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Economic Implications of China's Demographics in the 21st Century

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Economic Implications of China's Demographics in the 21st Century

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Abstract

This study assesses the economic implications of China's changing population in the 21st century using a numerical general equilibrium model. The simulations show that lower fertility rates yield lower saving rates. Since lower fertility rates reduce the future supply of labor, capital will become less productive. Consequently, if international capital mobility is high in China, a low fertility rate implies more future capital outflows. But if capital is less mobile, low fertility today lowers the domestic return to capital and raises the domestic return to labor. In addition, the paper finds no significant link between demographic structures and per capita income growth.

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I. Introduction

Owing to various social and economic factors, China's birth rate dramatically decreased from 33.43 per thousand in 1970 to 15.23 per thousand in 1999, with a corresponding large drop in its natural growth rate from 25.83 per thousand to 8.77 per thousand over the same period.[1] Such a change in fertility rates will alter the demographic structures and population size in China. If current birth rates remain unchanged, China will have an aging and shrinking population, with a lot of retirees and a reduced percentage of working people in the future.

This paper assesses the economic implications of these demographic changes by means of a numerical general equilibrium simulation analysis. Following Rius-Rull (2001), this study explicitly models how different fertility levels—the current fertility rate as well as ones in alternative scenarios—will affect future demographic structures. Then, within an Auerbach-Kotlikoff-style multiperiod overlapping-generations framework, it assesses the impact of different demographic structures on the Chinese economy in the 21st century. The focus of the analysis is on macroeconomic variables such as capital flows, the rate of saving, the return to capital, the return to labor, and growth in per capita income.

The analysis differs from others in the literature in two ways. First, rather than taking official population projections at face value, this paper, following Rius-Rull's approach (2001), analyzes the impact of different fertility levels on demographic structure and the corresponding macroeconomic implications. Second, rather than looking at the steady states, this analysis, similar in spirit to Auerbach and Kotlikoff (1983), studies the transitory path.

The economic intuitions behind the results are straightforward. According to the life-cycle investment theory, saving behavior varies with age. As fertility rates today determine future age distributions, there will be an impact on aggregate savings. At the same time, since current fertility affects the future labor force, the marginal product of capital and the marginal product of labor will be affected. This implies that investment demand will be a function of demographic structure. The degree of international capital linkages also plays a role. If capital mobility is high, the demographic structure will affect the direction of capital flows through induced changes in saving supply and investment demand. All of the above factors affect economic growth.

The preliminary findings of the numerical analysis are:

- The domestic savings rate will be lower under a low-fertility regime.
- With low capital mobility, the return to capital is lower with lower fertility rates.
- With low capital mobility, a lower fertility rate today results in a higher return to labor due to its relative scarcity.

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[1] For details, see *Beijing Review* (2000).

- With high capital mobility, lower fertility rates are accompanied by more capital outflows, due to a reduction in capital productivity and a fall in the return to capital.

- Demographic structures have a small effect on economic growth.

The paper is organized as follows: Section II presents the factual and theoretical background; Section III presents the model; Section IV discusses the methodology; Section V presents the results; and Section VI concludes.

II. Background

China's fertility rates have changed dramatically. The total fertility rate, the birth rate, the mortality rate, and the natural growth rate have generally been declining over the past five decades, as shown in Table 1 and Figure 1. The mortality rate has declined steadily until mid-1970. The birth rate and the natural rate surged in the 1960s; but after the 1970s, both rates have been mostly on a downward trend.

Table 1. Total Fertility Rate Trends in China
(Total number of children per woman in her lifetime)

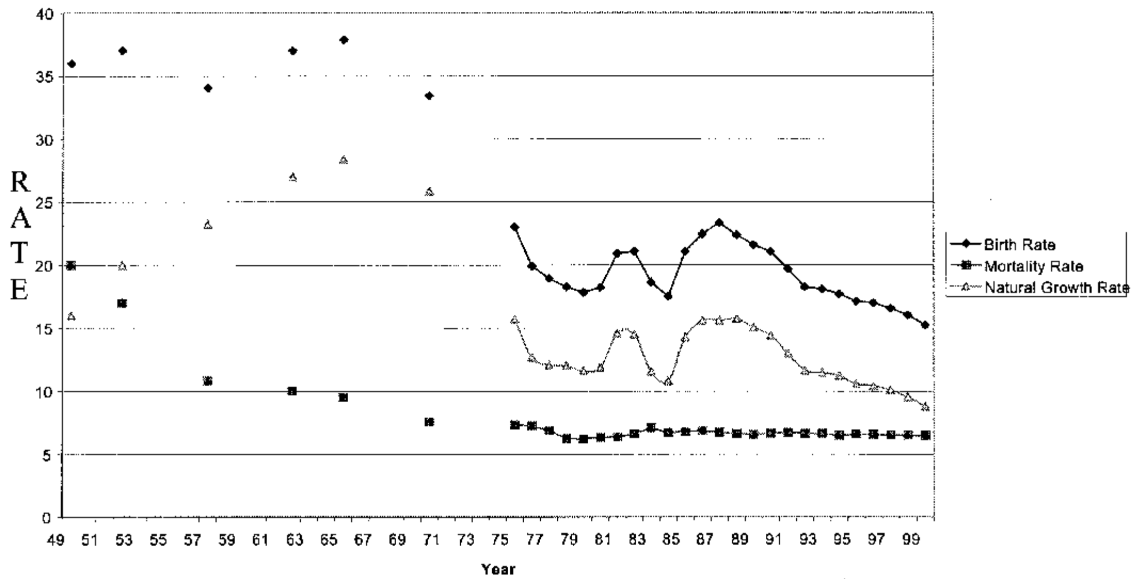
1950s	5.88
1960s	5.68
1970s	4.01
1980s	2.48
1990s	1.98

Note: Data between 1950 and 1989 come from *China Historical Population Data and the Relevant Studies, pp.* 1594–95; data between 1990 and 1995, and 1997 and 1999 come from *CIA World Factbook.* No data exist for 1996.

Fertility rates today affect future population in two dimensions: population size and population structure. Both population size and population structure have economic implications.

The key question about population size is whether China's population is so large that it hampers economic growth and development. Many scholars argue that China is a developing country with fixed natural resources, such as limited arable land, to support its huge population base. This is a Malthusian view: population, if unchecked, grows geometrically while production grows arithmetically; excessive population, will therefore be accompanied by famine, ill health, and poverty.

Figure 1. Birth Rate, Mortality Rate, and Natural Growth Rate
(Number per 1000 population)



Source: Data prior to 1985 come from *China Statistical Yearbook* (1985). The rest come from *China Statistical Yearbook* (2000).

Others argue that China's population size is not excessively large. Johnson (2000), for example, asserts that the Malthusian proposition is not relevant to China in the 21st century. He argues that Malthusian theory is only relevant if there is a fixed factor, primarily land in the case of China, that plays a significant role in the overall production. While land is a significant factor in agriculture, Johnson contends, it is not important in other sectors. Moreover, the share of primary industry in China has fallen from 50.5 percent of GDP in 1952 to 15.9 percent recently. Since historically the agricultural sector has always diminished when an economy grows, Johnson predicts that as Chinese GDP per capita increases further, the relative role of land will continue to decline in the future. More importantly, Johnson (2000) posits that the importance of fixed resources will also diminish over time, even within the agricultural sector as effective substitutes are found for land, such as better fertilizers, more advanced irrigation, and improved seed, thereby increasing the marginal product of land. He supports his argument by noting that, with no increase in land, the output of the primary sector rose by 417 percent during 1952–2000 while population increased by 120 percent over the same period; in other words, the per capita output of the primary sector in 2000 was 2.35 times the level in 1952. The huge increase in grain yields per hectare since 1952 shows that even within the agricultural sector, China has been successful in overcoming most of the problems associated with the fixed amount of land.

