# Missing Women, Gender Imbalance and Sex Ratio at Birth: Why the One-Child Policy Matters

Wang, Qingfeng

University of Nottingham Business School Ningbo China

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Qingfeng Wang

University of Nottingham Business School Ningbo China

**Abstract**

In this paper, we show that the one-child policy has played a significant role in the decline of China's fertility. The one-child policy had reduced China's fertility rate by an additional 11.5%, based on a year-on-year comparison with the case if China had not implemented the policy. The methodology we introduced in estimating the number of "missing women" improves on the method employed in Anderson and Ray (2010). Our findings suggest that the one-child policy resulted in a total of approximately 11 million missing women in China, and contributed to more than 50% of its outstanding gender imbalance. The adoption of the one-child policy has prevented around 50 million births, and is confirmed to be the major cause of China's highly skewed sex ratio at birth.

*Keywords*: Fertility rate, Missing women, Gender imbalance, the One-child policy

*JEL*: J13, J18

# 1. INTRODUCTION

Mao Zedong's belief in "the more people, the more power", or the "the more children, the more fortune", may have been the root cause of China's high fertility rate in the early 1960s (Potts 2006; Banister 1987). The high fertility rate in China in the 1960s and the early years of the 1970s led to a rapid population growth in China during that time. In 1970, China's population exceeded 800 million[1], with more than 90% of its population living under extreme poverty[2]. The rapidly-growing population led to fears of a population explosion, while the stagnation of China's economic growth at the time made the problems of a swelling population more significant. Without satisfactory economic growth, providing food to 800 million people was a daunting task being faced by Chinese leaders in the 1970s, and if they were unable to accomplish this undertaking, it could have led to devastating social unrest and/or political violence. The Great Leap Forward (1958-1959) and the Cultural Revolution (1966-1976) were both detrimental to, and had a lasting impact on, China's economic and social development. In Chinese history, most previous dynasty changes were because of hunger, with governments often overthrown by peasants. This is summarized in a well-known Chinese saying found in the Records of the Grand Historian (known as 史记[3] Shi Ji), which says:

Hunger breeds discontent (民人以食为天)[4].

It was in 1978 that Deng Xiaoping became the supreme-leader of China, two years after the death of Mao Zedong[5]. China's ideological focus was about to shift from utopian socialism towards more economic development. Under his leadership, the reformist economic policies of Deng Xiaoping,

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[1] In 1970, China was the most populated country, with a population of 800 million, which was approximately 300 million more than India, the second most populated country. Its population had grown from approximately 500 million to 800 million in less than 20 years, and another 100 million was added to China's population in the next six years. Based on a modern estimation of its population, China has been the world's most populated country since its Warring States era (400BC) (Banister 1992).

[2] People living on the equivalent of US$1.90 or less per day in 2011 purchasing price parity terms. In 1970, China had a GDP per capita of approximately 230 US dollars and was among the 10 poorest countries in the world.

[3] *The Records of the Grand Historian* was written by the great Chinese historian, Sima Qian (司马迁: 145BC-86BC), and recorded the 2,500 years Chinese history from the legendary Emperor Huang to the early years of Emperor Han Wu.

[4] 《史记·郦生陆贾列传》: "王者以民人为天，而民人以食为天." 《hànshū·lì yī jī chuán》: "wáng zhě yǐ mín wéi tiān，ér mín yǐ shí wéi tiān". The direct translation of the Chinese saying is "The king regards his people as heaven, people regard food as their heaven". Others have translated it as "People are the most important to an emperor, while foods are the most important to the people".

[5] Mao Zedong, or Chairman Mao, was the supreme leader of the People's Republic of China between 1949 and 1976.

Liu Shaoqi and others, which had been opposed and abandoned by Mao[6], began to roll out throughout China. These economic policies were labelled as the 'Open Door Policy'. Against a backdrop of this economic and social environment, the Chinese government commenced its one-child policy in 1979, which was aimed at accelerating the speed of bringing down its population growth both rapidly and effectively, and alleviating any potential social and economic problems as a consequence of a rapidly growing population.

A number of family planning policies were put in place before the one-child policy to slow down its population growth, including the "Later, longer, fewer" campaign (Tien 1980) which ran with the slogan that "One is not too few, two, just right, and three, too many" (Liang and Lee 2006). This campaign can be considered to have been effective in reducing the growth of China's population, as evidenced in the sharp decline of China's fertility rate during the campaign from six births to approximately three births per woman. However, the dramatic decline in the infant mortality rate and the significant increase in life expectancy[7] considerably offset the effectiveness of its ability to control China's population size. Given China's huge population, even a small growth in the fertility rate can still lead to a sizable increase in the population size. The one-child policy bore the mission of safeguarding social stability and economic gains, which could have been undermined by China's expanding population. The strictness of the policy was perfectly reflected in Deng Xiaoping's instruction to the State Population Council, in which he asserted that "so long as you bring the population down, I don't care how you do it."[8] China's one-child policy was considered by many as one of the most extreme examples of government intervention in human reproduction (e.g., Wang et al. 2013). As the policy imposed a one child per family limit on Chinese families[9], it freed millions of working-aged citizens from the burden of raising larger families[10], thereby helping to mobilize more resources, such as the labor force, into economic developments. At the inception of the one-child policy, China enjoyed a very low old-age

[6] In the early 1960s, their economic reforms were considered generally popular, which threatened the popularity of Mao. In 1966, Mao launched the Cultural Revolution, which aimed to root out right-wing capitalists, which included economic reformer Deng Xiaoping, who was forced to resign from all his political positions.

[7] Infant mortality in China declined dramatically from 227 per thousand births in 1949 to 79 per thousand in 1970, while life expectancy at birth increased significantly from approximately 35 years in 1948 to around 60 years in 1970, according to World Population Prospects: 2010 Revision.

[8] Bao Fu, Zhongguo Dalu, supra note 130, at 37.

[9] Exceptions were given to ethnic minorities, and families experiencing practical difficulties. The policy undertook several modifications, including the case of rural householders who could apply to have a second child if their first-born was a daughter; and parents could have two children when both parents were an only child. Families whose first child suffered from a disability or mental illness, could also have two children.

[10] Having a large family was a social norm and common practice before the one-child policy.

dependency ratio (7.8%), while it had a relatively high young-age dependency ratio (62.48%), and a large and growing working-age[11] population, which provided a solid and healthy population basis for China to implement its one-child policy, without weakening its labor supply for many years to come. The increasing ratio of the working-age to the non-working-age population (i.e. the demographic dividend) provided China with an abundant, young and cheap labor force to support its economic development, especially in the labor-intensive industries. Furthermore, members of the single child generation enjoy many privileges through being the only child of the family. Families with a single child, or those who expect to have only one child, can devote more human capital to their children (Becker et al. 1990; Zhang 2017). The one-child policy helped China to rapidly build up its human capital, triggered by an unnatural cause – the one-child policy - and this happened faster than it would have done if China had not implemented the policy. Furthermore, under the one-child policy, it became possible for families to save more money, which would otherwise have been spent on raising more children. In return, this hypothetical increase in savings could provide additional financial resources to China's economic development during its early years. Therefore, from an economic point of view, the one-child policy alongside the 'Open Door Policy' was able to provide significant support for the successful implementation of the reformist economic policies.

Between 1970 and 2015, China experienced a steady decline in its fertility rate, and it has dropped to a historical low of approximately 1.6 births per woman since 1995. In the meantime, a steady and continuous decline in the fertility rate was also taking place in countries across the world (e.g., Van De Kaa 1987), in both high and low fertility regimes (Strulik and Vollmer 2013), and across countries in different income categories (Wang and Sun 2016). An inverse relationship between income per capita and fertility rate has been reported (e.g., Schultz 2005). The decline in fertility rates observed during times of economic growth can be partly explained by the commonly observed phenomenon that economically well-off parents display a desire for a higher quality, rather than a higher quantity, of children (Becker and Lewis 1973). The increased level of urbanization and improved human capital strengthen the negative effects of economic growth on

[11] The size of the working-age population was approximately 1.42 times that of the non-working-age in 1978. On the one hand, the one-child policy helped to control the growth of the young cohort of the non-working-age population, while on the other hand, those who were born three to four decades before the one-child policy when China had a high fertility rate, poured into China's workforce during the one-child policy. All these factors ensured a large and growing working-age population during the era of one-child policy.

fertility (e.g., Wang and Sun 2016). Unlike most countries with a low fertility rate, China experienced an extremely skewed sex ratio at birth[12], both during and after the one-child policy era. Economic growth is unable to explain a large part of the sharp decline in China's fertility rate, which was in clear contrast to the slower declines recorded in other developed economies, and the significant changes in China's sex ratio at birth in recent decades.

The global population-control movement that "designed and advocated a number of policy measures aimed at lowering fertility rates across the world" (de Silva and Tenreyro 2017) coincided with the timing and speed of the fertility decline. Very different views exist on how the one-child policy affected China's fertility rate. On the one hand, many researchers share the view that the one-child policy did help to reduce China's fertility rate, but it is not considered to be the fundamental driving force for the current low fertility rate (e.g., Wang et al. 2013; Whyte et al. 2015). Some have argued that China could have reached a relatively low-level fertility rate even without the policy (e.g., Yong 2010), while others attribute the significant decline in China's fertility rate to the "Later, Longer and Fewer" campaign which prevailed in the 1970s, and the rapid economic growth witnessed since the 1980s (Whyte et al. 2015). On the other hand, de Silva and Tenreyro (2017) argued that "population control policies are likely to have played a central role in the global decline in fertility rates in recent decades, and can explain some patterns of that fertility decline that are not well accounted for by other socioeconomic factors". The one-child policy was much more punitive and stricter in its nature than the "Later, Longer and Fewer" campaign, as less severe measures were put in place in the campaign compared to those for the one-child policy. The main mechanism of the one-child policy was to have women at childbearing age sterilized, or to have a contraceptive intrauterine device (IUD) installed surgically after the birth of their first or second child[13]. This affected hundreds of millions of women (Kaufman 1993). For those who were determined not to comply with the rules, sanctions ranged from stiff financial fines, the withdrawal of their social benefits, removal from their jobs, confiscation of property, and even forced abortions (Jimmerson 1990). The large number of women at childbearing age who were sterilized or fitted with IUDs essentially guaranteed the efficacy of the implementation of the

[12] This refers to the number of male births per female births and is measured on a five-year average.

[13] This depends on the family's hukou status and whether they held agricultural or nonagricultural household registration (Hukou is a system of household registration in mainland China.), and also on the place in which their residence is registered, as the strictness in the implementation of the one-child policy varied across different provinces. Women with a non-agricultural hukou status were required to install a IUD after the birth of their first child, while women with an agricultural hukou status were required to install a IUD if their first born was a boy.

policy aimed at reducing China's fertility rate. The one-child policy was an unnatural way of controlling China's population growth, and there were many adverse consequences associated with the policy which could also have exerted an indirect impact on the fertility rate. On the economic front, in the year 2000, China had moved up 60 places in our sample of 186 countries from being among the five least developed countries in 1978. While it is evident that economic forces played an immensely important role in China's battle with its high fertility rate, its impact is unfolding gradually in reducing the fertility rate. Given that China's GDP per capita was only approximately US$1,771[14], or approximately US$5 per day in 2000, it is believed that the level of severity of the iron-fisted implementation of the one-child policy has been underestimated by many.

The one-child policy was enforced alongside several decades of rapid economic growth, which makes it very difficult to disentangle the effects of the policy from the effects of the rapid socioeconomic development. Meanwhile, the rapid economic growth has largely outshone the role played by the one-child policy in controlling China's population and in shaping the population structure. Therefore, it is not clear that how much the one-child policy contributed to China's low fertility rate, gender imbalance and highly skewed sex ratio at birth. And, it is important, although tremendously challenging to identify and measure quantitatively, how the one-child policy influenced China's fertility rate, as well as its gender imbalance, and the composition of its population. The relaxation of the one-child policy at the beginning of 2016 created a natural experimental setting, enabling researchers to study the extent to which the transition to low fertility was accelerated by the one-child policy, and its impact on a number of population dimensions, such as China's gender imbalance and sex ratio at birth. This paper improves on the existing literature in a number of dimensions. First, by employing a synthetic control method (Abadie et al. 2010; Abadie et al. 2015), we have been able to disentangle the impact of the one-child policy from other factors (e.g., economic factors), such as that on China's fertility rate. Using a synthetic control method, we have modelled the evolution of China's fertility rate, sex ratio at birth, and population distribution by age-group as if China had not implemented the one-child policy. The synthetic control method identifies and assigns weights[15] optimally to countries which shared large similarities in some of the populations, and economic and social characteristics with China,

[14] Data are in constant 2010 U.S. dollars.
[15] These weights minimize the Root Mean Squared Prediction Errors between the predictions and the actual observations of a given variable.

including population distribution by age and gender, fertility rates and levels of economic development. In the synthetic exercises, we also required these countries to be free from stringent population control policies and large-scale wars during the time period from 1968-2015. Following this approach, any decline in the fertility rate which can be attributed exclusively to the one-child policy can be largely untangled from the impact of China's socioeconomic development on its fertility rate. Our results confirm that the one-child policy contributed an additional 11.5% to the reduction in China's fertility rate when compared to the case if China had not implemented the policy. Due to the high failure rates of IUDs, the rural population's strong resistance to the one-child policy at its inception, and the higher than expected economic growth, the effectiveness of the policy was not as effective as some scholars have suggested. Our overall findings suggest that approximately 50 million live births [16] which were averted between 1980 and 2015 were attributable to the one-child policy, which is a significantly smaller number than those previously suggested at 400 (or 338) million[17] (e.g., Goodkind 2017; Wang et al. 2013) – a calculation which came originally from a project supported by China's National Population and Family Planning Commission (CNPFPC) (Yang et al. 2000). Our results suggest that the one-child policy noticeably accelerated the decline in China's fertility rate, and without the one-child policy, it would have taken many more years to achieve the current low level of the fertility rate.

