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Aging and economic growth: is there a role for a two-child policy in China?

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ABSTRACT

The current study seeks to determine the type of population policy China should implement to effectively promote economic growth, especially in the context of its aging population. Using multiagent simulation technology, I integrate the two-child policy into a complex model featuring population, resources, and economic growth. My simulation results indicate that under the constraining effect of aging on economic growth, the implementation of a two-child policy alone could promote economic growth, albeit in a limited fashion: it would be more economically advantageous to combine a two-child policy with policy that promotes human capital growth. These findings provide new evidence regarding the relationship between population aging and economic growth. It is insufficient to emphasize only a liberalization of birth restrictions and promote population growth: rather, a combination of various policies would be more successful. A cluster of policies that aim to increase both fertility *and* investment in human capital can effectively curb economic recession otherwise caused by an aging population, and such a policy cluster could concurrently increase the supply of new labor and improve skills that appreciate with age.

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1. Introduction

In recent years, there has been a surge of interest among researchers in the relationship between population aging and economic growth. Various studies have shown that population aging can slow economic growth (Peng, 2005), and that a shrinkage in the proportion of the young, working-age population can lower the overall labor force participation rate. However, some studies indicate that population aging does not necessarily delay economic growth (Fougère et al., 2009). Ultimately, the threat of an aging population tends to be overstated: it is frequently exaggerated by media and too often based on partial analysis (Herrmann, 2012).

China is a country with a large population, and so its population-aging trend is not unexpected. As of 2014, 15.53% and 10.06% of the population had reached the

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ages of 60 and 65, respectively. Additionally, the growth rate of China's working-age population has declined, and the absolute quantity of working age adults began to attenuate in 2015, resulting in a structural labor shortage (Fang & Wang, 2006). At the same time, China faces the pressures that come with economic development.

Therefore, to alleviate the problems that tend to accompany population aging, China brought to an end its one-child policy, which had been firmly enforced for over 30 years. In 2013, China put forward a selective two-child policy that specified that if either the husband or the wife had come from a single-child family, they could have a second child. Three years later, in 2016, another policy change allowed all couples to have a second child (i.e., a universal two-child policy) (Zeng, Zhang, & Liu, 2017). Since the implementation of the two-child policy, China's birth rate has increased (Zhai, Zhang, & Jin, 2014). While some studies believe that China's two-child policy can effectively promote the country's economic growth, still others believe the two-child policy can play only a limited role in this area (Li, 2016).

Can China's two-child policy effectively promote economic growth there? More specifically, can its two-child policy effectively constrain the adverse effects that population aging can otherwise impose on economic growth? Indeed, research on these issues can inform the creation of effective population policies and promote economic growth. The current study makes two significant contributions, as follows. (1) For analytical purposes, this study uses multiagent modeling and simulation methods and incorporates aging, economic growth, and two-child policies into a simulation system. (2) By setting various policy portfolio scenarios, I determine the optimal policy portfolio (i.e., that which best addresses population aging so as to promote economic growth in China).

The remainder of this paper is organized as follows. [Section 2](#) provides a literature review, and [Section 3](#) introduces the methodology used herein, including the simulation model and data used. [Section 4](#) reports the simulation results. [Section 5](#) concludes with regard to the research findings and outlines policy implications.

2. Literature review

There has been extensive research on the relationship between population aging and economic growth. To undertake such research while using multiagent modeling and computer simulation methods, I first need to define the term "economic growth." From there, the impact of population aging on economic growth can be analyzed from two perspectives. Finally, I can develop my own research method by analyzing those used in previous studies.

2.1. Economic growth and its influencing factors

There is no fixed definition for "economic growth." At the national level, it is generally defined in terms of continuous growth in gross domestic product (GDP) (Neuenkirch & Neumeier, 2015). However, some studies have shown that use of the GDP measure has its drawbacks: it does not, for example, consider environmental pollution or degradation (Hu, 2000). Some studies instead propose a "green GDP"

measure (Talberth & Bohara, 2006). In any case, GDP continues to be the most widely used measure of economic growth (Camba-Mendez, Kapetanios, Smith, & Weale, 2001), and it is used in the current study.