Furthermore, Johnson (2000) believes that population size has a positive effect on technology, citing that most empirical analyses find no adverse effect of population growth on economic growth. He contends that in most of human history, low population growth has accompanied low economic growth. Johnson points out that in the long run, a growing population has contributed to the enormous increase in knowledge, which in turn fosters economic growth. He argues that the larger is the population, the greater is the incentive to innovate since the reward from an innovation is a function of the number of people using it. In addition, the larger the population, the greater is the number of talented people capable of making innovations. Hence, in Johnson's view, population size is positively related to technological growth, which in turns raises economic growth.

Apart from the population size, fertility rates today have an impact on the future demographic structure, which affects the economy. Most of the economic literature on population structures has focused on the link between aging and savings. Rius-Rull (2001) studies the impact of the aging of the baby boom on capital accumulation in Spain. He finds that if fertility reverts to the patterns similar to the last 50 years, the aging of the baby boom will have little effect on savings; however, if fertility patterns remain at the current low levels, the aging of the baby boomers will have a significant negative impact on savings. Similarly, Heller and Symansky (1997) find that the aging Asian Tigers will exacerbate the declining world saving rate.

Other studies focus on the link between demographic structure and the return to investment. Bakshi and Chen (1994) find a strong link between demographic structure and asset returns in the United States and conclude that an aging economy will be accompanied by low asset prices. Both Bergantino (1998) and Brooks (2000a) find results consistent with Bakshi and Chen's seminal work. On the contrary, Poterba (2001) finds no robust evidence between asset returns and age structure. Brooks (2000b) studies the implication of capital flows for aging, and finds that as developed countries age faster than developing countries, there will be capital flows from developing countries to developed countries. [2]

III. Model

A. Demographic Structure

In this paper, the Chinese economy is represented by a multiperiod overlapping-generations model, adapted from Rios-Rull (2001). In this model, an agent may live up to 10 periods, with each model period representing 10 years in real time; thus an agent may live up to 100 years. Each agent is indexed by her age $a \in A = \{1,2,...,10\}$ and calendar time $t \in T = \{1,2,...\infty\}$. Each cohort (e.g., the cohort aged 20 in year 2010) is modeled by a representative agent. Throughout the paper, subscripts denote time and superscripts denote age. Each agent may die prematurely, with the probability of surviving from age a to age $a+1$ represented by l^a. Thus the unconditional probability of reaching age a is $\tilde{l}^a = \prod_{j=1}^{a-1} l^j$. [3] Let θ_t

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[2] See also Barro and Becker (1989),Willis (1985), Razin and Ben Zion (1975), and Eckstein and Wolpin (1982).

[3] Using the right data for the probability of dying in each period, we can calibrate the life-expectancy to correspond to the actual data.

denote the population distribution at calendar time t. Since the population is divided into ten age groups, θ_t is a 10×1 vector with each element giving the number of people in that age group. Then the law of motion of population is captured by a linear operator P where P is a 10×10 matrix such that $\theta_{t+1} = P\theta_t$. Essentially,

$$\begin{bmatrix} \theta_{t+1}^1 \\ \theta_{t+1}^2 \\ \theta_{t+1}^3 \\ \theta_{t+1}^4 \\ \theta_{t+1}^5 \\ \theta_{t+1}^6 \\ \theta_{t+1}^7 \\ \theta_{t+1}^8 \\ \theta_{t+1}^9 \\ \theta_{t+1}^{10} \end{bmatrix} = \begin{bmatrix} \phi^1 & \phi^2 & \phi^3 & \phi^4 & \phi^5 & \phi^6 & \phi^7 & \phi^8 & \phi^9 & \phi^{10} \\ l^1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & l^2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & l^3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & l^4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & l^5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & l^6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & l^7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & l^8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & l^9 & 0 \end{bmatrix} \begin{bmatrix} \theta_t^1 \\ \theta_t^2 \\ \theta_t^3 \\ \theta_t^4 \\ \theta_t^5 \\ \theta_t^6 \\ \theta_t^7 \\ \theta_t^8 \\ \theta_t^9 \\ \theta_t^{10} \end{bmatrix} \tag{1}$$

Here, $\phi = (\phi^1, \phi^2, ..., \phi^{10}) \in \Re^{10}$ is the number of children of each agent.[4] Thus, the number of the newborns next period is $\phi \bullet \theta$ as captured by the first element of the vector on the left-hand side, which equals the dot product of the first element of the first row of the matrix with the vector on the right-hand side. Since $\theta_{t+1} = P\theta_t$, we can rewrite the law of motion of the demographics as: $\theta_t = P^t\theta_0$, where θ_0 is the initial population distribution.

Following Strange (1988), we can rewrite θ_t as:

$\theta_t = S\Lambda^t S^{-1}\theta_0$, where $S = \begin{bmatrix} & & \\ x_1 & \dots & x_{10} \\ & & \end{bmatrix}$ and $\Lambda = \begin{bmatrix} \lambda_1 & & \\ & \dots & \\ & & \lambda_{10} \end{bmatrix}$ are the eigenvectors and eigenvalues of P respectively. Or, equivalently, $\theta_t = c_1\lambda_1^t x_1 + ... + c_{10}\lambda_{10}^t x_{10}$ where $c \equiv S^{-1}\theta_0$. Let $\bar{\lambda} \equiv \max_i |\lambda_i|$ then $t \to \infty$ implies $\theta_t \approx \bar{\lambda}^t c_1 x_1$.[5]

[4] To avoid double counting, the sex ratio and age of childbearing should be taken into consideration when computing the effective fertility rates, namely the first row of the matrix. Section IV will present data on childbearing age and the sex ratio.

[5] To see that, divide everything by $\bar{\lambda}^t$ and then take limit.

Thus, in the long run, the population is growing at a rate of n per period, where $1+n=\overline{\lambda}$, and the steady-state population distribution is $\theta_\infty = \overline{c}\overline{x}$, where $\overline{c}$ and $\overline{x}$ are the corresponding coefficient and eigenvalue for eigenvector $\overline{\lambda}$. Hence, in the balanced-growth path, $\theta_t = (1+n)^t \theta_\infty$.

B. Economy

Preferences

Each agent spends her first two periods as a child, making no consumption or financial decision. For simplicity, her utility in the first two periods is ignored. After she has grown up, if she does not die "prematurely," she works for four periods and then retires for the last four periods. In each period, she faces a probability of dying in that period. In the whole economy, a fraction of people of age a will survive to the next period, and one minus that fraction will die at age a.

Her utility function is the standard isoelastic or constant relative risk aversion (CRRA) function. Thus, an agent born at time s has the following life-time preference from the point of view of time s:

$$\sum_{a=3}^{10} \beta^a \tilde{l}^a U(c_{s+a-1}^a) = \sum_{a=3}^{10} \beta^a \tilde{l}^a \frac{(c_{s+a-1}^a)^{1-\gamma}}{1-\gamma} \tag{2}$$

where, c_t^a is the consumption of an agent of age a at time t.

Budget Constraint

In each period, an agent can allocate her income between consumption, which may include consumption of the agent's offspring, and investment (in the capital market). An agent of age a at time period t has income I_t^a where $I_t^a = k_t^a r_t + \varepsilon^a w_t$, and k_t^a is the capital an agent of age a at time t holds, r_t is the rental rate of capital (return to capital), w_t is the wage rate (return to labor) at calendar time t, and ε^a is the labor productivity of an agent of age a.