Second, this paper has investigated the consequences of the one-child policy, including the sex ratio at birth and the gender imbalance. China's economic success has largely downplayed the negative consequences of the policy. Given the prevailing and strong son preference culture in China, the one-child policy is very likely to have done more harm to the sex ratio at birth than the "Later, Longer and Fewer" campaign, as the policy imposed the limit for a very large number of Chinese families, while the "Later, Longer and Fewer" campaign was based on a voluntary family planning policy. The sex ratio for higher order births observed in China[18] was heavily skewed towards males during the policy compared to that seen during the "Later, Longer and Fewer" campaign, which coincided with the high number of incidents of Chinese parents' sex selection at birth, and a significant increase in the incidence of infanticides and sex-selective abortions. Because of its strong son preference culture, and the fact that abortion is not illegal in China

[16] In calculating the number of unborn children due to the one-child policy using the synthetic fertility rates, we have considered the year-to-year mortality rate at birth during the period of one-child policy.
[17] For the method used in estimating the 400 million and comments thereon, see Wang et al. (2013).
[18] For example, see Zeng et al. (1993) and Das Gupta (2005).

(Hesketh 2011), the one-child policy led to a high number of sex-selective abortions. Furthermore, a large number of missing girls have been reported or discussed as an unintended consequence of the one-child policy (e.g., Ebenstein 2010; Anderson and Ray 2010; Sen 1990; Coale 1991). Our findings confirm that the one-child policy is the major cause of China's distorted sex ratio at birth, which is currently standing at approximately 1.16 male births per female birth. Based on our estimated results, China could have a sex ratio at birth of approximately 1.07 if the "Later, Longer and Fewer" campaign had continued, rather than the one-child policy. The one-child policy is estimated to have resulted in a total of (approximately) 10,690,260 missing females in China between 1980 and 2015. Our estimations suggest that the one-child policy contributed more than 50% of the (approximately) 40 million gender imbalance observed in 2015.

Third, the paper details the impact of the one-child policy on China's population composition in respect of age. They confirm that the policy had a more profound impact on the younger age cohorts (i.e. the age-group 0-14 years and the age-group 15-19 years) when compared to the older age-groups (age-group 20-34 years). The significantly lowered young-age dependency ratio will be translated into a relatively higher old-age dependency ratio in the future.

A detailed description and analysis of these findings are presented in the main body of this paper, but two concerns remain, namely: 1) that China differs significantly in terms of its culture from many of the countries used in the study, and specifically, the impact of its son preference culture on the sex ratio at birth may not be observed in many of the countries used in the study. To incorporate this consideration into the study, we examined the robustness of the results regarding the sex ratio at birth by only using data from Confucian societies[19], including Hong Kong, Macau, Singapore, Taiwan, Japan and South Korea. However, the findings from using only Confucian societies were not qualitatively different from the findings when using other countries. 2) Those countries identified by the synthetic control method were very similar to China. If that was only true before the introduction of the one-child policy, not while it was in force, consequently, the replication of China's evolution of the outcome variables of interest can still be misleading. To test the robustness of the results by the countries identified by the synthetic control method, we examined the differences between these and China, and compared them with the differences

[19] Deep-rooted Confucian values and patriarchal family systems have contributed to a son preference culture in these countries/regions.

between China and other countries during the one-child policy in the difference-in-difference framework. Our findings confirm that the countries identified by the synthetic control method had either an insignificant difference with China during the policy or had a significantly smaller difference with China than the other countries.

The remainder of this paper is structured as follows. Section 2 describes the various datasets used and the methodologies adopted throughout the study, while Section 3 presents the main results of the paper, and Section 4 offers concluding remarks.

## 2. DATA AND METHODOLOGIES

2.1. *Data*

Throughout the paper, we have used data from the following data sources: the World Bank (the World Development Indicator 2017), the World Health Organization (WHO), World Population Prospects: 2017 Revision (United Nations Population Division), the World Urbanization Prospects: 2018 Revision (United Nations Population Division), the National Bureau of Statistics of China, KNOEMA[20], Lopez et al. (2001) and the Centre for Systemic Peace.

The GDP per capita (constant 2010 US$)[21] and the infant mortality rate (females and males separately) per 1,000 live births[22] are taken from the World Bank. The interstate, societal and communal warfare scores[23] are taken from the Centre for Systemic Peace, which is used to measure the political and social stability of a country. Data on life expectancy at birth (total years)[24], young, as well as old-age dependency ratios, population distributions (by age-groups and gender)[25], total

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[20]This can be accessed via https://knoema.com/

[21] This is the GDP divided by the mid-year population without making deductions for the depreciation of fabricated assets or for the depletion and degradation of natural resources.

[22] The vital registration data are the main sources of information on infant mortality rates. For developing countries, the absence of the complete registration data is common, and the WHO estimate the mortality rate using various techniques on the available registration, survey or census data. For example, the female infant mortality rate is the number of infants dying per 1,000 female live births before reaching one year of age in each year.

[23] These scores range from 1 to 10, with 1 being the lowest if there is political violence, and where 0 denotes no episodes of political or social unrest.

[24] This is the average number of years that a newborn child is likely to live, assuming that the mortality patterns at the time of its birth continue in the future. It has taken into account the overall mortality level of a population and the mortality patterns exist across all age-groups in a given year.

[25] We first obtained data, for example, on each population age-group (female) as a percentage of the total female population, as well as data on the percentage of the total female population of the total population in each year. Then, the percentage of a given

fertility rate[26] and the sex ratio at birth all come from the World Population Prospects: 2017 Revision, while the data on urban populations (referred to here as urbanization[27] in subsequent sections) is taken from the World Urbanization Prospects: 2018 Revision (United Nations Population Division). The number of newborns[28] between 1980 and 2015 comes from the National Bureau of Statistics of China and KNOEMA, and China's life table[29] is taken from Lopez et al. (2001). Most of the data covers a sampling period between 1968 and 2015. The data on interstate, societal and communal warfare scores were only used to eliminate from the synthetic exercises those countries which have undergone major episodes of political violence. All data are measured on an annual frequency. The dataset contains 186 countries that have no missing data on the variables discussed in this section.

### 2.2. *Methodologies*

The main empirical analysis and subsequent findings in the paper are based on the following methodologies. In this section, we first demonstrate how we employed the synthetic control method to estimate the impact of the one-child policy on China's fertility rate, and then we introduce the methods used to estimate the number of births prevented by the one-child policy, the extent of the gender imbalance, and the number of "missing women" during the one-child policy, respectively.

#### 2.2.1. *Synthetic Control Method – Fertility rate*

For the sake of clarity, we have only presented the application of the synthetic control method to the study of China's fertility rate. The same method has been applied to the studies regarding the impact of the one-child policy on other dimensions, such as China's sex ratio at birth. The rapid economic growth and social changes in China over the last few decades, alongside the one-child

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population age-group (female) as a percentage of the total population can be calculated as $\frac{\text{population age-group (female) as \% of total female population}}{\text{total female population as \% of the total population}}$.

[26] This represents the number of children that a woman would give birth to by the end of her childbearing age, in accordance with the age-specific fertility rates of the specified year. It is estimated as $\text{TFR} = 5 * \sum ASFR_a \ (for\ 5\ year\ age\ groups)$, where $ASFR_a$ represents the age-specific fertility rate for women in age-group a.

[27] Here, urbanization is measured using the percentage of the urban population to the total population in each year. A significant growth of an urban population is associated with economic transitions from an agriculture-based economy to a more industrialized economy.

[28] The number of births per year in China.

[29] The life table summarizes the mortality conditions prevailing in China, and is constructed using registered death data by age and sex. "Deaths at each age are related to the size of the population in that age-group, usually estimated from population censuses, or continuous registration of all births, deaths and migrations. The resulting age-sex-specific death rates are then used to calculate a life table" (Lopez et al. 2001).

policy and other factors, have jointly shaped the evolution of China's fertility rate. The synthetic estimations, using input from countries which share similar characteristics with China, have been used to capture the contributions of socioeconomic developments and factors other than the one-child policy on China's fertility rate, given that these countries have not implemented stringent population policies or experienced any large-scale wars. Thus, the difference between the actual fertility rate and its synthetic counterpart can be used to estimate the impact of the policy.

The one-child policy was introduced in 1979, so in the paper we have specifically assumed that the one-child policy exerted its impact on China's fertility rate beginning from the year 1980. Theoretically, the loss or gain in China's fertility rate as a result of the policy for the period 1980 to 2015 can be estimated using:

$$\Delta_{\mathrm{t,with-without}} = FR_{t,China} - FR_{t,Synth} \tag{1a}$$

$$\mathrm{Total}_{\Delta_{\mathrm{with-without}}} = \sum_{t=1980}^{2015} \Delta_{\mathrm{t,with-without}} \tag{1b}$$

$$\mathrm{Total}_{\Delta_{\mathrm{with-without}}}(\%) = \frac{\sum_{t=1980}^{2015} \Delta_{\mathrm{t,with-without}}}{\sum_{t=1980}^{2015} FR_{t,Synth}} \times 100\% \tag{1c}$$

where $FR_{t,China}$ represents China's actual fertility rate, and $FR_{t,Synth}$ represents the estimated fertility rate by using countries other than China, while $\mathrm{Total}_{\Delta_{\mathrm{with-without}}}$ measures the aggregated difference between China's actual fertility rate and its synthetic counterpart during the life of the one-child policy. The data on $FR_{t,China}$ are observed, but $FR_{t,Synth}$ are not observable. To construct a credible counterfactual $FR_{t,Synth}$, the synthetic control method was used to identify those countries which can be used to more accurately model the evolution of China's fertility rate if it had not implemented the one-child policy. We have used data from a sampling period between 1968 and 1979 to identify the appropriate comparable countries, based on a mixture of characteristics such as GDP per capita, population distribution in age and gender, infant mortality rates, the level of urbanization and sex ratio at birth, and with the requirement that none of the selected countries had implemented any stringent population control policies[30] nor had been

[30] We first ran synthetic exercises using different combinations of social, economic and population characteristics, until the difference between China's actual fertility rate and its synthetic rate could not be reduced any further. The algorithm performs 100 iteration (higher number of iterations do not produce significantly better results) and that process also identified and assigned optimal weights to those countries which were most similar to China. Then, we manually checked whether these countries had evidence of significant funding for family planning by consulting funding data in Nortman and Hofstatter (1978), Nortman (1982),

involved in any major wars between 1968 and 2015[31]. The synthetic control method then assigned regression weights to those countries to replicate the evolution of China's fertility rate. The combination of weights[32], which minimize the distance of

$$\text{argmin}_{\{w \in W\}} \sqrt{(u_{China} - u_{Synth}W)'V(u_{China} - u_{Synth}W)}\ , \quad (2)$$

have been used in the subsequent estimations of China's fertility rate. In equation (2), $u_{China}$ represents a vector containing the social, economic and population characteristics[33] of China prior to the one-child policy, while the matrix $u_{Synth}$ represents the same characteristics as $u_{China}$ for countries other than China. The vector W contains the non-negative weight assigned to the $i$-th country with $\sum_i w_i = 1$, while V is a $m \times m$ diagonal and positive definite matrix comprising the non-negative weights measuring the importance of each characteristic. These weights minimize the root mean squared prediction error between China's actual fertility rate and its synthetic fertility rate during the period 1968-1979. More specifically, the equations (1a to 1c) can be estimated using:

$$FR_{t,Synth} \cong \widetilde{FR}_{t,Synth} = \sum_{i=1}^{185} w_i * FR_{t,i} \quad (3a)$$

$$\Delta_{\text{t,with-without}} = FR_{t,China} - \widetilde{FR}_{t,Synth} \quad (3b)$$

$$\text{Total}_{\Delta_{\text{with-without}}} = \sum_{t=1980}^{2015} (FR_{t,China} - \widetilde{FR}_{t,Synth}) \quad (3c)$$

$$\text{Total}_{\Delta_{\text{with-without}}} (\%) = \frac{\sum_{t=1980}^{2015} (FR_{t,China} - \sum_{i=1}^{185} w_i * FR_{t,i})}{\sum_{t=1980}^{2015} \sum_{i=1}^{185} w_i * FR_{t,i}} \times 100\% \quad (3d)$$

where $i$ represents the $i$-th country.