Many studies focus on the factors that affect economic growth, and there is no overarching consensus among them. The theory of endogenous growth asserts that an economy can drive sustained growth without relying on external forces; according to that theory, endogenous technological progress is the determining factor that ensures sustained economic growth (Adak, 2015; Freire, 2019). The Solow growth model (Durlauf, Kourtellos, & Minkin, 2001) and the exogenous economic growth model have been put forward, and various factors thought to affect economic growth include capital (Hendrickson, Salter, & Albrecht, 2018), labor (Auzina-Emsina, 2014), the savings rate (Uddin, Alam, & Gow, 2016), the population growth rate (Bucci & Moritz Müller, 2018), and the technological progress rate (Alani, 2012).

In terms of policies that promote economic growth, I propose that technological innovation be encouraged and human capital increased. The term “human capital” refers to the capital embodied in a laborer (Pelinescu, 2015), including work skills, technical level, and health status (Ogundari & Awokuse, 2018). Nationally, achieving a higher level of human capital can promote innovation (Lenihan, McGuirk, & Murphy, 2019), improve technical level, promote effective resource allocation (Zallé, 2019), and ultimately support economic growth (Chen & Fang, 2018).

2.2. The impact of population aging on economic growth

The literature indicates that population aging can adversely affect a country's economic growth. In an emerging economy, lagging annual growth in the aging index and in the old age dependency ratio can curtail growth (Aurora, Renuga Nagarajan, & Silva, 2017). Bloom and Finlay (2009), for example, highlight the need in east Asia for policy that offsets the potentially negative effects of an aging population.

On the other hand, other studies suggest that population aging does not necessarily delay economic growth, and that it is influenced by several factors. For example, according to Li, Li, and Chan (2012), China's demographic structure is in a transitional phase, in which economic growth is fostered by increasing savings and investment rates among its aging population. Population aging fosters long-term growth in an endogenous growth framework; however, its effect depends on changes in both fertility and mortality (Prettner, 2013). Irmen (2017) indicates that an economy's steady-state growth rate becomes independent of its age structure, and that neither a higher life expectancy nor a decline in fertility affects economic growth in the long term. The assumptions behind that conclusion are rational capital planning and labor-saving technical change. Similarly, Hsu, Liao, and Zhao (2018) found that aging does not necessarily adversely affect growth in China. Nicole and Beer (2015) believe that in Europe, the Europe 2020 employment targets can suffice in compensating for the demographic burden imposed by population aging. A higher level of life expectancy increases among both young people and adults the incentive to innovate (Lancia & Prarolo, 2012). Thus, population aging leads to industry specialization, which in

turn intensively leverages age-appreciating skills and erodes the comparative advantage of industries for which age-depreciating skills are more important (Cai & Stoyanov, 2016).

2.3. Existing research methods

The literature leverages a variety of research methods, including the three-period overlapping generation model (Lancia & Prarolo, 2012; Choi & Shin, 2015), and Prettner (2013) incorporates endogenous growth models and semi-endogenous growth models. Other methods found in the literature include a computable general equilibrium model (Peng, 2008), a life-cycle model (Kolasa & Rubaszek, 2015), and a general equilibrium overlapping generations model (Hsu et al., 2018). However, Brucker (2008) indicates that traditional old-age dependency ratios can be misleading, as they do not account for differences in labor force participation rates.

Indeed, a literature review offers no consensus regarding the effect of aging on national economic growth. Multiple factors intertwine with aging and play a role in economic growth, be it positive or negative. In terms of research methods, many studies within the literature use a quantitative analysis model; many also use computer simulation. Nonetheless, no research to date employs multiagent modeling and simulation technology and systematically integrates the two-child policy, aging, and economic growth. The current study fills this gap in the literature by exploring these topics.

3. Methods

3.1. Why use a complex, multiagent model?

Several economics researchers have used an agent-based model (Gibson & Setterfield, 2015) in what is most commonly referred to as “agent-based computational economics” research. This model is based on complex adaptive system theory and integrates computer simulation technology to simulate the behavior of multiple heterogeneous agents. When undertaking dynamic simulation, the researcher can observe the behavior rules of various subjects. This model does not rely on traditional mathematical equations and econometric models; instead, it leverages computer programming to study nonlinear and heterogeneous economic agents (Carrão & WikAtique, 2019). For this reason, this model allows one to analyze nonlinear relationships, and this is especially useful; moreover, it is possible to introduce into the system a variety of influencing factors, as variables.