Furthermore, it is assumed that capital depreciates at a rate of δ; thus we have

$$k_{t+1}^{a+1} = i_{t+1}^{a+1} + (1-\delta)k_t^a \tag{3}$$

Following Rios-Rull, if an agent in a cohort dies, the survivors in the same cohort share the wealth and debts of that agent in a lump-sum manner denoted by Tr_t^a. Our budget constraints become:

$$c_t^a + k_{t+1}^{a+1} = (1-\delta+r_t)(k_t^a + Tr_t^a) + \varepsilon^a w_t \tag{4}$$

Since l^a of the agents of cohort a will survive to the next period whereas $1-l^a$ of them will die in this period, $Tr_{t+1}^{a+1} = \frac{1-l^a}{l^a} k_{t+1}^{a+1}$.

Bellman Equation

Thus, an agent's problem can be represented by the following Bellman equation:

$$V(k_t^a) = \max_{c_{ta}^t, k_{t+1}^{a+1}} U(c_t^a) + \beta l^a V(k_{t+1}^{a+1})$$
$$s.t.$$
$$c_t^a + k_{t+1}^{a+1} = (1-\delta + r_t)(k_t^a + Tr_t^a) + \varepsilon^a w_t \quad (5)$$
$$Tr_{t+1}^{a+1} = \frac{1-l^a}{l^a} k_{t+1}^{a+1}$$

The corresponding Euler's equation to the problem is:

$$U'(c_t^a) = \beta l^a (1+\delta + r_{t+1}) U'(c_{t+1}^{a+1}) \quad (6)$$

and the total capital held by an agent of age a at time t is:

$$\overline{k_{t+1}^{a+1}} = k_{t+1}^{a+1} + Tr_{t+1}^{a+1} = \frac{(1-\delta + r_t)k_t^a + w_t \varepsilon^a - c_t^a}{l^a} \quad (7)$$

Production

This is a production economy, with the production represented by the standard Cobb-Douglas function:[6]

$$F(A_t, H_t, K_t) = K_t^{\alpha}(A_t H_t)^{1-\alpha}$$

Here, the technology productivity A_t is growing at a constant rate of g per period: i.e., $A_{t+1} = (1+g)A_t$ or $A_t = (1+g)^t A_0$. Note H_t and K_t are aggregate labor and aggregate capital stock, respectively. They are the sum of individual supplies of capital and labor across age groups at period t and that's why they don't have a superscript to denote age.

International Linkages and Capital Mobility

International capital mobility implies China's population structure will affect its external balance as well as internal balance. In addition, the degree of mobility itself is important theoretically. By varying the degree of capital mobility, we can see how sensitive our results are to the openness of the capital market. The extreme cases of no capital mobility and perfect capital mobility are examined.

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[6] Since a Cobb-Douglas production function without a fixed factor is used, this model only addresses the economic implications of China's changing demographic structures as induced by different fertility levels, with the issues pertaining to the population size in the presence of a fixed factor ignored in the formal analysis.

C. Equilibrium

No Capital Mobility

The case with no international capital mobility corresponds to a fully dynamic general equilibrium, a standard framework in the family of rational expectation models. Thus, equilibrium is defined as follows:

A competitive equilibrium with no international capital mobility, under a fertility rate denoted by ϕ, *is a set of individual decision functions:* c_t^a *and* k_{t+1}^{a+1} *for a=3,4,5,6,7,8,9,10; t=1,2... with* $k_t^{11}=0, \forall t$ *and wages* $\{w_t\}_{t=1}^{\infty}$ *and return to capital* $\{r_t\}_{t=1}^{\infty}$ *such that:*

1. c_t^a *and* k_{t+1}^{a+1} *solve the individual problems (5) for a=3,4,5,6,7,8,9,10 and t=1,2..., i.e., they max (2) subject to (4) and therefore (6) and (7) hold.*
2. *Factor prices are competitively determined: i.e., they must be equated with the corresponding marginal products:*

$$\begin{aligned} r_t &= \alpha K_t^{\alpha-1}(A_t H_t)^{1-\alpha} \\ w_t &= (1-\alpha)K_t^{\alpha-1}A_t^{1-\alpha}H_t^{-\alpha} \end{aligned} \tag{8}$$

3. *Market clearing:*
   a. *The product market clears in every period: aggregate consumption plus aggregate investment equal GDP:*

$$\sum_{a=3}^{10}\theta_t^a(c_t^a+i_t^a)=F(A_t,K_t,H_t)$$

   b. *Factor markets (labor market and capital market) clear:*

$$\sum_{a=3}^{6}\theta_t^a\varepsilon^a=H_t$$

$$\sum_{a=3}^{10}\theta_t^a\overline{k_t^a}=K_t$$

4. *Demography is governed by:*

$$\theta_{t+1}=P\theta_t$$

The Balanced-Growth Path

As shown previously, for any constant fertility rate, there will be a steady-state age distribution θ_∞ with the population growing at the rate of *n*. Similarly, in the long run, there will be a balanced-growth path: define $k_t \equiv K_t/(A_t H_t)$ and $y_t \equiv Y_t/(A_t H_t)=k_t^{\alpha}$. The balanced-growth path of the economy, following the standard neoclassical growth model, is defined such that the per-effective-worker capital stock is constant over time: i.e.,

$k_t = k_{t+1} = k^{ss}$. In other words, on the balanced-growth path, all aggregate variables are growing at a constant rate of $g+n$, while per capita variables are growing at the rate of g. Also, in the balanced growth path, the return to capital is $r^{ss} = \alpha(k^{ss})^{\alpha-1}$ and $w_t = A_t[(k^{ss})^{\alpha} - r^{ss}k^{ss}]$.[7] In short, given the initial conditions and the fertility rates, the economy will converge to a balanced-growth path. Our focus is on the transitory path toward the balanced-growth path, i.e., the 21st century.

Perfect Capital Mobility

With perfect capital mobility, the return to capital is determined by the international rate of return to capital, r^{int}. Thus capital will flow in and out so as to equate the internal marginal product of capital with the international rate. In other words, equilibrium with perfect capital mobility is a partial equilibrium with prices exogenously given. Given the international rate, equilibrium conditions consist of consumer and producer maximization problems, namely, (6), (7), and (8).

IV. Data and Calibration

Actual data in 2000 are used as the initial conditions; data for subsequent years are generated endogenously by the model. Most data are obtained from the *China Statistical Yearbook* (1995, 2000) and *China Population Statistics Yearbook* (1999). Some other data are approximated.

To correctly implement the demographic dynamics as represented by the linear operation in (1), we need four items: the initial population distribution in the year 2000, a recent life table for China, the sex ratio, and the maternal age. The life table for China given in Table 2 is used to compute rows 2–10 in the matrix P given by equation (1) and for the utility maximization problems of the consumers. Childbearing age for Chinese women is between 15–49 (model periods 2–5), with more than 80 percent of children borne by women between 21–30 (period 3) and more than 15 percent by women between 31–40 (period 4), as summarized in Table 3, which is used to compute the first row in the matrix P given in equation (1). For example, if each woman can have z children in her life, then $\phi_3 = 0.8240 * 0.5045z$, and the number of new born babies next period will be ϕ_3 times the current population in the current period. The initial population composition is shown in Figure 2.

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[7] In general $r_t = \alpha k_t^{\alpha-1}$ and $w_t = A_t(y_t - r_t k_t)$.

Table 2. Life Table for China in 1990

Period	Survival Probability to the Beginning of the Next Period	Survival Probability to the Beginning of the Period (unconditional probability from birth)
1	0.951021846	1
2	0.991433028	0.951021846
3	0.986561925	0.942874469
4	0.980758139	0.930204051
5	0.958355501	0.912305194
6	0.894846864	0.874312702
7	0.742696744	0.782375979
8	0.455162644	0.581068093
9	0.134994812	0.26448049
10	0	0.035703494

Source: *China Statistical Yearbook* (1995).