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and Ross et al. (1993), and assessed the severity of their population policies based on the information found using Google searches. If a country had no major funding reported in supporting family planning and no headlines with content harshly criticizing its population policies, that validated the use of the country in the synthetic exercises (supposing the country had passed the 'no major war' requirement).

[31] This was done by using the war list table composed by the Centre for Systemic Peace, which can be accessed via http://www.systemicpeace.org/warlist/warlist.htm

[32] The combination of weights minimizing Eq. (2) was selected. The minimization was implemented using the SYNTH command in STATA. The combination of weights was robust to the number of iteration procedures executed by the routine. Greater weights were assigned to highly predictable variables (characteristics) (See Abadie et al., 2003 and Abadie et al., 2010).

[33] See Appendix A.

We have used a different combination of characteristics to carry out robustness tests of the estimation results. To further validate the estimation results, we also implemented a set of placebo estimates (difference-in-difference) on pairs of years from the pre-one-child period of 1970 to 1979, a period when the one-child policy was not in force, to confirm that countries identified by the synthetic methods were indeed very similar to China before the one-child policy. We also carried out a difference-in-difference test to confirm whether countries identified by the synthetic control method were more similar to China than the other countries during the era of the one-child policy.

2.2.2. *Method used in estimating the gender imbalance*

Using the synthetic fertility rate, the prevailing yearly infant mortality rates, the population distribution both by age-group and by gender as a percentage of the total population, and the reported number of newborns from 1980-2015, we were able to estimate the number of live newborns in each year between 1980 and 2015 if China had not implemented the one-child policy as:

$$LiveNewborn_{China,\ t} = \frac{NewBorn_{China,t}}{FR_{China,t}} \times \widetilde{FR}_{Synth,t} \times (1 - MortaInfant_{China,t}) \qquad (4)$$

where the mortality rate in infant births per 1000 is denoted as MortaInfant. The first term of the right-hand side of the equation (4) estimates the number of women who have given births in year t. This is a reasonable way of estimating the number of women who have given birth in year t as i) the one-child policy did not have significant impact on people's intention to have a child[34] and ii) the 35 year-old policy did not significantly reduce the number of women who were born during the policy and would reach childbearing age, given that the policy was not effective from 1980-1990. The next term in the equation estimated the number of newborns at year t, if China had not implemented the one-child policy, by multiplying the estimated number of women who had given birth in year t by its corresponding synthetic fertility rate, $\widetilde{FR}_{Synth,t}$. By taking into account the mortality rate in infant births, the equation estimated the number of live newborns at year t if China

[34] By using the survey data collected by JiangShu Provincial Population and Family Planning Commission with approximately 20,000 participants, we reported in another working paper that the one-child policy had no impact on people's intention to have a child.

had not implemented the one-child policy. Hence, the total number of living births prevented by the policy is calculated as

$$\text{LiveBirth}_{\text{China}} = \sum_{t=1980}^{2015}(\text{LiveNew}born_{China,\ t} - NewBorn_{China,t} \times (1 - \ MortaInfant_{China,t})).$$

Using the prevailing sex ratio at birth from 1980-2015, we were able to estimate the gender imbalance as a result of the one-child policy. The total gender imbalance is the difference between the estimated total gender imbalance under the one-child policy and the estimated total gender imbalance if China had not implemented the policy. The estimated total gender imbalance as a result of the one-child policy is calculated as follows:

$$\sum_{t=1980}^{2015} NewBorn_{China,t} * \left(1 - \ MortaInfant_{China,t}\right) \times \frac{SexRatioAtBirth_{China,t}-1}{SexRatioAtBirth_{China,t}+1} \quad (5)$$

where $SexRatioAtBirth_{China,t}$ represents the number of male births per female birth at year t, and the term $\frac{SexRatioAtBirth_{China,t}-1}{SexRatioAtBirth_{China,t}+1}$ captures the gender imbalance ratio at birth in year t.

The estimated total gender imbalance if China had not implemented the one-child policy can be estimated as:

$$\sum_{t=1980}^{2015} \frac{NewBorn_{China,t}}{FR_{China,t}} \times \widetilde{FR}_{Synth,t} \times \left(1 - MortaInfant_{China,t}\right) \times \frac{\widetilde{SexRatioAt\ Brith}_{Synth,t}-1}{\widetilde{SexRatioAt\ Brith}_{Synth,t}+1} \quad (6)$$

where $\widetilde{SexRatioAt\ Brith}_{Synth,t}$ is the estimated sex ratio at birth using the counterfactual unit (i.e. using those identified countries which best resembled the sex ratio of China prior to 1980). The difference between the results from equations (5) and (6) quantifies the contribution of the one-child policy to China’s gender imbalance.

2.2.3. *Method used in estimating the number of missing females*

In estimating the number of missing females in any given year during the one-child policy era, we first estimated the number of females that would have been born if China had not implemented the policy, using the following formula:

$$MissingFemale_{China,t} = LiveNewborn_{China,\ t} \times \frac{1}{\widetilde{SexRatioAt\ Brith}_{Synth,t}+1} \quad (7)$$

where $LiveNewborn_{China,\ t}$ represents the number of newborns in year t if China had not implemented the one-child policy, and $\frac{1}{\widetilde{SexRatioAt\ Brith}_{Synth,t}+1}$ quantifies the proportion of the newborns who were female. The infant mortality rate has been factored into the calculation of $LiveNewborn_{China,\ t}$ in equation (4).

Next, we calculated the number of females that were born during the one-child policy era in year t as:

$$Female_{China,\ t} = NewBorn_{China,t} * \left(1 - MortaInfant_{China,t}\right) * \frac{1}{SexRatioAtBirth_{China,t}+1} \quad (8)$$

Therefore, the difference between the results from equations (7) and (8) accounts for the number of missing females in year t as a consequence of the one-child policy. Our method improves on Anderson and Ray's (2010) equation (5), used in their estimation of the number of missing females in China in 2000, in at least two areas. First, our method used a more rigorously constructed reference ratio (or synthetic counterparts) of China's actual sex ratio at birth in estimating the number of missing females. Our reference ratio $\widetilde{SexRatioAt}\ Brith_{Synth,t}$ was constructed using countries which shared similar characteristics with China, rather than simply using the sex ratios at birth from developed countries, as in Anderson and Ray (2010). Furthermore, using the sex ratio at birth for developed countries alone is problematic, because they may not share similar social, economic, cultural and population characteristics with China. Second, our method estimated the total number of female births for the case in which China had not implemented the one-child policy, using a synthetic fertility rate and a synthetic sex ratio at birth (see equations (4) and (7)), which is clearly different from the total number of female births under the one-child policy. However, in estimating the number of "missing women" caused by the one-child policy, Anderson and Ray (2010) assumed the same total number of female births under the scenarios in which the one-child policy was either in place or not in place.

By using the actual and estimated gender distribution for each age-group, an assumed number of live births of 16 million per year in China between 2016 and 2035, and China's Life Table[35], we

[35] The life table of China is presented in Table C1 in Appendix C.

have estimated the population size and population distribution in age-groups in the year 2035 for both the scenarios with and without the one-child policy, and thereby we have evaluated the longer term effect of the policy on the evolution of the composition of China's population.

## 3. EMPIRICAL RESULTS

### 3.1. *The effect of one-child policy on China's fertility rate*

Figure 1 shows the evolution of the actual fertility rate in China and its synthetic counterfactual over the time period 1968-2015. The synthetic counterfactual follows closely the path of the actual rates for many years prior to 1980, which indicates a reasonably good fit of the synthetic to the actual. The one-child policy began contributing to the reduction in China's fertility rate from around 1992, as beginning in 1992 the solid line corresponding to China's actual fertility rate (which was observed under the one-child policy) is always below the broken line[36] (which represents the synthetic fertility rate). This finding is quite different from the suggestion made in Zhang (2017), which argued that "the one-child policy may have had a small short-term effect on fertility around 1979, but little or no additional long-term effect". Our finding suggests that the one-child policy was not effective in reducing China's fertility rate from 1980-1989, where the actual fertility rate (the solid curve) was significantly above its synthetic counterpart, and the one-child policy had its most pronounced negative effect on the fertility rate between 1995 and 2000 (see Fig. 1 and Table I). These results seemed puzzling at first, as many have suggested and/or expected that the one-child policy would be more effective at the beginning of the policy than during its later stages, which was a time when substantial economic growth took effect. Two potential reasons may well justify why the policy was not effective in the short term, namely the strong son preference, and the high failure rate of IUDs. First, the strong son preference found in rural culture, and pro-natal norms, have been traditionally strong in China's countryside. Traditionally, sons, but not daughters, have the obligation to provide support for their old-age parents, and rural China did not have a well-functioning old-age support system in the early 1990s (Wang 2006). The dominant traditional Chinese culture mandates that a bride must leave her natal

[36] The broken line indicates the path of China's fertility rate for the hypothetical case if China had not introduced the one-child policy. Hence, it is used to measure the impact of socioeconomic factors and factors other than the one-child policy on China's fertility rate.

family and become a permanent part of a trans-generational household of the groom's family. Thus, the bride transfers her emotional and economic royalties to her husband's family. Consequently, people from the countryside were concerned for their future economic security if they had only daughters, so it was in the interest of parents to have sons. A higher number of births than the birth quota set by the one-child policy may be required to have a son or to have a large family. With a strong son preference in rural areas (Goodkind 2015), many villagers' lifetime goal is to have sons (Li 1993; Wasserstrom 1984). More than two births per woman prior to the policy made it easier for those who possessed a strong son preference to have a son, while this became 'impossible'[37] for many families who wanted to have a son when the policy was in force. The anxiety caused by the policy persuaded many couples to marry and have children earlier than their counterparts in the 1970s (Wang et al. 2013).That may explain why, at the inception of the policy, it faced strong resistance from villagers and a rebound in China's fertility rate was observed in the 1980s (see the solid line in Fig. 1). Second, Chinese women were required to use an IUD after the birth of their first child or second child. This largely ensured that the policy could be executed very effectively[38]. However, the failure rate of IUDs was very high before 1990[39]. Therefore, the effectiveness of the policy in controlling China's fertility rate prior to 1990 was partially diminished by both the strong resistance from the farmers and the particularly high failure rates of the contraceptive methods employed at that time.

Figure 1 also captures the additional gain[40] (loss) that the one-child policy contributed to the decline in China's fertility rate from 1980-2015. As economic growth has already been factored into the evolution of the fertility rate in both curves in Figure 1, one possible reason, other than

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[37] An urban family, which held a non-agricultural (i.e. urban) hukou status, was not allowed to have two children under the policy, except under some special circumstances. Therefore, for an urban family, in the case of their first child being a daughter; while for rural families, if their first two children were daughters, the son preference became 'impossible' to realize if these families decided not to break the 'law' (i.e. the one-child policy).

[38]Approximately 71% of the 206 million married Chinese women of childbearing age were using a contraceptive device by 1988 (Kaufman 1993). Between 1980 and 2014, 324 million Chinese women were fitted with IUDs, while 108 million were sterilized (see, https://www.nytimes.com/2017/01/07/world/asia/after-one-child-policy-outrage-at-chinas-offer-to-remove-iuds.html).

[39] The 1982 "One per Thousand Fertility Survey" reported that 34.11% of all abortions obtained by the women surveyed were the result of IUD failure (China Population Information Center, 1984). In one county in 1987, where 32% of the women were using IUDs, 80% of the abortions reported by women in the sample were obtained after the failure of a contraceptive method, usually a stainless-steel IUD (Kaufman et al. 1989). The failure and expulsion rates of the single ring device were much higher than those of other IUDs.