As the behavior of an agent evolves, the value of a variable can change. In this way, a researcher can identify the key variables that drive the evolution process (Liu, 2017). This is especially important for policymakers, as it is difficult to institute a given socioeconomic policy while conducting what are essentially real-world experiments: especially when policies can have deleterious effects, such experiments are ethically impossible. However, the use of multiagent modeling and a simulation platform can compensate for this shortcoming. Using these tools, one can undertake policy experiments and present the results as three-dimensional visualizations. As such, by

using different policy scenarios, policymakers can clearly see the effects of the implementation of a given policy. In this way, the use of this method can help lay the foundation for the implementation of effective policies. In fact, the model has already been effectively applied to policy formulation in various fields, and achieved positive results (Drakaki, Gören, & Tziona, 2018; Gao et al., 2018).

This study builds a multiagent simulation system that considers population, the two-child policy, resources, and economic growth. By making full use of multiagent modeling, one can simulate the characteristics of a large number of agents and bring population policy and economic growth into the system at the same time, with the endpoint of effectively analyzing the consequences of the two-child policy with respect to economic growth.

3.2. Conceptual model

The conceptual model serves as the foundation of the simulation model. The conceptual model is based mainly on the existing theoretical and empirical research, but is also informed by original author contributions.

Land and other resources are essential to human survival. Humans use their work-related skills to develop resources such as land and earn income to satisfy their own consumption needs (Zallé, 2019). If there is a surplus, it can accumulate as wealth (i.e., GDP). As mentioned, at the national level, an increase in GDP connotes economic growth (Camba-Mendez et al., 2001). Meanwhile, fertility is achieved at the childbearing age, and reproductive behavior is affected by government policies, such as family-planning policies and the two-child policy (Liu & Liu, 2018). In the conceptual model, the population is differentiated by age ($f(\alpha)$) and comprises the young-age population ($Yage$), the working-age population ($Wage$), and the old-age population ($Oage$).

$$f(\alpha) = \begin{cases} Yage, <18 \\ Wage, 18 \leq \leq 65 \\ Oage, >65 \end{cases} \quad (1)$$

When an agent reaches the maximum life expectancy (θ), the agent exits and dies ($f(x)$). When no resources are available for consumption ($income = I \leq 0$), the agent will die out.

$$f(x) = 0, f(a) > \theta \text{ or } I \leq 0 \quad (2)$$

The land resource system provides survival resources for use by the population system. Here, land is classified as “abundant land” or “nonabundant land” (Wu, Wang, Xu, Tan, & Zhang, 1995). “Abundant land” refers to that which offers high-level economic benefits and generates no pollution during crop production and unit area utilization. Any land lacking in these characteristics is considered nonabundant (Shen et al., 2012). Based on these studies, I designed a variable (*percent-abundant-land*) that reflects the amount of abundant land.

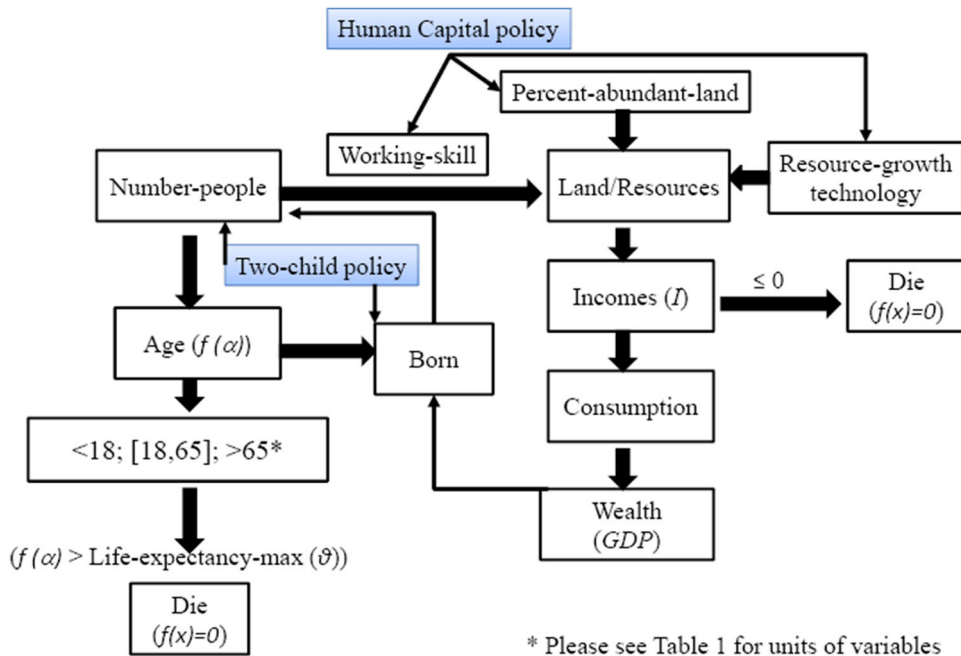


Figure 1. Framework of the conceptual model. *Source:* The author's design and calculation results.

