China's low fertility may not hinder future prosperity.

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Abstract

China's low fertility is often presented as a major factor which will hinder its prosperity in the medium- to long-term. This is because of the traditional association with population decline and, more particularly, population ageing with negative economic outcomes. In this vein, there is much discussion about the development of policies to increase fertility, even after decades of policies restricting the number of children most citizens are entitled to bear. In this paper, however, we argue that the traditional means of conceptualizing low fertility and the relationship to economic futures is over-simplified and may well be highly misleading. While fertility has indeed fallen to low levels, human capital accumulation has been very striking. Factoring in the relationship between demographic change and this human capital development and productivity (as well as more accurate measures of labour force participation) is possible through the generation of a new measure – namely the "Productivity Weighted Labor Force Dependency Ratio". When using this ratio, compared to more traditional measures, a very different, and much more optimistic, picture of the economic (and social) future of China can be envisaged.

Main Text

Introduction

Reassessing the "Demographic Time Bomb"

Low fertility appears to be very much back on the scientific and policy agenda. Recent years have seen Total Fertility Rates (TFRs) in some industrialized countries reach historic lows; even in unexpected settings such as Finland and the United States(1). Most recent data on births and pregnancies indicate further declines in the context of the current pandemic, with China reporting a steep decline in births in 2020 causing great alarm in state media(2). The standard narrative links such low fertility to increases in the pace and scale of population aging, with assumed negative consequences for the economy and the sustainability of public services; as well as more fundamental issues such as gerontocracy and intergenerational fairness; geopolitical clout; even the continued existence of a culture.

Around the world, deep concerns about this 'demographic time-bomb' are increasing and the European Commission has even appointed a Vice President for 'Democracy and Demography". But for governments, it is difficult to influence population aging directly(3). Despite being generally debunked, the concept of "replacement migration" lingers as a possible solution. More commonly, though, governments have tried to stimulate the fertility rate through more or less explicit policy interventions. The general failure of these interventions has led to the dual metaphors of the 'population time-bomb' and the (ageist) 'silver tsunami': slow-burning, yet inevitable events which will threaten societies in the long-run.

This narrative has been familiar in Europe, Japan and other parts of East Asia. Recently, however, much attention has been paid to China's demographic travails. Identifying Chinese fertility levels is fraught with difficulties, with ranges being derived from different sources and agencies(4). Currently, the officially reported TFR is 1.7. However, evidence from the 2015 Mini-Census suggests that overall TFR may be much lower, even close to 1.0(5).

In response, both central and local governments in China have been discussing further relaxations of the birth control policy; as well as designing more interventions to stimulate the fertility rate *within* the existing boundaries of the policy(3). The recent relaxations of the birth control policies have had relatively little impact; and fertility preference surveys reveal a sub-two-child norm among large segments of the population(3, 6) including the 'floating population' of internal migrants(7). In this context, further relaxations to permit more than two children per family may be unlikely to make any meaningful change to the overall TFR.

In many analyses, this "gloomy demographic forecast" for China is translated into economic (and even geopolitical) disaster. It is suggested that China is "getting old before it gets rich" and may thus not be able to catch up economically with the US as previously assumed. It is even an existential threat: "Population decline could end China's civilisation as we know it"(8).

These prognostications are partly based on a simplistic and misleading concept of age dependency which simply assumes that everybody above age 65 is an economic burden and every adult below this age is an asset without considering actual labor force participation and differential productivity resulting among others from different levels of education. The so-called "Age Dependency Ratio" [ADR], in contemporary China is around 38 - meaning there are 38 'dependents' aged over 65 or less than 15 per 100 'workers' aged between 15 and 64(9). By 2050, this is forecast to rise to 67 - as high as many contemporary European settings(1). Demographers have long argued, however, that this measure is misleading for addressing the economic implications of aging because it ignores dynamic changes in health and longevity as well as in labor force participation and productivity(10). When alternative measures of aging are applied to China, the overall picture of a 'crisis' as presented by traditional measures looks much more manageable(11)

Considering further dimensions of demographic change

Demography as the science that studies changing population size and structures is not only concerned with age structures but also with changing structures of educational attainment(12) and labor force participation by age and sex(13). Here we show that the future of China looks very different if such a multidimensional demographic approach is taken that also reflects the massive improvement of human capital that China has experienced and will continue to experience because the younger generation today is already much better educated than the older one and will replace it through the predictable mechanism of demographic metabolism.