[40] Note that the synthetic estimations, using countries which share similar characteristics with China, were used to capture the contributions of socioeconomic developments and factors other than the one-child policy on China's fertility rate. Therefore, the difference between the actual fertility rate and its synthetic counterpart can be used to measure the impact of the one-child policy on China's fertility rate. Here, the one-child policy has contributed to the decline of China's fertility rate from 1980-2015 if the solid line remains below the broken line.

economic growth which explains the decline in the fertility rate since around 1992 solely due to the one-child policy, is the fact that an increasing number of Chinese women were fitted with a higher quality IUD or inserted a birth control implant[41], and more women were sterilized, as required by the one-child policy. The one-child policy forcefully achieved an extremely high level of contraceptive use among Chinese women, which otherwise would have been very difficult, if not impossible, to achieve in such a short time period without the policy.

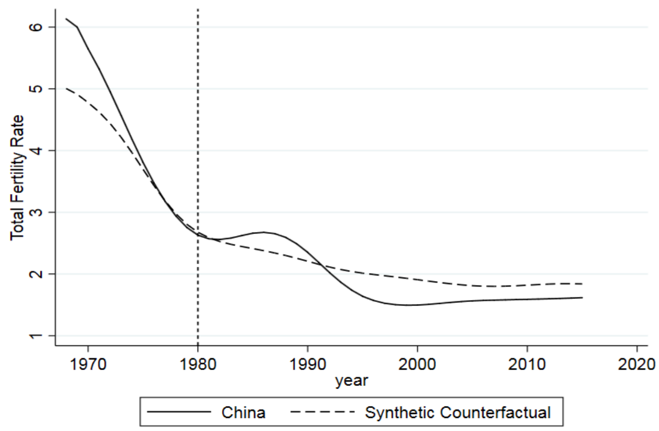


Fig. 1. China's fertility rate: actual (solid line) vs synthetic (broken line)

CNPFPC suggested that 400 million (or 338 million) births were averted for the period from 1970-1998 by the one-child policy. The estimation by CNPFPC covers the period since 1970, almost a decade before China's one-child policy was enacted, and when China experienced a very rapid decline in its fertility rate. Some have even suggested that "most of the (400 million) births averted were due to the rapid decline in China's fertility of that decade, not to the one-child policy" (Wang et al. 2013). Therefore, based on the estimations of the CNPFPC, it is not clear how many births were actually prevented by the one-child policy from 1980-2015. The unexpected rebound in China's fertility rate in the 1980s is a strong indication that the policy makers largely underestimated the general public's response to the one-child policy. The rebound in China's fertility rate in the 1980s, the high failure rates of IUDs and the subsequent years of better than expected economic growth all reduced the effectiveness of the one-child policy more than the CNPFPC expected. Table I shows the average percentage difference between China's actual fertility rate and its synthetic rate. This average is small for many years prior to 1980 (1974-1979),

[41] This is a thin tube, about the size of a matchstick (e.g., normally inserted under the skin of the upper arms), which releases hormones into the receiver's body, and may prevent the receiver from conceiving for up to 5 years.

which once again confirms a good fit of the synthetic to the actual. The results in Table I confirm numerically that the one-child policy was not effective from 1980-1992[42], as the actual fertility rate was considerably larger than its synthetic counterpart, and the policy was most effective during the time period 1995-2000. On average, the one-child policy contributed an additional of 11.5% reduction in China's fertility from 1980-2015 based on a year-on-year comparison with the case if China had not implemented the policy. Use method introduced in section 2.2.2, our estimation suggests that the policy prevented approximately 50 million births from 1980-2015.

**Insert TABLE I here**

Table I also reports the t tests results which examine whether there are significant differences in the effectiveness of the policy across different time periods. The Welch's t tests suggest that the policy was more effective during the post-1993 period than pre-1993 period. To some extent, our results support the view that the one-child policy is an important factor behind the current low fertility rate in China, in addition to the nation's rapid economic developments in the past few decades. Furthermore, the significant gap between China's actual fertility rate and its synthetic rate in 2015 suggests that it would take many more years to attain the current low fertility level if China had not implemented the one-child policy.

The above results are bound to be sensitive to the different choices of characteristics used in the synthetic exercises, as the change in the fertility rate of a population is not only subject to the level of economic development, but also subject to, for example, changes in the population distribution of those who are at a childbearing age across different age-groups. Furthermore, a skewed sex ratio in the reproductive age-groups may have an impact on crude birth rates, and hence on the fertility rate. Therefore, in carrying out the synthetic matching exercises, we have used various combinations of these factors to produce a good fit between the synthetic and the actual fertility rate which had the smallest root mean square error. Only those countries which shared a large number of similarities in some of these characteristics were likely to be good candidates in accurately modelling the evolution of China's fertility rate. If the actual units and the

[42] Above, we have provided specific reasons for the ineffectiveness of the one-child policy during these time periods.

counterfactual units differ significantly prior to the introduction of the policy, then the interpretation of the differences between the actual and the counterfactual are bound to be misleading (e.g., Saia 2017), as the observed differences are likely to have been caused by the fact that the actual units and the counterfactual units are essentially different. Taking the example where only the GDP per capita is used as the characteristic input for the synthetic exercise (see Fig. 2 - the plot on the left, Table II - column (2)), the subsequent estimations of China's fertility rate inevitably ignore the prevailing population structure of the other countries used in the synthetic exercise which may differ significantly from that of China. The results reported in Table I represent the best results[43] among all estimations obtained by using the different possible combinations of social, economic and population characteristics.

**Insert TABLE II here**

Table II reports some of the results generated from using different combinations of inputs for the synthetic exercises where the characteristic in column (1) were used to produce the results presented in Table I. The results reported in Table II and Figure 2 confirm that the previous reported results concerning the effects of the one-child policy on China's fertility rate outperform substantially the estimation results obtained by using other combinations of characteristics. We consistently found that the sex ratio at birth and the population distribution in both age and in gender under 40 delivered the best fit between China's actual fertility rate and its synthetic rate. In addition, the inclusion of factors such as GDP per capita and urbanization did not improve the fit, which may be because the economic factors have already been reflected in the changes of population distribution in these countries during the sampling time periods.

[43] This is confirmed by comparing the differences between the actual rate and the synthetic rate prior to the event.

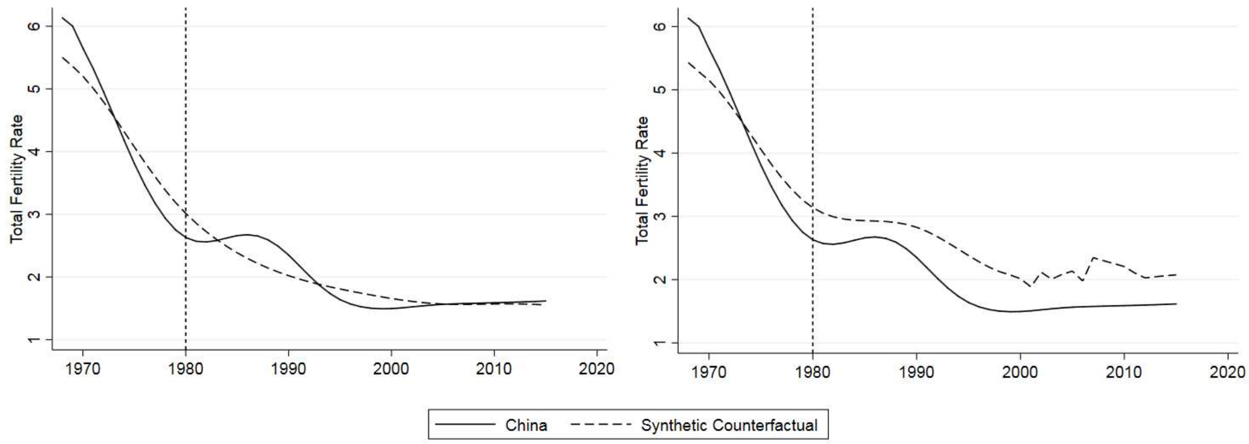


Fig. 2. The graph on the left was produced using only the GDP per capita, while that on the right was produced using the characteristics from column 5 in Table II in the synthetic algorithm

3.2. *The consequences of the one-child policy*

3.2.1. *The dark side of the one-child policy: Sex Ratio at Birth (SRB)*

According to the Population Division of the United Nations, the SRB of most countries lies between 1.04 and 1.06 male births per female birth for the years 1950-2005. All countries/regions with an abnormally high SRB (above 1.1) are in Asia (Guilmoto 2009). In Confucian societies, a strong son preference is commonly observed/practiced. Confucianism became the dominant philosophy in China during the Han dynasty (206 BC - 220 AD) and was also dominant in other East Asian countries such as Korea in the late Goryeo and early Joseon dynasties (Young-jin 2003). After the fall of the Qing dynasty, Confucianism was harshly criticized and its official status was ended after the 1911 Revolution. The influence of Confucianism was greatly suppressed during and after the Cultural Revolution, and was considered a feudal belief that needed to be removed from China. However, many of the teachings of Confucianism are still deeply rooted in Chinese culture and other Confucian societies. In Confucianism dominated societies, many people continue to uphold the traditional belief that "there are three unfilial things in your life, and to leave no posterity is the worst" (Shi 1982). A son is considered as someone who bears the responsibility for the continuation of the family genealogy. With limited access to advanced technology, such as ultra-sound machines, the strong son preference encouraged some families to take drastic action against their infant daughters, which is evident in the large number of female infanticide cases (Jimmerson 1990) and the number of baby girls who were abandoned (e.g., Johansson and Nygren

1991; Johansson 1995) in China during the era of the one-child policy. With technological advances, and the growing availability and affordability of ultra-sound machines, sex selective abortions became more common in China in the later years of the one-child policy, which contributed significantly to China's highly skewed SRB.

The Chinese government traditionally was/is particularly hesitant to intervene in family matters (e.g., Jimmerson 1990), including the question of abortion. The government's policies in response to sex selection abortions have been enforced weakly. The widespread use and declining cost of sex-selective abortion technology[44] has 'helped' the 'pioneer groups' in fulfilling the one-child policy, while maximizing the likelihood of having a son. China's SRB continued to deteriorate during the period of the one-child policy, and it has been well above 1.10 since 1990, and to date, China has maintained the record for having the highest SRB in the world[45]. Economic growth is confirmed to promote/accelerate the transition from favoring the quantity of children over the quality of children, but economic factors fail to explain the highly skewed SRB observed in Asian countries as none of the developed economies, with the exception of South Korea[46], had a SRB above 1.10. In China, those with a strong son preference uphold the belief that "raising a daughter is like watering your neighbors' garden"[47].

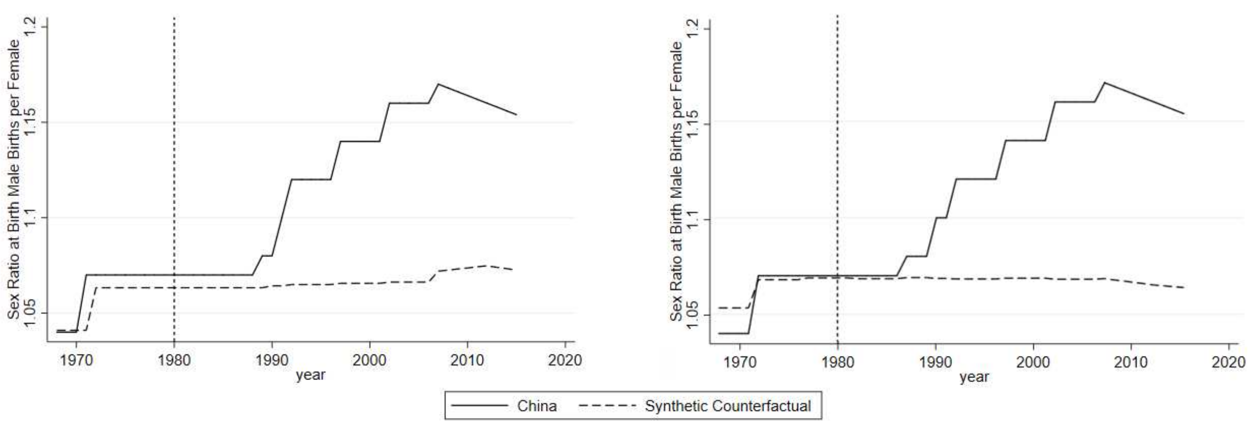


Figure 3. Sex ratio at birth: (a) China vs other Confucian societies, and (b) China vs other countries

[44] Even though doctors at both public and private hospitals are required by the authorities not to disclose the gender of an unborn baby, people still find a "backdoor method" with which to obtain the information.
[45] Based on the SRB data provided by the Population Division of the United Nations for 1968-2017.
[46] The son preference in South Korea was once believed stronger than in any other country (Goodkind 1999; Park and Cho 1995).
[47] Interestingly, Indian societies also possess very similar views.