Thanks to technological advances, nonabundant land can be transformed into abundant land (Kong, Zhang, Xu, & Qi, 2004). Additionally, an increase in human capital investment can enhance human working skills (Onkelinx, Manolova, & Edelman, 2016). In these ways, more survival-essential resources can be obtained and more wealth created. Changes in human capital are influenced by human capital policy (Yoon, 2006; Haini, 2019; Siddiqui & Rehman, 2016). To effectively simulate the impact of a two-child policy on economic growth, it is necessary to introduce a number of variables that effectively link the relationships among various agents and sub-systems. The effects of the policy are analyzed in the system. The design of these variables is based on the literature, but also on original author contributions. For example, according to the definition of “human capital” in the Section 2, the following variables are set in the model to measure human capital policy: *working-skills* refers to agents’ work-related abilities and skills, and *resource-growth technology* refers to technology that promotes resource growth (see Figure 1 and Table 1).

3.3. Simulation model

The simulation model is based on the conceptual model, and I use the NetLogo simulation platform. NetLogo is a programming platform that at once inherits the Logo language and improves upon the Logo language’s shortfalls. In modeling it can control tens of thousands of agents; therefore, NetLogo modeling can simulate the behavior of micro-level individuals and the emergence of macro-level models, as well as the relationships between them. Moreover, NetLogo is a platform used with

Table 1. Main variables: descriptions and sources.

Variable	Description	Unit	Source
<i>resources-city</i>	The number of resources in the city where the agents are located. Expressed as hypothetical values, where the larger the value is, the richer the city's resources are (e.g., land).	Rank value	Designed by the author
<i>max-resources-city</i>	The maximum number of resources in the city where the agents are located. An assumed value is used to represent the maximum resource limit for a particular period of time.	Rank value	Designed by the author
<i>age</i>	Agent age. Set demographic characteristics and structure by using different age groupings.	Year	Brunow and Hirte (2009), Cuaresma, Lábaj, and Pruzinsky (2014), Zhang, Zhang, and Zhang (2015), Lee and Shin (2019)
<i>incomes</i>	Agent incomes. Set different values to reflect the income of each subject.	Rank value	Islam (1996), Chen and Sun (2014), Su and Yao (2017)
<i>life-expectancy</i>	Agent life expectancy. Set the life expectancy values for each subject, including the maximum and minimum life expectancy values.	Year	Sunde (2011), He and Li (2018)
<i>consumption</i>	Amounts consumed by agents. Set different values to reflect the amount of resources the entity needs to survive.	Rank value	Designed by the author
<i>working-skills</i>	Agent's work-related abilities and skills. Set different values to reflect the difference in human capital.	Rank value	Yoon (2006), Siddiqui and Rehman (2016), Haini (2019)
<i>number-people</i>	The number of people.	Tens of millions	Designed by the author
<i>max-working-skills</i>	Maximum value of agent's work-related abilities and skills.	Rank value	Yoon (2006), Siddiqui and Rehman (2016), Haini (2019)
<i>consumption-max</i>	Maximum value of agent consumption.	Rank value	Designed by the author
<i>life-expectancy-min</i>	Minimum value of agent's life expectancy.	Year	Designed by the author
<i>life-expectancy-max</i>	Maximum value of agent's life expectancy.	Year	Designed by the author
<i>percent-abundant-land</i>	Percentage of abundant land.	%	Binswanger and McIntire (1987), Mo (2018)
<i>resource-growth-technology</i>	Technology used to enhance resource growth. Use different data values to indicate advancement in a technology.	Rank value	Sasmal (2012), Loupias and Wigniolle (2019)
<i>amount-resource-grown</i>	The amount of resources grown. Set different values to reflect changes in resources over a specific period of time.	Rank value	Designed by the author
<i>Wealth</i>	Humans use their work-related skills to develop resources and earn income to satisfy their own consumption needs. If there is a surplus, it can accumulate as wealth (GDP).	Rank value	Zaillé (2019)

success to simulate natural and social phenomena—especially those involving complex systems—over time.

