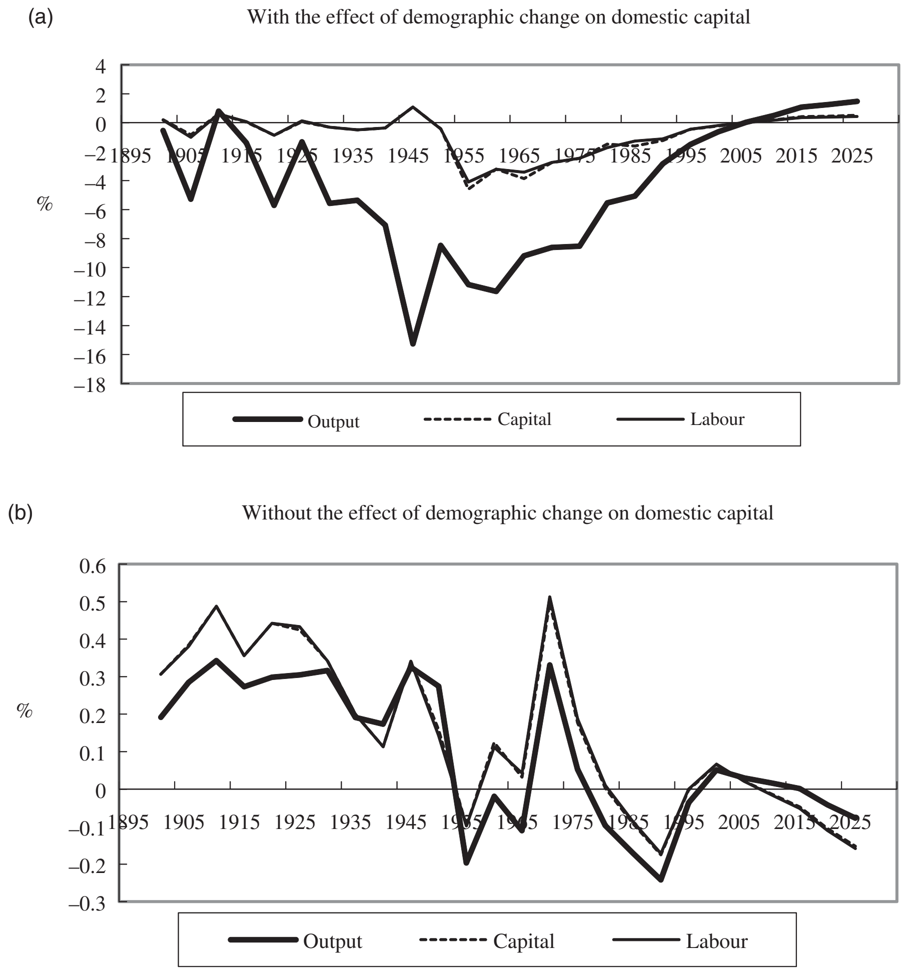

Fig. 4. Simulated changes in importance of agriculture in terms of output, capital, and labour

of nonagriculture before around 2000. Since the beginning of the twenty-first century, demographics have influenced and will continue to negatively influence both agriculture and nonagriculture in terms of output, labour, and capital. It is expected that the importance of agriculture will increase relative to nonagriculture in the future because demographic characteristics will influence nonagriculture more negatively than agriculture.

Fig. 3(b) illustrates the contribution of demographic change to agricultural and nonagricultural inputs and outputs when we do not consider the effect of demographic change on aggregate capital and only consider the effects of the growth in population and labour. The scale of the vertical axis in Fig. 4(b) is much smaller than that in Fig. 4(a), which implies that the effect of demographic changes on agriculture and nonagriculture is much smaller when we ignore its effect on aggregate capital. From 1905 to 2000, demographic changes are simulated to increase agricultural and nonagricultural outputs, but the simulated contribution of demographic changes to agricultural output is larger than that to nonagricultural output from 1905 to 1950. From 1955 to 1965, and from 1980 to 1995, demographic changes are simulated to contribute to the growth of nonagricultural 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 labour force. During that period, growths in population and labour influenced agriculture more favourably than nonagriculture. In 2000, the simulated effect of demographic change on agricultural output is still positive and the simulated effect on nonagricultural effect is negative. In 2005 and 2010, the simulated effects of demographic change on both agricultural and nonagricultural outputs are negative, but the effect on nonagricultural output is more negative than that on agriculture, primarily because growth in the labour force declined more than population growth. After 2010, the effect of demographic change on agricultural output is more negative than that on nonagricultural output. Population growth is expected to decline more than growth in the labour force, and Malthus's law may dominate. The population consuming food will decrease and agriculture will decline more than nonagriculture. The simulated effect of demographic change on agricultural capital is positive in 2000 and 2005, while the effect on nonagriculture is negative during the same period. Demographic change is simulated to negatively influence agricultural capital and positively influence nonagricultural capital after 2010. According to Table 1, depopulation tends to decrease agricultural capital and increase nonagricultural capital, and the decline in labour force growth tends to increase agricultural labour and decrease agricultural capital. It seems that depopulation will have a stronger effect on agricultural and nonagricultural capital than will the decrease in the labour force. Depopulation and a labour force decrease are simulated to decrease both agricultural and nonagricultural labour after 2005 and decrease agricultural labour more than nonagricultural labour after 2010.