Excessive discrimination against unborn girls[48] began to emerge during the one-child policy era, and many who possessed a strong son preference used it as a strategy with which to respond to the constraints of the one-child per family policy. Under the social conditions during the period of the policy[49], the strong son preference[50] and the culture of ancestor worship[51] strongly emboldened many Chinese people and their willingness and readiness to practice sex-selective abortions, as they anticipated distinct benefits of having a son rather than a daughter. The one-child policy significantly aggravated the impact of the strong son preference on China's SRB. The insignificant impact of the one-child policy on China's SRB, as observed at the beginning of the policy, was largely due to the high cost and limited availability of sex selection technology. We used both data from countries other than China, and data from Confucian societies only, to independently model China's SRB, the results of which are presented in both Figure 3 and Table III. The two estimation results are not qualitatively different from each other, and both suggest a much lower SRB (of approximately 1.07) if China had not implemented the one-child policy.

The actual population composition in gender of those who were born under the one-child policy suggests a total surplus of approximately 40 million[52] more males than females has accumulated in China from 1980-2015. Our estimations show that China could have a surplus of approximately 19 million[53] more males than females if it had not implemented the one-child policy. Therefore, the policy is estimated to have contributed approximately 21 million people to the current gender imbalance, or slightly more than 50% of the current outstanding gender imbalance.

**Insert TABLE III here**

[48] Discrimination against unborn girls is not uncommon in Chinese history, but not to the extent as was observed under the one-child policy. For a detailed account of this phenomenon, refer to Jimmerson (1990).

[49] Sex-selective abortion is not considered illegal in China, and the general public in China is tolerant towards abortions.

[50] "Even when sex selection is both accessible and acceptable, it will not be practiced in the absence of entrenched sex preference." (Guilmoto 2009).

[51] The rituals of ancestor worship are an integral part of Chinese culture (Schwartz 1985), and need to be performed by males.

[52] This was calculated using the newborn data for 1985-2015, the prevailing infant mortality rates for male births and female births, respectively, and China's life table for ages other than the age of 0, as well as the sex ratio at birth for each year.

[53] In estimating this (approximate) 19 million, we first estimated the number of women who gave birth in each year during the one-child policy using the actual fertility rate, and we then used the synthetic fertility rates and infant mortality rates to estimate the number of total live births which would have been the case if China had not implemented the one-child policy. Next, we estimated the number of males and females among each year's total live births using the synthetic sex ratio at birth. Finally, we discounted the size of the female and male population within each age-group (with a maximum span of five years of age difference as in China's life table) by their corresponding survival probability.

By using the total number of births of 18.23 million in the year 2000, and China's SRB of 1.169, as per Anderson and Ray (2010), by applying our method, our estimation suggests that China lost approximately 556,200 girls in the year 2000 owing to the one-child policy, which is significantly lower than the 885,000 missing girls suggested by Anderson and Ray (2010). In addition, by applying the method we introduced in Section 2.2.3, our estimation suggests a total of (approximately) 10,690,260 missing girls in China between 1980 and 2015 as a result of the one-child policy.

3.2.2. *Population composition by age and gender*

The one-child policy also affected the size and population composition of the age-group 0-34 years. The oldest age-group affected by the policy includes those who were born during the fourth quarter of 1980. In the following, we first report the impact of the one-child policy on the age-groups 0-14 years and 15-64 years, respectively. Next, we examine its impact on the smaller subgroups[54] (up to age 34) of the age-group 15-64 years.

Figure 4 reports the impact of the one-child policy on the age-groups 0-14 years (left) and 15-64 years (right). In the figure, the solid line represents the actual percentage of the age-group 0-14 over China's total population from 1968-2015, while the broken line represents its synthetic counterpart. Figure 4 shows that the differences between the actual and the synthetic results for the age-groups 0-14 years and 15-64 years, respectively, are both very small before 1980, which indicates a good fit of the synthetic to the actual. Based on the synthetic estimations, the one-child policy is estimated to have reduced the size of the age-group 0-14 years by approximately 3% of the average total population of China from 1980-2015. As the solid line is always well below the broken line between 1980 and 2015 (see the left graph), this indicates strongly that the one-child policy has effectively reduced the size of the age-group 0-14 years. It is important to note that the gap between the two curves from 1980-1994 partly carries the negative impact made by the "Later, Longer and Fewer" campaign on this age-group[55]. The gap between the two curves in the left graph is gradually widening, which is well supported by the fact that the one-child policy became more effective in reducing China's fertility rate as it moved towards the mid-1990s, and it had the most

[54] Each age-group contains individuals with a maximum age difference of four years.
[55] This is because those who were born between 1967 and 1979 represent part of the age-group 0-14 years during the first 13 years of the one-child policy.

profound impact on the age-group 0-14 years from 2000-2009, which is when the solid line descends at its steepest and diverges furthest from the broken line.

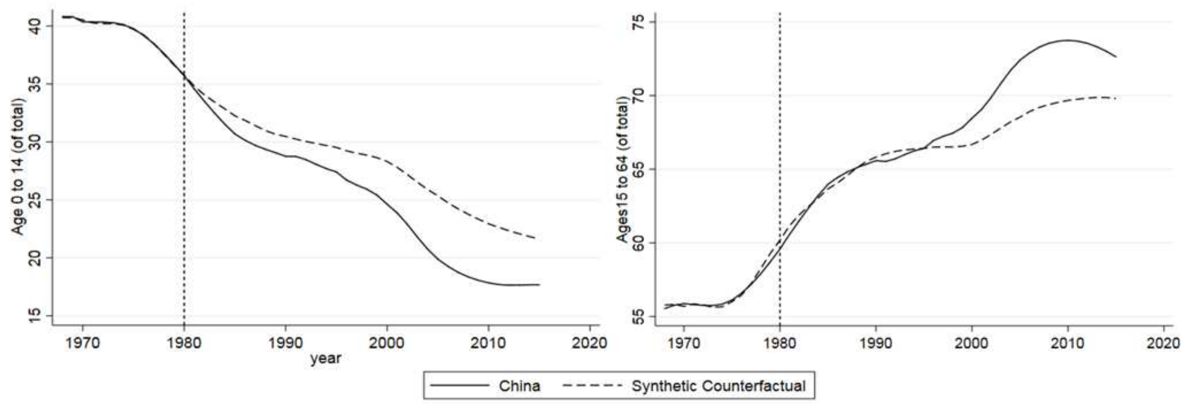


Fig. 4. Both graphs were produced using the characteristics in Column (1) of Table II in the synthetic algorithm

For the age-group 15-64 years, only those aged between 15 and 34 (i.e. those who were born between 1980 and 2000) were affected by the one-child policy, which represents approximately 40% of the age-group 15-64 years in 2015. Two very interesting observations may be made from the right-hand graph in Figure 4. First, the synthetic exercise has very accurately replicated the evolution of the age-group 15-64 years from 1980-1995 by correctly reporting that the one-child policy had no impact on those who were aged between 15 and 64 before 1995, as these individuals were born before implementation of the one-child policy. Those who were born from 1980-2000 joined the age-group 15-34 years from the year 1995[56] onwards. Second, the widening gap between the two curves, with the solid line above the broken line, clearly reveals that the one-child policy was not effective in bringing down the population size of the age-group 15-64 years.

Table IV reports the average percentage difference between the actual and synthetic percentages of the age-group 0-14 years over the total population[57]. The small difference between the actual and its synthetic counterfactuals prior to 1980 indicates a good fit of the synthetic to the actual. The estimation results in Table IV suggest that the one-child policy was most effective in controlling the population size of the age-group of 0-14 years from 2000-2009. The one-child policy, on average, reduced the size of the age-group 0-14 years by an additional (approximately)

[56] That was the point of time when the two curves were about to diverge significantly from each other.
[57] As the one-child policy was not effective on the 15-64 years age-group, we did not include its results in Table IV.

3% (≈.1466 *.2162[58]) of China's average population size from 1995-2015[59], than it would have done if China had not implemented the one-child policy.

**Insert TABLE IV here**

The impact of the one-child policy on China's population distribution by both age and sex are also highlighted in Figure 5, where it is evident that it changed dramatically between 1979 and 2015. The impact of the one-child policy on the age and sex distribution in the younger cohort population, namely those aged below 20 years old, are clearly evident by comparing the two 'Population Age Sex Pyramid 2015' graphs, which represent the population distribution by both age and sex for scenarios either with or without the one-child policy, respectively.


Fig. 5. China's population pyramid by age and sex

[58] 21.62% is the average of the synthetic percentages of the 0-14 years age-group over the yearly China's total population from 1995-2015.

[59] The time period 1995-2015 was used here rather than 1980-2015, because: 1) those who were born before the one-child policy was implemented constituted some proportion of the age-group 0-14 years during the different years between 1980 and 1994, which makes it difficult to evaluate the impact of the one-child policy on the same age-group from 1980-1994; 2) the one-child policy was not effective on China's fertility rate in the 1980s.

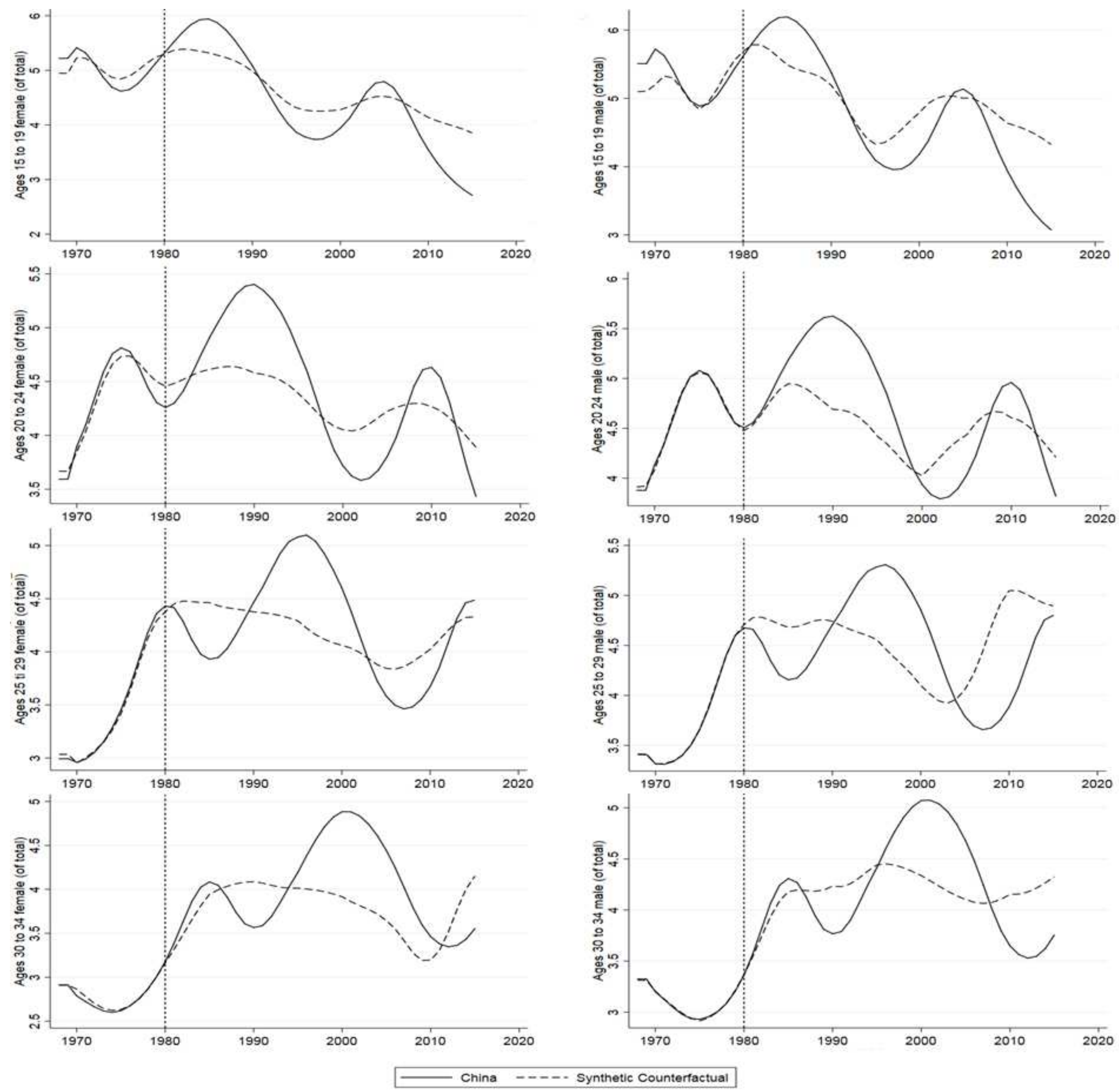


Fig. 6. Graphs produced using the characteristics from Column (1) in Table II in the synthetic algorithm

We carried out a more in-depth analysis of the impact made by the one-child policy on the subgroups[60] of the age-group 15-34 years. Figure 6 shows that the differences between the actual and synthetic results for each age-group as a percentage of China's total population were all small before 1980, which indicates a good fit of the synthetic to the actual. A key observation which should be borne in mind while interpreting Figure 6, and in the estimation of the impact made by the one-child policy on the subgroups of the age-group 15-34 years is that the policy exerted its

[60] Each sub-age-group has an age span of five years, except the age group 0-14 years.

impact on different sub-age-groups beginning in different years, and the fact that the policy was not effective in controlling China's fertility rate from 1980-1989 (i.e. equal to 10 years). For example, the age-group 15-19 years (females and males separately) who were born during the one-child policy era, began joining the age-group from 1995 onwards. Therefore, the policy exerted a significant impact on the age-group 15-19 years (females and males separately) beginning in 2005 (=1995+10). Therefore, Figure 6 needs to be interpreted together with Table V, subject to different starting years from which (see row (3) of Table V) the one-child policy affected these different age-groups.

