Front. Econ. China 2020, 15(2): 257–281
DOI 10.3868/s060-011-020-0012-3

RESEARCH ARTICLE

Yufei Liu[a], Xi Qu[b], Wei Wang[c], Xiaokun Chang[d]

Does Population Aging Hinder the Accumulation of Human Capital? Evidence from China

Abstract There is no consensus on the impact of population aging on education investment. To explore this question, we first build an overlapping generations (OLG) model to theoretically analyze the effect of population aging on human capital investment in China, and then test our theory by conducting an empirical study based on micro household data. We find the following. (1) Theoretically, the OLG model shows that population aging has a crowding-out effect on education investment. (2) Empirically, the results show that the share of education and training expenditures decreases by 5.27 percentage points as the ratio of old people in the household increases by 100 percentage points, which confirms the crowding-out effect of population aging on human capital investment. (3) The crowding-out effect is far more intense on urban households than on rural households since health care expenditures will be greater in urban areas as population aging increases. (4) A quantile regression indicates that the negative effect of population aging on the share of educational expenditure is concentrated in households with higher shares of education expenditures. We confirm the robustness of our results using regional fixed effect and instrumental variable (IV) regressions.

Keywords population aging, human capital investment, China family panel

Received June 31, 2019

[a] College of Business and Economics, Shanghai Business School, Shanghai 201400, China
[b] Antai College of Economics & Management, Shanghai Jiao Tong University, Shanghai 200030, China
[c] School of Public Economics and Administration and Shanghai Key Laboratory of Financial Information Technology, Shanghai University of Finance and Economics, Shanghai 200433, China
[d] School of Economics & Management, Shanghai Maritime University, Shanghai 201306, China
E-mail: yufei.liu@163.sufe.edu.cn (Yufei Liu), xiqu@sjtu.edu.cn (Xi Qu, corresponding author), wangwei2@mail.shufe.edu.cn (Wei Wang), xkchang@shmtu.edu.cn (Xiaokun Chang)

studies (CFPS), crowding-out effect, education expenditure
JEL Classification J11, J14, J24, I25, P25

1 Introduction

There are different opinions on the impact of population aging on education investment. The life cycle theory believes that population aging has a negative impact on education investment. The rationale is that as population aging increases, the burden on families and society will increase, leading to decreased educational resources devoted to the younger generation, thus creating a crowding-out effect on human capital accumulation. Meanwhile, increased life expectancy means longer life after retirement; therefore, the savings set aside by rational agents for their own elderly consumption will increase and thereby reduce investment in human capital (Pecchenino and Pollard, 2002). In contrast, endogenous economic growth theory believes that population aging will induce the household to pay more attention to population quality, since human capital is endogenous. In the long run, population aging is therefore conducive to human capital accumulation (Sala-i-Martin et al., 2004).

With the strict implementation of the family planning policy, China's birth rate declined dramatically in the 1990s, and the population structure has greatly changed since then. The rapid growth of the economy, improvement in living standards, and better medical technology have led to a rapid rise in the life expectancy of the Chinese. These trends have together caused China to become an aging society in the 21st century. According to the sixth census in 2010, the population aged 60 years old and above in Chinese mainland reached 178 million, accounting for 13.26% of the total population, and it increased by 3.36 percentage points compared to the fifth census in 2000. China's national economic and social development statistics bulletin data of 2018 showed that by the end of 2018, the population aged 60 years old and above in China reached 249 million, accounting for 17.9% of the total population. Additionally, the population aged 65 years old and above reached 11.9%, which is an increase of 4.87 percentage points when compared to its proportion of the total population (7.03%) in 2001. Thus, the rate of population aging is accelerating markedly.[1]

[1] Source: National Bureau of Statistics of China, http://www.stats.gov.cn/tjsj/zxfb/201702/t201702281467424.html

According to the United Nations (2011), the proportion of the population aged 60 years old and above in China will increase from 13.26% of the total population in 2010 to 20% in 2025, and will further rise to 31% by 2050. In addition, the proportion of working population (15–59 years old) is expected to decrease from 65% in 2000 to 62% in 2025, and to 53% in 2050 (as shown in Figure 1). By the year 2020, the growth rate of the working population will become negative. With the acceleration of aging, the demographic benefits derived from the comparative advantage of a cheap labor force will rapidly fade, and China will face the dilemma of “aging before getting rich.”

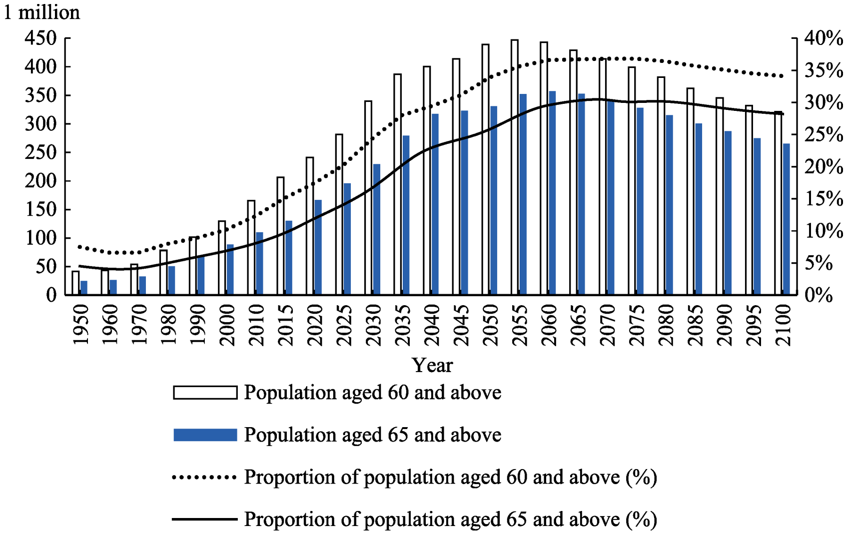

Figure 1 China’s Demographic Structure (1950–2100)

Source: United Nations (2011).

The theory of development economics argues that human capital plays an increasingly important role in economic and social development. Returns on human capital investment can be maintained at a high level, while returns on investment in material capital are lower and usually decline. Human capital is normally measured by both the quality and the quantity of the labor force. In terms of quantity, the size of the working population, the labor force participation rate, and the labor supply time are generally used as measurements. The quality of the labor force refers to the workers’ knowledge, skills, and work experiences. With the increase in population aging, the size and proportion of the working population tend to decrease; therefore, the quantity of human capital naturally declines. Thus, the key question is whether population aging will further decrease the quality of human capital, which can be investigated through education and training investments, since they are the key factors in the accumulation of human capital quality.

