



OPEN A decomposition study on the factors influencing China's total fertility rate changes between 1990 and 2020

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Low fertility is not conducive to healthy population development. The total fertility rate (TFR) is influenced by the education expansion (measured by the proportion of non-student women, NSP), marriage delay (measured by the proportion of married women, MP), and marital fertility rate (MFR). This study decomposes the TFR change into the changes in NSP, MP, and MFR using China's census and 1% population sample survey data. During 1990–2020, the changes in NSP, MP, and MFR contributed –22%, –90%, and 12%, respectively, to the changes in TFR. The continuous decline in NSP reduced the TFR, and the intensity continued to increase over time. As the primary negative driving force, the rapid decline in MP also consistently reduced the TFR. The marital fertility rate had a downward effect on the TFR before 2000 and an upward effect after 2000. The effects of NSP, MP, and MFR on the TFR varied with the birth order, age and region (among cities, towns, and villages). In summary, China's TFR has considerably changed in combination with changes in NSP, MP, and MFR. Without effective measures, China's TFR may further decline into the lowest-low fertility trap.

Keywords Total fertility rate, Education expansion, Marriage delay, Marital fertility rate, Decomposition, Change

The total fertility rate (TFR) has declined to a low level in many developed and middle-income countries with severe population ageing and negative growth, which causes social issues such as labour shortages, economic stagnation, and high healthcare and pension pressures. It is generally accepted among scholars worldwide that a TFR less than 2.1 corresponds to low fertility, a value less than 1.5 corresponds to very low fertility, and a value less than 1.3 corresponds to lowest-low fertility^{1–3}. China's TFR rapidly fell below the replacement level in the early 1990s; since then, China has entered a period of low fertility fluctuations⁴. Academics have reached the consensus that China's TFR is very low, but the exact numerical level of the TFR is unstable and controversial^{5–8}. To counteract a further drop in fertility and promote balanced and healthy development of the population, the Chinese government relaxed its birth control policy several times with the implementation of the selective two-child policy in 2013, universal two-child policy in 2016, and universal three-child policy in 2021, the effects of which have failed to produce a sustained baby boom^{4,9,10}. Data from the National Bureau of Statistics indicate that from 2020 to 2023, the annual number of births in China was 12.02 million, 10.62 million, 9.65 million, and 9.02 million, and the estimated TFRs were 1.28, 1.15, 1.07, and 1.00, respectively, with a continuous downward trend. Therefore, it is necessary to study the changing trends of the TFR and the impact of different factors. There are two main aspects of fertility changes in the literature: a socioeconomic and a demographic perspective.

Both birth control policy and socioeconomic development have contributed to China's fertility changes. On one hand, unlike developed countries, China's rapid fertility decline was mainly achieved by birth control policies in the early stage. Over time, socioeconomic development has been the decisive driving force of fertility changes^{11–13}. China's fertility policy has dramatically changed in recent decades. In the 1970s, China began implementing the “later, longer, fewer” policy. In the 1990s, all levels of government were strictly responsible for implementing the one-child policy. In the 2000s, many provinces and regions relaxed birth control and allowed eligible couples to have two children. After the 2010s, the government gradually liberalized birth control with the selective two-child policy, universal two-child policy and universal three-child policy^{4,14,15}. There are significant provincial and urban-rural disparities in China's fertility policies^{16,17}. In addition, other socioeconomic factors affect the fertility rate. Research worldwide has shown that the number of babies born during famine times

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plummet, as in the case of China's great famine of 1959–1960¹⁸. With respect to the Chinese zodiac preference, parents may prefer to have children in the Dragon years but not in the Goat years^{19,20}. There have been three baby booms in China: the first one occurred in the 1950s, the second one began at the end of the great famine and lasted until 1973, and the third one was during 1986–1990¹¹. The high cost of childrearing and work-family conflicts prevent parents from having more children. Moreover, the fertility concept of the younger generation has gradually transformed from traditional to modern, and their willingness toward marriage and childbirth has decreased^{21,22}.

The changes in TFR result from the combined effects of increased education, marriage postponement, and fertility rate within marriage in China from a demographic perspective. First, the expansion of female education (notably higher education) may directly or indirectly influence the TFR²³. There are pervasive studies on the relationship between education and fertility, and they generally find that a higher education level negatively impacts fertility^{24–26}. Directly, more schooling can postpone the age of marriage and childbearing; thus, the tempo effect will reduce the period fertility rate. The expansion of universities has dramatically improved women's education levels and significantly delayed their entry into marriage and childbirth^{27–29}. Chinese women usually complete their higher education after the legal age of marriage (20 years), and they do not marry or have children during their higher education. Education also indirectly negatively affects fertility by increasing opportunity costs and promoting gender identity²³. Women with higher education levels are likely to have better job opportunities and higher wages. However, parenting always takes too much time and energy for women, which may lead to lower income and even unemployment. Thus, highly educated women face greater opportunity costs and have fewer children^{30–32}. Moreover, highly educated women are more willing to devote themselves to their careers and colourful life instead of parenting. Therefore, highly educated women actively reduce the number of children to pursue individual value^{33,34}.

Second, postponing female marriage decreases the TFR. On one hand, the tempo effect of marriage delay can decrease the period fertility rate. In Chinese societies, most women give birth only after marrying. When the number of married women and new-born babies decreases, the period fertility rate decreases^{35,36}. On the other hand, later marriage leads to later fertility, and the long-term trend of late fertility may reduce the TFR. The extremely low fertility rate is usually related to the high birth order and late fertility age cohort³⁷. Marriage delay may cause fertility aging. The postponement of the age at first (or second) childbirth can reduce the possibility of having more children during the women's lifetime³⁸. In addition, the likelihood of infertility and miscarriage increases with women's age^{39,40}. From the empirical evidence, the decline in China's fertility was mainly attributed to the first-order TFR, and late marriage has dominated the first-order TFR decline³⁶. During 2000–2010, China's TFR declined by only 0.03, but women's marriage delay contributed to a decline of 0.17⁴¹. Some overseas studies have shown that the declining proportion of marriage has played an essential role in low fertility^{42,43}. In European countries, the main reason for the increase in fertility after 2000 was the weakening of marriage delay, which indicates a negative tempo effect on the TFR⁴⁴. The cohort TFR has also declined in Nordic countries, which is attributable to the declining first births and tempo effect⁴⁵.

Third, the changes in marital fertility rate impact the TFR. Non-marital childbearing behaviour has not become generally accepted in China, and the illegitimate birth rate has remained very low⁴¹. Although China has seen an increase in phenomena such as unmarried cohabitation and illegitimate childbirth, giving birth to a child within marriage remains the social norm¹⁷. A survey revealed that approximately 6% of Chinese couples did not have children after 3–5 years of marriage, and the percentage was lower than 1% after more than five years²¹. For both men and women, remaining unmarried is the main factor that prevents them from realizing fertility desires, and giving birth to children is a common choice after entering marriage^{46,47}. Empirical studies have revealed the critical role of the marital fertility rate in the variation in China's TFR. Jiang et al. and Retherford et al. noted that the decrease in China's TFR between 1990 and 2000 was attributable to marriage delay and the decline in marital fertility rate, which accounted for approximately two-fifths and three-fifths, respectively^{41,48}. However, as Yip et al. and Yang et al. reported, the increase in marital fertility rate increased the TFR during 2000–2010^{4,49}.

