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Key Points:
- The integrated effects of population policies and socioeconomic pathways on the population structure and economy are explored
- The population bust in China caused by the one-child policy will be relieved after the two-child policy, as indicated by all the SSPs
- Full relaxation of fertility control is recommended with the simultaneous implementation of other social policies (e.g., pension funds)

Supporting Information:
- Supporting Information S1

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Effect of Fertility Policy Changes on the Population Structure and Economy of China: From the Perspective of the Shared Socioeconomic Pathways

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Abstract Beginning in 2016, all couples in China were allowed to have two children without any restrictions. This paper provides population and economic projections under five shared socioeconomic pathways (SSPs) and three fertility policies. By replacing the one-child policy with the two-child policy, the population is predicted to continue growing until 2025–2035, with a peak of approximately 1.39–1.42 billion, and then to decline under four SSPs, with the exception of the fragmented world SSP3. As a result, the two-child policy will lead to mitigation of the pressure from labor shortages and aging problems to a certain extent. In addition, an increase in working-age people with higher education level relative to projections based on the one-child policy will lead to an increase in gross domestic product by approximately 38.1–43.9% in the late 21st century. However, labor shortages and aging problems are inevitable, and the proportion of elderly in China will be greater than 14% and 21% by approximately 2025 and 2035, respectively. Full liberalization of fertility is expected to reduce the share of elderly people by 0.7–1.0% and to lead to an increase in gross domestic product by 5.3–6.7% relative to the two-child policy in the late 21st century. The full liberalization of fertility policies is recommended, supplemented by increases in pension and child-rearing funds, improvement in the quality of health services for females and children, and extension of compulsory education to meet the needs of an aged society.

Plain Language Summary The one-child policy in China has been replaced by the two-child policy since 2016. What might the population and economy change if the one-child policy is continued in the 21st century? What can China benefit from the fertility policy changes? Is it necessary to allow people to choose their family size in China? We conducted multipopulation policies and multisocioeconomic development pathways combined analysis to explore the effects of fertility policy changes on population and economy in China. We found that population size by the late 21st century might be 28% less than that in 2010 at the one-child policy, and share of elderly (aged 65+) might be 49%. The implementation of the two-child policy can mitigate the labor shortages and aging problems to a certain extent, and the increased working-age population with higher education level can lead to a 38.1–43.9% increase in gross domestic product in the late 21st century. A further 0.7–1.0% reduction in elderly share of the total population and 5.3–6.7% increase in gross domestic product is projected in the late 21st century at the "full relaxation" policy. We believe that introduction of effects from fertility policy changes on socioeconomy can deliver useful information to decision makers.

1. Introduction

A warming climate induced mainly by human activities since the midnineteenth century has triggered unexpected extreme climate and weather events (Hansen et al., 2010; Lawrimore et al., 2011; Rohde et al., 2013; Trenberth et al., 2015). With a continuing warming trend projected in the future, the negative impacts of climate and weather extremes on human beings might increase further (Fischer & Knutti, 2015). Meanwhile, more socioeconomic sectors will be exposed to extreme events throughout the world (Cai et al., 2014; Donat et al., 2016; Field et al., 2012; Rosenzweig et al., 2014; Schewe et al., 2014; Su et al., 2018). Therefore, studies of changes in the future socioeconomy are as important as the climate projection in quantification of disaster risk and should be of great concern.

Scenarios are the key tools used to describe possible climatic, societal, and environmental changes in the future (Moss et al., 2010; O'Neill et al., 2017). The current parallel scenario development process began with representative concentration pathways, which reflect the atmospheric concentration targets of greenhouse gases and have been widely used to understand potential changes to the future climate (Huang et al., 2016; Su et al., 2016; Taylor et al., 2012; Van Vuuren et al., 2011). Future socioeconomic conditions that connect the impact of, adaptation to, and mitigation of climate change are generating increasing concern among multiple stakeholders regarding mitigation targets and liability (Kriegler et al., 2012). Shared socioeconomic pathways (SSPs) were developed by the climate change community to represent the different possible worlds. They form a framework with the representative concentration pathways and thereby contribute to the sixth climate model intercomparison project (Moss et al., 2010; O'Neill et al., 2014; Riahi et al., 2017; Van Vuuren et al., 2014, 2012). Five SSPs (SSP1: sustainability; SSP2: middle of the road; SSP3: regional rivalry; SSP4: inequality; and SSP5: fossil fuel development) describe the possible developments based on various combinations of low or high challenges to mitigation and adaptation (O'Neill et al., 2017, 2014). The SSPs have also been applied to assess the impacts of the changing environment on water scarcity, agriculture, flooding, and the sensitivities of future CO_2 emissions to socioeconomic development (Arnell & Lloyd-Hughes, 2014; Hanasaki et al., 2013; Marangoni et al., 2017; Schewe et al., 2014; Wiebe et al., 2015).

The SSP assumptions involve quantitative pathways for population growth and economic development (O'Neill et al., 2014). Currently, country-level population data sets have been developed by the International Institute for Applied Systems Analysis (IIASA; KC & Lutz, 2017). Based on the population projections by the IIASA, three gross domestic product (GDP) projections have been developed and are available from the Potsdam Institute for Climate Impact Research (PIK), the Organization for Economic Cooperation and Development, and the IIASA (Cuaresma, 2017; Dellink et al., 2017; Leimbach et al., 2017). Population scenarios under the different SSPs are translated into projections by age, sex, and educational attainment until 2100 for approximately 195 countries (KC et al., 2010, 2013; KC & Lutz, 2014; Lutz et al., 2007). The world's total population will reach a peak and then decline under SSP1, SSP2, SSP4, and SSP5, while persistent increasing trends are projected in the 21st century under SSP3 (KC & Lutz, 2017). Changes in the educational structure of populations were addressed explicitly by KC and Lutz (2017). Lower fertility, lower mortality, and economic growth are always associated with higher or better education (Lutz et al., 2008, 2014; Lutz & KC, 2011). Therefore, to improve the projections for individual countries, credible and quantitative information on the drivers of demographic change, such as the level of education and government policies, must be taken into account.

In China, the one-child policy was implemented in the late 1970s, and it has contributed to a decline in fertility with other social and economic factors (e.g., advances in female education and reductions in mortality; Basten et al., 2013; Feng et al., 2012; Peng, 2011). According to the latest census, the number of people aged 60 or above in China accounts for 13.3% of the total population (National Bureau of Statistics of China, 2011). The one-child policy has accelerated the aging process, shrunken the labor force, and produced a skewed sex ratio at birth (Hvistendahl, 2010). To actively address these issues, China began to relax the one-child policy in 2014. Beginning in 2014, couples in which either party was an only child were allowed to have two children (selective two-child policy) and beginning in 2016, all couples were allowed to have two children without any restrictions (universal two-child policy). As a result, the total fertility rate (TFR) is expected to increase in the short term, which will have a substantial effect on the population size and structure in the long run (Zeng & Hesketh, 2016; Zeng & Wang, 2014). These fertility policy changes will have potential effects on fertility, the aging of the population, the sex ratio, and health systems (Zeng & Hesketh, 2016). Most recent studies have the two-child policy included in the projection of population and economy in China under SSPs framework (Jiang, Wang, et al., 2018; Jiang, Zhao, et al., 2018; Jiang et al., 2017). But the effects of fertility policy changes on the population structure and economic development in China have not been given enough consideration.