A recent study has taken such a multidimensional approach to aging by stratifying the population of the 28 EU member states by not only age and gender, but also immigration status, labor force participation and educational attainment which is used as a proxy for productivity reflecting the fact that not all individuals are equally productive(13). The study then proposes alternative measures to the ADR such as the "Labor-Force Dependency Ratio" [LFDR] (which compares those economically active and inactive *of all ages*; and a "Productivity Weighted Labor Force Dependency Ratio" [PWLFDR] (which approximates differences in productivity through wage differentials associated with various levels of educational attainment). The study shows that these alternative dependency measures increase much less than the ADR and when combined with Canadian-style immigration policies even lead to a decline in economic dependency in the EU over the coming decades.

When applying these alternative measures of LFDR and PWLFDR to the future of China the situation is complicated by significant uncertainty about the baseline conditions, in particular the current level of fertility. There is much uncertainty surrounding both the recent history and current level of TFR in China which is likely to be within the range of an upper bound of around 1.7 (the official estimate) and around 1.0 (as derived from the 2015 1% sample survey). Rather than taking a position on what the TFR in China may well be, we simply calculate the implications of two alternative cases - a 'high' baseline of 1.7, and a 'low' baseline of 1.0.

Projections are performed with a dynamic discrete-time microsimulation model simulating life events of individuals (fertility, mortality, migration, education transitions, participation in the labor force) with Monte Carlo experiments. The base population in 2015 is synthetically built based on the Wittgenstein Centre for Demography and Global Human Capital population estimates by age, sex, and educational attainment and contains about 700,000 cases(9). Assumptions in regards to mortality (by age, sex, and education), migration (by age and sex), and expansion of education (by cohort and sex) are those from the medium scenario (SSP2) of the WIC projections(9), themselves built from statistical modeling of past trends and expert judgments (see Table 1 for a summary of assumptions). The model is run with two fertility assumptions, assuming a constant TFR of either 1.0 and 1.7 children per woman starting from 2015. The labor force participation is modeled from a cross-sectional survey using parameters from a logit regression (equations S1 to S3) estimated with microdata of the Chinese General Social Surveys (CGSS), from 2010 to 2017. Those parameters are assumed to stay constant throughout the projection. However, as the statistical model explicitly accounts for the higher propensity of working for high educated women, the expansion in education dynamically increases the general labor force participation among workers. The productivity weights by education level are estimated from Poisson regression parameters on the salary variable of the CGSS 2010-2017, excluding the population out of the labor force and controlling for age, sex, and year (see equation S5). Those weights, ranging from 0.36 for workers with no education to 2.03 for workers with a postsecondary education, are used to factorize the workers in the denominator in the calculation of the productivity-weighted labor force dependency ratio (see equation S4). Details on the methods and other data sources can be found in the supporting material.

Results

A picture of strongly improving human capital

Figure 1 depicts the multi-dimensional demographic changes by age, sex, education and labor force participation which we will likely see in the human capital of China over the upcoming decades. First of all, the figure illustrates that by 2040 both fertility scenarios still yield the exact same structures for the adult population above age 25 because the older cohorts have already been born. But due to the smaller number of children the lower fertility scenario results in a lower age-dependency ratio over the coming decades. As seen in Figure 2, the ADR of the low fertility scenario exceeds the one of the high fertility scenario only around 2050. Hence, even when assessed on the basis of the conventional ADR lower fertility might give China an economic boost for the next 20 years rather than being an economic burden.

When looking at the projected trends in the labor force dependency ratio (LFDR), the pace and scale of aging is slower and lower than when looking at the ADR (Figure 2), mainly because the increasing education of future adult cohorts of women is likely to boost their labor force participation. In addition, with this expected expansion of educational attainment of the future adult population, the human capital of the working population will improve drastically. Figure 1 shows that, for both scenarios, the share of the highly educated population among workers, in dark green, is expected to be much larger in 2040 as compared to 2015 simply because of the fully predictable fact that the younger already better-educated cohorts will move further up the age pyramid. When transposing this dynamic into the productivity-weighted labor force dependency ratio (Figure 2), there is virtually no increase in forecast dependency up to 2070, even under the low fertility scenario. While the total number of workers will start declining before 2025, those with a high level of education (postsecondary) will keep growing as new cohorts entering the labor market are much more educated than older ones retiring (see Figure S2).