Table 3. Childbearing Age and Sex Ratio in 1999

Actual Age	Model Period	Proportion of Children Borne by Mother at this Age (in percent)	Proportion of Female in the Cohort (in percent)
11–20	2	0.69	48.02
21–30	3	82.40	50.45
31–40	4	16.22	49.52
41–50	5	0.69	49.02

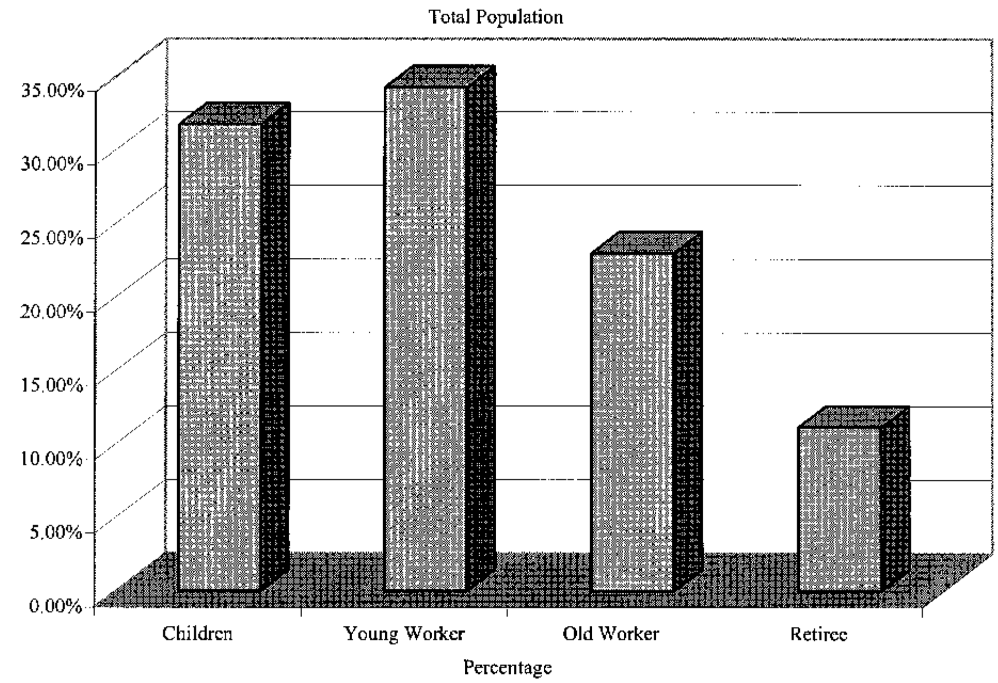
Source: *China Statistical Yearbook* (2000).

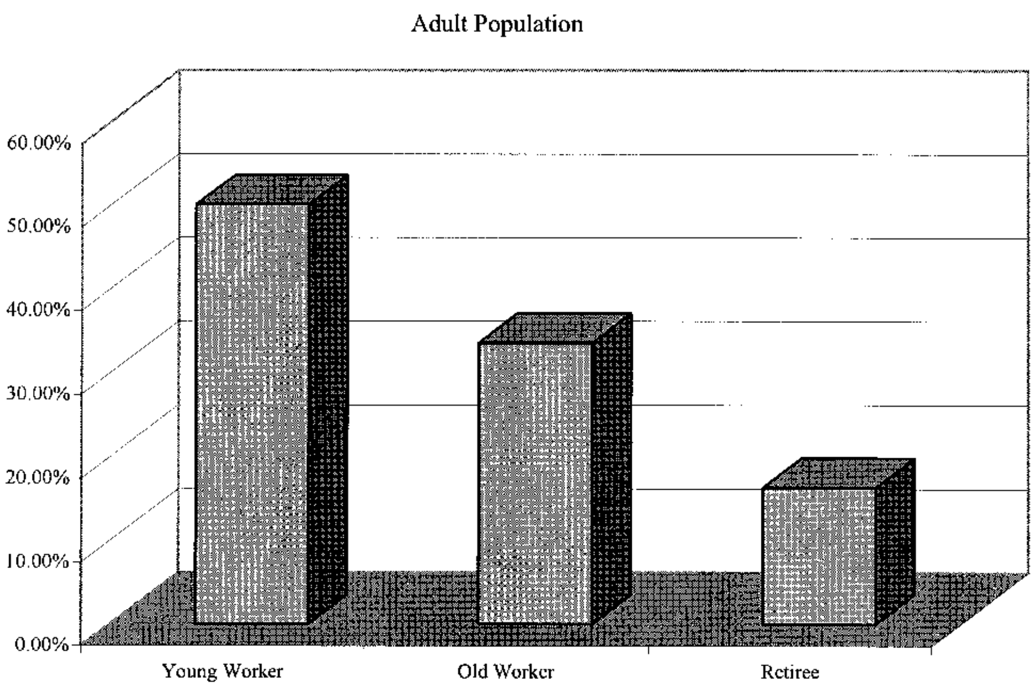
For the production function, we need actual data for the Chinese capital stock in the year of 2000. However, capital stock data for China are not available. Thus, it is approximated by the standard "perpetual inventory method:"

$$K_{t+1} = (1-\delta)K_t + I_t \tag{9}$$

Given the actual data on the gross investment in China from 1978 to 1999, an estimate of the capital stock in 1978, and a depreciation rate δ, we use (3) to estimate the Chinese capital stock in the year 2000. The initial period is far enough from 2000 that most capital stock would have depreciated by 2000, and thus the accuracy of the estimate for the initial period (1978) is not very important.

Figure 2. Population Composition in 1999





Children=Periods 1–2 (age=0–20); Young Worker=Periods 3–4 (age=21–40); Old Worker=Periods 5–6 (age=41–60); Retiree=Periods 7–10 (age=61–100); Source: China Statistical Yearbook 2000

The depreciation rate δ is assumed to be 6 percent following Young (2000). The capital stock in 1978 is estimated with Taiwanese data from the Penn World Table in the following way: the per capita capital stock for China in 1978 is assumed to be equal to that in Taiwan Province of China in the year when Taiwan Province of China had the same per capita GDP as the 1978 per capita GDP in China. The accuracy of this estimate is not crucial since with a 6 percent annual depreciation rate, most of the capital stock in 1978 is fully depreciated by 2000. More importantly, the actual capital stock in 1978 is very low compared with the capital stock accumulated during the subsequent 22 years because of the opening of China around 1980. The capital stock in China in 2000 is estimated to be 5.985 trillion yuan (in 1978 prices, corresponding to 21.53 trillion yuan in 1999 prices, or $2.6 trillion in 1999 U.S. prices).

In this model, people in periods 3–6 work; thus the labor force is taken from the population size of people in these age groups. Age-specific labor productivity is adapted from data in Young (2000) as below. Following Young (2000), the annual growth of total factor productivity A_t is assumed to be 1.8 percent annually, and the share of capital in GDP, α, is assumed to be 0.4.

Table 4. Age-Specific Productivity

Age	Period	Ln wage	Productivity Index (ε^a)
21–30	3	0.395	1.484384
31–40	4	0.56	1.750673
41–50	5	0.685	1.983772
51–60	6	0.635	1.887022

The relative productivity index comes from the relative wage rate estimates in Young (2000.) Note unit do not matter here; all we need is to compare how productive a worker at an age group is *relative* to those at another age group.

Given that the age-specific wealth distribution is not available for China, the U.S. age-wealth distribution from the Survey of Consumer Finances is used:

Table 5. Initial Age-Wealth Distribution
Approximated by U.S. Data

Period	Proportion of Wealth Held by the Age Group (in percent)
1	0.00
2	0.00
3	3.29
4	14.75
5	25.75
6	25.64
7	21.05
8	7.93
9	1.49
10	0.10
Total	100.00

Source: Data adapted from Rius-Rull (2001), where the U.S. age-wealth distribution is used to approximate that of Spain.