Fig. 3(b) implies that demographic change contributed to agriculture more favourably than nonagriculture before 2000, primarily because of an increase in population. According to Malthus's law, an increase in population increases agricultural outputs and inputs because more food is required to feed a larger population. The result in Fig. 3(b) is different from that in Fig. 3(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 stimulated by demographic changes was not the only factor that brought about industrialization after World War II. Technical changes in agriculture and nonagriculture sectors also remarkably influenced industrial structure. In this study, we do not discuss in detail about technical change. However, it would be important to discuss it in future research.

Fig. 3(c) shows the simulated contribution of demographic change to per capita income in cases for which the effects of demographic change on domestic capital are considered and not considered. This figure implies that capital accumulation stimulated by demographic change significantly contributed to economic growth in the late twentieth 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 negatively influence per capita income, although the high growth rate of the labour force encouraged economic growth. Fig. 3(c) indicates that economic growth will be negative according to the demographic situation in Japan, primarily because of a decrease in capital growth, although depopulation may increase per capita income in the future, if we do not consider the effect of demographic change on capital accumulation.

In this study, we attempt to calculate changes in the importance of agriculture based on the simulation results in Fig. 4. We define changes in the importance of agriculture in terms of output (capital, labour) as a contribution of demographic change to agricultural output (capital, labour) minus that to nonagricultural output (capital, labour). If the simulated change in the importance of agriculture is positive, it indicates that demographic change is simulated to influence agriculture more favourably than nonagriculture. Fig. 4 presents the results. The importance of agriculture is determined from Fig. 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 labour 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 severely than in terms of capital or labour. From 1955 to 1985, when simulated domestic capital was quite high, the importance of agriculture decreased significantly in terms of output and input. Fig. 4(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.

Fig. 4(b) is calculated from the results in Fig. 3(b). If we do not consider the effect of demographic change on capital accumulation, the demographic changes such as changes in population and labour influence the importance of agriculture in terms of capital or labour more than that in terms of output. Changes in population and labour increased the importance of agriculture until 1950. From 1955 to 1965, demographic change influenced nonagriculture more advantageously than agriculture in terms of output, while it influenced agriculture more favourably than nonagriculture with regard to capital and labour 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 labour 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 consider 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 in the labour force; therefore, the importance of agriculture will decrease according to Malthus's theory.

Finally, it is preferable to intuitively explain the above stated discussion. The reason for the increased relative importance of agriculture in case of a decrease in capital stock (owing to a decrease in population) is as follows. An increase in capital stock would increase per capita income and relatively increase the demand of nonagricultural goods, resulting from Engel's law. Therefore, a decrease in capital would decrease per capita income and relatively increase the demand for agricultural goods. This is an intuitive explanation of the above discussion.

This study also showed some other interesting findings. First, we showed the importance of agriculture in the future, and measured the extent of decrease in per capita income as population and capital decrease in the future (by using the values of EQ, EL, EK in Table 1). In other words, this study showed that population growth is necessary to avoid a decrease in per capita income in the future. Second, we measured the extent of growth in output (by using the values of Y_AQ, Y_MQ, Y_AL, Y_ML, Y_AK, Y_MK in Table 1) and input (by using the values of L_AQ, L_MQ, L_AL, L_ML, L_AK, L_MK, K_AQ, K_MQ, K_AL, K_ML, K_AK, K_MK in Table 1) when each of population, labour, and capital stock increase by 1%. Therefore, we can measure the change in industrial structure with a concrete number. In this way, this study reveals several fact findings, which are included in Table 1.

V. Conclusion

The effects of demographic change on agriculture and nonagriculture have been discussed using Malthus's model. However, the effects were not adequately researched in terms of capital accumulation. Many recent studies on economic development have focused on growth theory but fail to consider agriculture and nonagriculture. It is, therefore, important to discuss the interaction between agriculture and nonagriculture when we discuss development, because agriculture produces food, which is essential for life. The research of Kinugasa and Yamaguchi (2008) considered capital accumulation and analysed the effects of demographic changes on agriculture and nonagriculture.