The simulation platform is divided into three parts. The left part controls the system variables, and sliding blocks were designed for it. One can design various policy scenarios by controlling these variables. The middle part is a statistical display of the simulation results. Finally, the right part is the three-dimensional display of the simulation results. As the simulation time increases, simulation data are produced and maintained, and ultimately used in quantitative analysis.

3.4. Initialization and input data

Initialization of the simulation model requires the assignment of variables. Certain initial values are based on China's real-world conditions. For example, the value of China's *number-people* (population, expressed in tens of millions) as of 2016 is 138.3. Other variables are similarly based on research results. Meanwhile, to analyze trends under various experimental scenarios, I manually controlled for the effects of some important variables; one such variable is *max-resources*, which can assume different grade values. By enacting these levels of change in various experimental scenarios, one can observe the related impact. Some grade variables have no units; the main concern is the change in numerical level (Akl, Sarker, & Essam, 2019; Schweiger et al., 2019) for example the *wealth (GDP)* (see Table 2).

3.5. Comparative simulation

To analyze the effect of the two-child policy on economic growth in the context of an aging population in China, I designed three policy scenarios. Before the comprehensive two-child policy was implemented, only a select population was allowed to have two children (Sim_{BT1}). This policy scenario, as the benchmark, was compared to the other two scenarios.

The second policy scenario features the aging of China's population (i.e., increasing the *life-expectancy-max* variable). A fully liberalized two-child policy would increase the number of births, which would in turn increase the value of *number-population*

Table 2. Main variables: overview of baseline data.

Variable	Baseline value	Unit	Description
<i>max-resources</i>	50	Rank value	Controlled variable
<i>number-people</i>	138.3	Tens of millions	138.3 ^a
<i>max-working-skills</i>	5 [1, 20]	Rank value	Controlled variable
<i>consumption-max</i>	15 [1, 25]	Rank value	Controlled variable
<i>life-expectancy-min</i>	30 [1, 100]	Year	Controlled variable; baseline value is 30
<i>life-expectancy-max</i>	76.5 [1, 100]	Year	Controlled variable; baseline value is 76.5 ^b
<i>percent-abundant-land</i>	2.9 [1, 100]	%	2.9% ^c
<i>resource-growth-technology</i>	2.11 [1, 10]	%	2.11% ^d
<i>amount-resource-grown</i>	4 [1, 10]	Rank value	Controlled variable

^aStatistical data from the China National Bureau of Statistics for 2016.

^bIn 2016, China's life expectancy increased to 76.5 years. Source: Xinhua News Agency new media special line (Guangzhou), accessed September 29, 2017.

^cPercent of preferential farmland in mainland China. Source: 2016 China Land and Resources Bulletin (Li, 2017).

^dIn 2016, China's research and development investment intensity reached 2.11%. Source: Statistics Bulletin of national science and technology expenditure in 2016.

Table 3. Parameters of the different simulation scenarios.

Variable	Unit	Simulation	Scenario
Before the two-child policy			
<i>number-people</i>	Tens of millions	Sim _{BT1} 138.3	
<i>life-expectancy-max</i>	Year	76.5	
<i>max-working-skills</i>	Rank value	5	
<i>consumption-max</i>	Rank value	15	
<i>percent-abundant-land</i>	%	2.9	
<i>resource-growth-technology</i>	Rank value	2.11	
<i>amount-resource-grown</i>	Rank value	4	
After the two-child policy			
<i>number-people</i>	Tens of millions	Sim _{AT1} 143.3 ^a	Sim _{AT2} 143.3
<i>life-expectancy-max</i>	Year	80	80
<i>max-working-skills</i>	Rank value	5	6
<i>consumption-max</i>	Rank value	15	15
<i>percent-abundant-land</i>	%	2.9	8
<i>resource-growth-technology</i>	Rank value	2.11	3.22
<i>amount-resource-grown</i>	Rank value	4	8

^aChina's annual population will increase dramatically after the policy changes, with a peak increase of about 50 million births (Zhai et al., 2014).

Source: The author's design and calculation results.

(Sim_{AT1}). The third policy scenario also assumes an aging population and a fully liberalized two-child policy, but additionally assumes increased investment in human capital and technology, thus increasing the value of certain relevant variables (e.g., *max-working-skills* and *resource-growth-technology* [Sim_{AT2}]), as Table 3 shows.