In this paper, population by age, sex, and educational attainment from 2010 to 2100 is projected based on assumptions of future fertility, mortality, and migration under five SSPs for three fertility policies (the previous one-child policy, the latest universal two-child policy, and the assumed full liberalization). Subsequently, based on the population scenarios in 2010–2100 under the multipopulation policies and multidevelopment pathways, GDP in China is projected to explore the effects of different fertility policies on the economy.

2. Methodologies

2.1. SSPs

The SSPs were developed to describe future societal and environmental changes. The five SSPs (SSP1: sustainability; SSP2: middle of the road; SSP3: regional rivalry; SSP4: inequality; and SSP5: fossil-fuel development) represent different combinations of challenges to adaptation and mitigation that can reflect possible future socioeconomic developments (O'Neill et al., 2014, 2017).

China is a low-fertility country, with TFR of less than 2.9 from 2005 to 2010 (Basten et al., 2013; KC & Lutz, 2017). For low-fertility countries, sustainable development pathway SSP1 with low challenges to both mitigation and adaptation describes a future of decreased inequality, rapid technology changes, low-carbon energy sources, and high productivity. The level of education will be high. Low fertility and low mortality caused by increases in educational and health investments will lead to a relatively small population size. SSP2 assumes a world that follows the middle of the road, with moderate challenges to both mitigation and adaptation, such that social and economic trends do not change substantially from historical patterns. All parameters (fertility, mortality, migration, and education) are assumed to be at medium levels. In contrast to SSP1, SSP3 reflects high challenges to mitigation and adaptation, which translates into moderate economic growth, rapid population growth, slow technology changes, and low investments in human capital. High fertility, high mortality, and a low education level are assumed in this pathway. SSP4 reflects the path of inequality, with low challenges to mitigation but high challenges to adaptation. A large group of low-fertility countries will have low levels of development, continued low fertility, medium mortality and migration, and low levels of education. The fossil-fueled development pathway SSP5 describes a future with strong reliance on fossil fuels, rapid economic development and high investments in human capital, and low challenges to adaptation. Thus, low fertility, low mortality, and high levels of education are assumed. Additionally, the level of migration is assumed to be high due to highly marketable globalization (KC & Lutz, 2017; O'Neill et al., 2017). The assumptions of the SSPs with regard to the key influencing factors on population are shown in Table S1 in the supporting information.

2.2. Population Projection Model

A multidimensional population model is used to produce population projections (Rogers, 1975). The multidimensional population model has been successfully applied to North Africa, India, the Middle East, Southeast Asia (Goujon, 2002; Goujon et al., 2007; Goujon & McNay, 2003; Goujon & Samir, 2006), and China without considering the different development pathways (Meng et al., 2014).

Fertility, mortality, and migration rates by age and sex can be defined separately in the multidimensional projection model for different levels of education (Lutz & Goujon, 2001). In this paper, four educational categories, that is, no education, primary, secondary, and tertiary education, are applied to project population growth using different fertility, mortality, and migration rates. The total population is the sum of the population in each education category. Transitions between neighboring levels of age and sex result in movement of the population between dimensions. The detailed parameters are described below.

The initial demographic data for the projection are based on the Sixth National Population Census in 2010 and include information on fertility, deaths, and migration by age, sex, and level of education. There are four stages of education in China: preprimary education (children aged 3–5 in kindergarten), primary education (children aged 6–11), secondary education (teenagers 12–17), and tertiary education (postsecondary education). For convenience, children under 5 years of age are included in the "no education" group in this paper. The differences in the population distribution by age, sex, and education in the base year 2010 between the census data and the United Nations (UN) estimation are shown in Figure S1. The enrollment rates for secondary and tertiary education are 0.93 and 0.27, respectively, based on the census data, while the enrollment rates are 0.66 and 0.11, respectively, in the UN estimation. Therefore, the existing country-level population projection by the IIASA for the entire 21st century needs to be revised. In addition, the selective two-child policy and the universal two-child policy were implemented in 2014 and 2016, respectively. Before 2014, the well-known one-child policy and socioeconomic developments (e.g., education) exerted strong influences on population growth and resulted in lower fertility in China (Feng et al., 2012; Peng, 2011). After the implementation of the universal two-child policy, couples' desire for two children will gain momentum (Zeng & Hesketh, 2016; Zeng & Wang, 2014), and the fertility desire is approximately 1.8 based on surveys (Shi et al., 2017). The previous projection by the IIASA therefore needs to be updated to account for the changing population policy.

In this study, a multidimensional projection model is parameterized by following the assumptions of the SSPs but revising them based on regional characteristics, including changes of the population policy in China. Three levels, that is, low, medium, and high levels of fertility, mortality, migration, and educational parameters, are used to represent different development pathways (Table S1). Medium levels of fertility, mortality, migration, and education are assumed to maintain the current level of development. The details and settings for the SSPs assuming low, medium, and high levels of fertility, mortality, migration, and education in China are presented below.

Education. Three alternative educational scenarios are specified to project the population based on the education assumptions described by KC and Lutz (2017). The fast track scenario assumes that China will reach the educational level of Singapore and South Korea. The global education trend scenario assumes a moderate enrollment rate. The constant enrollment rate scenario maintains the current levels, with constant proportions of cohorts attending school. Census data from 2010 showed that the enrollment ratio for primary, secondary (junior and senior high school), and tertiary (graduate and above) education were 0.96, 0.93, and 0.27, respectively. The enrollment rates for primary, secondary, and tertiary individuals in South Korea are 1.00, 1.00, and 0.93, respectively, which represents a high enrollment rate. For the fast track scenario, the transition is assumed to occur (for China to achieve a high enrollment rate) by 2050 and to hold thereafter. For the global education trend scenario, the transition is assumed to occur (for China to achieve a medium enrollment rate), with the values reaching 0.98, 0.96, and 0.60, respectively, by 2050 and then to remain unchanged. For the constant enrollment rate scenario, the enrollment rate is assumed to remain at the current level.

Fertility. In the high fertility assumption, the TFR will be 20% higher than the medium fertility rate assumption by 2030 and 25% higher by 2050. The low fertility assumption is that the TFR will be 20% lower than medium fertility rate assumption by 2030 and 25% lower by 2050 (KC & Lutz, 2017). The fertility rates for the different education levels (no education, primary, secondary, and tertiary) are set separately. Based on the census data from 2010, the fertility rates for the four education levels are 1.58, 1.65, 1.27, and 0.84, respectively. The recorded TFR in 2010 was 1.2, but this figure is underreported. According to various domestic and international demographers (Basten et al., 2013; Zeng & Wang, 2014; Zhao & Zhang, 2010), the actual rate was approximately 1.45. Thus, the fertility rates for the four education levels are adjusted to 1.94, 2.02, 1.55, and 1.03, respectively (Table S2). The following are the medium fertility assumptions for different fertility policies in China: (1) Under the one-child policy, the fertility rates for the four education levels are assumed to remain unchanged, which will lead to a gradually decreasing TFR that will stabilize at 1.33 at the end of the 21st century. (2) Under the universal two-child policy, the national TFR of approximately 1.8 is more suitable to the coordinated development of population, economy, and society. It is expected that national TFR around 1.8 can lead to a population with relative reasonable population structure and peak value less than 1.5 billion. Lower national TFR might result in serious aging problems and labor shortages, while higher TFR might bring overpopulation (National Population Development Strategy Research Group, 2007). A "national TFR around 1.8" is a policy target that corresponds to the universal two-child policy (Zhai et al., 2016). After the implementation of the universal two-child policy, according to Shi et al. (2017), the ideal number of children is approximately 1.8. As shown in Table S4, two thirds of Chinese have a secondary level of education, and as a result, the fertility rate for the secondary education level is approximately 1.80. More people with lower education levels reside in rural areas compared to people with tertiary levels of education (Table S4). However, most rural couples were already allowed to have two children; thus, the effects of the universal two-child policy will be much stronger in urban areas than in rural areas. Therefore, according to the urban and rural settings established by Zeng and Wang (2014) and Zeng and Hesketh (2016), the fertility rates for the no education, primary, and tertiary education levels are set to increase by 7%, 7%, and 35%, respectively, and the TFR will stabilize at 1.64 by the end of the 21st century. (3) The implementation of the universal two-child policy will lead to an increase in the TFR to 1.72 in 2030, but this figure will stabilize to 1.64 in 2065. The "full relaxation" policy will allow people to choose their family size, and consequently the TFR will further increase to 1.76 before stabilizing at 1.68 in the late 21st century (Table S2). A TFR of 1.68 is close to the current average across all low-fertility countries, for example, the United States, Australia, Japan, Turkey, Germany, Russia, and Spain (Basten et al., 2013).