Discussion

A more positive outlook based on human capital

Our simulations show that, at least as far as demography is concerned, the oft-told story of economic stagnation or even annihilation is not already written. Yes, China will almost certainly have challenges associated with managing adjustments to population decline and increasing size of the elderly population, in particular, if fertility should have levels of 1.0 or even below as currently observed in South Korea(14). China does not yet have adequate pension coverage, particularly in rural areas, and to expand social welfare systems will be more challenging. China has already achieved significant education expansion only rivaled by earlier such expansions in much smaller Singapore and South Korea, but it also needs to ensure that these increases are translated (as we assume) into higher labor force participation and, in turn, higher productivity. This will require ensuring that the current education system is fit-for-purpose in terms of producing citizens with appropriate tools and skills; and that both society and the economy is properly equipped to allow the economic and social potential of all to be fully unleashed.

We recognise the limitations of our model. While the future improvement in the educational attainment of the adult population is a near certainty due to the already existing much better education of the younger cohorts the “demographic dividend”(15) in terms of improving economic performance resulting from this also depends on institutional and other factors that facilitate the translation of higher skills into higher productivity. In terms of data, not knowing the true baseline TFR is a clear challenge, but our simulations based on two widely differing assumptions show that the derived results are robust. The results also illustrate that the still widely used conventional ADR based on a one-dimensional demographic perspective of age alone gives only a very limited, if not misleading, picture compared to the multidimensional perspective which in addition gives explicit consideration to labor force participation and skills, two dimensions that are more directly linked to economic performance. The choice of in this sense better and more relevant indicators also has far-reaching implications for longer-term economic and geopolitical considerations and it will matter for specific policies because bad measures will likely result in bad policies.

Materials and Methods

All methods are given in *SI Appendix*.

References

1. United Nations, "World Population Prospects: The 2019 Revision" (Department of Economic and Social Affairs, Population Division, 2019).

2. H. Zhang, China's fertility rate falls below warning line, population may decline. *Glob. Times* (2020).

3. S. Gietel-Basten, *The "Population Problem" in Pacific Asia* (Oxford University Press, 2019).

4. W. Lutz, S. Scherbov, G. Y. Cao, Q. Ren, X. Zheng, China's uncertain demographic present and future. *Vienna Yearb. Popul. Res.* **5**, 37–59 (2007).

5. Z. Guo, S. Gietel-Basten, B. Gu, The lowest fertility rates in the world? Evidence from the 2015 Chinese 1% sample census. *China Popul. Dev. Stud.* **2**, 245–258 (2019).

6. Z. Zhenzhen, Y. Cai, W. Feng, G. Baochang, BELOW-REPLACEMENT FERTILITY AND CHILDBEARING INTENTION IN JIANGSU PROVINCE, CHINA. *Asian Popul. Stud.* **5**, 329–347 (2009).

7. M. Zhou, W. Guo, Fertility intentions of having a second child among the floating population in China: Effects of socioeconomic factors and home ownership. *Popul. Space Place* **26**, e2289 (2020).

8. A. Xie, Population decline could end China's civilisation as we know it. When will Beijing wake up to the crisis? *South China Morning Post* (2021).

9. WIC, Wittgenstein Centre Data Explorer Version 2.0 (2019) (March 26, 2019).

10. W. C. Sanderson, S. Scherbov, Remeasuring aging. *Science* **329**, 1287–1288 (2010).

11. Scherbov, S, Sanderson, W, Gieten-Basten, S, Better way to measure ageing in East Asia that takes life expectancy into account. *Australas. J. Ageing* **35**, 139–142 (2016).

12. W. Lutz, S. KC, Global human capital: Integrating education and population. *Science* **333**, 587–592 (2011).

13. G. Marois, A. Bélanger, W. Lutz, Population aging, migration, and productivity in Europe. *Proc. Natl. Acad. Sci.* **117**, 7690–7695 (2020).