Although there are other factors that affect the fertility rate, education, marriage, and marital fertility are the most critical. Education is an important socioeconomic variable and strongly correlated with many factors affecting fertility. On one hand, it directly affects women's marriage and marital fertility; on the other hand, it may indirectly affect fertility by affecting other factors. In East Asian countries, marriage and childbearing within marriage remain the choices of most women. Delaying marriage or never marrying directly reduces the period fertility level. Marital fertility is mainly influenced by socioeconomic factors such as education, income and occupation. Other influencing factors are not formally included in the model, and this research only focuses on the decomposition of three key factors. Furthermore, Chinese women's education, marriage, and reproductive behaviours have undergone great changes compared with other factors in recent decades. According to the census, the average years of education for Chinese women were 7.1 years in 2000 and 9.6 years in 2020. The average age at first marriage was 23.28 years in 2000 and 27.95 years in 2020. Therefore, these three factors are selected to decompose China's total fertility rate in this study.

Certain limitations remain in the literature. First, the current studies do not incorporate the impact of education expansion into the decomposition of influencing factors, whereas education expansion has greatly contributed to TFR changes. Although some scholars have explored the effect of education on fertility^{25,26}, there is limited quantitative research on the joint contribution of education expansion, marriage delay, and the marital fertility rate to China's TFR changes^{41,50}. Second, the timeliness and reliability of the data sources need to be improved. Most studies used census and population sampling survey data before 2015^{4,41,48}. The tabulated data of the 2020 Census were released, and the timeliness of previous studies can be improved. Although Li and Zhang used 2017 National Fertility Survey data to decompose the impact factors of TFR changes, the micro retrospective surveys have flaws that affect their scientific validity⁵⁰. Finally, the significant disparities among

birth order, urban-rural area, and age group in terms of TFR variations are worth further exploration and should be incorporated into policy formulation and implementation. Therefore, this article will attempt to fill the research gaps above mentioned.

Currently, there are few quantitative studies on the impacts of education expansion, marriage delay, and the marital fertility rate on the TFR variation. This study examines the effects of the proportion of non-student women (NSP, measuring the education expansion), proportion of married women (MP, measuring the marriage delay), and marital fertility rate (MFR) on changes in China's TFR using a decomposition model. Data from the census and 1% population sample surveys between 1990 and 2020 are used. This study assumes that all females strictly follow the “graduated-married-childbirth” behaviour path. The study will also consider the differences between birth orders, urban-rural areas, and age groups. This paper focuses on the relative level and internal variation in China's TFR instead of its precise numerical value. This study aims to provide new insights into the fertility change and policy-making in China.

Data and methods

Data sources

The data for this study are from successive censuses and 1% population sample surveys in China, including four censuses in 1990, 2000, 2010, and 2020, and three 1% population sample surveys in 1995, 2005, and 2015. The data include materials about the age structure, fertility status, marital status, and completion status of schooling of childbearing women aged 15–49 years at the national, city, township, and village levels (see Supplementary Table 1). The data from censuses and 1% population sample surveys are released by the National Bureau of Statistics (NBS), China's statutory and authoritative statistical agency. Notably, the number of registered births in the fourth census includes births in the first and second halves of 1989 and the first half of 1990, and this paper used the number of births in the entire year of 1989. Data on women's schooling in 2015 are missing, and the average of the indicators in 2010 and 2020 estimates the proportion of non-student in 2015. Data on the marital status in 2000 for urban and rural areas are also missing, and we calculated the proportion of married women for urban and rural areas based on the national change between 2000 and 2005.

The accuracy of the data concerning births published by the NBS has been highly controversial. Some scholars criticized the possibility of significant underreporting of births, which led to a distorted fertility rate^{7,51}. Others argued that there was insufficient evidence of massive and persistent underreporting of deliveries in China, and the birth data from the census were credible⁵². The NBS adjusted the number of births upwards but did not release adjustment details. Although some scholars adjusted for the number of births, the methodology and results widely vary, and there is no consensus⁵³. This article believes that the birth data from the NBS are reliable and uses tabulated data from the census and 1% population sample survey with no adjustments based on the following considerations. First, with the gradual relaxation of birth restrictions after 2010, residents and the government have no incentive to underreport births, and the data quality becomes more reliable. Second, it is widely believed that the 2020 census data are the most reliable and accurate due to new census measures such as ID card number collection, electronic and intelligent data collection, and the comparison of multi-department data. Third, the current study focuses on the relative level and internal structure of the TFR instead of its absolute level. The data sources have continuous survey and statistical standards and are comparable across periods. Fourth, without a scientific approach, data adjustment can cause data distortion, which may be more severe. Despite possible flaws, the censuses and 1% population sample surveys are the only sources to fulfill our research objectives.

Decomposition model

It is well known that structural decompositions are non-unique. There are two main structural decomposition methods to break down the product of three factors into the changes in its determinants in the literature: the approximate decomposition with mid-point weights and the average of the two so-called polar decompositions. In this case, the rate R can be expressed as $R = \alpha \beta \gamma$, where α , β and γ are the three factors. If these factors suppose the values A , B and C in population 1, and a , b and c in population 2, then the rates R_1 and R_2 are $R_1 = ABC$ and $R_2 = abc$. The difference between R_1 and R_2 can be decomposed:

From Gupta^{54–56}, he adopted the approximate decomposition with mid-point weights:

$$\begin{aligned} R_2 - R_1 &= abc - ABC = \left[\frac{bc + BC}{3} + \frac{bC + Bc}{6} \right] (a - A) \\ &\quad + \left[\frac{ac + AC}{3} + \frac{aC + Ac}{6} \right] (b - B) \\ &\quad + \left[\frac{ab + AB}{3} + \frac{aB + Ab}{6} \right] (c - C) \\ &= \alpha_effect + \beta_effect + \gamma_effect \end{aligned}$$

From Jiang et al.^{41,57}, they adopted the average of the two so-called polar decompositions:

$$\begin{aligned} R_2 - R_1 &= abc - ABC = \left[\frac{BC + bc}{2} \right] (a - A) + \left[\frac{aC + Ac}{2} \right] (b - B) + \left[\frac{AB + ab}{2} \right] (c - C) \\ &= \alpha_effect + \beta_effect + \gamma_effect \end{aligned}$$

Dietzenbacher and Los analyzed the advantages and disadvantages of the above two decomposition techniques through specific cases⁵⁸. In their empirical analysis for the Netherlands from 1986 to 1992, results were calculated for 24 equivalent decomposition forms. They examined the outcomes of two main approaches. The solution of applying mid-point weights yields a decomposition that is not exact. The terms have a complex weighting structure; moreover, they do not have the same type of weights (1/3 and 1/6 in Gupta's studies). Although it might seem a solution to the problem of the marked sensitivity, in fact, it only conceals the problem. The average of the two so-called polar decompositions appears to be remarkably close to the average of the full set of 24 decompositions. It should be emphasized that taking the average of the two polar decompositions is still exact but not as intuitively appealing as the other solution. Therefore, this article prefers to use taking the average of the two polar decompositions for two reasons: (1) the average of the two polar decompositions can produce more exact results than the approximate decomposition with mid-point weights in the general case; (2) the average of the two polar decompositions without complex weights has a simpler form than the other one, although it is intuitively less appealing or attractive (asymmetrical but dual).