For the low fertility assumption, the TFR will stabilize at 0.97–1.22 (under the SSP1, SSP4, and SSP5 pathways), 1.23–1.42, and 1.26–1.42 in the late 21st century for one-child, two-child, and full liberalization policies, respectively (Table S3). Compared with SSP1 and SSP5, the higher fertility in SSP4 is mainly caused by the lower educational level. Constant decreasing trends in TFR are shown in the 21st century for the low fertility assumption under SSP1 and SSP5 for all three fertility policies (Table S3). For the high fertility assumption, the TFR will be 1.71, 2.05, and 2.11 in the late 21st century under the three fertility policies, respectively (Table S3).

Mortality. Under the medium scenario, life expectancies are assumed to approach the forerunner developed countries, with a constant increase of 2 years per decade. Under the low (high) mortality assumption, life expectancies are assumed to increase 1 year less (more) than in the medium scenario. A higher level of education corresponds to a longer life expectancy, and a 5-year difference is assumed for the no education and tertiary educated population. The difference between the no education and primary educated population is assumed to be 1 year, and there is assumed to be a 2-year difference between the secondary and tertiary educated population (KC & Lutz, 2017). The present lifespan is calculated based on observed mortality rates by age and sex in the base year 2010. According to the median assumption for China by the UN, the life expectancy for men (women) will increase from 74.23 (77.23) in 2010–2015 to 86.71 (88.18) in 2095–2100.

Migration. Although the provincial population can be substantially affected by migration, national-scale migration from and to other countries can be ignored for China. Following the projections by the UN, the medium assumption for the net migration rate is expected to increase from −0.357 per 1,000 population in 2010–2015 to −0.154/1,000 population in 2095–2100. Under the low and high migration assumptions, the net migration will be zero and twice that of the medium assumption, respectively.

2.3. Economic Model

The Cobb-Douglas production model is used to estimate GDP as a function of total factor productivity (TFP), capital stock (K), and labor input (LI). The equation is as follows:

$$Y = TFP * K^{\alpha} * LI^{1-\alpha}.$$

where Y is GDP, TFP is total factor productivity, K is capital stock, LI is the labor input, and α is the output elasticity on capital.

LI is a function of the actual number of working people (labor force participation, LFP) and the effective factor on labor. The LFP can be calculated using the working-age population (POP) and the LFP rate (LFPR), which is distinguished by age classes (aged 15–64 years and 65+). The effective factor on labor (H) is a function of education as represented by mean years of schooling (MYS). China's MYS in 2010 was approximately 9.1 years. Each additional year of schooling beyond the eighth year leads to a 6.8% increase in human capital, which corresponds to the average estimates for Organization for Economic Cooperation and Development countries (Hawksworth, 2006; Leimbach et al., 2017). The equations are as follows:

$$LI = (POP_{15\text{-}64} * LFPR_{65+} + POP_{15\text{-}64} * LFPR_{65+})^{*} H$$
$$H = e^{0.94+0.068*(MYS\text{-}8)}, \quad MYS > 8$$

The working-age population and education level are derived from the SSP population projections in this paper. According to the Sixth National Population Census, the LFP rate in 2010 data was 0.77 for the population aged 15–64 and 0.19 for the population aged 65+. The LFP rate for the working-age population aged 15–64 is assumed to be at medium, medium, low, medium, and high levels of participation under SSP1, SSP2, SSP3, SSP4, and SSP5, respectively, and will converge to 0.7, 0.7, 0.6 (the low end of the historical values for 2010 for the high income USA and EU15, medium income China and India, and low income Sub-Saharan Africa), 0.7, and 0.8 (upper end of historical values) in 2100 by linear interpolation. The LFP rate for the working population aged 65 and above is assumed to remain constant at the level of 2010 (Leimbach et al., 2017).

The parameters for GDP, TFP, K, and α in the base year 2010 are derived from the China Statistical Yearbook. TFP growth for different SSPs are assumed according to Leimbach et al. (2017). The capital stock K is calculated using the pursued approach under the condition that projections for LI and TFP are available. The parameters in the K calculation under different SSPs for China are described by Leimbach et al. (2017).

3. Results

Under the currently implemented two-child policy and the possible full liberalization policy, projections of the population by age, sex, and education and of the economy are presented and compared with those under the previous one-child policy.

3.1. Projected Population Size

Population trajectories for China are shown in Figure 1. If the previous one-child policy were followed, the population projections under SSP1, SSP2, SSP3, SSP4, and SSP5 would remain close to each other until approximately 2020. The population would peak at a 1,372.0 million (peak value in 2020), 1,390.5 million (2025), 1,407.3 million (2025), 1,369.8 million (2020), and 1,371.6 million (2020) under SSP1, SSP2, SSP3, SSP4, and SSP5, respectively. These differences among SSPs are mainly caused by the fertility assumptions. Even in the high fertility assumption under SSP3, which is 25% higher than in the medium assumption in 2050, the TFR (1.71) is below the replacement level (the average number of live births per woman required to keep the population size constant in the absence of migration). By the mid-21st century (2055), visible differences are projected, with the widest range between SSP3 and SSP4, at 145.1 million. By the late 21st century (2090), this range will further widen to 369.7 million. The population trajectories under SSP2 lie in the middle, at 1,390.5 million in 2025, 1,262.0 million in 2055, and 950.3 million in 2090. The population size under both SSP1 and SSP5 will decrease to 1,370 million in 2025, 1,214 million in 2055, and 784 million in 2090, which is higher than that under SSP4 but less than under SSP2. The fertility rates for SSP1, SSP4, and SSP5 are all below 1.3 in the late 21st century under the one-child policy (Table S3), but the mortality rate under SSP1 and SSP5 with a higher education level is lower than that under SSP4.

Under the two-child policy, a nonlinear trend is found in the population trajectories, with peak values appearing in approximately 2025 (population size: 1,389.4 million), 2035 (1,423.6 million), 2100 (1,614.4 million), 2025 (1,385.4 million), and 2025 (1,389.1 million) under SSP1–SSP5, respectively. The greatest differences are found between SSP3 and SSP4. The trajectories under SSP2 lie in the middle, with 1,416.8 million people in 2025, 1,382.6 million in 2055, and 1,242.9 million in 2090. The projected population under SSP1 and SSP5 are both 968 million for the late 21st century, about 27% less than that in 2010. Compared to the one-child policy, the largest difference is found under SSP3, in which the population will increase with a TFR greater than 2.0 in the late 21st century for the two-child policy (Table S3).