3.6. Model validation and robustness

There is no generally accepted method by which to assess the validity and robustness of agent-based models (Balci, 1998). However, the approach used is considered one of model verification and validation, and use of this approach is supported by the literature. Additionally, the use of multiple data sources improved the validity of the model (e.g., determined whether the conceptual model was a reasonably accurate representation of real-world conditions) (Law & Kelton, 1991).

Furthermore, the removal of errors from the simulation program helped preclude the incorrect application of the conceptual model, and thus guaranteed the model's validity and robustness. I used an iterative process that adjusts poorly characterized experimental variables, to accommodate extreme conditions and sensitivity. The calibration process improved the goodness of fit between the model and the data. Through these tests, I pinpointed those changes within the model's dynamic evolving patterns that stemmed from changes in the values of certain parameters. Therefore, based on the simulation results, the results of the effect of the two-child policy on economic growth can be deemed acceptable.

4. Results and discussion

4.1. Descriptive statistics of results

Table 4 presents the results of the three simulation scenarios (Sim_{BT1}, Sim_{AT1} and Sim_{AT2}). The third simulation scenario yields a minimum GDP of 2677.00, which is greater than that obtained with either of the other two simulation scenarios (2371.00 and 2481.00); it

Table 4. Statistical analysis of the description of three simulation scenarios.

Simulation scenario	GDP (Wealth) Unit: Rank value				
	Range	Minimum	Maximum	Mean	Std. Deviation
Sim _{BT1}	1336.00	2371.00	3707.00	2964.70	328.35
Sim _{AT1}	1562.00	2481.00	4043.00	3074.00	439.01
Sim _{AT2}	3559.00	2677.00	6236.00	4510.90	1210.13
Difference analysis					
Sim _{BT1}	T = -3.93		Sig. (two-tailed) p = 0.00		
Sim _{AT1}	T=-11.41		Sig. (two-tailed) p = 0.00		
Sim _{AT2}					

Source: The author's design and calculation results.

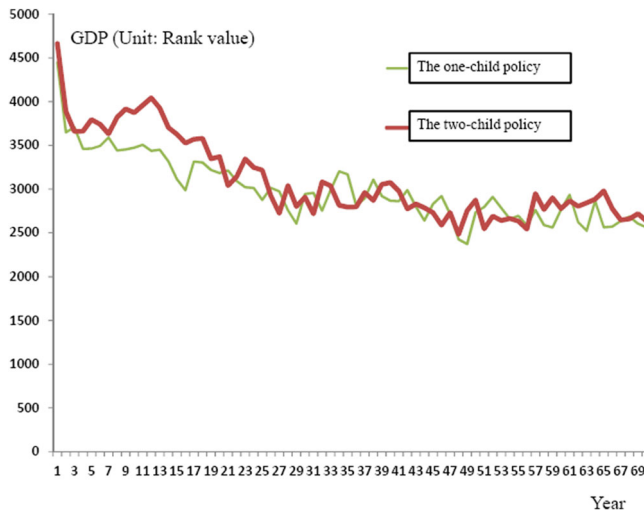


Figure 2. Simulation results before and after implementation of the two-child policy. Source: The author's design and calculation results.

also yields a maximum GDP of 6236.00, which is greater than that obtained from the other two (3707.00 and 4043.00). The third simulation also exhibits the largest mean GDP.

The results of these three simulation scenarios are statistically significant. As Table 4 shows, there are significant differences between Sim_{BT1} and Sim_{AT1} ($T = -3.93$; $p = 0.00$). There are also statistically significant differences between Sim_{AT1} and Sim_{AT2} ($T = -11.41$; $p = 0.00$).

4.2. Sim_{BT1} and Sim_{AT1}

The simulation results indicate that under a population-aging trend, the implementation of the two-child policy in China is conducive to promoting economic growth. Figure 2 shows that, in the simulation period, economic growth would be significantly lower in the absence of the two-child policy than it would be in its presence. Statistical analysis of the simulation data under the two scenarios uncovers significant differences between the two ($T = -3.93$; Sig. (two-tailed) $p = 0.00$).

Since the implementation of the two-child policy, the number of births in China has increased; various studies also reach this conclusion (Zeng & Hesketh, 2016).

Although the rate of population growth is lower than expected, China's birth rate has indeed increased (Liu & Liu, 2018). This addition to the population can ease the population-aging trend and eventually become a new part of the labor force. To a certain extent, the policy promoted economic growth during the simulation period; however, had the two-child policy not been implemented in China, the one-child policy would have prevailed—and under *that* policy, the model shows that over the simulation period, economic growth in China would have slowed. Clearly, in the absence of the two-child policy, China's outlook vis-à-vis economic growth would not have been favorable.