In order to cope with the increasing challenges of population aging, China must complete the transition from an emphasis on quantity to quality; therefore, exploring the impact of population aging on family education and training investments is of theoretical and practical significance. In China, especially under the one-child policy, parents pay much more attention to the education quality of the next generation. To explain why parents attach such importance to their children's education quality, the existing literature usually analyzes this concept from the perspective of self-interest or of altruistic motivation. Zhang et al. (2001) argue that parents' cultivation of their children is altruistic, and the human capital investment behavior of the family promotes economic growth. Ehrlich and Lui (1991) regard the investment of parents in their children's education as a transactional behavior and an insurance mechanism within the family and between generations, and they believe that parents pay attention to the education of their children due to the self-interest motives of raising children who aid the parents as they get old. However, these studies' hypothesis of a single motivating factor may not fully conform to the reality of China. First, Chinese families have a Confucian cultural tradition of altruism. Hence, parents' cultivation of their children is often unrequited, and is often the nature of "consumption." Second, as the social security system has not fully covered, the importance of children's future human capital and income, to supplement parents' pension resources, has increased, and parents' cultivation of children may also be based on self-interest motivations. In this study, by incorporating the self-interest and altruistic motivations, we build an overlapping generations (OLG) model to theoretically analyze the mechanism through which population aging affects human capital investment and then test our theory by conducting an empirical study based on the China Family Panel Studies (CFPS) data.

The contributions of this paper can be summarized as follows. First, compared with the existing literature that usually analyzes parents attaching importance to children's quality from a self-interest or altruistic motivation perspective, we construct an OLG model to discuss the mechanism of how population age structure affects family education investment by taking both self-interest and altruistic motivations into consideration. Second, we conduct empirical testing by using the micro household data from the CFPS. Third, our findings indicate that there is a significant difference between urban households and rural ones regarding the crowding-out effect of population aging on human capital investment and that the negative effect of population aging on the proportion of education expenditure is concentrated among households with higher shares of expenditure on education. Lastly, we perform robustness checks by using a provincial fixed effect regression and an instrumental variable (IV) regression.

The rest of the paper is organized as follows. Section 2 summarizes the relevant literature. Section 3 introduces the OLG model to assess the effects of population aging on household education investment. Section 4 describes the CFPS 2012 data. Section 5 presents the empirical analysis. Section 6 concludes the paper. The details of the model's derivation are contained in the Appendix.

2 Literature Review

Considerable literature has shown that population aging affects education investment. With respect to theoretical modeling, Blanchard (1985) is the first to introduce population structure into the classical macroeconomic model and analyze the effect of demographics in a general equilibrium framework. He shows that if non-altruistic agents can survive indefinitely, the neoclassical economic theory regarding the Ricardo equivalence will no longer hold. Becker et al. (1990) assume that the stock of human capital in the next generation is a linear function of parents' education investment and conclude that when human capital exceeds a certain value, the economy would achieve an ideal equilibrium of high growth, low fertility, and low mortality. Later, Cipriani and Makris (2006) verify the positive correlation between life expectancy and human capital investment through an OLG model. Fougère et al. (2009) build a computable dynamic OLG model to investigate the effect of population aging on labor supply and human capital investment, where population aging creates more opportunities for the younger generation's human capital investment. In addition, they point out that previous researchers have often overlooked the effects of aging on time allocation. In fact, population aging can lead to changes in the rate of return on production factors, which would play significant roles in production capacity. They calculate the long-term effects of higher education labor on productivity, and the simulation results show that more spending on education would reduce production capacity at first, but significantly increase production capacity when the young generation grew up, and eventually, the human capital accumulation effect would make up for the aging burden effect. Namely, in the long run, population aging is conducive to the accumulation of human capital. Furthermore, scholars have constructed a two-phase OLG model with the assumption of self-interest behavior to investigate the influence of population transitions on economic growth. In this kind of model, a typical agent's investment in children's education has the nature of "consumption" as well as "investment." Andersson (2001) summarizes the influence of age structure on macroeconomics as "population change, human capital, and economic growth." Namely, age structure affects the accumulation of human capital and the economic growth. Thus, through theoretical modeling, most studies suggest that population aging has a positive effect on human capital accumulation.

In terms of empirical research, Poterba (1997) finds that in the United States, for every 1% increase in those aged 65 and above, per capita education expenditures would decrease by approximately 0.3%, thereby evidencing the crowding-out effect of population aging on education resources. However, related to the basis of this study, Ladd and Murray (2001) narrow the scope of the sample and show that population aging is not accompanied by a downward pressure on education spending. Fougère et al. (2009) find that the decline in the return of material capital raises the present value of future wage income and consequently increases household investment in human capital. Barro and Sala-i-Martin (1997) find that prolonged life (reduced mortality) has a positive impact on the investments in education. Meanwhile, some scholars believe that the impact of population aging on education investment depends on the manifestation of aging and the stage of the aging society. For example, Miyazawa (2006) suggests that population aging caused by declining fertility is unfavorable for education investment, while a decline in mortality (or longevity) is conducive to education investment. Zhang et al. (2003) propose an inverse U-shaped relationship between mortality and education investment. The reason is that in the early stage of a decline in mortality, the increase in retirement income through increased investment in education exceeds the reduction in education for older people's consumption. In the later stage of the decline in mortality, these two mechanisms are switched, therefore, the impact of population aging on education investment depends on the stage of the aging process.

From the above analyses, we see that both theoretically and empirically, there is no consensus on the impact of population aging on human capital investment. Due to the compulsory one-child policy, Chinese parents pay more attention and invest more in their child's education. Although the birth policy has been gradually liberalized, people's concepts have changed. Parents have become used to caring more about the quality of their children's lives instead of having more children. Research on this topic in China is still limited and needs to be further extended through both theoretical and empirical studies. This study attempts to fill this gap and may enrich the existing literature.

3 Theoretical Model Construction and Analysis

3.1 Household

A typical agent lives through three periods: childhood, adulthood, and old age. Children do not have the ability to work, so their labor supply is 0. An adult's labor supply is 1 unit and is denoted as wage income, $w_t h_t$. Children's human capital stock depends on their parents' education investment expenditure, e_t, and their parents' human capital stock, h_t. The cost of parents' support is the proportion, *m*, of wage income. With increasing life expectancy, more resources will be used for the elderly. The longer the parents live, the larger is *m*. As life spans increase, support and medical care expenditures must be increased. The social security tax is τ_t. The elderly consumption of a typical agent mainly depends on the savings of young adults, s_t, the support of their children, $mw_{t+1}h_{t+1}$, and social security payments, P_{t+1}. First, parents care about their children and spend part of their income on their children's education. Second, the quality of their children's education is an old-age resource for the parents, that is, part of the children's income in adulthood is used for their parents' old-age life expenditures.

A typical agent has the following utility:

$$U_t = \ln C_t^y + \beta \ln C_{t+1}^o, \tag{1}$$

where β represents the time discount factor and C_t^y and C_t^0 represent youth and old age consumption, respectively.

