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# Demographic Change and Directed Technological Change

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# Demographic Change and Directed Technological Change

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In this paper, we analyze the implications of demographic change, i.e., the aging of society, on the direction of technological change and the rate of economic growth. Taking demographic change as an exogenous event, the simple variant of Acemoglu's theory of directed technical change implies that (1) the elderly-care related technology must be a promising area of innovation and (2) the optimal growth rate must be lower in aging societies than in young ones, suggesting that the slowdown of economic growth may be an optimal response of the economy to population aging. The analytical framework is simple and robust such that this model can be used to assess various policy options concerning the demographic change in Japan and other countries.

Key words: Aging, Directed technical change, Economic growth

JEL classification: E30, G01



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# 1 Introduction

What is the implication of rapid aging of the society to technological change and economic growth in the long-run? In this paper we analyze the above question with a modified version of the simple framework of directed technological change, proposed by Acemoglu (1998, 2002). Acemoglu's idea is based on the induced technical and institutional innovation by Hayami and Ruttan (1970). See also Ruttan and Hayami (1984). Since Acemoglu's theory of directed technical change focuses on the supply side, Acemoglu's theory must imply that the aging of the workers enhance the R&D in elderly-labor augmenting technology. Thus the theory predicts that the firms will invent and use new technologies that utilize the elderly labor more intensively than today.

In this paper we focus on the demand-side effect of demographic change. The aging of the society can be modeled as a change in preference that increases the demand for elderly care services. The model of endogenous technological change shows the consequences of this demand-side change on the direction of the technological change and the rate of economic growth.

Natural implication of our analysis is that the innovations in the technology related to the elderly care is promising for firms. The optimal growth rate, i.e., the growth rate in the balanced growth path (BGP) should be lower in the aging society.

# 2 Model

## 2.1 Setup

We consider a closed economy with discrete time, in which an infinitely-lived representative household lives. The representative household consists of infinitely many young agents and old agents. Measures of young agents and old agents are $N_{yt}$ and $N_{ot}$ respectively. The young agents consume the goods, $c_t$, and the old agents consume the services, $s_t$. Every period a cohort of measure 1 is born in the representative household and the cohort of age $N$ dies. Total population is $N$. Each cohort can work $N_y$ years and they retire at the age $N_y + 1$. Thus in the initial steady state, $N_{yt} = N_y$ and $N_{ot} = N_o = N - N_y$. We consider a sudden change in the demography such that the life expectancy $N$ increases by 20 % and $N_y$ increases by 10 %. The final steady state where the economy converges to after the change is that $N' = 1.2N$, $N'_y = 1.1N_y$, and $N'_o = 1.2N - 1.1N_y = 1.1N_o + 0.1N$. As we see that $N'_o/N'_y > N_o/N_y$, this demographic change is a model of the aging of the society.

We compare the macroeconomic variables between the initial and the final steady states. The supply side is the two-sector version of the expanding variety model à la Rivera-Batiz and Romer (1991). Each young cohort provides the constant labor supply: $L = 1$ and old cohort does not provide the labor.

The consumption good for young agents and the service for elderly agents are both produced competitively from labor and the intermediate goods. The intermediate goods producers are monopolistically competitive firms and they produce the intermediate goods from the consumption good. The productivity of the consumption goods sector is measured by $N_{ct}$, the variety of the intermediate goods for production of the consumption good. Similarly, the productivity of the service sector is measured by $N_{st}$, the variety of the intermediate goods for production of the services.

## 2.2 Optimization problems

**Household:** The objective of the household is to maximize the sum of the utilities of the members of the household. The young members obtain utility from consuming the good and the old members obtain utility from consuming the service. Thus the household's problem is as follows.

$$
\begin{aligned}
&\max\ E_0 \sum_{t=0}^{\infty} \beta^t [N_y \ln c_t + N_o \ln s_t] \\
&\text{s.t.} \qquad N_y c_t + p_t N_o s_t + I_{ct} + I_{st} = w_t L + \int_0^{N_{ct}} \pi_{cit} d_i + \int_0^{N_{st}} \pi_{sit} d_i, \\
&\qquad\quad N_{ct+1} = \chi I_{ct} + (1-\delta) N_{ct}, \\
&\qquad\quad N_{st+1} = \chi I_{st} + (1-\delta) N_{st},
\end{aligned}
$$

where $p_t$ is the relative price of the service in terms of the consumption good.

**Consumption Goods Producer:** They maximize the profits in the competitive market.

$$
\max_{x_i, l_c} \frac{1}{\eta} \left( \int_0^{N_{ct}} x_{it}^{\eta} di \right) l_{ct}^{1-\eta} - \int_0^{N_{ct}} p_{it} x_{it} di - w_t l_{ct}.
$$

**Service Producer:** They maximize the profits in the competitive market.

$$
\max_{z_i, l_s} \frac{p_t}{\eta} \left( \int_0^{N_{st}} z_{it}^{\eta} di \right) l_{st}^{1-\eta} - \int_0^{N_{st}} p_{it} z_{it} di - w_t l_{st},
$$

**Demand for intermediate goods:** The FOCs for the optimizations of consumption goods sector and the service sector decide the demand function for the intermediate goods.

$$
\begin{aligned}
p(x) &= l_{ct}^{1-\eta} x^{\eta-1}, \\
p(z) &= p_t l_{st}^{1-\eta} z^{\eta-1},
\end{aligned}
$$

**Intermediate goods for production of the consumption good:** The producer maximizes the profits in the monopolistic market. The cost of producing $x$ units of the intermediate good is $\psi_c x$ units of the consumption good.