China's population-aging trend has been aggravating economic growth, thus affecting the sustainability of the country's economic development. As seen in the literature findings, population aging has a negative impact on many aspects of national health, including economic growth (Chomik, McDonald, & Piggott, 2016; Lee & Shin, 2019). In particular, labor-intensive industries continue to play an important role in China's economic development (Wei, 2017), and shortfalls in new labor have constrained development in these industries. On the other hand, elderly individuals are now more becoming increasingly older and hence prone to physical discomfort and serious illness; these changes result in increases in personal medical and nursing expenses and reduced savings. As such, the aging of a population will constrain the overall savings rate, and such a constraint will reduce savings funds, directly reduce the scale of investment, and reduce the national economic growth rate (Gao & Zhang, 2018).

4.3. *Sim_{AT1}* and *Sim_{AT2}*

The simulation results also indicate that the combination of the two-child policy and increased human capital investment will bring about better economic growth. According to Figure 3, compared to the implementation of the two-child policy alone, the two-child policy in conjunction with a human capital policy will work better to promote economic development. In statistically analyzing the simulation data under

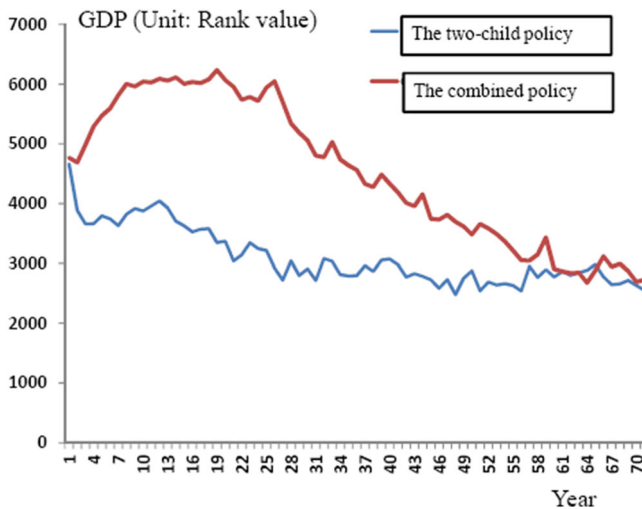


Figure 3. Simulation results of the two-child policy and human capital policy. *Source:* The author's design and calculation results.

the two scenarios, significant differences between them become apparent ($T=-11.41$; Sig.(two-tailed) $p=0.00$).

The direct effect of the two-child policy is an increase in the *quantity* of people; however, human capital policy promotes economic growth from the perspective of population *quality*. Especially in the context of population aging, the effect of human capital policy becomes more prominent. The findings in the literature support this conclusion (Bowlus, Mori, & Robinson, 2016). Population aging creates more opportunities for young individuals to invest in human capital and supply more skilled labor in middle age (Fougère et al., 2009). Consequently, the reduced young-adult labor supply initially lowers economic growth and exacerbates the economic costs of aging, but current (future) middle-aged cohorts are (will be) more skilled and work for a longer time; these conditions will eventually improve economic growth and lower the cost of population aging. Furthermore, with the accelerated development of the aging population, a new “aging products” market will be created that will increase the demand for equipment, raw materials, and intermediate products, and promote physical capital investment. The literature cites similar views (Magalhães, Stevens, & Thornton, 2017).

5. Conclusions and recommendations

5.1. Conclusions

The current study uses multiagent modeling and simulation technology to simulate the effect of China’s two-child policy on that country’s economic growth, in the context of its aging population. I built a multiagent simulation model involving population, resources, and technology, and constructed different policy scenarios. My simulation results show that China’s implementation of the two-child policy can increase its labor supply, relative to non-implementation. Furthermore, the policy promotes economic growth and, to a certain extent, alleviates the population-aging trend. The simulation results also show that the in-tandem implementation of the two-child policy and human capital policies will be more conducive to economic growth than the two-child policy alone.

5.2. Recommendations

These conclusions have important reference value in promoting economic development in the context of population aging. This trend is especially obvious in China; at the same time, the country faces environmental pollution and socioeconomic transformation. Despite the increase in the number of births after implementing the two-child policy, the expected effect on aging was not found to be significant. The main reason for this is the current decline in the desire to have children. This attenuation relates in part to deficiencies in social security, which increase child maintenance costs. Therefore, a feasible policy would be to incentivize giving birth (e.g., offering more paid maternity/paternity leave, better kindergarten services, and a maternity/paternity allowance).