However, they did not consider the effects of population and labour. Moreover, they researched only past effects and failed to consider domestic capital and capital depreciation. They also failed to consider the factor distortion problem in their model. This study considers capital accumulation, total labour, and population, and analyses the effects of demographic changes on agriculture and nonagriculture in the past, the present, and the future. Our study confirms that it is important to consider capital accumulation when discussing the effects of demographic change on agriculture and nonagriculture; our simulation results differed significantly when we did not consider the effects of demographic change on capital accumulation.

Our simulation analyses indicate that demographic changes can significantly influence capital accumulation and the importance of agriculture. A decrease in the number of children and an increase in adult longevity stimulated capital accumulation, promoted economic growth, and increased the importance of nonagriculture to a significant extent from the middle of the twentieth century until around 2000. Japan took advantage of the first and second demographic dividends in the second half of the twentieth century, which may have contributed to industrialization and decreased the importance of agriculture. Today, Japan is experiencing depopulation, although the second demographic dividend continues. The decline in population growth may increase the importance of nonagriculture with a decline in the demand for food. However, more importantly, a decline in labour force growth results in a decline in capital accumulation, which in turn will decrease the importance of nonagriculture more than agriculture. Therefore, the importance of nonagriculture will not continue and the relative importance of agriculture may increase in the near future.

This study does not consider the effects of demographic changes on technical change. However, demographic changes could significantly influence technical change, as Yamaguchi (1982, 2001) indicated. Analysing this issue is an important subject for future research. Moreover, this study assumed only a lifecycle 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. Today, the social security system plays an important role in intergenerational transfer. The difficulty in analysing intergenerational transfer is that obtaining reliable data is not easy; however, this analysis is important in taking intergenerational transfer into account in the future.

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Appendix 1. Outline of general equilibrium growth accounting model

The general equilibrium growth accounting model is formulated using the following 12 equations.[21] This is different from Yamaguchi (1982, 2001) and his colleagues.

$$Y_A = aQP^{\eta}E^{\zeta} \text{ : Agricultural demand function} \tag{A1}$$

$$Y_A = T_A L_A^{\alpha} K_A^{\beta} B^{1-\alpha-\beta} \text{ : Agricultural production function} \tag{A2}$$

$$Y_M = T_M L_M^{\gamma} K_M^{\delta} \text{ : Nonagricultural production function} \tag{A3}$$

$$L = L_A + L_M \text{ : Sectoral allocation of labour} \tag{A4}$$

$$K = K_A + K_M \text{ : Sectoral allocation of capital} \tag{A5}$$

$$w_A = m_1 \alpha P_A \left(\frac{Y_A}{L_A}\right) \text{ : Wage} = \text{(Degree of Distortion)} \times \text{(Value marginal product of labour)} \tag{A6}$$

$$w_M = m_2 \gamma P_M \left(\frac{Y_M}{L_M}\right) \text{ : Interest rate} = \text{(Degree of Distortion)} \times \text{(Value marginal product of capital)} \tag{A7}$$

$$r_A = m_3 \beta P_A \left(\frac{Y_A}{K_A}\right) \text{ : Interest rate} = \text{(Degree of Distortion)} \times \text{(Value marginal product of capital)} \tag{A8}$$

$$r_M = m_4 \delta P_M \left(\frac{Y_M}{K_M}\right) \text{ : Interest rate} = \text{(Degree of Distortion)} \times \text{(Value marginal product of capital)} \tag{A9}$$

$$w_A = m_w\, w_M \text{ : Wage gap in the two sectors} \tag{A10}$$

$$r_A = m_r\, r_M \text{ : Interest rate in the two sectors} \tag{A11}$$

$$P'QE = P_A Y_A + P_M Y_M \text{ : Identical equation for income} \tag{A12}$$

The subscript A represents the agricultural sector and the subscript M represents the nonagricultural (or manufacturing) sector. The notation m_i ($i = 1, 2, 3$, and 4) in Equations A6–A9 represents the degree of imperfect competition in input markets of each sector. The exogenous variables are agricultural technical growth (T_A), nonagricultural technical growth (T_M), population (Q), total labour force (L), aggregate capital (K), land (B), demand shifter of agricultural products (a), and the wage gap between the agricultural and nonagricultural sectors (m_W). The endogenous variables are agricultural output (Y_A), nonagricultural output (Y_M), agricultural labour (L_A), nonagricultural labour (L_M), agricultural capital (K_A), nonagricultural capital (K_M), relative prices of agricultural and nonagricultural products (P), and income (E).[22]