The coefficient of relative risk aversion, γ, as in equation (2) is set to be 1.5. Then, given a CRRA coefficient γ, the time discount factor β is picked so that the simulated investment/GDP ratio in the beginning of the 21st century under the benchmark fertility level matches the actual data. The benchmark fertility is chosen to be 1.8 children per woman. Consequently, the simulated investment/GDP in the first decade of the 21st century under the benchmark fertility rate is around 37 percent, which is similar to recent data for China.

In the case of perfect capital mobility, we need an international rate of return to capital. This rate is picked such that the simulated ratio of capital inflows to GDP is close to 5 percent in the first period of the model because the ratio of capital flows to GDP in 1999 was around 5 percent. This rate is assumed constant throughout the 21st century.

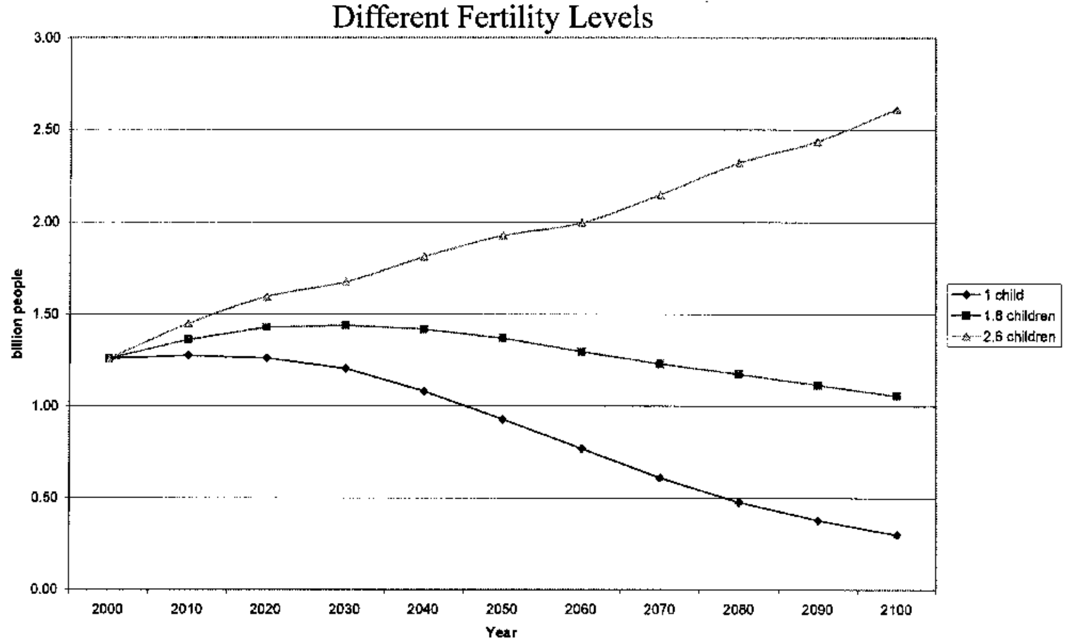
V. Results

Economic outcomes corresponding to three fertility levels are reported: a low fertility rate of 1 child per woman, the benchmark fertility rate of 1.8 children per woman, and a high fertility rate of 2.6 children per woman.[8]

A. Demographic Profiles for 21st Century China

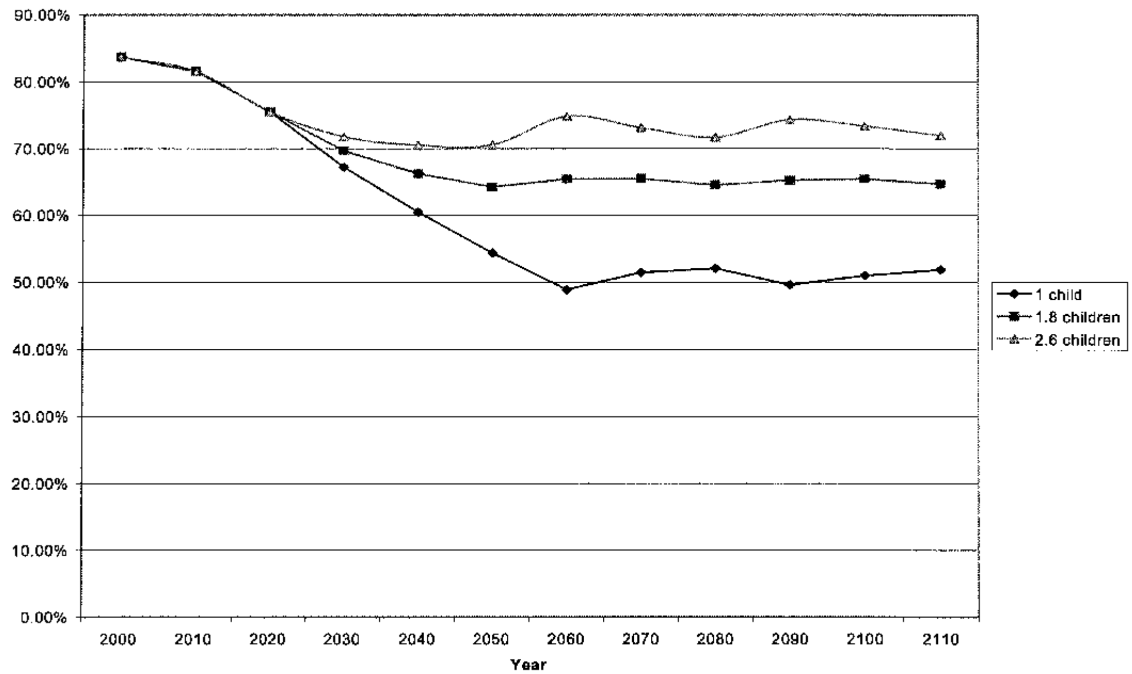
The population in China under different fertility levels is shown in Figure 3, and the percentage of adult population in the labor force is shown in Figure 4. Lower fertility rates imply a lower percentage of population in the labor force because lower fertility rates result in a higher percentage of old people who do not work.

Figure 3. Population Size in the 21st Century Under Different Fertility Levels



[8] For the solution method, see Appendix I.

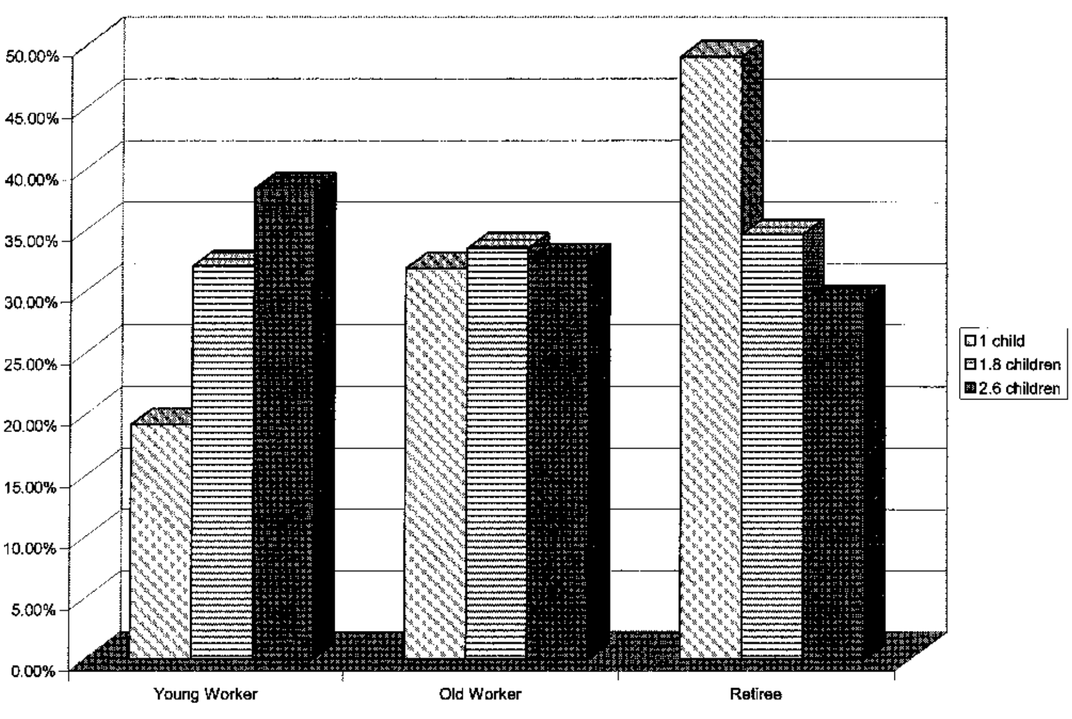
Figure 4. Percentage of Adult Population in the Labor Force



Note: Adults are people aged 21 and above, i.e., agents in model periods 3-10.