The simulation results also show the positive role of increasing human capital investment in the context of population aging. Therefore, rather than solely institute a two-child policy, it is more important to implement a human capital policy, increase human capital investment, and promote improvements in population quality. The main policies relating to such investments attach importance to worker training, so as to enhance their skill base and improve the overall worker knowledge system. Improving the basic education level of the entire population should also be a goal: by increasing education expenditures, the human capital stock of the whole society can be increased.

However, there are two outstanding issues worth noting—namely, the number of children and human capital accumulation. The literature shows that at the micro level, an increase in the number of children can *preclude* human capital accumulation, as having extra children compels a household to reduce the per-child investment it makes in education (Van & Bovenberg, 1997; Raurich & Seegmuller, 2019). To counter this reduction in human capital accumulation, steps need to be taken in addition to the two-child policy (and its attendant increase in the per-family number of children). In addition to the aforementioned improvements to social security and child maintenance costs, there is a need to increase policies that promote macro-level human capital accumulation.

This study, like any study, has some limitations. Not all the factors that can affect economic growth are included in the simulation system used herein. Additionally, there persists a certain gap between the simulation framework and real-world conditions. Nonetheless, this explorative study does provide context and serve as a starting point for further investigation, and will support future studies in population aging and economic growth.

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Appendix 1. Explanation for the method used

The current study's research method is based on complex adaptive system theory and the use of computer simulation software. I have designed various simulation scenarios for the current study, and the optimal results are screened. The advantage of this method is that it does not depend on the use of mathematical equations; it can therefore be used to study nonlinear and heterogeneous economic agents. The method is divided into four main steps: (1) Build a conceptual model, (2) Build a simulation model, (3) Initialize and input data, and (4) Validate the model. I provide below the details of each of these steps.

A1. Build a conceptual model

The conceptual model is the foundation of the simulation model. Construction of the conceptual model is based mainly on the theoretical and empirical literature, but additionally includes original author contributions. The model completes the construction of the entire simulation system's framework. The various variables within the system are based on this model.

A2. Build a simulation model

The simulation model is based on the conceptual model, and the NetLogo simulation platform is used for simulation. The model transforms the theoretical framework and variables of the conceptual model, thus making the computer identifiable. This transformation does not require the creation of mathematical equations; rather, it leverages computer programming

language through the command statement (command center) to achieve interaction among the various subjects (e.g., **clear-all**, **set max-resources 50**, **ask patches**, and **set if... ..**). These individual commands involve different functional modules. Some examples follow.

to setup

```
clear-all
set max-resources ()
setup-patches
setup-turtles
update-lorenz-and-gini
reset-ticks
```

end

The combination of these functional modules comprises the whole of the simulation model, which includes output modules for various graphics and tables.

A3. Initialize and input data

Initialization of the simulation model requires the assignment of variables. Certain initial values are based on China's real-world conditions; other variables are similarly based on research results. Meanwhile, to analyze trends under various experimental scenarios, I manually controlled for the effects of some important variables.

A3.1. Sim_{BT1}

Before the comprehensive two-child policy was implemented in China, only a select population was allowed to have two children. This policy scenario, as the benchmark, was compared with the other two scenarios.

A3.2. Sim_{AT1}

The second policy scenario features the aging of China's population. A fully liberalized two-child policy would increase the number of births, which would in turn increase the value of *number-population*.

A3.3. Sim_{AT2}

The third policy scenario also assumes an aging population and a fully liberalized two-child policy, but additionally assumes increased investment in human capital and technology.

A4. Model validation

There is no generally accepted method by which to assess the validity and robustness of agent-based models (Balci, 1998).

1. The approach used is considered one of model verification and validation, and use of this approach is supported by the literature. Additionally, the use of multiple data sources improved the validity of the model (e.g., determined whether the conceptual model was a reasonably accurate representation of real-world conditions) (Law & Kelton, 1991).
2. The removal of errors from the simulation program helped preclude the incorrect application of the conceptual model, and thus guaranteed the model's validity and robustness.
3. I used an iterative process that adjusts poorly characterized experimental variables, to accommodate extreme conditions and sensitivity. The calibration process improved the goodness of fit between the model and the data.