Similar to the two-child policy, under the full liberalization policy, the population will peak in 2025, 2040, 2100, 2025, and 2025 under SSP1–SSP5, reaching 1,389.4 million, 1,426.2 million, 1,696.6 million, 1,385.4 million, and 1,389.1 million, respectively. The largest differences are mainly at the end of the 21st century. In 2090, the total population will reach 999.1 million, 1,288.9 million, 1,616.2 million, 955.1 million, and 999.1 million under SSP1–SSP5, respectively. The TFR will reach 2.11 under SSP3, while constant decreases in the TFR are found for SSP1 and SSP5 even under the full liberalization policy (Table S3).

The current universal two-child policy and possible full liberalization policy would lead to at least a 5-year delay in the peak population and a 1.1–2.6% increase in the peak population compared to the previous one-child policy under four SSPs, with the exception of SSP3, for which a persistent increase in the size of the population is projected. With policy changes from the one-child to the universal two-child or full liberalization, the gaps in the size of the population under the different SSPs will widen. The population size will increase by 6.8–12.0% and 21.6–37.1% in 2055 and 2090, respectively, under the two-child policy relative to the one-child policy. Further increases of 0.6–1.0% and 2.5–4.0% are expected in 2055 and 2090, respectively, under the full liberalization policy relative to the two-child policy (Figure 2).

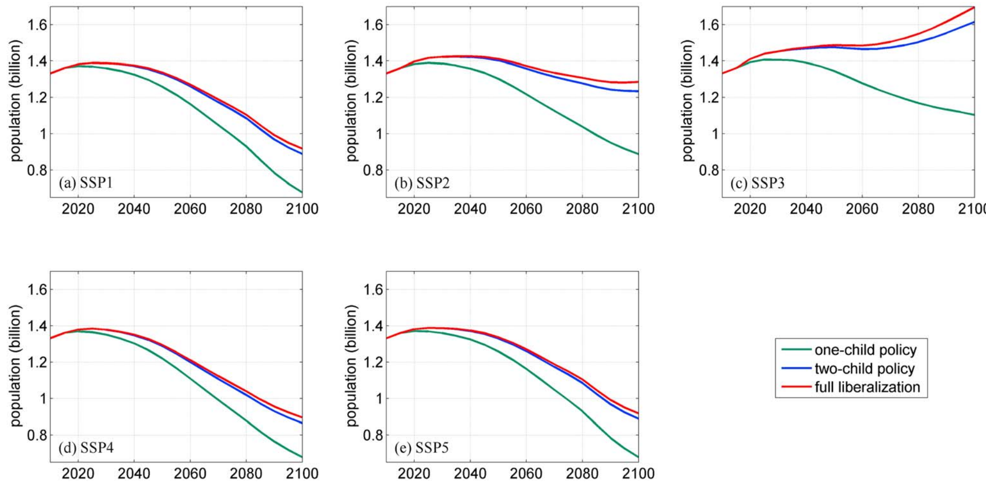

Figure 1. Comparison of projected populations in China for 2010–2100 under the SSPs and fertility policies (a-e). SSP = shared socioeconomic pathway.

3.2. Projected Population Structure

The population age pyramid in China from the 2010 census shows that the population sizes of children (age: 0–14), people of working age (15–64), and the elderly (>65) were 221.3 million, 992.6 million, and 118.9 million, respectively, accounting for 16.6%, 74.5%, and 8.9% of the total population (Figure S1).

If the one-child policy were followed, under the continuing historical trend reflected by SSP2, decreases are projected in terms of the proportion of both the working-age population and children, while the elderly share of the total population would increase at a rate of 3.2% per decade. The share of elderly people in China will be about 14% and 21% in 2024 and 2034, respectively, and will be 32% and 35% in 2055 (mid-21st century) and 2090 (late 21st century), respectively. The results under SSP1 and SSP5 are similar due to similar fertility, mortality, and educational attainment assumptions. Under SSP1 and SSP5, the elderly population will increase at a rate of 5.0% per decade in the 21st century and reach 38% and 49% of the total population in 2055 and 2090, respectively. Under SSP4, the elderly population will increase at a rate of 4.0% per decade, which is lower than that under SSP1 and SSP5 due to the higher mortality and lower level of educational attainment. The elderly proportion will reach 34% and 41% of the total population under SSP4 in 2055 and 2090, respectively. With high fertility, high mortality, and low education level, a lowest increase rate of 1.4% per decade is projected for the elderly under SSP3, and the elderly proportion will stabilize at 23% since the mid-21st century (Figures 3a–3e).

Compared with the one-child policy, a higher proportion of children and a lower proportion of the elderly can be found throughout the 21st century under all the SSPs with the universal two-child policy and the full

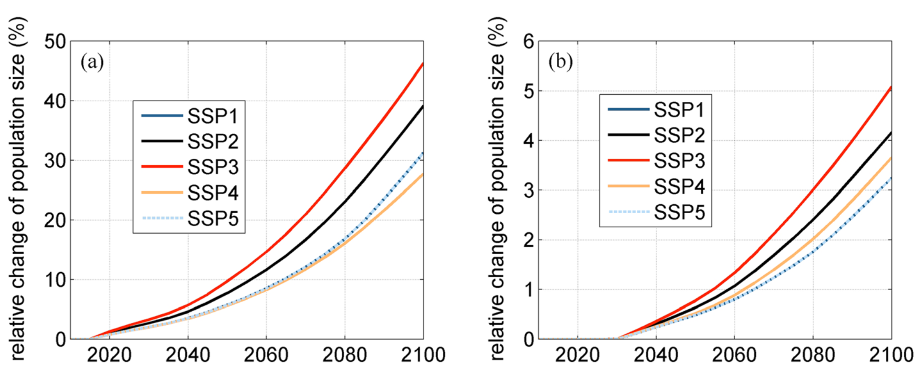

Figure 2. Relative changes of population size under the universal two-child policy with relative to the one-child policy (a), under the full liberalization policy with relative to the universal two-child policy (b). SSP = shared socioeconomic pathway.