The corresponding budget constraints are

$$C_t^y + S_t^y = h_t w_t (1 - m - \tau_t) - e_t, \tag{2}$$

$$C_{t+1}^o = (1 + \mathrm{r}_{t+1}) S_t^y + m h_{t+1}^y w_{t+1} + P_{t+1}. \tag{3}$$

Equation (2) indicates that a typical agent's wage income is allocated to consumption (C_t), savings (S_t), support for parents (mw_th_t), social security ($\tau_tw_th_t$), and investment in children's education (e_t). Equation (3) indicates that a typical agent's consumption in old age is mainly derived from his or her savings in the youth period $S_t(1 + r_{t+1})$, the support of their children ($mw_{t+1}h_{t+1}$), and social security (P_{t+1}). Parents' cultivation of their children is both beneficial to themselves and egoistic. On the one hand, parents care about their children, spend part of their income on their children's education and gain utility from the cultivation of their children. On the other hand, the quality of education and training they provide for their children is a pension resource when the parents get old; that is to say, part of the adult income of the children is obtained by the parents and used for the parents' living expenses in their old age. In the case of a typical adult with a fixed income, when more of his or her resources are used for providing for the aged, the more likely it is that his or her education expenditures on his or her children will be crowded out and lower. In addition, more education expenditures may result in higher quality of the next generation, which will provide more resources for the aged in the future. It is therefore a trade-off.

Children's human capital accumulation is as follows:

$$h_{t+1}^y = e_t^\theta (h_t^y)^{1-\theta}, \quad 0 < \theta < 1, \tag{4}$$

where h_{t+1}^y represents the human capital stock of the offspring, h_t^y represents the human capital stock of the parent, and e_t represents the parent's educational expenditures on their children.

The utility maximization is obtained under budget constraint conditions.

$$C_{t+1}^o = \beta (1 + r_{t+1}) C_t^y, \tag{5}$$

$$C_t^y = \frac{1}{1+\beta} \left\{ \left[\left(1 - m - \tau_t\right) h_t^y w_t - e_t \right] + \frac{m h_{t+1}^y w_{t+1} + P_{t+1}}{1 + r_{t+1}} \right\}. \tag{6}$$

Finally, we obtain the optimal savings level as follows:

$$S_t^y = \frac{1}{1+\beta} \left\{ \beta \left[\left(1 - m - \tau_t\right) h_t^y w_t - e_t \right] - \frac{m h_{t+1}^y w_{t+1} + P_{t+1}}{1 + r_{t+1}} \right\}. \tag{7}$$

3.2 Enterprise

We assume that the economy is completely competitive and set the production function as follows:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha}, \tag{8}$$

where Y_t is the total output, K_t is the material capital input, A_t is the technical level, and L_t is the labor input. As enterprises are competitive, maximizing profits means that the net marginal output is equal to the factor price:

$$w_t = (1-\alpha)A_t k_t^{\alpha}, \tag{9}$$

$$1 + r_t = \alpha k_t^{\alpha-1}, \tag{10}$$

where w_t is the level of wages given by the enterprise, $1+r_t$ is the material capital rent, and $k_t = K_t / (A_t L_t)$.

3.3 Equilibrium

For the sake of simplicity, suppose that the social security system is a pay-as-you-go system. When the old age insurance fund is balanced, we have:

$$w_t h_t^y \tau_t N_t^y = P_t N_t^o, \tag{11}$$

where N_t^y and N_t^0 are the total numbers of young adults and elderly people in period t, respectively.

Set

$$N_t^y = \gamma^N N_t^o,$$

$$\gamma^N = 1 + g^N,$$

where γ^N represents the ratio of the total number of young adults to the total population in period t, and g^N is the population growth rate.

Through equation (11), we obtain the elderly social pension insurance in period $t+1$ as follows:

$$p_{t+1} = \frac{w_{t+1} h_{t+1}^y \tau_{t+1} N_{t+1}^y}{N_{t+1}^o} = w_{t+1} h_{t+1}^y \tau_{t+1} \gamma_{t+1}^N. \tag{12}$$

In a closed market, the elderly leave no legacy after death, and the capital market and the labor market are clear. Therefore, we can conclude:

$$K_{t+1} = S_t^y N_t^y, \tag{13}$$

$$L_t = (1-m)N_t^o h_{t-1}^y \gamma_{t-1}^y \sigma_t^h , \sigma_t^h = h_t^y / h_{t-1}^y . \tag{14}$$

Solving the first order derivative with respect to education expenditure, we obtain

$$e_t = \frac{\theta(1-\alpha)\left(m+\tau_{t+1}\gamma_{t+1}^N\right)}{\alpha}\frac{S_t^y}{1-m-\tau} . \tag{15}$$

Then, we get the steady state of material capital stock k* as follows:

$$k^* = \left\{\frac{\alpha\beta(1-m-\tau)(1-\alpha)}{\gamma^A\left\{\alpha(1+\beta)(1-m\text{-}\tau)+(\beta\theta+1)(1-\alpha)\left[m+\tau\gamma^N\right]\sigma^h\right\}}\right\}^{\frac{1}{1-\alpha}} . \tag{16}$$

Since $s = \frac{\gamma^A(1-m)}{(1-\alpha)(1-\tau)}k^{*1-\alpha}$, in a steady state, we obtain the per capita savings rate as follows:

$$s = \frac{\alpha\beta(1-m-\tau)(1-m)}{\alpha(1+\beta)(1-m-\tau)+(\beta\theta+1)(1-\alpha)\left(m+\tau\gamma^A\right)\sigma^h} . \tag{17}$$

Eventually, we derive the education investment rate r_e as follows:

$$r_e = \frac{\beta\theta(1-m-\tau)(1-\alpha)\left(m+\tau\gamma^N\right)\sigma^h}{\alpha(1+\beta)(1-m-\tau)+(\beta\theta+1)(1-\alpha)\left(m+\tau\gamma^N\right)\sigma^h} . \tag{18}$$

According to equation (18), we conclude $\partial r_e / \partial\gamma^N > 0$ and form the following hypothesis: The education investment rate (the proportion of education expenditure to disposable income) will decrease as the share of the elderly population increases relative to the share of the young and middle-aged population.

In the following section, we will form an empirical model to test the above hypothesis by using the micro household data from the CFPS.

4 Data Source and Model Construction

4.1 Data Source

The data used in this paper are from the CFPS, which draws on the experience of several famous international surveys (such as the PSID, CDs, HRS, and NYLS). Organized and implemented by the China Social Sciences Research Center of

Peking University, the CFPS is a national, comprehensive social tracking survey project designed to track three levels of data, namely the community, the family, and the individual. These data reflect changes in Chinese society, economy, population, education, and health, and provide a database for academic research and public policy analysis (Bodvarsson et al., 2016). At the community level, the database collects information on the political environment, village appearance, infrastructure, population, resources, transportation, health, financial revenue expenditures, and other macro-level data. At the family level, it collects data on family structure and relationships, living conditions, social interaction, income and expenditures, asset status, and other multidimensional data. At the individual level, it includes data on personal education, occupation, income, psychological and physical condition, marriage, and so on.