Figure 5 shows the adult age distribution in 2100. With low fertility, the proportion of retirees in the adult population will be much higher towards the end of the 21st century.

Figure 5. Adult Composition in 2100



B. Economic Implications with Immobile Capital

Table 6 shows the estimated return to capital under the different fertility rates. The results indicate two patterns: first, the return to capital in the three fertility regimes decreases over time. This is due to two mutually reinforcing factors: percentage of workers in the population decreases in all of the fertility regimes, thereby lowering the marginal return to capital; and as capital accumulates, the law of diminishing return implies that the return to capital will also be lower over time. The second pattern is that the return to capital is higher with higher fertility rates because the relative abundance of labor in the future due to higher fertility rates today implies a higher return to capital.

Table 6. Return to Capital (with Immobile Capital)

Year	Number of Children per Woman			Number of Children per Woman		
	1	1.8	2.6	1	1.8	2.6
	absolute scale			relative scale (1.8 children=1)		
2000	1.53	1.53	1.53	1.00	1.00	1.00
2010	1.30	1.31	1.31	0.99	1.00	1.01
2020	1.13	1.14	1.16	0.99	1.00	1.01
2030	1.00	1.07	1.14	0.93	1.00	1.07
2040	0.93	1.06	1.18	0.87	1.00	1.11
2050	0.87	1.06	1.20	0.82	1.00	1.13
2060	0.84	1.09	1.26	0.77	1.00	1.15
2070	0.91	1.08	1.21	0.84	1.00	1.12
2080	0.89	1.06	1.19	0.83	1.00	1.12
2090	0.85	1.08	1.24	0.78	1.00	1.15
2100	0.89	1.08	1.21	0.82	1.00	1.13

Note: 2000 refers to 2000-09, 2010 refers 2010-19, and so on. This notation is used in similar tables throughout the paper.

Return to Labor

As shown in Table 7, there are also two analogous patterns for the return to labor: first, the return to labor rises over time, regardless of the fertility regime. The reason is that the labor-to-population ratio decreases over time while capital rises; the former makes labor more scarce while the latter makes labor more productive, with both mutually reinforcing factors boosting the return to labor. The second pattern is that the return to labor is higher under the lower fertility rate because labor is more scarce, therefore raising wages even more.

Table 7. Return to Labor (with Immobile Capital)

Year	Number of Children per Woman 1	1.8	2.6	Number of Children per Woman 1	1.8	2.6
	absolute scale			relative scale (1.8 children=1)		
2000	0.25	0.25	0.25	1.00	1.00	1.00
2010	0.27	0.27	0.27	1.01	1.00	1.00
2020	0.30	0.30	0.30	1.01	1.00	0.99
2030	0.33	0.31	0.30	1.05	1.00	0.96
2040	0.34	0.31	0.29	1.10	1.00	0.93
2050	0.36	0.31	0.29	1.14	1.00	0.92
2060	0.37	0.31	0.28	1.19	1.00	0.91
2070	0.35	0.31	0.29	1.12	1.00	0.93
2080	0.35	0.31	0.29	1.13	1.00	0.93
2090	0.36	0.31	0.28	1.18	1.00	0.91
2100	0.35	0.31	0.29	1.14	1.00	0.92

Capital per Effective Labor

Table 8 shows capital per effective labor. Regardless of the fertility rate, capital per worker rises because of the accumulation of capital over time. Lower fertility results in higher per worker capital due to the scarcity of labor.

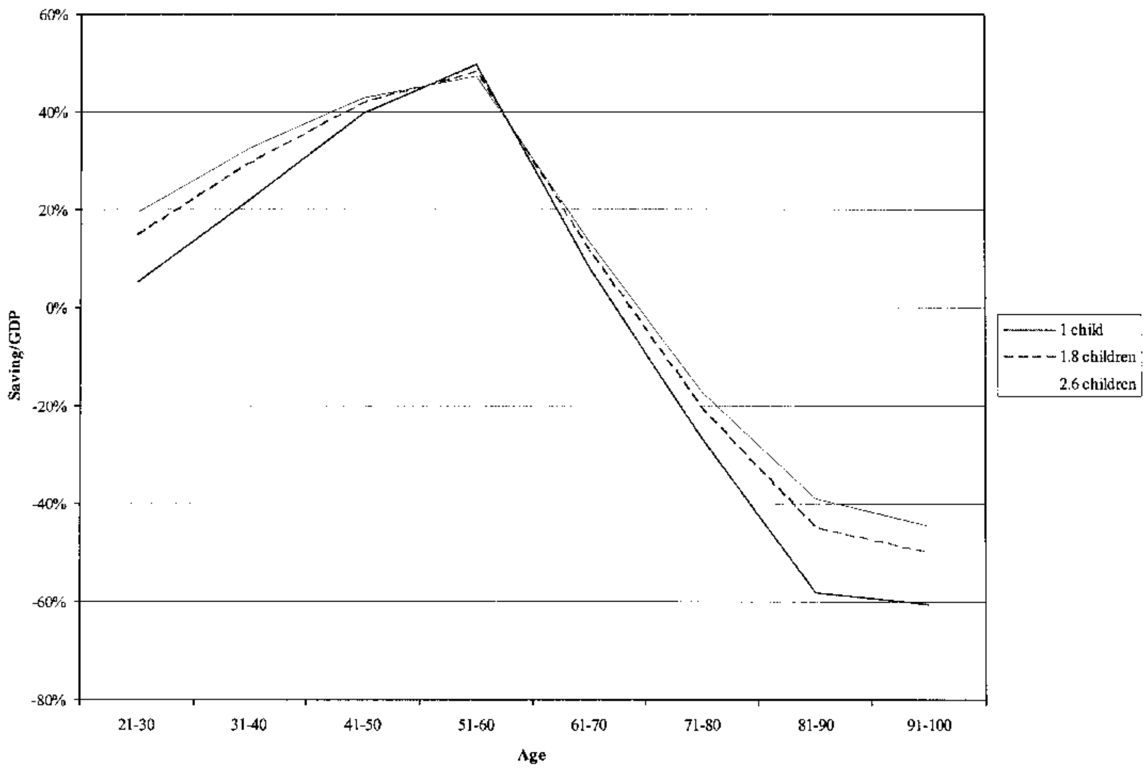
Table 8. Capital per Effective Labor (with Immobile Capital)

Year	Number of Children per Woman 1	1.8	2.6	Number of Children per Woman 1	1.8	2.6
	absolute scale			relative scale (1.8 children=1)		
2000	0.11	0.11	0.11	1.00	1.00	1.00
2010	0.14	0.14	0.14	1.01	1.00	0.99
2020	0.18	0.17	0.17	1.02	1.00	0.98
2030	0.22	0.19	0.17	1.13	1.00	0.90
2040	0.25	0.20	0.17	1.26	1.00	0.84
2050	0.27	0.20	0.16	1.39	1.00	0.82
2060	0.29	0.19	0.15	1.54	1.00	0.79
2070	0.26	0.19	0.16	1.34	1.00	0.83
2080	0.27	0.20	0.16	1.36	1.00	0.83
2090	0.29	0.19	0.15	1.50	1.00	0.79
2100	0.26	0.19	0.16	1.38	1.00	0.82

Note: Capital per effective labor is capital relative to labor augmented by technology; see Romer (1996).