From Equations A1 to A12 in the above model, other than the eight abovementioned variables, agricultural wage (w_A), nonagricultural wage (w_M), agricultural interest rate (r_A), and nonagricultural interest rate (r_M) are also endogenous. From Equations A6 to A11, w_A, w_M, r_A, and r_M are cancelled out and the following two equations are derived (we define N_w and N_r as $N_w = m_w m_2/m_1$, $N_r = m_r\, m_4/m_3$).

$$\frac{N_w}{N_r} = \frac{P(\alpha Y_A L_M)}{(\gamma Y_M L_A)}$$

$$1 = \frac{P(\beta Y_A K_M)}{(\delta Y_M K_A)}.$$

[21] Yamaguchi (1982, 2001) conceived his model to include a degree of competitiveness between the agricultural and nonagricultural sectors.
[22] Table A1 gives the definitions of these parameters.

From these equations, we obtain the following:

$$\frac{N_w}{N_r} = \frac{(\alpha\delta K_A L_M)}{(\gamma\beta K_M L_A)}$$

$$P = \frac{[(\alpha\delta)^\delta \gamma T_M N_w^\gamma N_r^\delta]}{[(\delta\beta)^\delta \alpha T_A L_A^{\alpha-\gamma} K_A^{\beta-\delta} B^{1-\alpha-\beta}]} \quad \text{(A13)}$$

The static model with 12 equations (from Equations A1 to A12) 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:

$$\begin{aligned}
\dot{Y}_A &= \dot{a} + \dot{Q} + \eta\dot{P} + \zeta\dot{E} \\
\dot{Y}_A &= \dot{T}_A + \alpha\dot{L}_A + \beta\dot{K}_A + (1-\alpha-\beta)\dot{B} \\
\dot{Y}_M &= \dot{T}_M + \gamma\dot{L}_M + \delta\dot{K}_M \\
\dot{L} &= l_A\dot{L}_A + l_M\dot{L}_M \\
\dot{K} &= k_A\dot{K}_A + k_M\dot{K}_M \\
\dot{N}_w - \dot{N}_r &= \dot{K}_A - \dot{K}_M + \dot{L}_M - \dot{L}_A \\
\dot{P} &= \dot{T}_M - \dot{T}_A + (\gamma-\alpha)\dot{L}_A + (\delta-\beta)\dot{K}_A \\
&\quad - (1-\alpha-\beta)\dot{B} + \gamma\dot{N}_w + \delta\dot{N}_r \\
\dot{Q} &= \chi\dot{Y}_A + (1-\chi)\dot{Y}_M - \dot{E} \qquad \text{(A14)}
\end{aligned}$$

A dotover a variable, such as $\dot{Y}_A$, denotes the growth rate. l_A represents the share of agricultural labour to total labour, l_M is the share of nonagricultural labour to total labour, k_A is the share of agricultural capital in aggregate capital, k_M is the share of nonagricultural capital in aggregate capital, and χ is the share of agricultural income to total income.

These equations can be expressed through a matrix, as follows:

$$\underbrace{\begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & -\eta & -\zeta \\
1 & 0 & -\beta & 0 & -\alpha & 0 & 0 & 0 \\
0 & 1 & 0 & -\delta & 0 & -\gamma & 0 & 0 \\
0 & 0 & 0 & 0 & l_A & l_M & 0 & 0 \\
0 & 0 & k_A & k_M & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -1 & -1 & 1 & 0 & 0 \\
0 & 0 & \beta-\delta & 0 & \alpha-\gamma & 0 & 1 & 0 \\
\chi & 1-\chi & 0 & 0 & 0 & 0 & 0 & -1
\end{pmatrix}}_{Z}
\underbrace{\begin{pmatrix}
\dot{Y}_A \\ \dot{Y}_M \\ \dot{K}_A \\ \dot{K}_M \\ \dot{L}_A \\ \dot{L}_M \\ \dot{P} \\ \dot{E}
\end{pmatrix}}_{x=}$$

$$= \underbrace{\begin{pmatrix}
\dot{a} + \dot{Q} \\
\dot{T}_A + (1-\alpha-\beta)\dot{B} \\
\dot{T}_M \\
\dot{L} \\
\dot{K} \\
\dot{N}_w - \dot{N}_r \\
\dot{T}_M - \dot{T}_A - (1-\alpha-\beta)\dot{B} + \gamma\dot{N}_w + \delta\dot{N}_r \\
\dot{Q}
\end{pmatrix}}_{b} \quad \text{(A15)}$$