4.2 Model Construction

Based on our theoretical model, we construct the following econometric model to investigate the influence of population aging on the household education investment rate:

$$edu\_rate_i = \beta_0 + \beta_1 old\_ratio_i + \alpha_1 X_i + \varepsilon_i \, , \tag{19}$$

where edu_rate_i is the education investment rate of each household; old_ratio_i is the proportion of people aged 65 and above in each family; X_i is a set of control variables including the dummy variable $young\_child_i$, the logarithm of per capita disposable income of a family ($ln\_p\_income_i$), the share of urban population where the family is located ($urbliz_i$), the dummy variable $education_i$, and the logarithm of current household wealth of each family ($ln\_housing_i$). $\square_{i,}$ is a zero mean, constant variance error term. The main parameter we focus on is β_1, which captures the effect of population aging on the education investment rate.

4.3 Variable Description

The dependent variable in this paper is the household human capital investment ratio. The CFPS conducted a detailed survey of families' total expenditures and itemized consumption expenditures. One of the questions on household human capital investment is, "What was the expenditure on family education and training in the past year?" We take this variable as the total education and training expenditures of each household. Our dependent variable is defined as the education and training expenditures divided by the per capita disposable income of the family, which measures the proportion of education and training expenditures. The core explanatory variable of this paper is population age structure.

The data provided by the CFPS include detailed age information about family members. We use the age information of 57,155 individuals in the family membership table and form a new data set to calculate the proportion of people aged 65 and above. Therefore, the core explanatory variable in this study is the proportion of people aged 65 and above in each family (*old_ratio*). Other control variables include the logarithm of the per capita disposable income of the family (*ln_p_income*), which represents the economic level of each family; the share of urban population where the family is located (*urbliz*); a dummy variable indicating the education level of family members (*education*, which equals 1 if the highest educational level of family members is bachelor's degree and above, and 0 otherwise); a dummy variable indicating whether the family includes a child aged 0–15 years old (*young_child*, which equals 1 if the family has at least one child aged 0–15 years old, and 0 otherwise); and the current household wealth of each family (*ln_house*). Finally, we obtain a representative sample of 4,243 households. The descriptive statistics are listed in Table 1.

Table 1 Summary Statistics

Variable type	Variable name	Variable definition	Obs.	Mean
Dependent variable	*edu_rate*	Proportion of education and training expenditures	4,243	0.0756
Core explanatory variable	*old_ratio*	Proportion of people aged 65 and above in each family	4,243	0.0585
Control variable	*young_child*	Dummy variable equal to 1 if there is at least one child aged 0–15 years old; otherwise 0	4,243	0.2147
	ln_p_income	Logarithm of household per capita disposable income	4,243	9.1866
	education	Dummy variable equal to 1 if the highest level of education for a family member is a bachelor's degree or above; otherwise 0	4,243	0.1197
	ln_house	Current household wealth of each family	3,818	11.6435
	urbliz	Share of the urban population where the family is located	4,243	0.5296

5 Empirical Results

5.1 Basic Identifications

Using Stata 13.1, we regress equation (19) and report the estimates in Table 2. Columns (1) to (6) list the estimates obtained without and with control variables. Column (1) estimates the main effect of population aging on human capital investment, ignoring all the other covariates. This regression shows a significantly negative effect of population aging on the education investment rate, which is consistent with our theoretical model mentioned above. From columns (2) to (6), where we add the control variables *young_child*, *ln_p_income*, *education*, *ln_house*, and *urbliz* in turn, the estimated coefficient of population aging is still significantly negative in all models. Taking column (6) which controls all variables as an example, the coefficient of population aging is –0.0527, which means that as the ratio of old people in the household increases by 100 percentage points, the share of education and training expenditures decreases by 5.27 percentage points. Population aging does lead to a decline in household educational and training spending, confirming the crowding-out effect on human capital accumulation. With respect to the control variables, the estimate of the dummy variable *young_child* is significantly positive, which means that if the family has at least one child aged between 0 and 15 years old, the family's education investment will increase by an average of 6.51 percentage points. The estimated coefficient of per capita disposable income is significantly negative, which means that as per capita disposable income rises, education expenditure does not rise as much as income.[2] The estimated coefficient of education is significantly positive, which means that households will spend more on education and training expenditures when the highest level of education for a family member is a bachelor's degree or above (Chiappori et al., 2017; Joensen and Nielsen, 2018). The estimated coefficient of urbanization is significantly positive, which is consistent with the results from Akita and Miyata (2008). Generally, urbanization represents the level of regional economic development.

[2] Since our dependent variable is the proportion of education and training expenditures, which is defined as the education and training expenditures divided by the per capita disposable income of the family, the coefficient of per capita disposable income is negative. As per capita disposable income increases, the denominator of the proportion of education and training expenditures will decrease, but the total education and training expenditures may not decrease, which suggests that as per capita disposable income rises, educational expenditure does not rise as much as income rises.

The higher the urbanization level, the higher is the proportion of spending on education and training. The estimated coefficient of the current household wealth of each family is also significantly positive, which is consistent with Lovenheim (2011). The higher the current household wealth of the family, the greater amount of the family's education and training expenditures.

Table 2 Effect of Population Aging on Human Capital Investment[3]

	(1)	(2)	(3)	(4)	(5)	(6)
	edu_rate	*edu_rate*	*edu_rate*	*edu_rate*	*edu_rate*	*edu_rate*
old_ratio	**–0.0274*****	**–0.0398*****	**–0.0510*****	**–0.0504*****	**–0.0523*****	**–0.0527*****
	(0.00876)	**(0.00832)**	**(0.00813)**	**(0.00811)**	**(0.00825)**	**(0.00823)**
young_child		0.0568***	0.0677***	0.0655***	0.0662***	0.0651***
		(0.00256)	(0.00259)	(0.00262)	(0.00273)	(0.00274)
ln_p_income			–0.0184***	–0.0198***	–0.0217***	–0.0225***
			(0.00120)	(0.00123)	(0.00137)	(0.00138)
education				0.0160***	0.0140***	0.0145***
				(0.00333)	(0.00347)	(0.00346)
ln_house					0.00376***	0.00237***
					(0.000827)	(0.000890)
urbliz						0.0354***
						(0.00852)
_cons	0.0772***	0.0658***	0.233***	0.245***	0.216***	0.221***
	(0.00122)	(0.00127)	(0.0109)	(0.0112)	(0.0127)	(0.0127)
N	4,243	4,243	4,243	4,243	3,818	3,818
R^2	0.002	0.106	0.153	0.158	0.167	0.171

Note: The asterisks denote the significance level: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. The standard errors appear in brackets.