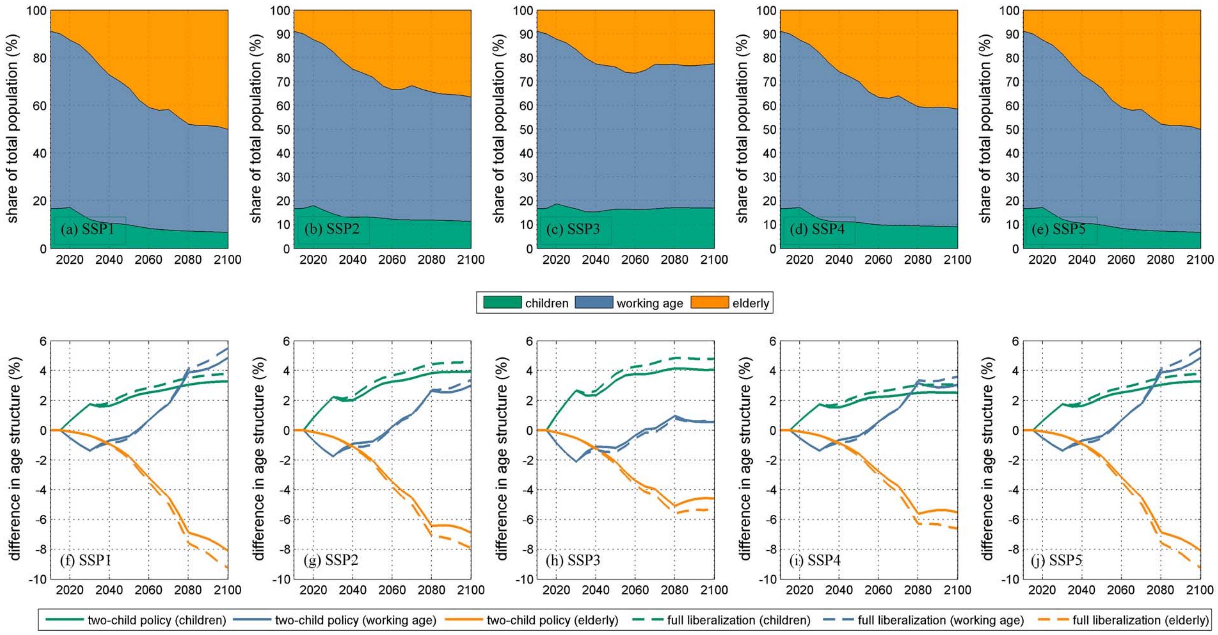

Figure 3. Projected population structures in China for the one-child policy (a–e), the two-child policy, and the full liberalization policy under five SSPs during 2010–2100. Difference in age structure between the two-child policy or the full liberalization policy and the one-child policy is shown in (f)–(j). SSP = shared socioeconomic pathway.

liberalization policy (Figures 3f–3j). Moreover, the increase in the proportion of children and the decrease in the proportion of elderly individuals continue over time. However, the proportion of the working-age population under both the universal two-child policy and the full liberalization policy will be lower than that under the one-child policy before 2040–2060, but this proportion will become higher thereafter under all five SSP scenarios. This phenomenon can be explained by the fact that the relaxation of family planning policy will lead to increased fertility and an increase in the population of children contemporaneously. However, there will be a 15-year lag before these children grow up and join the labor force. Relative to the one-child policy, the proportion of elderly people under the two-child policy will decrease by 2.2–2.8% (under five SSPs) and by 4.6–7.0% in 2055 and 2090, respectively. A further 0.2% and 0.7–1.0% reduction of the elderly share of the total population is projected under the full liberalization policy in 2055 and 2090, respectively. The current population policy and possible full liberalization policy will lead to an approximately 0.7–1.1% reduction in the proportion of elderly people per decade compared to the previous one-child policy.

The projections of the working age and elderly populations presented in Figure 4 show that the persistent decrease in the working-age population under the one-child policy will be alleviated as a result of the changes in population policy. Under the one-child policy, the working-age population will decline from 0.99 billion in 2010 to 0.35 billion, 0.50 billion, 0.68 billion, 0.38 billion, and 0.35 billion in 2090 under SSP1, SSP2, SSP3, SSP4, and SSP5, respectively. Under the two-child (full liberalization) policy, the working-age population will be 0.12 (0.14) billion under SSP1, 0.19 (0.21) billion under SSP2, 0.26 (0.30) billion under SSP3, 0.11 (0.13) billion under SSP4, and 0.12 (0.14) billion under SSP5 greater than that under the one-child policy by the late 21st century. The size of the elderly population will not be affected by the changes in population policy until the policy-affected populations become old; it is projected to reach a peak in 2060 and then decrease.

Pressure from labor shortages will increase with an increase in the elderly population. The dependency ratio (ratio of the non-working-age population to the working-age population) will increase from 0.34 in 2010 to approximately 0.81 (mean of the five SSPs), with a range of 0.74–0.88, in the mid-21st century (2055) under all three fertility policies, which is 2.4 times the level in 2010 and will further change to approximately 1.01 (0.68–1.25), 0.89 (0.66–1.06), and 0.88 (0.66–1.03) by the late 21st century under the one-child, two-child, and full liberalization policies, respectively (Figure 5). That is, the effects of the universal two-child policy and the full liberalization policy will be apparent in the second half of the century and will ease the pressure

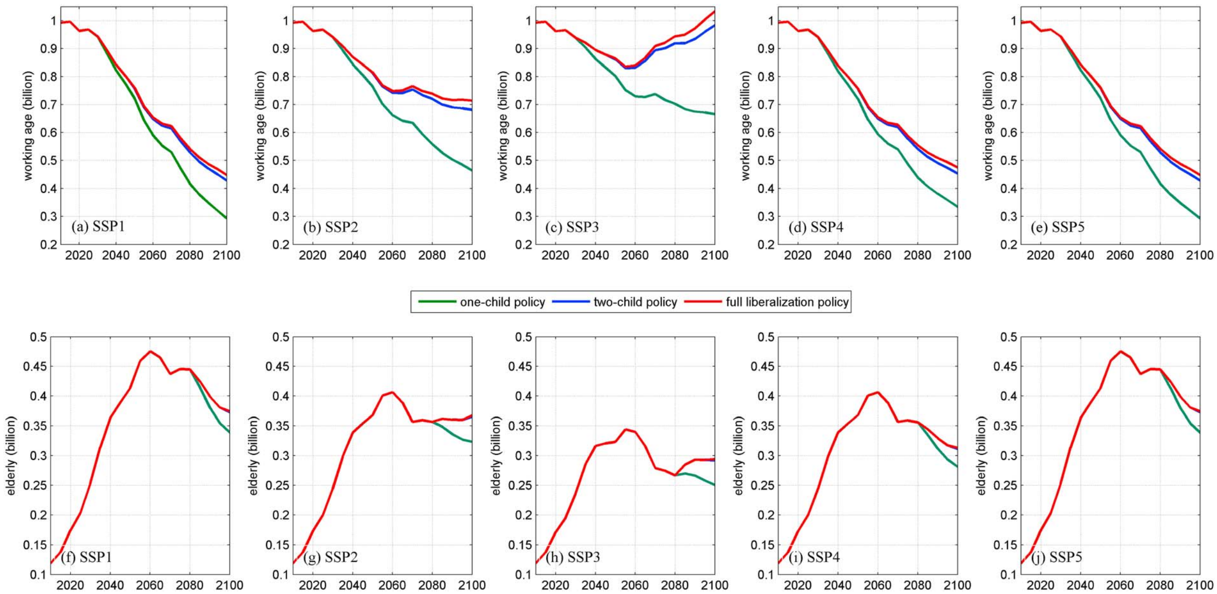

Figure 4. Projected working age population (a–e) and elderly population (f–j) in China in 2010–2100 for the one-child policy, the universal two-child policy, and full liberalization policy under five SSPs. SSP = shared socioeconomic pathway.

caused by the labor shortage. In the near term, the dependency ratio is slightly higher under the two-child and full liberalization policies than that under the one-child policy due to the increased newborn population (Figure 5).

3.3. Projected Educational Level

In 2010, the sizes of the population with no education, primary, secondary, and tertiary education were approximately 152 million, 357 million, 705 million, and 118 million, respectively.