Table V presents the impact of the one-child policy on different subgroups of the 15-34 years age-group (females and males separately). The results in row (6) of Table V, clearly show that the 15-19 and 20-24 years age-groups are considerably smaller than 25-29 and 30-34 years age-groups. This is justified, given that the one-child policy was more effective from 1995-2000[61] than it was from 1980-1989[62]. Overall, the estimated percentage of males over the total population across the different age-groups is consistently larger than that of females, and the gender imbalance is larger in the younger age cohorts than the older age cohorts (see rows (4) and (5)) as a result of the growing skewedness of the sex ratio at birth among the younger cohorts. The weighted average negative impacts of the one-child policy on the 15-34 years age-group is estimated to be approximately 1% of the average population size for China from 1980-2015 (the sum of the figures in row (9)).

**Insert TABLE V here**

In summary, the one-child policy has reduced the size of the 0-34 years age-group by approximately 3% of China's average population size for the 0-14 years age-group and approximately 1% for the 15-34 years age-group. This reduction represents a reduction of close to 50 million living births prevented by the policy after taking into account the corresponding yearly

[61] Those who were born during the period 1995-2000 represent the age-group 15-19 years old. The effectiveness of the one-child policy in its earlier years was offset by the low quality of the contraceptive methods and the strong resistance by villagers.
[62] Those who were born during the period 1980-1989 represent the age-group 25-34

infant mortality rates, which is consistent with our earlier estimation regarding the number of unborn children using a synthetic fertility rate.

3.2.3. *Age dependency ratios*

Prior to the one-child policy, China had an old-age dependency ratio of close to 8%, but it enjoyed a relatively low old-age dependency ratio (14.84%) in 2017 when compared to the high-income countries (25.4%), the Eurozone (31.77%) and North America (23.66%) (See, Panel A in Table C1 in Appendix C).

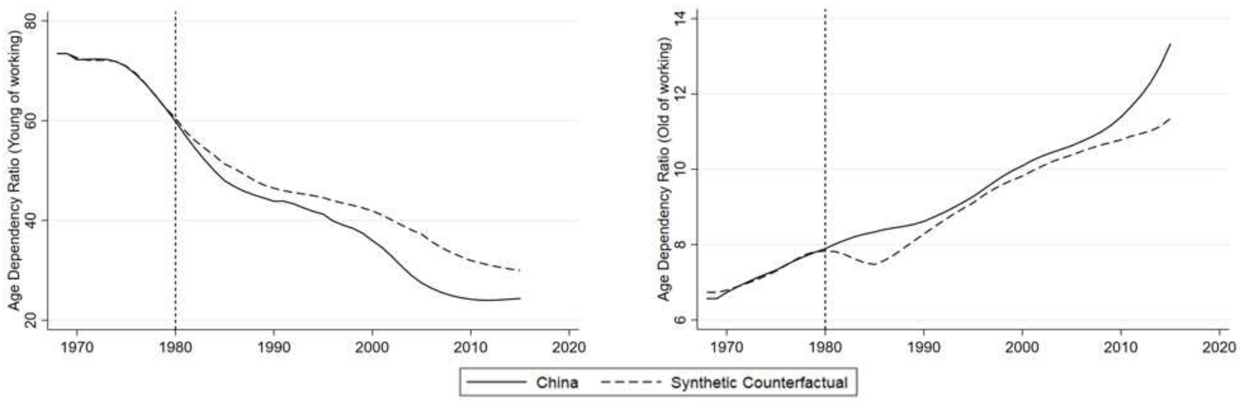


Fig. 7. Young-age dependency ratio (left) and Old-age dependency ratio (right)

Figure 7 compares between the actual and its synthetic young-age dependency ratio (left) and the old-age dependency ratio (right), correspondingly. Our results suggest that by the end of 2015, the one-child policy, on average, increased China's old-age dependency ratio by approximately 2% compared to what it would have been if China had not implemented the one-child policy.

The policy is found to have had a more profound impact on China's young-age dependency ratio than on its old-age dependency ratio[63]. During the period of the one-child policy and the decades of economic growth, China's actual young-age dependency ratio (using the age range of 0-14 years) has dropped sharply from 62% in 1979 to approximately 24% in 2015. This ratio prior to the implementation of the policy was considerably higher than that of the developed economies. However, by 2017, China's young-age dependency ratio had fallen below most of the developed

[63] Note: the values on the vertical axis of the left hand side graph are bigger than those on the right.

economies[64]. The one-child policy is found to have contributed an additional 10.61% reduction to China's young-age dependency ratio (Table VI).

**Insert TABLE VI here**

Table VII reports our predictions of China's population size and its population compositions in different age-groups in 2035, with and without the one-child policy, and in 2055. As life expectancy is likely to increase and low fertility rates are likely to persist in China, it may experience a sharp increase in its old-age dependency ratio in the coming few decades. In estimating the change in the size of the 20+ years age-group, we increased the age of each of the individuals who were in the same sub-age-group of 0-64 as in the year 2015 by 20 years. As 20 is a integer multiple of five, this shifts individuals from one age group to the next older age group without altering the original composition of the individuals within each age-group, given that each sub-age-group has an age span of five years. Hence, the size of each corresponding age-group (those who were born before 2016[65]) after the shift will only be subject to the natural death rate[66] of its individuals.

**Insert TABLE VII here**

In estimating China's population size for 2035, we separately estimated the size of the 0-19 years age-group, which represents the newborns from 2016-2035, as well as the 20-64 and 65-85+ years sub-age-groups (detailed procedures are presented in Appendix B). Our estimations suggest that China's population size will reach between 1.578 billion and 1.598 billion by 2035. Its old-age

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[64] See, panel A of Table C1 in Appendix C.
[65] Therefore, all individuals from the same age-group will be simultaneously moved into the same age-group which is 20 years older than they were in the original age-group.
[66] It is measured according to the average central death rates (these are provided in the Life Table) for each age-group.

dependency ratio, using two different measures[67], are between 42% and 46%, which is more than three times its level in 2015 (approximately 13%), while its young-age dependency ratio will grow by only a few percentage points higher than the level in 2015, assuming 16 million live births per year. The demographic dividend in 2035 is estimated at half of its level in 2015. The one-child policy is estimated to reduce China's population size by up to approximately 66 million by 2035 (compare between columns (3) and (4)). China is estimated to have approximately one quarter of its total population aged 65+ years (it was below 10% in 2015) in 2035, and this will grow to more than 30% in 2055 assuming a 16 million live births per year between 2036 and 2055. By 2055, China is estimated to have an old-age dependency ratio of approximately 60%[68] and 67%[69] using two different measures, and the demographic dividend will disappear completely by 2055. China will enter an era of negative population growth between 2036 and 2055 if its fertility rate remains below 2 between 2036 and 2055.

3.3. *Robustness check*

We used all countries other than China as a comparison group to examine the effect of the one-child policy on such issues as China's fertility rate in a difference-in-difference framework. Table VIII shows the results of the difference-in-difference estimates, comparing the pre-policy[70] data to the post-policy data separately for each of the synthetic exercises we carried out in Section 3.2. The reported coefficient is the interaction of the one-child policy dummy[71] with a post-policy dummy. The regressions also include a year dummy and the one-child policy dummy. The results presented in the upper panel of Table VIII (using all countries other than China) represent the difference between China and the other countries, not including those countries identified by the synthetic method. Our findings suggest that the movements of the variables of interest of these countries are significantly different from those of China during the one-child policy.

**Insert TABLE VIII here**

[67] The first measure is defined as the ratio between the population size of the 65+ years age-group and the population size of the 15-64 years age-group. The first measure is defined as the ratio between the population size of those aged $65^{+}$ years and those aged 20-64 years.
[68] This is measured as the ratio between the population size of those aged $65^{+}$ years and those aged 15-64 years.
[69] This is measured as the ratio between the population size of those aged $65^{+}$ years and those aged 20-64 years.
[70] Pre-policy represents the time periods before the one-child policy.
[71] This is the dummy which is used to distinguish China from other countries.

Next, we used data from 1968 to 2015 for countries identified by the synthetic control method for each of the synthetic exercises[72], which allowed me to examine whether the one-child policy has significantly differentiated China from countries which were very similar to China in terms of their characteristics (including the dependent variables in Table VIII) before the implementation of the policy. The results presented in the lower panel of Table VIII confirm that these countries were either not significantly different from China during the one-child policy era, or that the differences were much smaller than between other countries and China. Thus, it confirms that the countries selected by the synthetic method were robust in modeling China in terms of the variables of interest.

**Insert TABLE IX here**

To further validate the estimated results from the synthetic control method, we also implemented a set of placebo estimates (difference-in-difference) on pairs of years from the pre-policy period of 1970 to 1979, a period before the one-child policy had been introduced. Taking fertility rates[73] as an example, if there are no significant differences in the fertility rates between China and those countries used in the synthetic exercises before the one-child policy era in the difference-in-difference framework, then this once again confirms these countries to be very similar to China in terms of the evolution of the fertility rate during the years before 1980. The reported coefficient is the interaction of the China dummy[74] with a year dummy. The regressions also include a year dummy and the China dummy. These estimations of various pairs, which are all particularly small and insignificant, are reported in Table IX.

## 4. CONCLUSION

Using the natural experiment[75] created by the one-child policy, this paper documents the impact of the policy on various population dimensions in China, including the fertility rate. In this study,

[72] See relevant tables for the countries used in each of the synthetic exercises.
[73] The placebo estimates for the old-age dependency ratio, the young-age dependency ratio, the sex ratio at birth and various age groups can be provided upon request.
[74] This is the dummy which is used to distinguish China from the other countries.
[75] The end of the one-child policy at the beginning of 2016 created a natural experimental setting.

we have used a non-parametric and novel technique to disentangle the role of the one-child policy from other factors (e.g., economics) in explaining the change of China's fertility rate, of its population distribution in different age-groups (females and males separately), and its highly skewed sex ratio at birth. Our findings highlight the extent to which the one-child policy has affected China's fertility rate, the population distribution by age as well as by gender in the younger cohorts, and on the sex ratio at birth. The synthetic matching exercises suggest that China could have a fertility rate of approximately 1.80 rather than the current rate of approximately 1.60 if China had not implemented the one-child policy. Our two separate estimations, with one using synthetic fertility rates and the other using a synthetic population distribution for different age-groups (females and males separately), both confirmed that the one-child policy may have prevented approximately 50 million births from 1980-2015.

The study of the impact of the one-child policy on population distribution by age-group yielded two key findings. First, once we controlled for the impact of factors (e.g., economic development) other than the one-child policy on population distribution by age-group, the one-child policy was found to have reduced significantly the size of the 0-14 years age-group. Second, the significantly lowered young-age dependency ratio in 2015 will be translated into a relatively higher old-age dependency ratio in the future.

Infanticide, the abandonment of baby girls, and sex selection abortions are some of the darker consequences of the one-child policy. Our findings confirm that the one-child policy has severely distorted China's sex ratio at birth, and this is one of the most severe consequences of the policy. The damaging effect of the one-child policy on China's sex ratio at birth is likely to have been driven by the fact that the policy placed much of China's rural society in a dilemma between fulfilling the policy and maximizing the probability of having a son.

China has completed its transition from a "demographic transitional" society, where the subsequent fertility decline led to a sluggish population growth, to a "post-transitional" society, where death rate is low and the fertility rate is below the replacement level. Our findings have potentially important policy implications. First, China has gradually shifted towards older demographics, largely due to the low birth rate and increased life expectancy during the last few decades. The currently high demographic dividend will be translated into a much higher old-age dependency ratio, given a slower rate of growth of the younger age-groups. This strongly suggests that China needs to fully relax its population control policies, such as the current two-child policy, and rather begin promoting a population policy which will encourage more births to rebalance the population age distribution. Second, the heavily skewed sex ratio at birth can lead to, for example, a lack of matches between males and females, which could also affect China's future population growth. In China's efforts to boost its population growth, beside promoting/incentivizing more births, the Chinese government needs to find ways to quickly and effectively bring down this particular ratio. Third, the growing aging population will place a huge burden on China's future generations and on the social and health-care systems. Policy makers in China need to find innovative solutions to address the predicted soaring demand for old-age care from the rapidly-growing number of elders.