Consistent with the life-cycle investment hypothesis, the simulations confirm that young people save relatively little, middle-aged agents save the most, and retirees dissave. A saving-age profile for an agent born in 2030 is displayed in Figure 6. The result shows that a low fertility level results in lower saving rates throughout agents' lifetime because a higher fertility level implies a higher return to capital, thereby encouraging saving. Thus, lower fertility today results in lower aggregate saving rates in the future, as shown in Table 9.[9]

Figure 6. Age-Saving Profile for Agents Born in 2030
(with Immobile Capital)



[9] Due to the "humped shape" of the age-saving profile, saving rates may actually rise in the initial years as the population ages, but they will inevitably decline in subsequent years.

Table 9. Aggregate Saving Rates (with Immobile Capital)

Year	Number of Children per Woman 1	1.8	2.6	Number of Children per Woman 1	1.8	2.6
	absolute scale (In Percent)			relative scale (1.8 children=1)		
2000	38.45	37.76	37.26	1.02	1.00	0.99
2010	35.54	34.68	34.10	1.02	1.00	0.98
2020	31.82	31.10	30.62	1.02	1.00	0.98
2030	28.98	28.19	28.04	1.03	1.00	0.99
2040	26.90	26.96	27.64	1.00	1.00	1.03
2050	24.14	26.81	28.82	0.90	1.00	1.07
2060	21.80	27.90	30.77	0.78	1.00	1.10
2070	24.88	27.66	29.20	0.90	1.00	1.06
2080	24.82	27.09	28.75	0.92	1.00	1.06
2090	22.62	27.65	30.23	0.82	1.00	1.09
2100	24.20	27.64	29.39	0.88	1.00	1.06
Average	**27.65**	**29.40**	**30.44**	**0.94**	**1.00**	**1.04**

Effects of demographic structures on per capita income are less clear. As shown in Table 10, in some years, per capita income growth associated with a low fertility is higher than that with a high fertility, but the reverse is true for other years. In any case, the difference in per capita GDP growth across different fertility regimes is not large.

Table 10. Annual Per Capita Income Growth (with Immobile Capital)

Year	Number of Children per Woman 1	1.8	2.6	Number of Children per Woman 1	1.8	2.6
	absolute scale (In Percent)			relative scale (1.8 children=1)		
2000	5.33	4.58	3.90	1.16	1.00	0.85
2010	4.03	3.38	2.85	1.19	1.00	0.84
2020	2.90	2.90	2.99	1.00	1.00	1.03
2030	2.72	2.68	2.47	1.02	1.00	0.92
2040	2.45	2.65	2.59	0.92	1.00	0.98
2050	2.17	3.07	3.56	0.71	1.00	1.16
2060	3.07	3.09	2.97	0.99	1.00	0.96
2070	3.26	2.88	2.65	1.13	1.00	0.92
2080	2.76	3.04	3.32	0.91	1.00	1.09
2090	3.00	3.07	3.02	0.98	1.00	0.98

C. Economic Implications with Mobile Capital

Under perfect capital mobility, the return to capital in China is exogenously determined by the international rate of return to capital, and all economic variables will be functions of this international rate. The international rate of return to capital is calculated such that the simulated capital inflow/GDP ratio in the first period matches actual recent data, and it is assumed to remain fixed at that rate. The case of perfect mobility is interesting for two reasons. First, it shows how sensitive our results are to the extreme assumption that the return to capital is exogenous rather than endogenous. Second, and more importantly, it shows how different fertility regimes affect capital flows. Since the actual direction and magnitude of capital flows depend on many other factors, we focus only on the relative direction and magnitude of capital flows among the different fertility regimes.

As shown in Table 11, a lower fertility level is associated with relatively low net capital inflows because the relative scarcity of labor implies a lower return to capital, thereby making investment in China less attractive.[10]

Table 11. Net Capital Flows as a Percent of GDP

Year	Number of Children per Woman 1	1.8	2.6
	relative scale (1.8 children=0)		
2000	0.00	0.00	0.00
2010	0.00	0.00	0.00
2020	-3.95	0.00	3.95
2030	-7.33	0.00	6.13
2040	-10.26	0.00	6.84
2050	-13.23	0.00	8.88
2060	-5.97	0.00	5.46
2070	-7.18	0.00	6.04
2080	-11.53	0.00	8.34
2090	-7.42	0.00	5.95
2100	-7.03	0.00	5.97

Note: Negative numbers indicate to net capital outflows.

[10] Although the rate of saving is lower with a lower fertility rate, this effect is dominated by the fall in the investment demand due the relative scarcity of labor. For the theoretical reasoning behind this result, see Appendix II.

Table 12 indicates that a lower fertility rate results in slightly lower savings rates.

Table 12. Aggregate Saving Rates (with Mobile Capital)

Year	Number of Children per woman 1	1.8	2.6
	relative scale (1.8 children=1)		
2000	1.00	1.00	1.00
2010	1.00	1.00	1.00
2020	1.00	1.00	1.00
2030	1.02	1.00	0.98
2040	1.01	1.00	0.99
2050	0.94	1.00	1.04
2060	0.82	1.00	1.07
2070	0.86	1.00	1.04
2080	0.90	1.00	1.05
2090	0.84	1.00	1.07
2100	0.85	1.00	1.05
Average	**0.93**	**1.00**	**1.03**

In terms of per capita economic growth, the results are similar to the case with immobile capital. As shown in Table 13, demographic structures do not have a significant impact on the per capita income growth.

Table 13. Annual Per Capita Income Growth (with Mobile Capital)

Year	Number of Children per Woman 1	1.8	2.6
	relative scale (1.8 children=1)		
2000	1.17	1.00	0.84
2010	1.18	1.00	0.85
2020	1.01	1.00	1.03
2030	1.06	1.00	0.90
2040	1.01	1.00	0.94
2050	0.80	1.00	1.15
2060	0.99	1.00	0.95
2070	1.09	1.00	0.92
2080	0.94	1.00	1.10
2090	0.98	1.00	0.98

VI. Conclusion

This paper considers how fertility levels today affect the economy in the future using a numerical general equilibrium simulation analysis. While this type of analysis has been applied to the United States and other industrialized countries, one of the contributions of this paper is to apply this method to China, the most populous country in the world.

The study shows that savings are lower with low fertility rates In addition, with low fertility rates, future returns to capital will fall while returns to labor will rise. In other words, the study finds that the fall in demand for capital due to labor shortage is greater than the fall in supply due to the dissaving of the elderly. Consequently, when capital mobility is high, the simulation predicts more capital outflows in the future with a low-fertility regime today. Finally, the study shows that the effects of demographic structures on growth rates of per capita income are very small.

The analysis could be extended in a number of ways. It would be interesting, for example, to address the Malthusian hypothesis with an explicit treatment of land in the production function. Another fruitful area for further research would be to explore the link between technology and population.