If the one-child policy is continued, the population with lower education (no education or primary education) would decrease in the 21st century under all SSPs. The population with secondary education would peak in approximately 2030–2035 and then decrease gradually. For the population with a tertiary educational level, an increasing trend is projected in the coming decades, even under the scenarios of SSP3 and SSP4 with a constant school enrollment rate. Under SSP2 with a continued trend of historical patterns, the population with a tertiary education would be higher than that with secondary education and would be the largest cohort late in the century. Under the assumption of the most rapid educational growth rate to the level of Singapore and South Korea under SSP1 and SSP5, the population with tertiary education would be the largest cohort in 2070, and the proportion of people with tertiary education would be 63%, 42%, and 63% under SSP1, SSP2, and SSP5, respectively, late in the century. Under SSP3 and SSP4, where the school enrollment rate in the current period remains constant, the population with secondary education would always be the largest and would account for 55–60% of the total population (Figure 6).

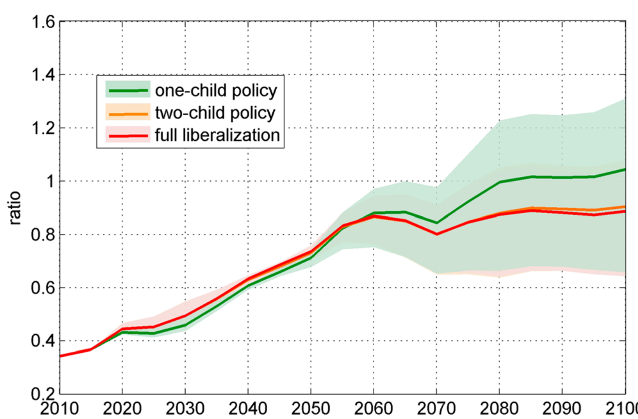

Figure 5. Ratio of nonworking age population to working age population in 2010–2100 for the one-child policy, the universal two-child policy, and full liberalization policy under five SSPs. Shadows and bold lines represent range and ensemble of five SSPs. SSP = shared socioeconomic pathway.

Relative to the one-child policy, an increase in the population with different educational levels is projected under all the SSPs for both the two-child and full liberalization policies. In the late 21st century, the largest increases would be found in the population with tertiary education under SSP1, SSP2, and SSP5 and in the population with secondary education under SSP3 and SSP4. Compared to the changes from the one-child policy to the two-child policy, fewer changes would occur from the two-child policy to the full liberalization policy. In the late 21st century, relative to the two-child policy, a further 5.6–6.8%, 5.1–6.1%, 1.4–3.2%, and 1.9–

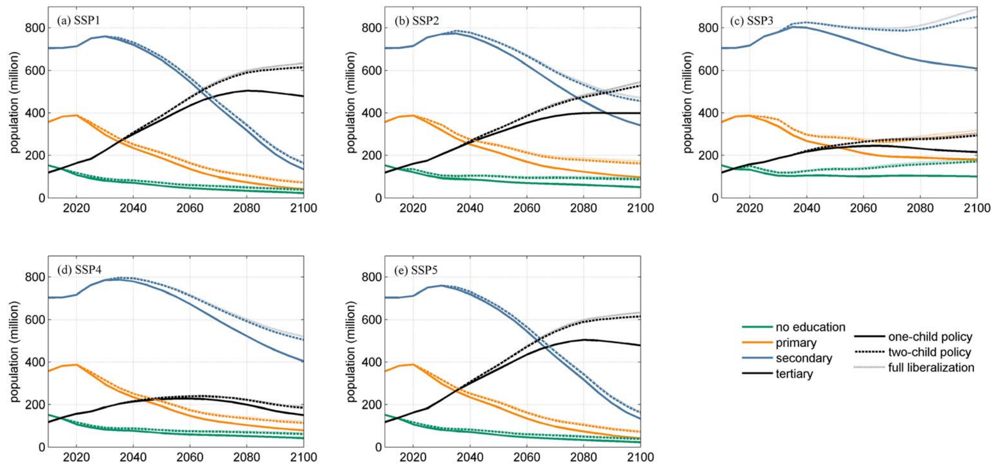

Figure 6. Changes of population with different educational levels under the different fertility policies and SSPs (a-e). SSP = shared socioeconomic pathway.

2.7% increase in the population with no education, primary, secondary, and tertiary education, respectively, is projected under the full liberalization policy for the different SSPs (Figure 6).

Education plays an important role in economic growth. Labor input into the economy is affected not only by the number of working-age people (aged 15–64 years and 65+) but also by the effective labor factor, which can be represented by the mean years of schooling (MYS). With an increase in the proportion of people with a higher level of education, the MYS will increase. The changes in the MYS among the population aged 15+ are presented in Table 1. Fewer changes in the MYS are projected under the different population policies for each development pathway, although differences are found among the SSPs under each population policy. Under SSP2, the MYS will increase from 9.1 years in 2010 to 11.5 years in the midcentury and will reach 12.9 years by late in the century. A higher education level can be found for SSP1 and SSP5 under the assumption of the fastest growth rate to the educational level of Singapore and South Korea, with the MYS reaching 14.2 years in the late 21st century. However, SSP3 and SSP4 show a relatively stable MYS in the second half of the 21st century under the assumption that the increase in the enrollment rate at each educational level will stagnate.

3.4. Development of the Economy

When the one-child policy is followed, a constant increase in GDP is projected under SSP2 and SSP5, while GDP either increases first and decreases then or remains stable under the other SSPs. When the GDP projections are standardized to 2015 prices, a peak of 46.5 trillion is projected in approximately 2070 under SSP1, 49.1 trillion in 2100 under SSP2, 33.5 trillion in 2100 under SSP3, 39.2 trillion in 2060 under SSP4, and 70.4 trillion in 2100 under SSP5. Under the two-child policy, all the trajectories show a persistent increasing trend, with the peak reaching 58.9 trillion, 69.5 trillion, 48.1 trillion, 45.5 trillion, and 97.9 trillion in the late 21st century under SSP1–SSP5, respectively, but a continuous decrease in the economic growth rate will occur in the second half of the century, especially for SSP1 and SSP4 (Figure 7). The percentage changes will be 6.0–9.1% for the five SSPs under the two-child policy relative to the previous one-child policy in the mid-21st century, which will increase to 38.1–43.9% late in the century. Furthermore, the percentage changes relative to the two-child policy will further increase by 0.5–0.6% in the midcentury and 5.3–6.7% late in the century under the different SSPs with the implementation of the full liberalization policy (Figure 7f).

Table 1
Mean Years of Schooling Among Population Aged 15 Years and Above in the Year 2010, 2055, and 2090 Under Five SSPs

	One-child policy			Two-child policy			Full liberalization		
Pathways	2010	2055	2090	2010	2055	2090	2010	2055	2090
SSP1	9.1	11.9	14.2	9.1	12.0	14.3	9.1	12.0	14.3
SSP2	9.1	11.5	12.9	9.1	11.6	13.0	9.1	11.6	13.0
SSP3	9.1	10.9	11.1	9.1	10.9	11.1	9.1	10.9	11.1
SSP4	9.1	10.9	11.2	9.1	10.9	11.2	9.1	10.9	11.2
SSP5	9.1	11.9	14.2	9.1	12.0	14.3	9.1	12.0	14.3

Note. SSP = shared socioeconomic pathway.