Conflict of Interest: The authors declare that they have no conflict of interest.

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TABLE I

*Average difference between China's actual fertility rate and its synthetic rate*

| | 1974-1979 | 1980-2015 | | | | Welch's t-test | | |
|---|---|---|---|---|---|---|---|---|
| | | a.1980-92 | b. 1980-15 | c. 1993-15 | d. 1995-00 | b – a | c – b | d – c |
| % difference actual vs synthetic | −2.16<br>(.007) | 6.362<br>(.04313) | −11.476<br>(.1305) | −17.651<br>(.085) | −24.100<br>(.0247) | −6.948<br>***<br>d.f.=43 | −2.248<br>***<br>d.f.=60 | −3.792<br>***<br>d.f.=28 |
| *Countries used in the synthetic exercise (Weights)*: | | | | | Cuba (.61); Mexico (.228); Singapore (.059); Thailand (.048); Virgin Islands (.055) | | | |

NOTE. Table I reports the percentage difference between China's actual fertility rate and its synthetic rate during the time period 1974-2015, which is defined as $\frac{\sum_u^v \frac{FR_{China,t} - FR_{Synth,t}}{FR_{synth,t}}}{v-u+1}$, where u and v are integer numbers between 1974 and 2015. The time period 1968-1979 has been used to assign optimal weights to countries which were selected to produce the synthetic fertility rates. Negative numbers in the table quantify the additional contributions of the one-child policy in reducing China's fertility rate relative to the case if it had not implemented the policy. To partly capture the effectiveness of the one-child policy over different time periods, it also reports the difference between China's actual fertility rate and its synthetic fertility rate for different time periods. Four different time periods after the introduction of the policy have been specified in the table. Code 'a' is used to denote for the time period 1980-1992, 'b' for 1980-2015, and 'c' for 1993-2015, while 'd' covers 1995-2000.Welch's t-tests[76] have also been carried out to compare the effectiveness of the policy during these four different time periods. Standard errors are reported in parentheses. *** denotes p<0.001, and d.f. represents the degree of freedom associated with each of the t tests.

[76] $t = \frac{\bar{x}_1 - \bar{x}_2}{s}$, where $s = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$, and the degree of freedom is calculated as d.f.=$\frac{(\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2})^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1-1}+\frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2-1}}$

TABLE II

*Different combinations of characteristics as inputs for the synthetic: fertility rates*

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| % difference actual vs synthetic | −2.16 | −9.62 | −9.62 | −9.62 | −9.94 |
| | (.007) | (.0168) | (.0168) | (.0168) | (.0200) |
| Fertility rates [a] | Y | Y | Y | Y | Y |
| Economic (GDP per capita) | N | Y | Y | Y | Y |
| Social development (urbanization) | N | N | Y | Y | Y |
| Sex ratio at birth | Y | N | N | N | Y |
| Population age distribution below 40 [b] | Y | N | N | N | N |
| Population age distribution above 40 | N | N | N | N | Y |
| Life expectancy at birth, total years | N | N | N | Y | Y |
| Root Mean Squared Prediction Error | .01351 | .400061 | .400061 | .400048 | .436181 |

*Notes:* The table reports the average percentage difference between China's actual fertility rate and its synthetic fertility rate during the time period 1974-1979, which is defined as $\frac{\sum_u^v \frac{FR_{China,t} - FR_{Synth,t}}{FR_{Synth,t}}}{v-u+1}$, where u and v are integer numbers between 1974 and 1979. Column (1) reports the results presented in Table I. The reported results in Columns (2) to (5) use different combinations of characteristics.

[a] Fertility rates before 1979 were included in the synthetic exercises in producing results in Columns (1) and (5), while fertility rates before 1978 were used in Column (6).

[b] The percentage of each subgroup of the age group of 0-39 years (females and males separately) over the total population in each year during the time period 1974-1979, with each age-group containing individuals with a maximum age difference of four years (for example, age-group 35-39 years), with the exception of age-group 0-14 years.

TABLE III

*Average difference between China's actual and synthetic sex ratios at birth*

| | 1968-79 | 1980-2015 | Countries/regions (Weights) |
|---|---|---|---|
| % difference actual vs synthetic: China vs other Confucian societies | 0.63<br>(0.0022) | 5.44<br>(.0055) | Hong Kong (.394); North Korea (.045); Macao (.109); Singapore (.288); Vietnam (.164) |
| % difference actual vs synthetic: China vs other countries | 0.53<br>(.0016) | 5.47<br>(.0059) | Bahrain (.068); Cuba (.194); Hong Kong (.084); Luxembourg (.098); Suriname (.476); Virgin Islands (.081) |

*Notes:* The table reports the percentage difference between China's actual sex ratio at birth and its synthetic rate during the time period 1968-2015, which is defined as $\frac{\sum_u^v \frac{SRB_{China,t} - SRB_{Synth,t}}{SRB_{Synth,t}}}{v-u+1}$, where u and v are integer numbers between 1968 and 2015. Standard errors are reported in brackets.

TABLE IV

*Average percentage difference between actual and synthetic: age-group 0-14 years*

| | 1968-1979 | 1980-2015 | | | | Welch's t-test | | |
|---|---|---|---|---|---|---|---|---|
| | | a.1980-92 | b. 1980-2015 | c. 1993-2015 | d. 2000-2009 | b – a | c – b | d – c |
| % difference actual vs synthetic | 0.103 | −4.47 | −14.66 | −19.98 | −24.06 | −4.97 | −2.21 | −2.74 |
| | (.002) | (.0176) | (.1005) | (.0826) | (.0564) | *** | *** | *** |
| | | | | | | d.f.=29 | d.f.=48 | d.f.=43 |
| Countries/regions (Weights): | Cuba (.511); Cabo Verde (.162); Antigua and Barbuda (.117); United Arab Emirates (.063) French Polynesia (.06); Kazakhstan (.04); Virgin Islands (.036); Bahrain (.01) | | | | | | | |

*Notes:* The table reports the percentage difference between the actual percentages of the age-group 0-14 years over China's total population and its synthetic percentages during the time period 1968-2015, which is defined as $\frac{\sum_u^v \frac{FR_{China,t} - FR_{Synth,t}}{FR_{synth,t}}}{v-u+1}$ by replacing the fertility rates with their corresponding percentages for the age-group 0-14 years over the total population in each year, where u and v are integer numbers between 1968 and 2015. The time period 1968-1979 has been used to identify and assign optimal weights to countries which were used to produce the synthetic results. Negative numbers in the table quantify the additional contributions of the one-child policy in reducing the size of the age-group 0-14 years relative to the case if China had not implemented the one-child policy. To partly capture the effectiveness of the one-child policy during the different time periods, the table also reports the differences between the actual percentage of the age-group 0-14 years over the total population and its synthetic for different time periods. Four different time periods have been specified in the table. Code 'a' is used to denote the time period 1980-1992, 'b' for 1980-2015, and 'c' for 1993-2015, while 'd' covers 2000-2009. In addition, Welch's t-tests have been carried out to compare the effectiveness of the one-child policy during these four different time periods. Standard errors are reported in parentheses. *** denotes p<0.001, and d.f. represents the degree of freedom associated with each of the t tests.

TABLE V

*Average difference between the actual and synthetic size of the age-groups of the total population (by gender): 1980-2015*[a]

| | | 15-19 Female | 15-19 Male | 20-24 Female | 20-24 Male | 25-29 Female | 25-29 Male | 30-34 Female | 30-34 Male |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Year of birth | Since 1980 | Since 1980 | Since 1980 | Since 1980 | Since 1980 | Since 1980 | Since 1980 | Since 1980 |
| 2 | The age-group begins from year | Since 1995 | Since 1995 | Since 2000 | Since 2000 | Since 2005 | Since 2005 | Since 2010 | Since 2010 |
| 3 | From this year onwards, the effect of one child policy can be measured on this age-group | From 2005 | From 2005 | From 2010 | From 2010 | From 2015 | From 2015 | From 2015 | From 2015 |
| 4 | Actual as % of total population | 2.71 | 3.07 | 3.43 | 3.83 | 4.48 | 4.80 | 3.55 | 3.75 |
| 5 | % More males than females (of total population as in 2015) | 0.36 | | 0.40 | | 0.32 | | 0.20 | |
| 6 | % of the age-group of total population (2015) | 5.78 | | 7.26 | | 9.28 | | 11.30 | |
| 7 | % Difference: actual vs synthetic | −1.144 | −1.249 | −.459 | −.392 | N/A | N/A | N/A | N/A |
| 8 | % Difference: actual vs synthetic | −12.96 | −14.2 | −.232 | −.341 | N/A | N/A | N/A | N/A |
| | | (.131) | (.117) | (.082) | (.068) | | | | |
| 9 | % Weighted average reduction | −.526 [b] | −.508 | −.001 | −.001 | N/A | N/A | N/A | N/A |

*Notes:* The table reports the percentage difference between the actual and synthetic percentage of an age-group over China's total population (females and males separately) from 1980-2015, which is defined as $\frac{\sum_{t=u}^{v}\frac{FR_{actual,t}-FR_{Synth,t}}{FR_{actual,t}}}{v-u+1}$ by replacing the fertility rates with their corresponding percentage of each age-group over China's total population in each year (females and males separately), where u and v are integer numbers between their starting years specified in row (3) and 2015. Negative figures in the table quantify the impact of the one-child policy on reducing the size of each age-group relative to the case where China had not implemented the one-child policy.

[a] We refer readers to Panel C of Table C1 in Appendix C for details of the countries/regions which have been used to produce the results in the table.

[b] This is calculated by $\frac{\sum_{t=u}^{v}(\frac{PercentageOftheAgeGroup}{total})_{synth,t}}{v-u+1} * (-12.96\%)$, where $-12.96\%$ represents the average difference between the actual percentage of the female population of the age group over the total population and its synthetic percentage, which may be found as the first figure in row (8). The other values in the final row can be calculated similarly.

TABLE VI

*Average difference between the actual and synthetic age dependency ratios*

| | % difference between actual and synthetic | |
|---|---|---|
| | 1968-1979 | 1980-2015 |
| Old-Age Dependency Ratio [a] | 0.085 | 2.24 |
| | (.00741) | (.05573) |
| *Countries/Regions used in the synthetic (Weights)* | Bahamas (.048); Bahrain (.091); Germany (.044); Guam (.128); Hong Kong (.146); Macao (.023); Moldova (.179); Maldives (.029); Samoa (.341) | |
| Young-Age Dependency Ratio [b] | 0.397 | −10.61 |
| | (.00707) | (.0993) |
| *Countries used in the synthetic (Weights)* | Antigua and Barbuda (.058); Bahrain (.082); Cuba (.554); Kazakhstan (.006); Micronesia (.126); Philippines (.078); Qatar (.096) | |

*Notes:* In the table, the old-age dependency ratio is defined as the ratio between the population size of the age-group 65+ years and the population size of the age-group 15-64 years in each year. The young-age dependency ratio is defined as the ratio between the population size of the age-group 0-14 years and the population size of the age-group 15-64 years in each year.

TABLE VII

*China's population distribution in 2015 and 2035 (with and without the one-child policy), and in 2055*

| | (1) 2015 under the one-child policy | (2) 2015 without the one-child policy | (3) 2035 [a] under the one-child policy: 1979-2015 | (4) 2035 without the one-child policy | (5) 2055 [b] |
|---|---|---|---|---|---|
| Population size (Billion) | 1.37462 | 1.42474 | (1.57808, 1.59773) | (1.64295, 1.66256) | 1.56359 |
| 65+ (Billion) | .13119 | .13119 | .39447 | .39447 | .49920 |
| 20-64 (Billion) | .92001 | .92113 | .85677 | .92164 | .74439 |
| 15-64 (Billion) | .99866 | 1.01205 | (.93761, .94246) | (.96056, .96225) | .83439 |
| 0-19 (Billion) | .32342 | .37242 | (.32684, .34853) | (.34184, .36145) | .32000 |
| 0-14 (Billion) | .24303 | .28150 | (.24599, .26380) | (.26131, .27609) | .22600 |
| Old-Age Dependency Ratio: (65+)/(15-64) [c] | 13.32% | 12.96% | (41.81%, 41.85%) | (40.07%, 41%) | 59.83% |
| Old-Age Dependency Ratio: (65+)/(20-64) | 14.26% | 14.24% | 46.04% | 42.80% | 67.06% |
| Young-Age Dependency Ratio: (0-14)/(15-64) | 24.347% | 27.81% | (27.99%, 28.70%) | (27.20%, 28.69%) | 38.35% |
| Young-Age Dependency Ratio: (0-19)/(20-64) | 35.08% | 42.43% | (38.15%, 40.68) | (37.09%, 39.22%) | 42.99% |
| Demographic dividend: (15-64)/(0-14 and 65+) | 2.6547 | 2.45 | (1.3378, 1.4640) | (1.435, 1.465) | 1.02 |
| Demographic dividend: (20-64)/(0-19 and 65+) | 2.066 | 1.83 | (1.153, 1.188) | (1.219, 1.252) | 0.91 |
| Population growth (yearly) | Between 1980-15 .512% | Between 1980-15 .537% | Between 2016-35 (0.642%, 0.650%) | Between 2016-35 (.920%, .923%) | Between 2036-55 (−.57%, −.55%)[d] |

*Notes:* [a] We specifically assumed a SRB of 1.1 and 16 million live births per year between 2016 and 2035

[b] We specifically assumed a SRB of 1.1 and 16 million live births per year between 2036 and 2055.