Algorithm and Solution Method

Normalization

For numerical reasons, it is useful (and customary) to normalize the system by dividing everything in the consumer's problem by the (labor-augmenting) technology A_t. Specifically, let $\hat{c}_t^a \equiv c_t^a / A_t$ and $\hat{k}_t^a \equiv \bar{k}_t^a / A_t$, then (2) becomes:

$$[A_0(1+\tilde{g})^{s-1}]^{1-\gamma} \sum_{a=3}^{10} \hat{\beta}^a \tilde{l}^a \frac{(\hat{c}_{s+a-1}^a)^{1-\gamma}}{1-\gamma} \tag{10}$$

where $\hat{\beta} \equiv \beta(1+\tilde{g})^{1-\gamma}$. Since the utility function is ordinal, we can ignore the constant $[A_0(1+\tilde{g})^{s-1}]^{1-\gamma}$. Denote $\hat{w}_t \equiv w_t / A_t = y_t - r_t k_t$, with $w_t = A_t(y_t - r_t k_t)$, where $k_t \equiv K_t /(A_t L_t)$ and $y_t \equiv Y_t /(A_t L_t)$. Hence after normalization, (6) and (7) become:

$$\begin{aligned} U'(\hat{c}_t^a) &= \hat{\beta} l^a (1+\delta+r_{t+1}) U'(\hat{c}_{t+1}^{a+1}) \\ \hat{k}_{t+1}^{a+1} &= \frac{(1-\delta+r_t)\hat{k}_t^a + \hat{w}_t \varepsilon^a - \hat{c}_t^a}{l^a(1+\tilde{g})} \end{aligned} \tag{11}$$

Numerical Algorithm

Individual Consumer's Life-Cycle Problem

Following Judd, the method of "shooting" is used to solve an individual's life-cycle problem: since an individual starts with zero assets, given a rate of return to capital, we estimate an initial consumption level and then use (11) to find subsequent consumption levels and capital holdings. As a result, we can keep improving our estimate of the initial consumption level until each agent dies with zero assets.

Overlapping-Generations Equilibrium

The method follows that of Judd (1998, Chapter 16). First, the balanced-growth path prices are solved assuming that in 400 years the Chinese economy will reach the balanced-growth path. (In fact, it reaches the balanced-growth path in about 150 years.) Thus, the remaining task is to find the prices in the 400 years such that markets clear in every period. This is done as follows:

Step 0: Choose an initial estimate $(r_t^0, w_t^0)_{t=1}^{40}$. (A convenient choice is the balanced-growth path r and w.)

Step 1: Given the estimate $(r_t^i, w_t^i)_{t=1}^{40}$, compute the capital supply path for each age cohort in different times by solving each agent's life-cycle problem.

Step 2: Find the aggregate capital supplied and compute the implied marginal product of capital and marginal product of labor: $(r_t^d, w_t^d)_{t=1}^{40}$.

Step 3: When each component of $(r_t^d - r_t^i, w_t^d - w_t^i)_{t=1}^{40}$ is small enough, the estimates are taken as final; otherwise, go to step 4.

Step 4: Compute a new guess of $(r_t^{i+1}, w_t^{i+1})_{t=1}^{40}$, with $r_t^{i+1} = r_t^i + \mu(r_t^d - r_t^i)$ and $w_t^{i+1} = w_t^i + \mu(w_t^d - w_t^i)$ for some $\mu < 1$, where μ is an extrapolation parameter needed to ensure that the system is stable. Go back to Step 1 and start over again.

A Classical Interpretation

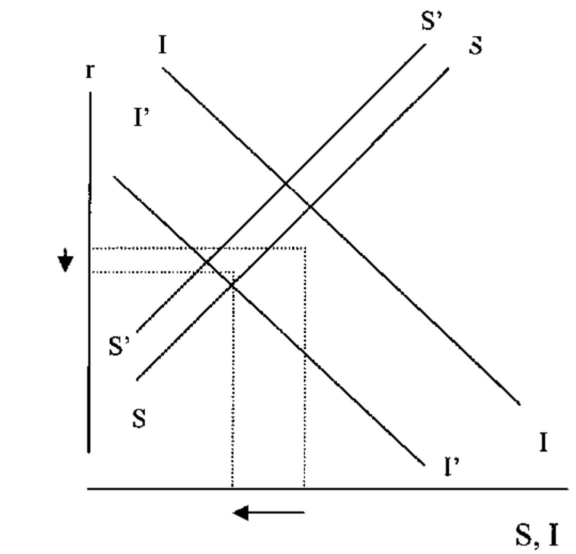
Much of this paper can be summarized by a classical supply-demand analysis of capital. The supply of capital is derived from the consumer's utility-maximization problem. The supply schedule of capital is upward sloping because as the return to capital rises, consumers save more and therefore accumulate more capital. From life-cycle investment theories, saving is a function of age, with young and old people dissaving. Hence, as the population ages, the supply schedule of capital shifts to the left. If the demand for capital is unchanged, then an aging population implies a higher return to capital.

On the other hand, the demand for capital depends on the productivity of capital, derived from the schedule of the marginal product of capital. Since labor and capital are complements, a decrease in labor makes capital less productive. When an economy ages, there will be a decline in the supply of labor. Thus, when the population ages, the demand schedule for capital also shifts to the left.

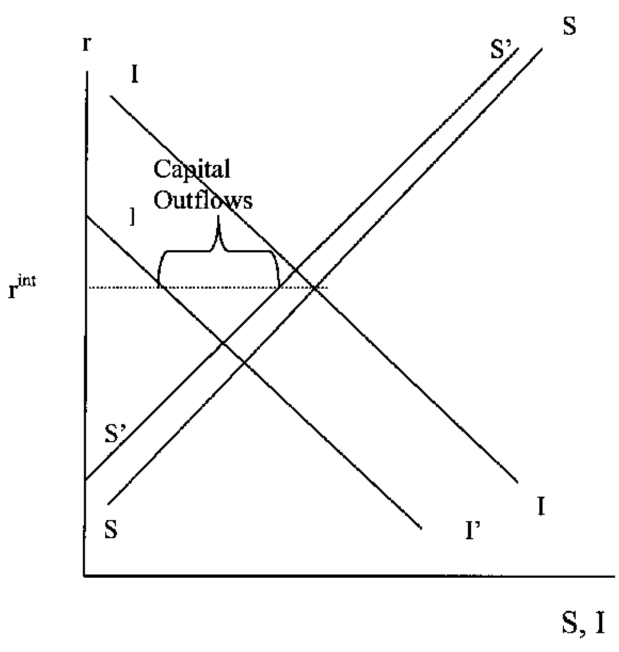
As a result, when a population ages, both the demand and the supply curves of capital shift to the left. The equilibrium quantity of capital, recalling that saving is equal to investment in a closed economy, falls unambiguously. But what about the equilibrium return to capital? Since both the supply and demand curves shift to the left, we cannot assess the implications for the equilibrium return to capital without resorting to a quantitative analysis.

Likewise, if capital is perfectly mobile, we cannot assess the direction of capital flows when the domestic economy is aging without a quantitative analysis. One might think that an aging economy will result in capital inflows because there are lower domestic savings in the economy. But this is just the supply-side story. In fact, with population aging, both the demand and the supply of capital fall. Thus the impact on the direction of capital flows is determined by the relative forces of changes in the supply and demand of capital.

The following diagrams illustrate the main ideas:



As the population ages, both savings and investment fall. This is represented by a shift of the saving curve from S to S' and a shift of the investment curve from I to I'. As a result, the equilibrium quantity of savings, falls unambiguously. However, the equilibrium return to capital depends on the relative magnitude of the shifts in the investment curve and the saving curve. If the decline in investment is greater than that in savings (as drawn in the diagram), the return to capital falls. The opposite will be true if the decline in savings is greater.



With perfect capital mobility, the impact on the direction of capital flows also depend on the relative magnitude of the shifts in the savings and investment curves. Consider the diagram on the left. Assume that net capital flows were zero before the population aging occurs. As the population ages, both savings and investment fall. If the decline in investment is greater than that in savings (as drawn), then net capital inflows will fall. The opposite will be true if the decline in savings is greater.

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