The equation $Zx = b$ can also be represented as $x = Z^{-1}b$. Each component of the matrix of Z^{-1} is the GRM. For example, the component of the first row and the fifth column of Z^{-1}, c_{15}, represents $\partial\dot{Y}_A/\partial\dot{K}$, which gives the percentage increase in agricultural output for a 1% increase in 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,[23] 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 depreciation rate. Net national saving ($S_t - \xi K_t$) is equal to the aggregate national income minus total consumption; therefore,

$$\begin{aligned}
(K_{t+1} + F_{t+1}) - (K_t + F_t) &= w_t(1 - \nu n_t)A_t N_{1,t} + r_t(K_t + F_t) \\
&\quad - (n_t c_{0,t} N_{0,t} + c_{1,t} N_{1,t} + c_{2,t} N_{2,t}) \qquad \text{(A16)}
\end{aligned}$$

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 A16, we can obtain Equation 4 in Table 2.

Appendix 3. Assumptions in the simulation analysis and parameters

In the simulation analysis of domestic capital in Equation 5 in Table 2 and growth of domestic capital, under the following assumptions. Each age consist of 30 years.; child age from (0 to 29 years old), prime-age(30 to 59 years), and old age (60 to 89 years) . Each period should also consist of 30 years, however, in Equation 5 in Table 2, the capital in the next period is based on saving behaviour 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 behaviour of prime age adults 5 years previously. $\dot{K}$, growth rate of domestic capital per 1 year, is calculated every 5 years.

The value of the following parameters are assumed referring to Higgins (1994).[24] The utility weights are assigned as: $\lambda_0 = 0.5$, $\lambda_1 = 1$, 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.

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

[23] 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.

[24] It might be problematic to use the parameter of Higgins (1994), which is constant and not specific to Japan. However, it is quite difficult to obtain these parameters based on available data, so we use the same parameter as Higgins.

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

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.

Regarding demographic variables, population data are from *Japan Statistical Yearbook*. Labour force data are obtained from Ohkawa and Shinohara (1979) (from 1890 to 1950), 'Historical Statistics of Japan' (from 1950 to 2000), and Cabinet Office in Japan (2004) (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 $x+1$.[25] The child survival index is defined as $\sum_{x=30}^{59} L_x / \sum_{x=0}^{29} L_x$. 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).

When we calculate contribution of demographic change to agricultural and nonagricultural inputs and outputs, we use GRMs presented in Table 1. Yamaguchi (1982, 2001) calculates these from 1880 to 1965, whereas we recalculate them from 1970 to 2000. After 2005, we assume that GRMs are constant at the values of 2000.

Appendix 4

Table A1. Definitions of variables and parameters

Variables	Definitions	Parameters	Definitions
(i)	Definition of growth accounting model	Parameters	
Y_A	Agricultural output	η	Price elasticity of agricultural products
Y_M	Nonagricultural output	ζ	Income elasticity of agricultural products
L_A	Agricultural labour	α	Share of agricultural labour in agricultural output
L_M	Nonagricultural labour	β	Share of agricultural capital in agricultural output
K_A	Agricultural capital	γ	Share of nonagricultural labour in nonagricultural output
K_M	Nonagricultural capital	δ	Share of nonagricultural capital in nonagricultural output
P	Relative prices of agricultural and nonagricultural products	l_A	Share of agricultural labour in total labour
P'	Consumer price index	l_M	Share of nonagricultural labour in total labour
E	Income per capita	k_A	Share of agricultural capital in total capital
w_A	Agricultural wage	k_M	Share of nonagricultural capital in total capital
w_M	Nonagricultural wage	χ	Share of agricultural income in total income
r_A	Agricultural interest rate		
r_M	Nonagricultural interest rate		
T_A	Agricultural technical growth		
T_M	Nonagricultural technical growth		
L	Total labour force		
B	Land	(i)'s Variables	Continued from (i) of left side
a	Demand shifter of agricultural products	m_1	Distortion of agricultural labour
m_w	Wage gap between agricultural and nonagricultural sectors	m_2	Distortion of nonagricultural labour
N_w	$= m_w m_2 / m_1$	m_3	Distortion of agricultural capital
N_r	$= m_r m_4 / m_3$	m_4	Distortion of nonagricultural capital
(ii)	Definition of OLG Model	Parameters	
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 III)
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		
W	Aggregate capital		
K	Domestic capital		
F	Foreign capital		
N_0	Number of children		
N_1	Number of prime-age adults		
N_2	Number of the elderly		
p	Child survival rate		
d	Ratio of domestic capital to aggregate capital		

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