According to the literature review, from the perspective of demography, the TFR is influenced by several factors, of which education expansion, marriage delay, and the marital fertility rate are the most critical factors. The study assumes that all females of reproductive age follow the “graduated-married-childbirth” behaviour path. This assumption indicates that a woman aged 15–49 first graduates from school, subsequently marries, and finally has children. The proportion of married students is low in China, and marrying only after graduation is common for most females⁵⁹. Nonmarital childbirths are also rare in China, regarded as illegitimate, and not culturally accepted^{48,49,60}. Therefore, this study does not consider students' marriage and nonmarital births.

Referring to previous studies^{4,50,61}, based on the traditional marriage and fertility norm of “graduated-married-childbirth,” education expansion is measured by the proportion of non-student women (NSP), and marriage postponement is measured by the proportion of married women (MP). The proportion of non-student women (NSP) is equal to the number of non-student women divided by the average number of women of childbearing age. The proportion of married women (MP) is equal to the number of non-student married women divided by the number of non-student women. The marital fertility rate (MFR) is equal to the number of births divided by the number of non-student married women. The decomposition of the total fertility rate in this study is as follows: TFR is the total fertility rate, NSP^a is the proportion of non-student women at a specific age, MP^a is the proportion of married women at a specific age, and MFR^a is the marital fertility rate of women at a specific age. The age-specific fertility rate of women is $ASFR^a = NSP^a \times MP^a \times MFR^a$.

The total fertility rate (TFR) can be calculated from Eq. (1):

$$\begin{aligned} TFR &= \sum_{a=15}^{49} ASFR^a = \sum_{a=15}^{49} NSP^a \times MP^a \times MFR^a \\ &= \sum_{a=15}^{49} \frac{NSP^a \times MP^a \times MFR^a}{2} + \sum_{a=15}^{49} \frac{NSP^a \times MP^a \times MFR^a}{2} \end{aligned}$$

The subscripts 1 and 2 denote periods 1 and 2, respectively; then, the difference in TFR between the two periods can be expressed as Eq. (2) with four terms:

$$\begin{aligned} TFR_2 - TFR_1 &= \sum_{a=15}^{49} NSP_2^a \times MP_2^a \times MFR_2^a - \sum_{a=15}^{49} NSP_1^a \times MP_1^a \times MFR_1^a \\ &= \sum_{a=15}^{49} \frac{NSP_2^a \times MP_2^a \times MFR_2^a}{2} + \sum_{a=15}^{49} \frac{NSP_2^a \times MP_2^a \times MFR_2^a}{2} \\ &\quad - \sum_{a=15}^{49} \frac{NSP_1^a \times MP_1^a \times MFR_1^a}{2} - \sum_{a=15}^{49} \frac{NSP_1^a \times MP_1^a \times MFR_1^a}{2} \end{aligned}$$

According to the studies of Jiang et al.^{41,57}, eight intermediate terms with different subscripts (representing the effects of different combinations of factors and periods on the total difference) below should be included in Eq. 2 for the decomposition:

$$\begin{aligned} &\sum_{a=15}^{49} \frac{(NSP_2^a \times MP_1^a \times MFR_1^a)}{2} - \sum_{a=15}^{49} \frac{(NSP_2^a \times MP_1^a \times MFR_1^a)}{2} = 0 \\ &\sum_{a=15}^{49} \frac{(NSP_2^a \times MP_2^a \times MFR_1^a)}{2} - \sum_{a=15}^{49} \frac{(NSP_2^a \times MP_2^a \times MFR_1^a)}{2} = 0 \\ &\sum_{a=15}^{49} \frac{(NSP_1^a \times MP_2^a \times MFR_2^a)}{2} - \sum_{a=15}^{49} \frac{(NSP_1^a \times MP_2^a \times MFR_2^a)}{2} = 0 \\ &\sum_{a=15}^{49} \frac{(NSP_1^a \times MP_1^a \times MFR_2^a)}{2} - \sum_{a=15}^{49} \frac{(NSP_1^a \times MP_1^a \times MFR_2^a)}{2} = 0 \end{aligned}$$

There are total twelve minor terms in the difference equation. Then, terms with the same factors ($NSP_2^a - NSP_1^a$), ($MP_2^a - MP_1^a$) and ($MFR_2^a - MFR_1^a$) are combined. Therefore, the difference in TFR between two periods can be decomposed as shown in Eq. (3):

$$\begin{aligned} \text{TFR}_2 - \text{TFR}_1 &= \sum_{a=15}^{49} \text{NSP}_2^a \times \text{MP}_2^a \times \text{MFR}_2^a - \sum_{a=15}^{49} \text{NSP}_1^a \times \text{MP}_1^a \times \text{MFR}_1^a \\ &= \sum_{a=15}^{49} (\text{NSP}_2^a - \text{NSP}_1^a) \times \frac{(\text{MP}_1^a \times \text{MFR}_1^a + \text{MP}_2^a \times \text{MFR}_2^a)}{2} \\ &\quad + \sum_{a=15}^{49} (\text{MP}_2^a - \text{MP}_1^a) \times \frac{(\text{NSP}_2^a \times \text{MFR}_1^a + \text{NSP}_1^a \times \text{MFR}_2^a)}{2} \\ &\quad + \sum_{a=15}^{49} (\text{MFR}_2^a - \text{MFR}_1^a) \times \frac{(\text{NSP}_1^a \times \text{MP}_1^a + \text{NSP}_2^a \times \text{MP}_2^a)}{2} \end{aligned}$$

The first term on the right side of Eq. (3) represents the effect of the change in NSP on the change in TFR, the second term represents the effect of the change in MP on the change in TFR, and the third term represents the effect of the change in MFR on the change in TFR. Although there are other formulas for three-factor decomposition, the above method is appropriate.