[3] We sincerely thank one of the referees for suggesting that we use some panel data to analyze the research question. Based on the referee's suggestion, we use regional-level data to test the impact of population aging on education investment by using total consumption expenditures on culture, education, and entertainment as a proxy variable for education expenditure. The results show that the estimated coefficient of population aging is still significantly negative, which is consistent with Harris et al. (2001). In this paper, our contribution involves building an OLG model, conducting empirical testing using micro data, presenting the differences between urban and rural areas, and using a quantile regression to test for heterogeneity. However, due to data limitations, the macro data cannot be used directly to test our theory. For example, there is no separate measure of aging for urban and rural areas in China's provincial panel data. In addition, family education investments are mixed in total consumption expenditures on culture, education, and entertainment. There are no separate statistics on family education expenditure, which may result in contrasting conclusions. Therefore, we use the macro (regional-level) data to show some overall patterns and the micro (household-level) data to test our main hypothesis.

5.2 Distinguishing between Urban and Rural Samples

Considering China's huge urban-rural gap, there are great differences in the economic development and education investment across different regions (Li, 2014). Therefore, we divide the total sample into rural families and urban families, and rerun the regression. The results are shown in Table 3. These estimates show that the effect of population aging is still negative in both rural and urban areas, but the magnitude of the coefficient is larger in urban areas, implying that the crowding-out effect of population aging on household education investment is greater in urban areas than in rural areas. The reason might be that with better economic and social conditions, urban families emphasize health care more than rural families do, and when population aging increases, greater portions of urban households' disposable incomes will be spent on health care. Therefore, the crowding-out effect of population aging on education and training expenditures is more obvious in urban areas.

Table 3 Regression Results Distinguishing between Urban and Rural Samples

	All samples	Rural	Urban
	edu_rate	*edu_rate*	*edu_rate*
old_ratio	**–0.0527*****	**–0.0347*****	**–0.0801*****
	(0.00823)	**(0.00979)**	**(0.0147)**
young_child	0.0651***	0.0693***	0.0571***
	(0.00274)	(0.00328)	(0.00486)
ln_p_income	–0.0225***	–0.0222***	–0.0268***
	(0.00138)	(0.00151)	(0.00301)
education	0.0145***	0.0201***	0.00654
	(0.00346)	(0.00521)	(0.00519)
ln_house	0.00237***	0.000467	–0.00299
	(0.000890)	(0.000961)	(0.00257)
urbliz	0.0354***	0.0644***	–0.00433
	(0.00852)	(0.0105)	(0.0150)
_cons	0.221***	0.220***	0.371***
	(0.0127)	(0.0146)	(0.0337)
N	3,818	2,686	1,132
R^2	0.171	0.197	0.162

Note: The asterisks denote the significance level: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. The standard errors appear in brackets.

5.3 Mechanism Regression

To understand how population aging crowds out education and training expenditures, we now turn to the mechanism estimation. In the above theoretical model, as population aging increases, household expenditures on health care increase, which squeezes out household education and training expenditures, especially in China, since the social security system is not well developed. In order to test this mechanism, we use the household per capita health care expenditure ratio (*med_ratio*) as the dependent variable to rerun the regressions, and the final estimates are shown in Table 4. The results show that the coefficients of population aging are significantly positive, which indicates that as population aging increases, the ratio of per capita health care expenditures increases, which crowds out education and training expenditures. In addition, the estimated coefficient for urban areas is significantly greater than that for rural areas, which is consistent with Table 3, suggesting that the crowding-out effect of population aging on household human capital investments is greater in urban areas than in rural areas.

Table 4 Mechanism Regression Results

	All samples	Rural	urban
	ln_p_med_exp	*ln_p_med_exp*	*ln_p_med_exp*
old_ratio	**1.328*****	**1.250*****	**1.432*****
	(0.174)	**(0.223)**	**(0.277)**
young_child	0.129**	0.146*	0.103
	(0.0585)	(0.0758)	(0.0920)
ln_p_income	0.179***	0.139***	0.252***
	(0.0295)	(0.0347)	(0.0576)
education	0.0564	–0.126	0.0904
	(0.0736)	(0.119)	(0.0983)
ln_house	0.0672***	0.0504**	–0.00118
	(0.0189)	(0.0219)	(0.0492)
urbliz	0.480***	0.816***	–0.0187
	(0.183)	(0.243)	(0.285)
_cons	3.018***	3.367***	3.558***
	(0.272)	(0.336)	(0.638)
N	3,549	2,517	1,032
R^2	0.055	0.037	0.056

Note: The asterisks denote the significance level: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. The standard errors appear in brackets.

5.4 Quantile Regression

Since the least-squares estimation is based on the zero conditional mean assumption of the error term, which is sensitive to the probability distribution and extreme values, we introduce and use the quantile regression method to further test the heterogeneous effects of population aging on household educational expenditures. We use 0.1, 0.5, and 0.9 as the quantile regression points. The final regression results are shown in Table 5. From the quantile regression results, we observe that the estimates of population aging are significantly negative only at the 0.5 and 0.9 quantile points, and the coefficients of the core explanatory variable are different at different quantile points, indicating that the negative effect of population aging on the proportion of educational expenditures is concentrated in households with higher shares of education expenditures.

Table 5 Quantile Regression Results

	0.1	0.5	0.9
	edu_rate	*edu_rate*	*edu_rate*
old_ratio	**–0.00497**	**–0.0326*****	**–0.112*****
	(0.00362)	**(0.00924)**	**(0.0235)**
young_child	0.0133***	0.0665***	0.112***
	(0.00120)	(0.00307)	(0.00781)
ln_p_income	–0.00613***	–0.0210***	–0.0364***
	(0.000607)	(0.00155)	(0.00394)
education	0.00204	0.0128***	0.0310***
	(0.00152)	(0.00388)	(0.00988)
ln_house	0.000981**	0.00340***	0.00302
	(0.000392)	(0.000999)	(0.00254)
urbliz	0.00878**	0.0341***	0.0683***
	(0.00375)	(0.00957)	(0.0243)
_cons	0.0488***	0.178***	0.405***
	(0.00561)	(0.0143)	(0.0364)
N	3,818	3,818	3,818
R^2	0.0284	0.0934	0.1326

Note: The asterisks denote the significance level: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. The standard errors appear in brackets.

5.5 Provincial Fixed Effect

Because of the differences in history, culture, climate, and resources among provinces, these factors affect the population structure; these factors do not change with time, but are related to other explanatory variables. Therefore, we estimate the impact of aging population on education and training expenditures by controlling the provincial fixed effect. The results are reported in Table 6.

Table 6 Regional Fixed Effect Results

	All samples	Rural samples	Urban samples
	edu_rate	*edu_rate*	*edu_rate*
old_ratio	**–0.0516***	**–0.0327***	**–0.0851***
	(0.00813)	**(0.00974)**	**(0.0146)**
young_child	0.0667***	0.0713***	0.0578***
	(0.00271)	(0.00328)	(0.00483)
ln_p_income	–0.0241***	–0.0239***	–0.0294***
	(0.00137)	(0.00151)	(0.00306)
education	0.0143***	0.0177***	0.00737
	(0.00341)	(0.00518)	(0.00519)
ln_house	0.00281***	0.000196	0.000368
	(0.000901)	(0.000986)	(0.00286)
urbliz	0.0263	0.0320	0.00394
	(0.0554)	(0.0410)	(0.0631)
_cons	0.222***	0.239***	0.339***
	(0.0248)	(0.0216)	(0.0449)
Control provincial variable	yes	yes	yes
N	3,818	2,686	1,132
R^2	0.207	0.225	0.206

Note: The asterisks denote the significance level: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. The standard errors appear in brackets.