[c] 'The old-age dependency ratio: (65+)/(15-64)' is defined as the ratio between the population size of the 65+ years age-group and the population size of the 15-64 years age-group in each year. The other age dependency ratios are defined similarly.

[d] Approximately 19 million live births per year between 2036 and 2055 is required to maintain a non-negative population growth, or approximately 2 births per woman who is at childbearing age (we have used the estimated female population size of those aged between 5 and 29 years in 2035 to account for the number of women who will be at childbearing age between 2036 and 2055, and assuming that the prevailing sex ratio at birth among the population who are aged between 5 and 29 years is approximately 1.1 male births per female).

TABLE VIII

*Difference-in-difference estimates*

| | Dependent Variables (DV) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **1980-2015: Comparison between China and all countries other than China during the one-child policy era** | | | | | | | | | | |
| | (1) | (2) | (3) | (4) | (5) | | | | | |
| | Fertility | SRB | Old-Age Dependency Ratio | Young Age Dependency Ratio | Age group | | | | | |
| | | | | | (I) 0-14: Female | (II) 0-14: Male | (III) 15-19 Female | (IV) 20-24 Female | (V) 25-29 Female | (VI) 30-34 Female |
| Impact on DV | −1.258 *** (.3394) | 0.060 *** (.0067) | 1.192 *** (.2968) | −18.817 *** (2.0694) | −4.345 *** (.5192) | −4.305 *** (.5005) | −0.234 (.1744) | −0.018 (.164) | 0.519 *** (.1455) | .770 *** (.0934) |
| N | 8928 | 8928 | 8928 | 8928 | 8928 | 8928 | 8928 | 8928 | 8928 | 8928 |
| **1980-2015: Comparison between China and the comparison group [a]** | | | | | | | | | | |
| | (1) | (2) | (3) | (4) | (5) | | | | | |
| | Fertility | SRB | Old-Age Dependency Ratio | Young-Age Dependency Ratio | Age group | | | | | |
| | | | | | (I) 0-14: Female | (II) 0-14: Male | (III) 15-19 Female | (IV) 20-24 Female | (V) 25-29 Female | (VI) 30-34 Female |
| Impact on DV | −0.464 (.395) | 0.040 *** (.0077) | −0.464 (.4862) | −11.160 *** (3.377) | −2.140 *** (.632) | −2.184 *** (.598) | −0.053 (.1966) | 0.0057 (.1784) | 0.1922 (.1678) | −0.078 (.1623) |
| N | 288 | 192 | 480 | 384 | 428 | 428 | 384 | 576 | 577 | 337 |

Notes: [a] Readers are referred to the relevant tables for the countries/regions which should be used in producing estimates in each column in the lower panel of the table.

All regressions include a year dummy, and a dummy for the one-child policy. The impact on the dependent variables is the coefficient on the one-child policy dummy × post-policy. Standard errors are reported in brackets. *** indicates the statistical significance at 1%.

TABLE IX

*Placebo Effects based on Pre-policy data* [a]

| | Fertility Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
| 1970 | −0.280 | −0.583 | −0.901 | −1.234 | −1.542 | −1.819 | −2.051 | −2.239 | −2.379 |
| | (2.731) | (2.750) | (2.771) | (2.778) | (2.791) | (2.803) | (2.814) | (2.821) | (2.819) |
| 1971 | | −0.303 | −0.622 | −0.954 | −1.263 | −1.539 | −1.772 | −1.960 | −2.099 |
| | | (2.756) | (2.777) | (2.784) | (2.797) | (2.809) | (2.820) | (2.827) | (2.825) |
| 1972 | | | −0.319 | −0.651 | −0.960 | −1.236 | −1.469 | −1.656 | −1.796 |
| | | | (2.795) | (2.802) | (2.815) | (2.827) | (2.838) | (2.845) | (2.843) |
| 1973 | | | | −0.332 | −0.641 | −0.917 | −1.150 | −1.338 | −1.478 |
| | | | | (2.823) | (2.836) | (2.847) | (2.858) | (2.865) | (2.863) |
| 1974 | | | | | −0.308 | −0.585 | −0.817 | −1.005 | −1.145 |
| | | | | | (2.843) | (2.854) | (2.866) | (2.872) | (2.870) |
| 1975 | | | | | | −0.276 | −0.509 | −0.696 | −0.836 |
| | | | | | | (2.867) | (2.878) | (2.885) | (2.883) |
| 1976 | | | | | | | −0.232 | −0.420 | −0.560 |
| | | | | | | | (2.890) | (2.896) | (2.894) |
| 1977 | | | | | | | | −0.186 | −0.327 |
| | | | | | | | | (2.907) | (2.905) |
| 1978 | | | | | | | | | −0.140 |
| | | | | | | | | | (2.912) |
| N | 372 | 372 | 372 | 372 | 372 | 372 | 372 | 372 | 372 |

Note: [a] The dataset used in Table IX covers observations between 1970 and 1979 for those countries used in the synthetic exercises for the fertility rate.

All regressions include a year dummy, and a China dummy. The impact on the dependent variables is the coefficient on the China dummy × a year dummy. Standard errors are reported in brackets.

# APPENDIX A. POPULATION CHARACTERISTICS

Infants Mortality Rate per 1000 live births; life expectancy; percentage of population of the following age groups of total: 0-14 years age group; 15-64 years age group, 65+ years age group, 0-14 years female (male) age group, 15-19 years female (male) age group, 20-24 years female (male) age group, 25-29 years female (male) age group, 30-34 years female (male) age group, 35-39 years female (male) age group, 40-44 years female (male) age group, 45-49 years female (male) age group; 50-54 years female (male) age group, 55-59 years female (male) age group, 60-64 years female (male) age group, 65+ years female (male) age group, the level of urbanization, sex ratio at birth.

## APPENDIX B. PROCEDURES USED IN CONSTRUCTING TABLE VII

We separately estimated (a) the age-group 0-19 years; (b) the age-groups 20-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, and 60-64 years; and (c) the age-groups 65-69, 70-74, 75-79, 80-84, and 85+ years. It is most challenging to estimate the age-group of newborns between 2016 and 2035, which represents the age-group 0-19 years. In the estimation of the age-group 0-19 years in 2035, We estimated the newborns by assuming 16 million new births per year, and a sex ratio of 1.10 between 2016 and 2035, as well as taking into account the average central death rates between different ages for males and females, respectively (see Table C1 in Appendix C), that is:

$$PopulationSize_{0-19} = \sum_{t=u}^{v}[16 \times \frac{1.1}{2.1} \times (1 - mortality_{infant,male,t}) \times (1 - nMx_{average,male,t}) \quad + \\ 16 \times \frac{1}{2.1} \times (1 - mortality_{infant,female,t}) \times (1 - nMx_{average,female,t})] \ ,$$

where $nMx_{average,t}$ is the average central death rate at age $t \in [u, v]$ for males and females, respectively, with u and v as the initial age and final age of each age-group respectively, based on the ages given in Table B1.

In the estimations of the population size of the corresponding sub-age-groups for the age-group 20-64 years, we only needed to take into account the average central death rate of each age between the different ages specified in Table C1 in Appendix C. Taking the estimation of the age-group 20-29 years as an example, where the population size is estimated using:

$$PopulationSize_{age20-29} = \sum_{t=0}^{9}[PopulationSizeMale_{age:\,t} \times (1 - nMx_{average,male,age:\,t+20}) + \\ PopulationSizeFemale_{age:t} \times \ (1 - nMx_{average,Female,age:\,t+20})] \qquad (*)$$

where P$opulationSizeMale_{age:\,t}$ represents the population size of males at age $t \in [0,9]$, and $nMx_{average,male,age:\,t+20}$ represents the central death rate for males at age t+20 with the integer $t \in [0,9]$.

The size of the age-group 65-84 years can be estimated using a modified version of the equation (*). We deconstructed the 85+ years age-group into three age-groups, namely 85-89, 90-94 and 95+ years, and we then used the age and gender distribution for the age-groups 50-54, 55-59 and 60-64 years in 2015 (using their percentages over the total population) to represent the population and gender distribution of the age-groups 85-89, 90-94 and 95+ years in 2035, respectively. Then, by using a modified version of the equation (*), we were able to estimate the population size in the year 2035 for the age-groups 65-85, 85-89, 90-94 and 95+ years, and for each gender. Once we had estimated the population size for each age-group, estimates for all the other items in Table VII could be calculated.

Table C1

| | Panel A. Age Dependency Ratio (2017) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Income | | | | | Regions | | | | |
| | World | China | High | Upper Middle | Middle | Lower Middle | Low | North America | Euro Area | Central Euro | East Asia | South Asia |
| Old /working % | 13.30 | 14.84 | 25.4 | 13.88 | 11.14 | 8.55 | 6.17 | 23.66 | 31.77 | 25.69 | 14.9 | 8.75 |
| (0-14) Young/working % | 39.68 | 24.66 | 25.8 | 29.55 | 38.73 | 47.38 | 77.2 | 28.29 | 23.29 | 22 | 28.4 | 44.24 |

Panel B. Life Table - China (1999) [b]

| Age | 0 | 1 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| nMx [a] (Male) | .0268 | .0024 | .0008 | .0007 | .0011 | .0014 | .0013 | .0018 | .0023 | .0031 | .005 | .0081 | .0131 | .0222 | .0363 | .0612 | .0991 | .1572 | .2643 | .562 | .647 | .99 |
| nMx (Female) | .03 | .0027 | .0006 | .0005 | .0009 | .0012 | .0011 | .0014 | .0016 | .0023 | .0036 | .0057 | .0088 | .0149 | .0245 | .0431 | .0703 | .1145 | .2136 | .48 | .589 | .92 |

Panel C: Counties/Regions (Weights)

| | |
|---|---|
| 15-19 Female | Macedonia (.313), Samoa (.278), Cuba (.255), Bahrain (.074), Romania (.016), Maldives (.013), Virgin Islands (.05) |
| 15-19 Male | Cuba (.269), Niger (.203), Macedonia (.169), Samoa (.128), Virgin Islands (.075), Malta (.052), Aruba (.01), United Arab Emirates (.002) |
| 20-24 Female | Macedonia (.362), Samoa (.162), French Polynesia (.161), Bahrain (.092), Tunisia (.067), Macao (.056), Norway (.045), Colombia (.032) Micronesia, Fed. Sts. (.017), Ireland (.005), |
| 20-24 Male | Macedonia (.299), Cabo Verde (.253), Cube (.182), French Polynesia (.092), Macao (.074), United Arab Emirates (.064), Virgin Islands (.035) |
| 25-29 Female | Aruba (.033), Bahrain (.119), Colombia (.064), French Polynesia (.139), Guam (.029), Hungary (.045), Macao (.136), Madagascar (.161), Micronesia, Fed. Sts. (.213), Romania (.025), Tunisia (.036) |
| 25-29 Male | French Polynesia (.199), Bahrain (.166), Cabo Verde (.144), Macao (.137), Norway (.127), Virgin Islands (.077), Germany (.069), Cuba (.052), Antigua and Barbuda (.024), Grenada (.016) |
| 30-34 Female | Macao (.215), Micronesia, Fed. Sts. (.185), Romania (.167), Guam (.153), French Polynesia (.125), Bahrain (.082), Hungary (.074) |
| 30-34 Male | French Polynesia (.262), Cabo Verde (.173), Macedonia (.163), Cuba (.108), Hong Kong (.106), Bahrain (.099), Romania (.055), Macao (.03), Suriname (.004) |

NOTE: [a] nMx is the estimates of central death rates.

[b] The central death rates of 90+ are not available in Lopez (2001). We consult the available central death rate of other countries such as of Australia life table.

APPENDIX C.