The present study will also decompose the TFR by birth order, urban-rural area and age groups, and it is necessary to explain the specific methods. Consistent with the TFR decomposition method of the whole population, the TFR decompositions by birth order and urban-rural area are only different in sample. The birth order is divided into the first, second, and higher order. The urban area includes city and town, whereas rural area is village. The urban or rural area is based on current residence but not place of origin for rural-urban migrants. In China’s census, a city refers to a municipality or city established by the administrative system, which usually includes residential, industrial and commercial areas. A town is a small city, usually a government seat outside the main urban area. Villages refer to areas outside cities and towns with a low population density and mainly agricultural production. For the TFR change by age, we decomposed each age specific fertility rate (the age specific fertility rate) and then added them up. The TFR change by age is in fact the ASFR change. This article is not interested in age composition and age effects. It only focused on the heterogeneity of fertility rate change across ages rather than its composition effect, just like by birth order and by cities, towns, and villages. In other words, this paper assumes that the age composition of women of childbearing age remains unchanged.

The Excel software was used for all statistical analyses in this research (see Supplementary Table 2).

Results
Levels and trends of TFR, NSP, MP, and MFR

Table 1 presents the levels and trends of the TFR, NSP, MP, and TMFR. China’s TFR showed an initial downward trend, followed by an upward trend in the last three decades. It rapidly declined from 2.250 in 1990 to below the replacement level of 1.427 in 1995 and has since fluctuated below the very low level. Between 2000 and 2005, the TFR slightly increased by 0.117. During 2005–2015, the TFR decreased to 1.047 in 2015. After 2015, the TFR significantly rebounded to a relatively high level of 1.296 in 2020. The TFR by birth order revealed the same trends. The first-order TFR (TFR1) was greater than the second-order TFR (TFR2), and the second-order TFR was greater than the higher-order TFR. The TFR in urban-rural areas exhibited a similar trend. The village TFR (TFRv) was greater than the town TFR (TFRt), and the town TFR was greater than the city TFR.

The proportion of non-student women (NSP) aged 15–49 declined from 95.70% in 1990 to 81.97% in 2020, which indicates an increase in proportion of students or education expansion. The proportion of married women (MP) aged 15–49 declined from 79.82% in 1990 to 67.11% in 2020, which indicates delaying marriage or never marrying. The total marital fertility rate (TMFR) measures the total fertility rate among women ever married. The TMFR initially declined but subsequently increased during 1990–2020. However, the difference between TMFR and TFR steadily increased from 0.534 in 1990 to 1.864 in 2020. The TMFR remained stable from 1995 to 2015, but the gap between TMFR and TFR widened, which indicates that other factors decreased the TFR.

There are significant disparities across age groups in the ASFR, NSP, MP, and ASMFR. As shown in Fig. 1 (a), the age-specific fertility rate (ASFR) curves tend to delay the peak age, decrease the peak level, and cause

Year	1990	1995	2000	2005	2010	2015	2020
TFR (the total fertility rate, aged 15–49)	2.250	1.427	1.221	1.338	1.188	1.047	1.296
TFR1 (first order)	1.009	0.959	0.867	0.891	0.728	0.556	0.626
TFR2 (second order)	0.720	0.358	0.288	0.384	0.381	0.416	0.535
TFR3+ (higher order)	0.522	0.110	0.066	0.063	0.079	0.075	0.136
TFRc (cities)	1.517	1.090	0.866	0.927	0.887	0.818	1.111
TFRt (towns)	1.629	1.209	1.076	1.278	1.161	1.078	1.396
TFRv (villages)	2.537	1.557	1.434	1.654	1.444	1.265	1.544
NSP (the proportion of non-student women aged 15–49, %)	95.70	94.40	92.23	90.01	87.10	84.54	81.97
MP (the proportion of married women aged 15–49, %)	79.82	77.92	75.97	75.27	72.17	70.17	67.11
TMFR (the total marital fertility rate aged 21–49)	2.555	1.910	1.885	2.051	2.003	2.083	3.103
TMFR – TFR (difference)	0.534	0.625	0.752	0.848	0.877	1.105	1.864

Table 1. TFR, NSP, MP, and TMFR levels and trends in China. The legal minimum age for Chinese women required to marry was 20 years, and the TMFR for women aged 15–20 was misestimated due to marriage or childbirth underreporting. Therefore, data for women aged 21–49 are included in the TMFR and TMFR – TFR.