Population policy changes will affect the size of the working-age population and the elderly population as well as the MYS, and thereby influence regional economic growth. The relative changes due to the changes in policy and the contributions of different influencing factors are shown in Table 2. In the mid-21st century, GDP

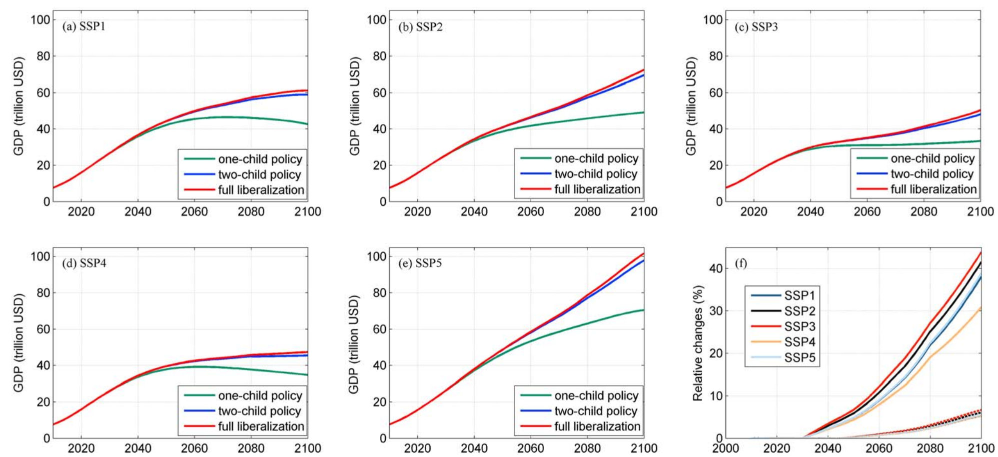

Figure 7. Projections of GDP in China for the one-child policy, two-child policy, and full liberalization policy under five SSPs (a–e) and relative changes for the different fertility policies (f). Solid lines in (f) are the changes of GDP for the two-child policy with relative to the one-child policy, and the dashed lines in (f) denote the further increase of GDP for the full liberalization policy as compared to results for the two-child policy. SSP = shared socioeconomic pathway; GDP = gross domestic product.

will increase by 2.3–3.4 trillion under the two-child policy for different SSPs and by 2.5–3.6 trillion under full liberalization relative to the one-child policy. The increase in the working-age population caused by the policy change will be responsible for more than 90% of the increase in GDP. Increases in the elderly population will not affect the relative changes in GDP until the late 21st century, with a contribution of approximately 3%. A larger contribution of education is found for SSP1 and SSP5 in the mid-21st century at approximately 8.4% due to the assumption of a higher enrollment rate at each education level. The enhanced education under SSP1 and SSP5 with the two-child policy (or full liberalization) would contribute approximately 0.25–0.29 (0.27–0.30) trillion and 0.42–0.60 (0.48–0.70) trillion to GDP in 2055 and 2090, respectively. For SSP2, the enhanced education would increase GDP by 0.14 (0.29) trillion and 0.11 (0.12) trillion with a shift from the one-child policy to the two-child (or full liberalization) policy in the middle and late 21st century, respectively, while less or even negative effects of education are projected under SSP3 and SSP4 due to the assumption of a low level of education.

If the previous one-child policy is continued, decelerated growth in GDP per capita is projected under SSP1, SSP2, SSP3, and SSP4 (Figure 8). However, rapid growth in GDP per capita in the 21st century is found under SSP5 at a rate of 10.5 thousand per decade in the 21st century, as this scenario has the fastest economic development and a decreased size of the population. In the near term, the increased GDP per capita is mainly due to the increased GDP for different SSP pathways. In the late 21st century, the increase in GDP per capita is mainly affected by the decrease in the size of the population, especially under the SSP1 and SSP4 pathways, in which GDP will decrease (Table S5).

Although increases in GDP per capita are projected under the two-child and full liberalization policies for different SSPs, the relative increase in GDP per capita caused by the policy change from the previous one-child policy to the current two-child (or possible full liberalization) policy will be found in the second half of the century with value higher 3.3 (3.7), 0.9 (1.0), 1.3 (1.5), and 6.1 (6.9) thousand USD than that in the previous one-child policy in the late century under SSP1, SSP2, SSP4, and SSP5, respectively (Figure 8). However, decreasing GDP per capita in the 21st century for the current two-child (or the possible full liberalization) policy relative to the previous one-child policy is projected under SSP3, mainly due to the increased population.

Table 2
Changes of Economy Due to Fertility Policy Changes (From the One-Child Policy to the Two-Child or the Full Liberalization Policy) Under Five SSPs (△1: Difference Between the Two-Child and the One-Child Policy; △2: Difference Between the Full Liberalization and the One-Child Policy)

		Economy (trillion USD)		Contribution (%) Working age		Elderly population		Education	
	Year	2055	2090	2055	2090	2055	2090	2055	2090
△1	SSP1	2.95	13.12	90.9	92.0	0.0	3.9	8.6	3.2
	SSP2	3.27	15.52	95.5	95.7	0.0	3.4	4.2	0.7
	SSP3	2.83	11.36	100.6	97.7	0.0	3.0	−0.6	−0.7
	SSP4	2.32	8.84	100.2	97.0	0.0	4.0	−0.2	−1.0
	SSP5	3.38	20.07	91.0	92.5	0.0	3.5	8.5	3.0
△2	SSP1	3.16	14.86	91.0	92.4	0.0	3.5	8.4	3.2
	SSP2	3.49	17.63	95.6	96.1	0.0	3.0	4.0	0.7
	SSP3	3.02	12.94	100.7	97.9	0.0	2.8	−0.7	−0.7
	SSP4	2.49	10.23	100.3	97.3	0.0	3.5	−0.3	−0.8
	SSP5	3.61	22.74	91.1	92.8	0.0	3.1	8.4	3.1

Note. SSP = shared socioeconomic pathway.

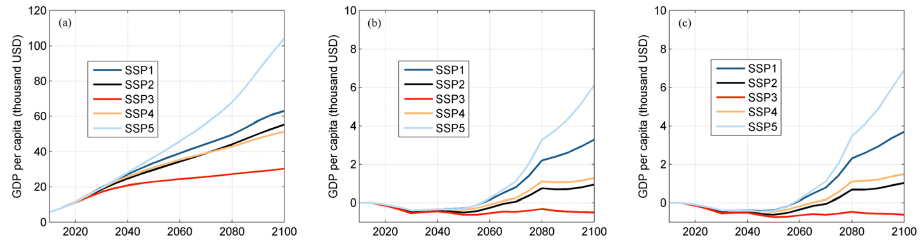

Figure 8. GDP per capita for one-child policy under five SSPs (a), changes of GDP per capita under the two-child policy with relative to the one-child policy (b), and changes of GDP per capita under the full liberalization policy with relative to the one-child policy (c). SSP = shared socioeconomic pathway; GDP = gross domestic product.

4. Conclusions and Discussion

By taking into account three policy interventions (the previous one-child policy, current two-child policy, and possible full liberalization policy) and new parameters from the latest 2010 population census, this study projects the population and economic growth in China under the five SSPs. This is the first time that both the newly implemented policy and census data have been used for population projections up to the year 2100 under the framework of SSPs. The integration of new information from the latest population census with the different development scenarios allows us to produce more realistic projections and explore the effects of fertility control policies with different levels of uncertainty.