All these estimates are negative and statistically significant at the 1% level, which further confirms the aforementioned results that population aging does have a negative effect on education and training expenditures.

5.6 IV Regression

Due to the possible causal relationship between aging and education investment, we also examine the endogeneity between population aging and education expenditure. We use the provincial mean proportion of people aged 65 and above where the household is located (excluding the household itself) as the instrumental variable, and report the IV estimation results in Table 7.

Table 7 IV Regression Results

	IV Regression *edu_rate*	**IV Regression** *edu_rate*	**IV Regression** *edu_rate*	**IV Regression** *edu_rate*	**IV Regression** *edu_rate*
old_ratio	–0.246*	–0.205*	–0.211*	–0.296**	–0.280**
	(0.134)	(0.122)	(0.122)	(0.142)	(0.139)
young_child	0.0610***	0.0720***	0.0702***	0.0743***	0.0726***
	(0.00451)	(0.00494)	(0.00506)	(0.00627)	(0.00615)
ln_p_income		–0.0204***	–0.0219***	–0.0252***	–0.0258***
		(0.00205)	(0.00201)	(0.00249)	(0.00247)
education			0.0151***	0.0107**	0.0115**
			(0.00376)	(0.00460)	(0.00454)
ln_house				0.00463***	0.00309***
				(0.00100)	(0.00102)
urbliz					0.0378***
					(0.00953)
_cons	0.0769***	0.260***	0.272***	0.252***	0.255***
	(0.00732)	(0.0243)	(0.0238)	(0.0253)	(0.0251)
N	4,243	4,243	4,243	3,818	3,818

Note: The asterisks denote the significance level: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. The standard errors appear in brackets.

From columns (1) to (5), the results show that the coefficients of population aging are still negative, which confirms the crowding-out effect of population aging on household education investment.

6 Conclusion

This paper examines the effect of population aging on family education and training expenditures. Through a theoretical modeling analysis, we find that population aging leads to a decrease in family education investment rate. Namely, population aging has a crowding-out effect on household human capital accumulation. Using the micro data provided by the CFPS, the empirical results show the following. (1) As the ratio of old people in the household increases by 100 percentage points, the share of education and training expenditures decreases by 5.27 percentage points. (2) The crowding-out effect of population aging on household education investment is far more intense in urban households than in rural households, since health care expenditures would be greater in urban areas as population aging increases. (3) The quantile regression indicates that the negative effect of population aging on the share of educational expenditure is concentrated in the households with higher shares of education expenditures. (4) Our results are also robust given the results of a regional fixed effect regression and an IV regression.

Currently in China, with population aging rapidly intensifying, economic growth is sluggish, and the country has entered the "new normal" phase. The country is facing challenges of sustainable economic development. China needs to make full use of its existing resources, create conditions to continuously improve the quality of the accumulated human capital, and offset the declining labor supply before the population demographic benefits turn into problems and the "infinite supply" of labor ends. Increasing the level of human capital accumulation emerges as one of the most effective ways to solve the aging population crisis. In response to the growing challenges of population aging, China needs to complete its transition from a labor quantity advantage to a population quality advantage before a fundamental shift in the demographic age structure occurs. Increasing education investment to improve the quality of the working population and labor productivity, and transitioning the industrial structure from a traditional labor-intensive structure to a capital and technology-intensive structure, is the fundamental path to realizing economic transformation and upgrade in China. Meanwhile, the government should further reform the social security system and expand the coverage of social security to reduce the crowding-out effect of population aging on human capital investment.

Acknowledgments The authors gratefully acknowledge financial support from the National Social Science Foundation of China (No. 17ZDA049), the Natural Science Foundation of

China (No. 71773071, 71973097), the 2019 Shanghai Philosophy and Social Science Planning Education Youth Project (No. B1903), the Shanghai Pujiang Program (No. 16PJC034), and the Shanghai Business School Venus Project (No. 18KY-PQMX-03). The editors' and referees' constructive comments for the paper are also gratefully acknowledged. The authors accept responsibility for remaining errors.

References

Akita T, Miyata S (2008). Urbanization, educational expansion, and expenditure inequality in Indonesia in 1996, 1999, and 2002. Journal of the Asia Pacific Economy, 13(2): 147–167 doi:10.1080/13547860801923558

Andersson B (2001). Scandinavian evidence on growth and age structure. Regional Studies, 35(5): 377–390 doi:10.1080/713693829

Barro R, Sala-i-Martin X (1997). Technology diffusion, convergence and growth. Journal of Economic Growth, 2(1): 1–26 doi:10.1023/A:1009746629269

Becker G S, Murphy K M, Tamura R (1990). Human capital, fertility, and economic growth. Journal of Political Economy, 98(Part II): S12–S37

Blanchard O J (1985). Debt, deficits, and finite horizons. Journal of Political Economy, 93(2): 223–247 doi:10.1086/261297

Bodvarsson O B, Hou J W, Shen K (2016). Aging and migration: Micro and macro evidence from China. Frontiers of Economics in China, 11(4): 548–581 doi:10.3868/s060-005-016-0029-5

Chiappori P A, Salanié B, Weiss Y (2017). Partner choice, investment in children, and the marital college premium. The American Economic Review, 107(8): 2109–2167 doi:10.1257/aer.20150154

Cipriani G P, Makris M (2006). A model with self-fulfilling prophecies of longevity. Economics Letters, 91(1): 122–126 doi:10.1016/j.econlet.2005.11.008

Ehrlich I, Lui F T (1991). Intergenerational trade, longevity, and economic growth. Journal of Political Economy, 99(5): 1029–1059 doi:10.1086/261788

Fougère M, Harvey S, Mercenier J, Mérette M (2009). Population ageing, time allocation and human capital: A general equilibrium analysis for Canada. Economic Modelling, 26(1): 30–39 doi:10.1016/j.econmod.2008.05.007

Harris A R, Evans W N, Schwab R M (2001). Education spending in an aging America. Journal of Public Economics, 81(3): 449–472 doi:10.1016/S0047-2727(00)00133-X

Joensen J S, Nielsen H S (2018). Spillovers in education choice. Journal of Public Economics, 157: 158–183 doi:10.1016/j.jpubeco.2017.10.006

Ladd H F, Murray S E (2001). Intergenerational conflict reconsidered: County demographic structure and the demand for public education. Economics of Education Review, 20(4): 343–357 doi:10.1016/S0272-7757(00)00058-3

Li C (李春玲) (2014). Trends of educational inequality (1940–2010)—A reexamination of urban and rural unequal educational opportunities (教育不平等的年代变化趋势 (1940–2010)——对城乡教育机会不平等的再考察). Sociological Studies (社会学研究), 27(2): 65–89