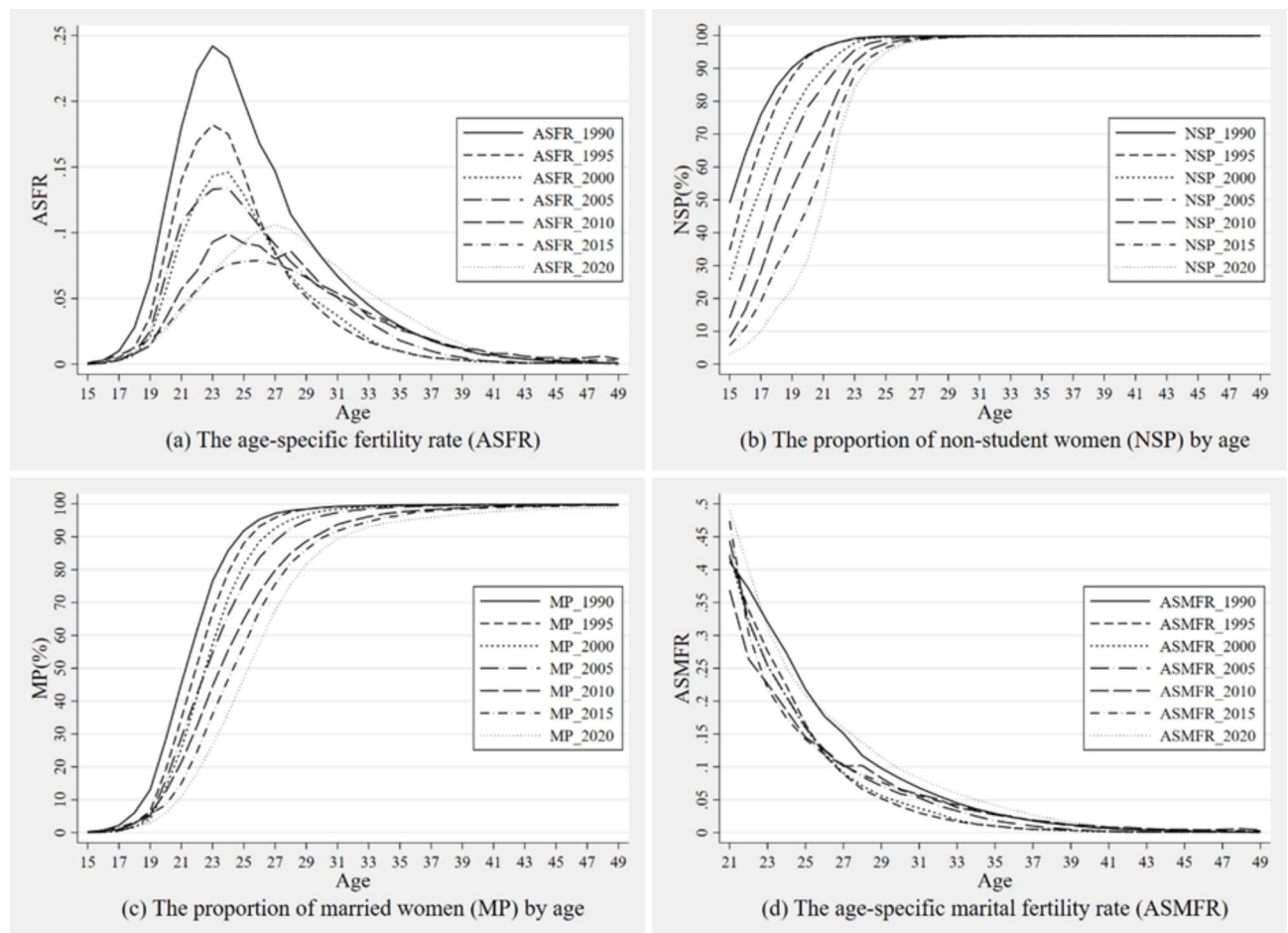


Fig. 1. ASFR, NSP by age, MP by age and ASMFR from 1990 to 2020.

an overall shift to the right. The primary childbearing age for Chinese women is 20–39 years. The peak age at which the highest fertility rate occurs is gradually delayed. The peak level of the ASFR constantly declined from 0.242 in 1990 to 0.079 in 2015 and significantly rebounded after 2015. The ASFR curves show an overall shift to the right, which indicates childbearing delay. Figure 1 (b) presents the proportion of non-student women (NSP) by age. The percentage of women aged 15–25 who are not in formal education has substantially decreased over time, which indicates education expansion. From 1990 to 2020, at 15 years of age (high school entry), the NSP cumulatively decreased by 45.9%. At 18 years of age (college entry), the NSP experienced the sharpest decline (67.5%). At 22 years of age (master entry), the NSP decreased by 27.6%. At 25 years of age (doctoral entry), the NSP slightly decreased by 4.7%. Notably, the decline in NSP for those aged 18–21 accelerated after 1995.

Figure 1c shows the proportion of married women (MP) by age. In 1990–2000, the proportion of married women experienced a downward trend, with reproductive years of 20–35. The largest decline in MP was observed among women aged 21–26. The MP curve was less delayed before 2005, but the delay accelerated after 2005, which indicates more significant marriage delays in the younger cohorts. Figure 1d displays the age-specific marital fertility rate (ASMFR). The ASMFR curve fluctuated in a complicated manner across age groups in different periods. In 1990–1995, there was a sudden decrease in ASMFR at all ages. In 1995–2010, the ASMFR continuously decreased in the younger age group of 21–25 years but noticeably increased in the older age group of 26–35. During 2010–2015, a moderate decrease in ASMFR was observed for the 23–29 age group. The ASMFR of 2020 demonstrated a dramatic increase at all ages and exceeded that of most previous years.

Benchmark decomposition of the TFR change

As shown in Table 2, this study initially explored the overall contributions of NSP, MP, and MFR to the TFR variations. During 1990–2020, China's TFR was 2.250 in 1990 and decreased by 0.954 to 1.296 in 2020. The contributions of the change in NSP, MP, and MFR to the TFR change are approximately -0.213 (-22.3%), -0.862 (-90.4%), and 0.121 (12.7%), respectively. During 1990–1995, of the 0.823 decrease in TFR, only 0.007 (0.8%) was due to a decrease in NSP, 0.235 (28.5%) was due to a decrease in MP, and 0.581 (70.7%) was due to a decrease in MFR. During 1995–2000, the decreases in NSP, MP, and MFR contributed 14.0%, 85.0%, and only 1.0%, respectively, to the decline. During 2000–2005, the TFR increased by 0.117. The decreases in NSP and MP reduced the TFR by 0.029 and 0.009, whereas the increase in MFR increased the TFR by 0.155. During 2005–2010, the changes in NSP and MP decreased the TFR by 0.049 and 0.155, respectively, whereas the difference in

Year	Initial TFR	Final TFR	Change (Percent)			
			Total	NSP	MP	MFR
1990–1995	2.250	1.427	−0.823 (−100.0%)	−0.007 (−0.8%)	−0.235 (−28.5%)	−0.581 (−70.7%)
1995–2000	1.427	1.221	−0.206 (−100.0%)	−0.029 (−14.0%)	−0.175 (−85.0%)	−0.002 (−1.0%)
2000–2005	1.221	1.338	0.117 (100.0%)	−0.029 (−24.5%)	−0.009 (−7.9%)	0.155 (132.4%)
2005–2010	1.338	1.188	−0.150 (100.0%)	−0.049 (−32.9%)	−0.155 (−103.1%)	0.054 (36.0%)
2010–2015	1.188	1.047	−0.141 (−100.0%)	−0.045 (−31.8%)	−0.108 (−76.4%)	0.012 (8.2%)
2015–2020	1.047	1.296	0.249 (100.0%)	−0.054 (−21.8%)	−0.180 (−72.4%)	0.483 (194.2%)
1990–2020	2.250	1.296	−0.954 (−100.0%)	−0.213 (−22.3%)	−0.862 (−90.4%)	0.121 (12.7%)

Table 2. Decomposition of the change in TFR from 1990 to 2020.

Year	First-order TFR (TFR1)			Second-order TFR (TFR2)			Higher-order TFR (TFR3+)		
	NSP	MP	MFR	NSP	MP	MFR	NSP	MP	MFR
1990–1995	−10.7	−377.9	288.6	−0.3	−10.8	−88.9	−0.1	−1.8	−98.1
1995–2000	−28.7	−164.0	92.7	−3.2	−30.4	−66.4	−0.4	−7.4	−92.2
2000–2005	−106.8	−3.5	210.3	−2.5	−7.4	109.9	−10.6	−50.8	−38.6
2005–2010	−27.3	−73.5	0.8	−164.2	−1114.9	1179.1	−2.8	−27.4	130.2
2010–2015	−21.7	−45.5	−32.8	−18.9	−73.9	192.8	−21.1	−104.9	26.0
2015–2020	−59.7	−171.4	331.1	−9.4	−43.6	153.0	−2.4	−14.3	116.7
1990–2020	−47.4	−172.0	119.4	−15.1	−94.9	10.0	−0.9	−7.3	−91.8

Table 3. Decomposition of the change in TFR by birth order (%).

MFR caused an increase in TFR by 0.054. During 2010–2015, the decreases in NSP and MP contributed 0.045 (21.8%) and 0.108 (72.4%) to the decline, respectively, and the increase in MFR slightly increased the TFR by 0.012 (8.2%). During 2015–2020, the TFR increased by 0.249. The changes in NSP and MP decreased TFR by 0.054 and 0.180, whereas the change in MFR increased the TFR by 0.483.