The effects of population policy changes are mainly reflected in changes of fertility levels. Future fertility is a key factor in reliably projecting the size of the population. Due to various uncertain determinants (e.g., urbanization and education) of fertility, population projections based on either simple assumptions of total fertility or relatively complex total fertility deduced through combination of urban and rural fertility usually overestimated (United Nations, 2011; Zeng & Hesketh, 2016; Zeng & Wang, 2014). The uncertainties in population projections can be reduced by taking into account the child-bearing behaviors of people with different education levels. By considering the fertility trajectories of people with different levels of education, the TFR for the medium assumption under SSP2 will converge to 1.33, 1.64, and 1.68 in the late 21st century under the abolished one-child policy, the current two-child policy, and the possible full liberalization policy, respectively, and these values are all lower than the long-term convergent level of fertility of 1.75 in low-fertility countries (Basten et al., 2013). Under SSP2, population policy changes can lead to an increase in total fertility, but the decrease in the size of the population seems to be inevitable, with total fertility below the replacement level. The current fertility rate in East/Southeast Asian low-fertility countries with unrestricted fertility policies is approximately 1.27 (average of the TFR for Singapore, South Korea, Japan, and China-Hong Kong during the period 2010–2015 based on datasets from the UN Population Division), which is close to our low assumption for the long-term convergent level of fertility under the SSP1 or SSP5 by 25% less than the medium assumption of 1.68 (Table S2). Under the SSP1 and SSP5 pathways with low fertility assumptions and high levels of education, China will be in a “low-fertility trap” (Lutz et al., 2006), and the country's TFRs will continue to fall even under the possible full liberalization policy. Under the high fertility assumption for SSP3, the TFRs are assumed to be 2.05 and 2.11 under the two-child and full liberalization policies, respectively, which are 25% higher than under the medium assumption (Table S3). Thus, regardless of the possible pathways, the size of the population might increase under SSP3 with high fertility.

If the one-child policy is continued, the population would peak in 2020–2025 at approximately 1.37–1.41 billion and then gradually decrease under all of the development pathways. With the decrease in the size of the population, social pressures from aging problems and labor shortages would become more serious. The proportion of elderly population in China would be exceed 14% and 21% in 2023–2025 and 2033–2036, respectively, under the different SSPs, and further grow to 32% and 35% in the middle and late century, respectively, under SSP2, and would be 38% and 49%, respectively, under SSP1. With an increasing proportion of the elderly population and a decreasing working-age population, pressure from labor shortages would increase significantly, and the dependency ratio would increase to 2.4 and 3.0 times the current level in the middle and late 21st century, respectively. Furthermore, a decrease in the working-age population, as a key factor influencing the economy, would result in a decrease in the GDP growth rate, which might even become negative in the late 21st century under SSP1, SSP3, and SSP4.

Labor shortages and aging problems will be inevitable, but they can be mitigated to a certain extent by the current two-child policy. *First*, a decline in the population is projected under most of the SSPs (except for SSP3), but at least a 5-year delay in the peak value is projected under the current two-child policy compared to the previous one-child policy. Although the effect is marginal, with a peak that is only 1.1–2.6% higher, but increase of population size will be 22–37% under the five SSPs by the end of the 21st century. Under SSP3, with high fertility, high mortality, and a low education level, the size of the population will increase to 1.6 billion in the late 21st century. Our findings that the implementation of the universal two-child policy will result in prolonged population growth from 2010 to 2100 are consistent with projections by Zeng and Hesketh (2016), but their projected population sizes are higher when compared with our estimated results under the SSP2 continuation of historical trend pathway since they do not consider the effects of education. Fertility and mortality are influenced by education, with higher levels of education being consistently associated with lower fertility and lower mortality (Lutz et al., 2014; Lutz & KC, 2011). Thus, education-specific fertility and mortality should be taken into consideration. *Second*, compared to the one-child policy, the labor shortages and aging problems can be alleviated by the increase in the working-age population and the decrease in the proportion of the elderly population under the two-child policy. The two-child policy will boost the size of the working-age population when the new births in the current period join the labor market in approximately 2030. However, the pressure from labor shortages will not be eased until the midcentury because the dependency ratio under the two-child policy will still be higher than that under one-child policy in the first half of the century. *Third*, compared to the one-child policy, more working-age people with higher educational levels are projected under the universal two-child policy, which will lead to a 6.0–9.1% and 38.1–43.9% increase in GDP in the middle and late century, respectively, under the five SSPs. The increased GDP with the policy changes can be ascribed mainly to the changes in the working-age population, and partly to changes in the size of the elderly population and the educational structure. Better education can lead to long-term economic growth (Lutz et al., 2008). Under pathways with an assumed higher enrollment rate for different levels of education, the increased working-age population caused by the fertility policy change has a higher education level. Approximately 8.4% and 3.0% increases in GDP by fertility policy change can be ascribed to the higher education levels in the middle and late 21st century, respectively, under SSP1 and SSP5. *In addition*, along with changes in the size of the population and the economy, GDP per capita is projected to increase under all the SSPs and population policies. However, the relative increase in GDP per capita caused by the policy change from the previous one-child policy to the current two-child policy will be found only in the second half of the century under all other SSPs except SSP3. In the late 21st century, higher changes in GDP per capita between the one-child and two-child policies are projected for SSP1 and SSP5, with values reaching 3.3 and 6.1 thousand USD, respectively.

The universal two-child policy alone seems insufficient to solve the long-term prospects for labor shortages and aging problems. In addition, SSP1 and SSP4 are preferable to the implementation of the Paris Agreement (Hulme, 2016), but lower GDP growth rates are found for SSP1 and SSP4 than for the other SSPs in the second half of this century. Further relaxation of the fertility control policy may be needed to address the unavoidable social problems and promote economic growth, especially under SSP1 and SSP4. Full relaxation of fertility control, which can further mitigate the shortages in the labor force and the aging problems through a higher proportion of the working-age population and a lower proportion of the elderly population under each SSP, is therefore recommended. However, the effects of a full liberalization policy will again be limited. Despite the full relaxation of fertility control, actual fertility will not reach a high level because it is also determined by the other factors, such as mother's career, pressure from child rearing, and parental lifestyle (Jones, 2012; Zhang et al., 2016; Z. Zheng et al., 2009). Nevertheless, a further increase of 0.6–1.0% (under five SSPs) in the size of the population, a 0.2% reduction in the elderly share of the total population, and a 0.5–0.6% increase in GDP in the mid-21st century are projected under the full liberalization policy relative to the two-child policy, with the equivalent figures being 2.5–4.0%, 0.7–1.0%, and 5.3–6.7%, respectively, in the late 21st century. The effects of a full liberalization policy will appear in the late period of this century. The advantages from full liberalization can be quantified by the changes in the size of the population and the economy under all the SSPs in the long run.

Because of limited improvements in relieving the pressure from aging problems and labor shortages under the full liberalization policy compared to the universal two-child policy, other measures beyond fertility policy should also be considered, explored and implemented. First, policies that enhance education should be implemented, such as the National Mid- and Long-term Reform and Development Plan (2010–2020) and the plan to shift compulsory education from 9 to 12 years. A working-age population with a higher level of education can lead to further economic growth due to higher productivity. Second, one of the major challenges for China in the long run is pension fund balances, which are the key to achieving "a sense of security" for elderly people when the country becomes a more aged society. The pension system should therefore be strengthened. In addition, the current compulsory retirement age is 60. Thus, there is substantial room to raise the compulsory retirement age to 65 for both men and women, which would make it comparable to developed countries. After the implementation of the two-child or full liberalization policy in the near term, pressure will increase to improve child-rearing services and the provision of quality maternal health services. Solid measures must be taken to meet this demand. For example, three-generation living, as proposed in the "13th Five-Year Plan" for the development of Shenzhen's (in Guangdong Province) pension service industry, should be encouraged, as older grandparents can look after the children, and parents' labor participation rate can increase.

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