Lovenheim M F (2011). The effect of liquid housing wealth on college enrollment. Journal of Labor Economics, 29(4): 741–771 doi:10.1086/660775

Miyazawa K (2006). Growth and inequality: A demographic explanation. Journal of Population Economics, 19(3): 559–578 doi:10.1007/s00148-005-0047-6

Pecchenino R A, Pollard P S (2002). Dependent children and aged parents: Funding education and social security in an aging economy. Journal of Macroeconomics, 24(2): 145–169 doi:10.1016/S0164-0704(02)00024-1

Poterba J M (1997). Demographic structure and the political economy of public education. Journal of Policy Analysis and Management, 16(1): 48–66 doi:10.1002/(SICI)1520-6688(199724)16:1<48::AID-PAM3>3.0.CO;2-I

Sala-i-Martin X, Doppelhofer G, Miller R I (2004). Determinants of long-term growth: A Bayesian Averaging of Classical Estimates (BACE) approach. The American Economic Review, 94(4): 813–835

United Nations (2011). World Population Prospects, the 2010 Revision. New York: United Nations, Population Division, Accessed on January 12, 2019, www.un.org/esa/population

Zhang J, Zhang J, Lee R (2001). Mortality decline and long-run economic growth. Journal of Public Economics, 80(3): 485–507 doi:10.1016/S0047- 2727(00)00122-5

Zhang J, Zhang J, Lee R (2003). Rising longevity, education, savings, and growth. Journal of Development Economics, 70(1): 83–101 doi:10.1016/ S0304-3878(02)00088-3

Appendix

(1) Solving the Optimal Savings Level

$$U = \ln C_t^y + \beta \ln C_{t+1}^o , \tag{A1}$$

$$C_t^y + S_t^y = (1 - m - \tau_t) h_t w_t - e_t , \tag{A2}$$

$$C_{t+1}^o = (1 + r_{t+1}) S_t^y + m h_{t+1}^y w_{t+1} + P_{t+1} . \tag{A3}$$

According to (A2) and (A3), we get

$$\frac{C_{t+1}^o}{(1 + r_{t+1})} - \frac{m h_{t+1}^y w_{t+1} + P_{t+1}}{(1 + r_{t+1})} = S_t^y .$$

According to (A1)–(A3), we construct the Lagrangian function as follows:

$$L = \ln C_t^y + \beta \ln C_{t+1}^o + \lambda \left\{ C_t^y + \frac{C_{t+1}^o}{1 + r_{t+1}} - (1 - m - \tau_t) h_t w_t + e_t - \frac{m h_{t+1}^y w_{t+1} + P_{t+1}}{1 + r_{t+1}} \right\} .$$

Solving for the first order condition of C_t^y and C_{t+1}^0, we obtain

$$\frac{1}{C_t^y}+\lambda=0,\quad \frac{\beta}{C_{t+1}^o}+\frac{\lambda}{1+r_{t+1}}=0,$$

$$C_{t+1}^o=\beta(1+r_{t+1})C_t^y,$$

$$C_t^y=\frac{1}{1+\beta}\left\{\left[\left(1-m-\tau_t\right)h_t^y w_t-e_t\right]+\frac{mh_{t+1}^y w_{t+1}+P_{t+1}}{1+r_{t+1}}\right\},$$

$$C_{t+1}^o=\frac{\beta(1+r_{t+1})}{1+\beta}\left\{\left[\left(1-m-\tau_t\right)h_t^y w_t-e_t\right]+\frac{mh_{t+1}^y w_{t+1}+P_{t+1}}{1+r_{t+1}}\right\},$$

Then, we can get

$$S_t^y=\frac{1}{1+\beta}\left\{\beta\left[\left(1-m-\tau_t\right)h_t^y w_t-e_t\right]-\frac{mh_{t+1}^y w_{t+1}+P_{t+1}}{1+r_{t+1}}\right\}. \tag{A4}$$

(2) The Process of Solving Investment in Education

Solving for the first order condition of e_t, we obtain

$$\frac{\partial L}{\partial e_t}=\frac{1}{C_t^y}\cdot\frac{\partial C_t^y}{\partial e_t}+\frac{\beta}{C_{t+1}^o}\cdot\frac{\partial C_{t+1}^o}{\partial e_t}+\lambda\cdot\frac{\partial C_t^y}{\partial e_t}+\frac{\lambda}{1+r_{t+1}}\cdot\frac{\partial C_{t+1}^0}{\partial e_t}$$
$$+\lambda-\frac{\lambda}{1+r_{t+1}}\left(mw_{t+1}\cdot\frac{\partial h_{t+1}^y}{\partial e_t}+\frac{\partial P_{t+1}}{\partial e_t}\right)=0,$$

$$\frac{1}{C_t^y}=-\lambda,\ \frac{\beta}{C_{t+1}^o}=-\frac{\lambda}{1+r_{t+1}}.$$

From this, we obtain

$$\lambda-\frac{\lambda}{1+r_{t+1}}\left(mw_{t+1}\cdot\frac{\partial h_{t+1}^y}{\partial e_t}+\frac{\partial P_{t+1}}{\partial e_t}\right)=0\Rightarrow mw_{t+1}\cdot\frac{\partial h_{t+1}^y}{\partial e_t}+\frac{\partial P_{t+1}}{\partial e_t}=1+r_{t+1},$$

$$h_{t+1}^y=e_t^\theta(h_t^y)^{1-\theta},0<\theta<1\Rightarrow\frac{\partial h_{t+1}^y}{\partial e_t}=\theta e_t^{\theta\text{-}1}(h_t^y)^{1-\theta},$$

$$w_t h_t^y\tau_t N_t^y=P_t N_t^o,\ p_{t+1}=\frac{w_{t+1}h_{t+1}^y\tau_{t+1}N_{t+1}^y}{N_{t+1}^o}=w_{t+1}h_{t+1}^y\tau_{t+1}\gamma_{t+1}^N,$$

$$P_{t+1}=\tau_{t+1}\gamma_{t+1}^N\mathrm{w}_{t+1}h_{t+1}^y\Rightarrow\frac{\partial P_{t+1}}{\partial e_t}=\mathrm{w}_{t+1}\tau_{t+1}\gamma_{t+1}^N\frac{\partial h_{t+1}^y}{\partial e_t}$$

$$\Rightarrow mw_{t+1}\cdot\frac{\partial h_{t+1}^{y}}{\partial e_t}+w_{t+1}\tau_{t+1}\gamma_{t+1}^{N}\frac{\partial h_{t+1}^{y}}{\partial e_t}=1+r_{t+1}\Rightarrow\frac{\partial h_{t+1}^{y}}{\partial e_t}=\frac{1+r_{t+1}}{w_{t+1}\left(m+\tau_{t+1}\gamma_{t+1}^{N}\right)},$$

$$e_t^{\theta-1}=\frac{1+r_{t+1}}{\theta\left(h_t^{y}\right)^{1-\theta}w_{t+1}\left(m+\tau_{t+1}\gamma_{t+1}^{N}\right)},$$