$$\max_x l_c^{1-\eta} x^\eta - \psi_c x.$$

FOC implies that $\psi_c = \eta l_c^{1-\eta} x^{\eta-1}$ thus

$$x = \left(\frac{\eta}{\psi_c}\right)^{\frac{1}{1-\eta}} l_c. \tag{1}$$

**Intermediate goods for production of the service:** The producer maximizes the profits in the monopolistic market. The cost of producing $z$ units of the intermediate good is $\psi_s z$ units of the consumption good.

$$\max_z p l_s^{1-\eta} z^\eta - \psi_s z.$$

FOC implies that $\psi_s = \eta p l_s^{1-\eta} z^{\eta-1}$ thus

$$z = \left(\frac{\eta p}{\psi_s}\right)^{\frac{1}{1-\eta}} l_s. \tag{2}$$

# 3 Equilibrium

We focus on the BGPs and compare the BGPs corresponding to different sets of $(N_y, N_o)$ and $(N'_y, N'_o)$. FOC for household implies

$$\frac{C}{N_y}\frac{N_o}{S} = p, \tag{3}$$

where $C = N_y c$ and $S = N_o s$. The resource constraint for the consumption good is $C + M = \eta^{-1} N_c x^\eta l_c^{1-\eta}$, where $M = \psi_c N_c x + \psi_s N_s z$. Therefore,

$$C = N_c \left(\frac{\eta}{\psi_c}\right)^{\frac{1}{1-\eta}} \left(\frac{1-\eta^2}{\eta^2}\right) \psi_c l_c - N_s \left(\frac{\eta p}{\psi_s}\right)^{\frac{1}{1-\eta}} \psi_s l_s. \tag{4}$$

The resource constraint for the service is

$$S = \eta^{-2}\frac{\psi_s}{p}\left(\frac{\eta p}{\psi_s}\right)^{\frac{1}{1-\eta}} l_s \tag{5}$$

The resource constraint for labor is

$$l_c + l_s = N_y. \tag{6}$$

In the BGP the value of a firm that produces the intermediate good for the consumption good sector is

$$V_c = \frac{\beta}{g-\beta}(1-\eta) l_c^{1-\eta} x^\eta, \tag{7}$$

and the value of a firm that produces the intermediate good for the service sector is

$$V_s = \frac{\beta}{g-\beta}(1-\eta)p l_s^{1-\eta} z^{\eta}, \tag{8}$$

where $g$ is the gross growth rate of the economy. Since the R&D costs the consumption goods and, we have $\chi V_c = \chi V_s = 1$ in the BGP, where the R&D in both sectors take place regularly. This condition implies

$$\left(\frac{\eta}{\psi_c}\right)^{\frac{\eta}{1-\eta}} l_c = p^{\frac{1}{1-\eta}} \left(\frac{\eta}{\psi_s}\right)^{\frac{\eta}{1-\eta}} l_s, \tag{9}$$

$$\chi^{-1} = \frac{\beta}{g-\beta}(1-\eta) l_c^{1-\eta} x^{\eta}. \tag{10}$$

Since the wage rate is equalized in the both sectors, we have

$$w = \frac{1-\eta}{\eta} N_c \left(\frac{x}{l_c}\right)^{\eta} = \frac{1-\eta}{\eta} p N_s \left(\frac{z}{l_s}\right)^{\eta} \tag{11}$$

Equations (1)–(11) determines the BGP. Equation (9) and (11) imply that

$$\frac{N_c}{N_s} = \frac{l_c}{l_s}. \tag{12}$$

This equation and (9) imply that

$$\frac{N_c}{N_s} = \left(\frac{\psi_c}{\psi_s}\right)^{\frac{\eta}{1-\eta}} p^{\frac{1}{1-\eta}}. \tag{13}$$

Equations (4) and (5) imply

$$\frac{C}{S} = \left(\frac{N_c}{N_s}\right)^2 \left(\frac{\psi_s}{\psi_c}\right)^{\frac{\eta}{1-\eta}} \left(1-\eta^2\right) p^{-\frac{\eta}{1-\eta}} - \eta^2 p. \tag{14}$$

Equations (3), (13), and (14) imply

$$\frac{N_o}{N_y} \left[\left(\frac{\psi_c}{\psi_s}\right)^{\frac{\eta}{1-\eta}} (1-\eta^2) p^{\frac{1}{1-\eta}} - \eta^2\right] = 1. \tag{15}$$

**Comparative statics:** Equation (15) shows that the population aging, i.e., an increase in $N_o/N_y$ drives $p$ down. Equation (13) implies that the decrease in $p$ decreases $N_c/N_s$. Equation (6) and (12) imply that the decrease in $N_c/N_s$ leads to a decrease in $l_c$. Finally, equations (1) and (10) imply that the population aging causes the BGP growth rate $g$ to decrease.

In sum, we have the following observations concerning the population aging:

- The relative price of elderly-care services ($p$) decreases as the relative population of elderly people increases.
- Relative productivity of consumption goods sector to service sector ($N_c/N_s$) decreases as the relative population of elderly people increases.
- Economic growth rate in the BGP ($g$) decreases as the relative population of elderly people increases.

# 4 Conclusion

The simple analytical framework of directed technological change shows that the population aging may causes the decrease in the relative price of elderly-care services, relative increase in the innovations of elderly-care related technology, and the slowdown of the optimal growth rate. These implications are based on a simple framework and so they are robust.

We posit an asymmetric assumption that the R&D and production of the intermediate goods in the service sector necessitate the consumption goods as the inputs, while the R&D and production of the intermediate goods in the consumption goods sector also necessitate the consumption goods as the inputs. This assumption may be crucial in deriving the slowdown of optimal economic growth in the aging society. Although we believe this assumption is fairly reasonable, we need to assess the plausibility and the implications in depth in the future research.

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