In summary, the decline in NSP and MP always reduced the TFR, whereas the increase in MFR increased the TFR instead of causing it to decrease after 2000. First, the decrease in NSP, i.e., education expansion, consistently negatively affected the TFR, and the effect intensity gradually increased. Second, the decrease in MP, i.e., marriage postponement, always played a negative role in TFR and is the primary factor in reducing the TFR in China. Third, the change in MFR had a downward effect on the TFR before 2000 but increased the TFR after 2000. Especially during 2000–2005 and 2015–2020, the increase in MFR had the most pronounced upward impact on the TFR.

Decomposition of the TFR change by birth order

Table 3 presents the decomposition of the change in TFR by birth order. The decline in first-order TFR and second-order TFR was mainly attributable to the decrease in NSP and MP, whereas the decrease in MFR caused a prominent decline in higher-order TFR. The changes in NSP and MP had a downward effect on the TFR of first-, second-, and higher-order births, but the effect decreased with increasing birth order. From 1990 to 2020, the change in NSP contributed 47.7% to the decrease in TFR1, 15.1% to the decrease in TFR2, and 0.9% to the decrease in TFR3+. The change in MP contributed 172.0% to the decrease in TFR1, 94.9% to the decrease in TFR2, and 7.3% to the decrease in TFR3+. Moreover, the impact of the change in NSP on TFR1 peaked during 2000–2005 (−106.8%), that on TFR2 peaked during 2005–2010 (−164.2%), and that on the TFR3+ peaked during 2010–2015 (−21.1%). The effect of the variation in MP on the TFR of the first-, second-, and higher-order births also exhibited a similar pattern. Therefore, the impact of education expansion and marriage delay on the TFR change had a birth-order diffusion (or transfer) effect, sequentially from lower-order births to higher-order births. However, the impact of the change in MFR on the TFR by birth order widely varied across time. Between 1990 and 2020, the change in MFR contributed 119.4% to the change in TFR1 and 10.0% to the change in TFR2 but −91.9% to the change in TFR3+.

Decomposition of the TFR changes by city, town, and village

The urban areas include cities and towns, whereas rural areas refer to villages. As shown in Table 4, the changes in NSP and MP had a more substantial effect on the decline in urban TFR than on the rural TFR. On one hand, between 1990 and 2020, the change in NSP contributed 31.9%, 77.3% and 21.0% to the decrease in TFRc, TFRt, and TFRv, respectively; the change in MP contributed 157.7%, 225.5% and 77.2% to the decrease in TFRc, TFRt, and TFRv, respectively. The downward effect of the change in NSP on TFRc peaked at 103.9% during 2005–2010, that on the TFRt peaked at 51.2% during 2010–2015, and that on the TFRv peaked at 31.7% during 2010–2015. The effect of MP on the decrease in TFR for cities, towns, and villages exhibited similar characteristics. Thus, the impact of both education expansion and marriage delay on the TFR change also reflected an urban-rural

Year	TFR for Cities (TFRc)			TFR for Towns (TFRt)			TFR for Villages (TFRv)		
	NSP	MP	MFR	NSP	MP	MFR	NSP	MP	MFR
1990–1995	−6.9	−35.6	−57.5	−1.1	−33.4	−65.5	−0.6	−25.4	−74.0
1995–2000	−8.7	−80.2	−11.1	−2.4	18.4	−116.0	−3.5	−67.8	−28.7
2000–2005	−11.4	−34.2	145.6	−9.6	−5.4	115.0	−16.0	−0.7	116.7
2005–2010	−103.9	−292.2	296.1	−49.1	−127.6	76.7	−16.2	−80.1	−3.7
2010–2015	−20.5	−137.3	57.8	−51.2	−132.7	83.9	−31.7	−37.4	−30.9
2015–2020	−6.5	−27.1	133.6	−16.8	−44.0	160.8	−26.1	−71.1	197.2
1990–2020	−31.9	−157.8	89.7	−77.3	−225.5	202.8	−21.0	−77.2	−1.8

Table 4. Decomposition of the change in TFR by city, town, and village (%).