$$S_t^{y}=\frac{1}{1+\beta}\left\{\beta\left[\left(1-m-\tau_t\right)h_t^{y}w_t-e_t\right]-\frac{mh_{t+1}^{y}w_{t+1}+P_{t+1}}{1+r_{t+1}}\right\}\Rightarrow$$

$$e_t=\left(1-m-\tau_t\right)h_t^{y}w_t-\frac{mh_{t+1}^{y}w_{t+1}+P_{t+1}}{\beta(1+r_{t+1})}-\frac{1+\beta}{\beta}S_t^{y}$$

$$=\left(1-m-\tau_t\right)h_t^{y}w_t-\frac{h_{t+1}^{y}w_{t+1}\left(m+\tau_{t+1}\gamma_{t+1}^{N}\right)}{\beta(1+r_{t+1})}-\frac{1+\beta}{\beta}S_t^{y}$$

$$=\left(1-m-\tau_t\right)h_t^{y}w_t-\frac{e_t^{\theta}(h_t^{y})^{1-\theta}w_{t+1}\left(m+\tau_{t+1}\gamma_{t+1}^{N}\right)}{\beta(1+r_{t+1})}-\frac{1+\beta}{\beta}S_t^{y}$$

$$e_t\left[1+\frac{e_t^{\theta-1}(h_t^{y})^{1-\theta}w_{t+1}\left(m+\tau_{t+1}\gamma_{t+1}^{N}\right)}{\beta(1+r_{t+1})}\right]=\left(1-m-\tau_t\right)h_t^{y}w_t-\frac{1+\beta}{\beta}S_t^{y}$$

$$\Rightarrow e_t\left(1+\frac{1}{\theta\beta}\right)=\left(1-m-\tau_t\right)h_t^{y}w_t-\frac{1+\beta}{\beta}S_t^{y},$$

$$h_{t+1}^{y}=e_t^{\theta}(h_t^{y})^{1-\theta},\quad 0<\theta<1,\ w_t=(1-\alpha)A_tk_t^{\alpha},1+r_t=\alpha k_t^{\alpha-1},$$

$$K_{t+1}=S_t^{y}N_t^{y},$$

$$L_t=(1-m)N_t^{o}h_{t-1}^{y}\gamma_{t-1}^{y}\sigma_t^{h},\sigma_t^{h}=h_t^{y}/h_{t-1}^{y},$$

$$e_t\left(1+\frac{1}{\theta\beta}\right)=\left(1-m-\tau_t\right)h_t^{y}w_t-\frac{1+\beta}{\beta}S_t^{y}.$$

Finally, we obtain, $e_t=\dfrac{\theta(1-\alpha)\left(m+\tau_{t+1}\gamma_{t+1}^{N}\right)}{\alpha}\dfrac{S_t^{y}}{1-m-\tau}$. (A4)

(3) Solving Steady State Per Capita Capital Stock

According to (A4) and (A5), we get

$$L_t=(1-m)N_t^{o}h_{t-1}^{y}\gamma_{t-1}^{y}\sigma_t^{h},\sigma_t^{h}=h_t^{y}/h_{t-1}^{y}, \tag{A6}$$

$$S_t^{y}=K_{t+1}/N_t^{y}=A_{t+1}L_{t+1}k_{t+1}/N_t^{y}$$
$$=A_{t+1}(1-m)N_{t+1}^{o}h_t^{y}\gamma_t^{y}\sigma_{t+1}^{h}k_{t+1}/N_t^{y}=A_{t+1}(1-m)h_{t+1}^{y}k_{t+1},$$

$$S_t^y = \frac{1}{1+\beta}\left\{\beta\left[\left(1-m-\tau_t\right)h_t^y w_t - e_t\right] - \frac{mh_{t+1}^y w_{t+1} + P_{t+1}}{1+r_{t+1}}\right\} \Rightarrow$$

$$\beta e_t + (1+\beta)S_t^y = \beta(1-m-\tau_t)h_t^y w_t - \frac{mh_{t+1}^y w_{t+1} + P_{t+1}}{1+r_{t+1}}$$

$$\left[\beta\gamma(1-\alpha)\left(m+\tau_{t+1}\gamma_{t+1}^N\right) + \alpha(1-m)(1+\beta)\right]S_t^y$$

$$= \beta\alpha\left(1-m-\tau_t\right)h_t^y w_t - \frac{\alpha\left(1-m-\tau_t\right)\left(m+\tau_{t+1}\gamma_{t+1}^y\right)w_{t+1}h_{t+1}^y}{(1+r_{t+1})},$$

for $\frac{w_{t+1}}{1+r_{t+1}} = \frac{(1-\alpha)A_{t+1}k_{t+1}^{\alpha}}{\alpha k_{t+1}^{\alpha-1}} = \frac{(1-\alpha)A_{t+1}k_{t+1}}{\alpha}$.

We obtain

$$\left\{\beta\gamma(1-\alpha)\left(m+\tau_{t+1}\gamma_{t+1}^N\right) + \alpha(1-m)(1+\beta)\right\}A_{t+1}(1-m)h_{t+1}^y k_{t+1}$$

$$= \beta\alpha(1-m)\left(1-m\text{-}\tau_t\right)h_t^y(1-\alpha)A_t k_t^{\alpha} - \left(1-m\right)\left(m+\tau_{t+1}\gamma_{t+1}^y\right)(1-\alpha)A_{t+1}k_{t+1}h_{t+1}^y.$$

At steady state, $k_{t+1} = k_t$, we get the steady state of material capital stock k^*,

$$k^* = \left\{\frac{\alpha\beta(1-m-\tau)(1-\alpha)}{\gamma^A\left\{\alpha(1+\beta)(1-m-\tau) + (\beta\gamma+1)(1-\alpha)\left(m+\tau\gamma^A\right)\gamma^h\right\}}\right\}^{\frac{1}{1-\alpha}}. \quad \text{(A7)}$$

(4) Solving per Capita Savings

$$s = \frac{\alpha\beta(1-m-\tau)(1-m)}{\alpha(1+\beta)(1-m-\tau) + (\beta\theta+1)(1-\alpha)\left(m+\tau\gamma^A\right)\gamma^h}. \quad \text{(A8)}$$

(5) Steady-State Education Investment Rate

Set per capita disposable income as M, we conclude

$$\frac{S_t^y}{M} = s, r_e = \frac{e_t}{M}, \frac{r_e}{s} = \frac{e_t}{S_t^y} \Rightarrow r_e = \frac{e_t}{S_t^y}\cdot s,$$

$$r_e = \frac{\beta\theta(1-m-\tau)(1-\alpha)\left(m+\tau\gamma^N\right)\gamma^h}{\alpha(1+\beta)(1-m-\tau) + (\beta\theta+1)(1-\alpha)\left(m+\tau\gamma^N\right)\gamma^h}. \quad \text{(A9)}$$