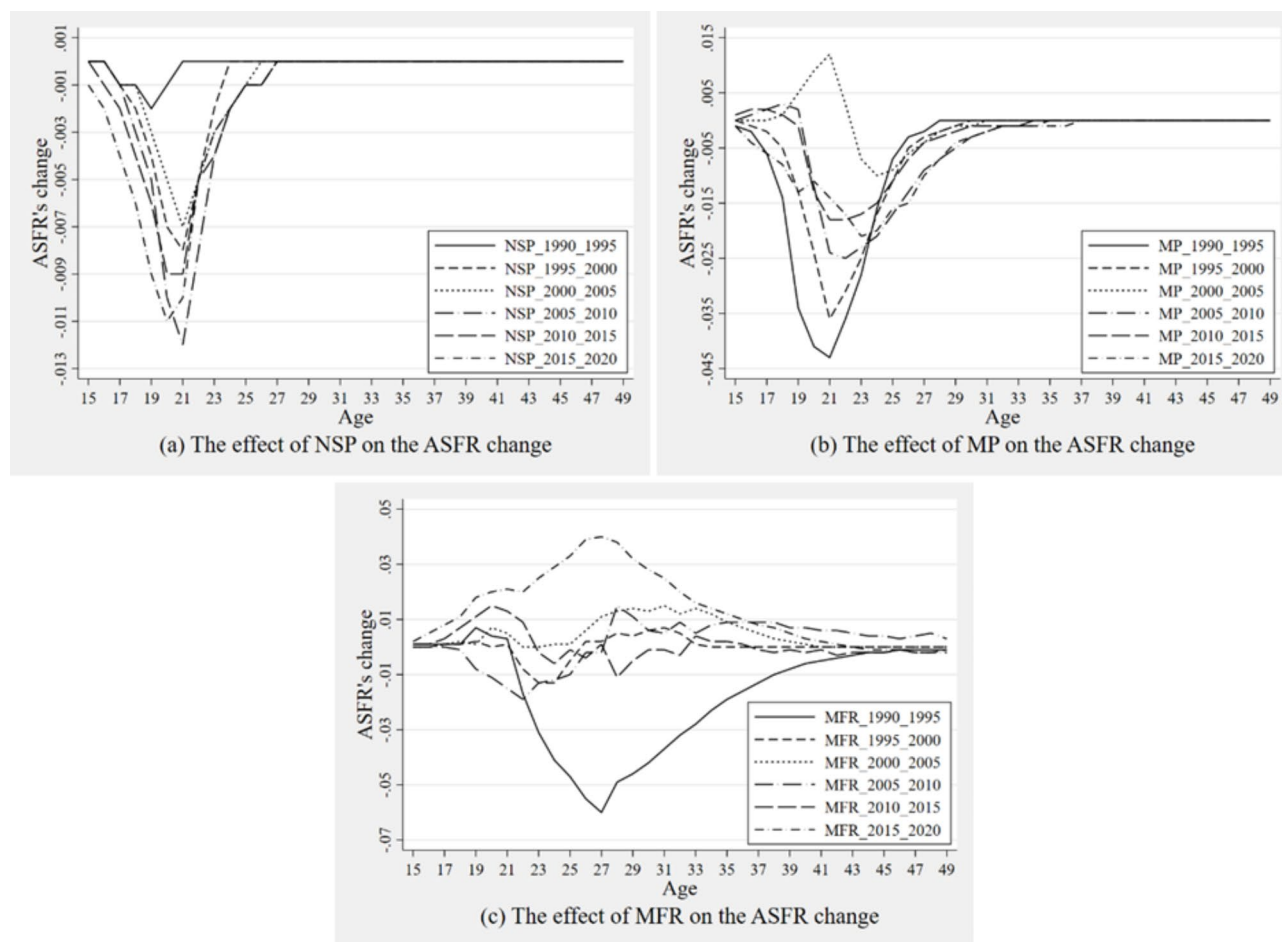


Fig. 2. Effects of the NSP, MP and MFR on the change in ASFR.

diffusion (or transfer) effect. Additionally, the impact of MFR on the change in TFR significantly diverged across urban and rural areas and over time. From 1990 to 2020, the change in MFR increased TFRc (89.7%) and TFRt (202.8%) but decreased TFRv (−1.8%). Before 2000, the change in MFR reduced both urban and rural TFRs. After 2000, the change in MFR increased the urban TFR but reduced the rural TFR during 2005–2015.

Decomposition of the ASFR change

The behaviours of education, marriage, and childbearing markedly vary across ages. This article assumes that the age composition of reproductive-aged women remains unchanged during these periods. This study does not consider age composition or age effects. First, Fig. 2a displays the impact of the NSP on the change in ASFR. The change in NSP had a minimal effect on the ASFR during 1990–1995 but had a significant effect after 1995. Between 1995 and 2020, the reduction in NSP of women aged 15–25 led to a sustained downward effect on the ASFR. The peak age for the impact of the change in NSP on the ASFR was concentrated at approximately age

21, which suggests that college-aged women experienced the most significant reduction in NSP. The downward effect of the change in NSP before the peak age generally increased over time. Thus, the education expansion effect increased for women aged 15–21 (high school and college students), whereas the education expansion effect was relatively stable for women aged 22–27 (graduate students).

Figure 2b shows the effect of the MP on the change in ASFR. The impact of the change in MP on the ASFR was mainly observed for the age group of 15–30 years. The effect of the change in MP on the ASFR was only positive only during 2000–2005 on the age group of 16–22, and it was negative during other periods. The curve of the effect of the MP change on the ASFR had an overall rightward shift due to marriage postponement. Moreover, the peak age at which the change in MP had the greatest effect on the ASFR gradually increased from 21 to 23 years. The peak level of the decrease in ASFR due to the change in MP also gradually decreased from -0.043 during 1990–1995 to -0.021 during 2015–2020. In addition, the absolute and relative levels of the impact of MP change remained high with a primarily downward effect on the ASFR.

Figure 2c shows the effect of the MFR on the change in ASFR. The impact of the MFR change on the ASFR was reflected in the broader age group of 15–40 years. During 1990–1995, the MFR at ages 22–40 negatively contributed to the change in ASFR and peaked at 27 years. The effect of the MFR on the ASFR change during 1995–2010 was mainly downward at ages 15–25 and upward at ages 26–49. The upward effect of MFR on the ASFR was significantly higher in 2005–2010 than in the other years at ages 40–49. During 2010–2015, the MFR change for women aged 23–32 significantly reduced the ASFR. Between 2015 and 2020, the change in MFR had a substantial upward effect on the ASFR of women aged 15–40 with a peak age of 27 years.

Discussion

This section discusses the changes in TFR to complement or correct the previous quantitative analysis. We attempt to explain how fertility policy adjustments, educational reforms, and baby boom generation affected the changes in TFR. During 1990–1995, the TFR plummeted because the strict family planning policy was enforced⁶¹. In the early 2000s, local provinces gradually implemented the “one-and-a-half-child” policy and relaxed birth spacing, which allowed eligible couples to have another child. In the 2010s, the selective and universal two-child policy was successively introduced to encourage all couples to have two children. During 2000–2005 and 2015–2020, the growth in MFR had the most significant upward impact on TFR due to the relaxation of the birth control policy, which is consistent with the findings of some studies^{4,50,52}. During 2015–2020, the MFR had a substantial upward effect on the change in TFR, which indicates that the universal two-child policy in 2016 increased the fertility level at least in the short term. The expansion of education continued to decrease the TFR from 1995 to 2000. The NSP hardly changed before the expansion of college enrolment in 1998, but there has been a tremendous increase since then²⁹. Only the direct effect of the NSP on the TFR was decomposed, which is underestimated.

During 2000–2005, the MP had a minor negative effect on the TFR. The proportion of married women younger than 22 years in 2005 was slightly greater than that in 2000, probably because of the impact of the baby boom in the late 1980s⁶². In general, the expansion of education and delays in marriage are mainly driven by social and economic development instead of the birth policy; the marital fertility rate is affected by the birth policy and socioeconomic factors. Therefore, consistent with previous studies, the birth control policy played a dominant role in the early years of China's TFR decline, but as time progressed, the decline in TFR was primarily attributable to social and economic development^{11,13}.

There are significant heterogeneities in birth order, urban-rural region, and age among the factors that affect the change in TFR. On one hand, the contributions of education expansion and marriage delay to the TFR differ with birth order. The findings of our research support previous claims that during the early periods of TFR decline, the decline in the second- and higher-order TFRs made the main contribution, but during the later periods, the decline in the first-order TFR dominated the decline^{4,52}. The declining effects of the NSP and MP on the TFR decreased with increasing birth order; thus, there was more room for the first-order TFR to decrease with the increase in education and marriage delay. This finding also indicates a birth-order transfer effect of education expansion and marriage delay on the TFR from lower to higher birth orders. The decomposition by birth order has further elucidated the reasons behind the demographic effects, which responded to the limitations of the study by Jiang et al.⁴¹.

The contributions of education expansion, marriage delay, and the marital fertility rate to the TFR varied across cities, towns, and villages. During 1990–2000, increased education, delayed marriage, and the marital fertility rate negatively affected the TFR for both urban and rural women. During 2000–2020, education expansion and marriage postponement dominated the decrease in TFR for women in cities and towns; for women in villages, the marital fertility rate still drove the decrease in TFR, which is consistent with the findings of prior studies^{17,41}. The results also reveal an urban-rural transfer effect of education expansion and marriage delay on the TFR from urban to rural regions. There are marked urban-rural differences in China, where education expansion and marriage delay generally start in urban areas and gradually spread to rural areas^{63,64}. Many rural couples enjoy the “one-and-a-half-child” or “two-child” policy; therefore, the stimulus effect of the birth control policy adjustment was more remarkable in urban areas than in rural areas during 2005–2010 and 2010–2015¹⁶.

The impacts of education expansion, marriage delay, and the marital fertility rate on the TFR also differ among age groups. Education expansion and marriage delay decreased the TFR, especially among younger age groups (15–30 years); however, the impact of the marital fertility rate on the TFR occurred throughout the reproductive years (15–49 years). Between 1995 and 2015, the marital fertility rate reduced the TFR for women younger than 26 years and increased the TFR in the over 26 age group, which reflects childbearing delay at young ages and childbearing recovery later in life⁴¹. The above changes and differences in TFR may be influenced by the underreporting of births. However, the policies that led to the underreporting of births were gradually

eliminated after 2010, and this paper focuses on the relative level and internal structure of the TFR. The data quality may not affect our conclusions.

In addition, future trends in China's TFR are noteworthy. It is difficult to observe a fundamental reversal and rebound of the TFR in China. In the foreseeable future, the expansion of higher education, postponed marriage or never-married, and low desire for marital fertility will have a downward effect on the TFR. Several studies have shown that China's population with higher education continues to expand. The number of people with a college degree per 100,000 people increased from 8930 in 2010 to 15,467 in 2020. Since the 1990s, China's gross enrolment rate in higher education has increased tenfold (over 50%), and China has the largest-growing population with higher education⁶⁵. Compared with many other countries, there is still more room to expand higher education in China. The gross enrolment rate of higher education was 54.4% in 2020 in China, 95.4% in 2013 in South Korea, 90.3% in 2014 in Australia, 85.8% in 2015 in the United States, 69.8% in 2013 in Singapore, and 63.4% in 2014 in Japan⁶⁶. Some studies noted that the universalization of higher education in China will continue to advance in the future and will enter the intermediate stage in approximately 2030⁶⁷.

The marriage delay and single status may continue to decrease China's fertility. The age of first marriage for Chinese remains relatively low. The average age of first marriage for Chinese women was 27.9 years in 2020, whereas it was 29.4 years in Japan in 2020⁶⁸, 30.2 years in Korea in 2010⁶⁹, and 30.9 years in Western European countries in 2002⁷⁰. This finding indicates that there is more room for further marriage delay for Chinese females. The never-marrying phenomenon is becoming more common. In Western European countries, the percentage of lifetime unmarried individuals reached 11.4% in 2002⁷⁰. The percentage of Japanese women who never married at age 50 increased from 5.8% in 2000 to 10.6% in 2010, 14.9% in 2015, and 17.8% in 2020⁶⁸. The current proportion of Chinese women who are unmarried for life remains very low at approximately 0.2% in 2000, 0.4% in 2010, and 1.0% in 2020. However, some scholars predict that the proportion of lifetime unmarried Chinese women in the 1980 birth cohort may have reached 1.5–6.4%, and the changing trend in younger birth cohorts will accelerate⁷¹. As the gender gap in educational attainment shrinks or reverses in China, highly educated women often face challenges in finding an ideal partner, and there are increasingly many urban leftover women⁷².

The marital fertility willingness of younger generations will remain low even after birth restrictions have been lifted. Young women pursue more education and career development, and the childrearing costs remain high. China's average fertility desire of approximately 1.8 is significantly lower than 2.1⁷³. The childbearing intention of urban women is even lower: only approximately 30% of those with one child plan to have a second child⁷⁴. On one hand, the main factors that hinder the realization of the desire to have children include heavy financial burdens, childcare deficits, and work-family conflict. A study revealed that more than two-thirds of mothers who did not want a second child reported high financial burdens, especially housing and education costs²¹. China's public childcare system has not been well developed, and children are mainly cared for by family members (mothers and grandparents)⁷⁵. Women face severe work-family conflicts, and the job market is not friendly to females with gender discrimination⁷⁶. On the other hand, certain studies reported that the relaxation of birth control policies failed to increase the fertility rate in the long term^{4,9}, and the number of annual births continuously declined in 2021 and 2022. Therefore, without comprehensive pronatalist measures nationwide, China's TFR might further decrease and fall into the trap of lowest-low fertility.

Conclusion

The current study has several limitations. First, this study supposes that all women of childbearing age follow the behaviour path of "graduated-married-childbirth" and neglects the phenomena of student marriage and nonmarital childbirth, which may cause certain biases. Second, the decomposition model supposes that education expansion, marriage delay, and marital fertility are independent factors. The decomposition method may underestimate or overestimate the effect. Other methods for three-factor decomposition may yield different results but do not change the main findings. Third, the tabulated TFR from China's census is controversial. Although the data quality is flawed, as discussed, which may not fundamentally impact the results. Fourth, the study does not formally incorporate age distributions into the model and neglects the age composition and effect. Finally, the minimum time unit of the data and analysis is five years, which could not be used to analyse the TFR changes in more detail, such as annual data. Despite these limitations, our study sheds new light on China's fertility changes.

In summary, this study explored the characteristics of the changes in China's TFR and the effects of education expansion, marriage delay, and marital fertility. The main findings are as follows. First, China's TFR rapidly declined to below the replacement level of 2.1 in the early 1990s and subsequently fluctuated below the very low level of 1.5 since 1995. Second, the proportion of non-student women has continued to decline, which consistently decreased the TFR; the long-term decline in the proportion of married females was the primary driving factor that decreased the TFR; the marital fertility rate had a downward impact on the TFR before 2000 and an upward impact after 2000. Third, the effects of the NSP, MP, and MFR on the TFR exhibit marked differences in birth order, urban-rural region, and age group. In the future, without effective measures, China's TFR may further decline into a trap due to higher education expansion, marriage postponement or never-married, and low fertility desire.

Data availability

The datasets or materials used to support the findings of this study are publicly available from the National Bureau of Statistics of China or available from the Additional file 1.

Received: 29 February 2024; Accepted: 14 November 2024

Published online: 15 November 2024

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Acknowledgements

The authors would like to thank all institutions and staff for their help on data collection and suggestions on manuscript revision.

Author contributions

C.C. conceived the original study idea and developed the study design. C.C. and G.T. collected the study materials. C.C. and X.X. did the statistical analysis and interpretation. C.C. and G.T. wrote the first draft of the text. X.X. and G.T. reviewed and edited the article. All authors approved the final version of manuscript.

Funding

This research was funded by the National Social Science Fund of China: A Study on the Urban-Rural Heterodromous Marriage Squeeze in the Context of Gender Imbalance (Grant No. 21BRK005).

Declarations

Ethics approval and consent to participate

All materials are publicly available from the survey conducted by the National Bureau of Statistics of China, and informed consent was given on the first page of the survey. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1038/s41598-024-79999-4>.

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