14. X. Peng, Coping with population ageing in mainland China. *Asian Popul. Stud.* **17**, 1–6 (2021).

15. W. Lutz, *et al.*, Education rather than age structure brings demographic dividend. *Proc. Natl. Acad. Sci.*, 201820362 (2019).

Figures

Figure 1. Age pyramid by education (Low = lower than secondary, Medium =upper secondary and High = post-secondary) and labor force status (Inactive, Active), China, (A) 2015; (B) 2040 under TFR=1 scenario; (C) 2040 under TFR = 1.7 scenario.

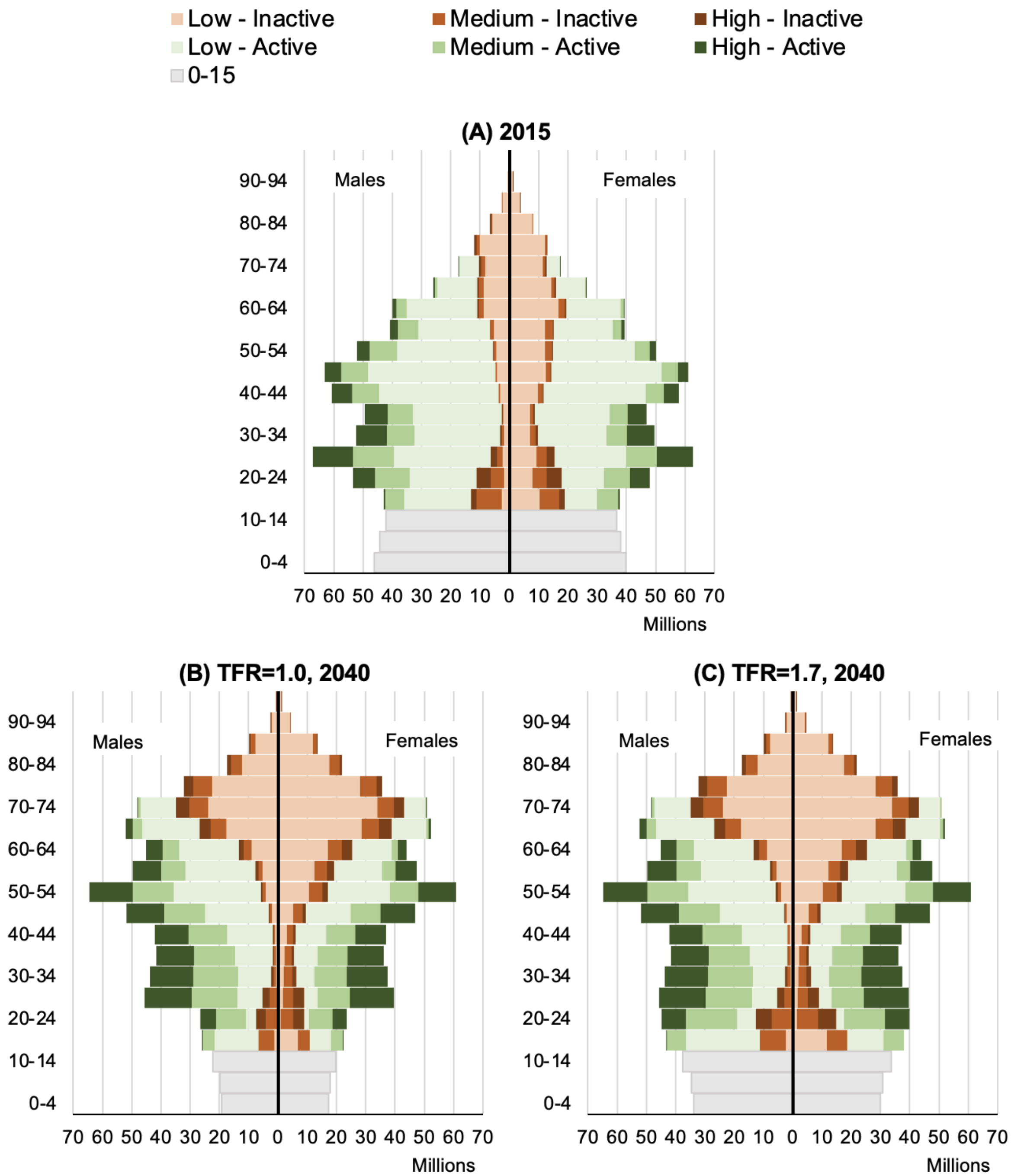
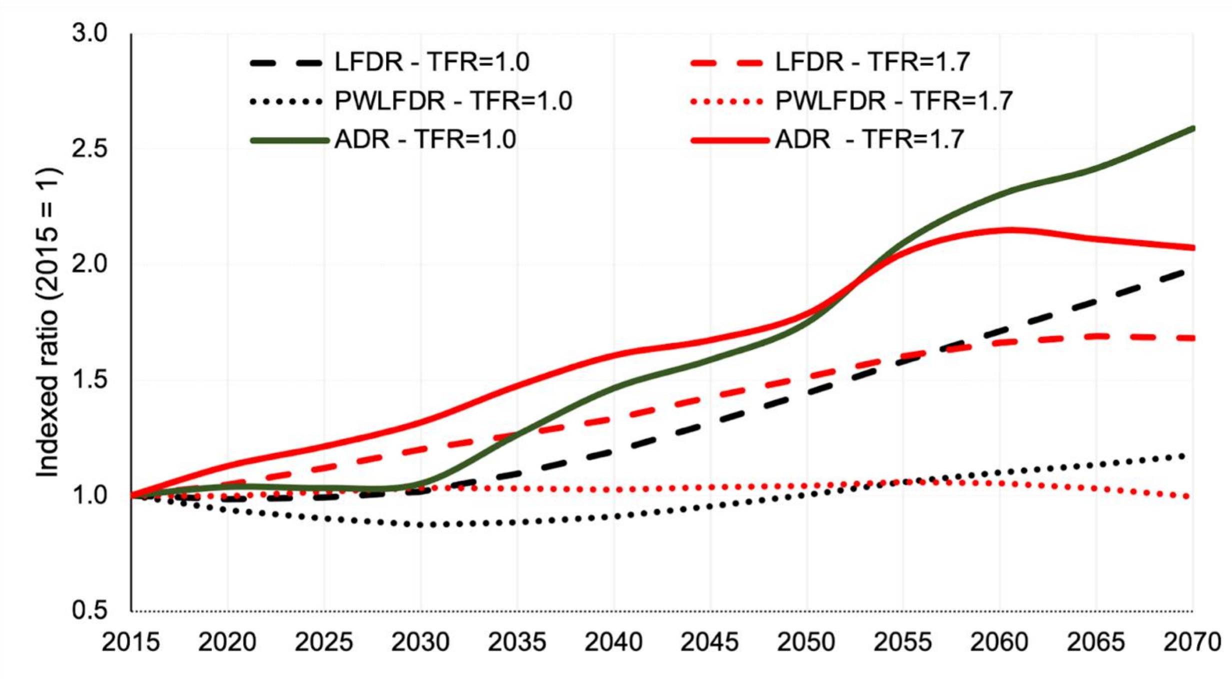


Figure 2. Projected dependency ratios according to two TFRs, China, 2015-2070 (2015=1). *ADR: Age Dependency Ratio (pop<15 & pop65+) / pop15-64). LFDR: Labor Force Dependency Ratio (Inactive/Active). PWLFDR: Productivity-weighted Labor Force Dependency ratio (Inactive/Active weighted by productivity, see supplementary materials)*



Table

Table 1. Summary of assumptions

		2015	2040	2070
Life expectancy				
Women	No education	76.1	79.9	85.0
	Primary incomplete	76.8	80.6	85.7
	Primary	77.5	81.3	86.4
	Lower secondary	79.0	82.7	87.7
	Upper secondary	79.9	83.6	88.5
	Postsecondary	80.7	84.4	89.3
Men	No education	71.3	74.8	79.6
	Primary incomplete	72.4	75.9	80.6
	Primary	73.4	76.9	81.6
	Lower secondary	75.6	79.0	83.7
	Upper secondary	76.8	80.3	84.9
	Postsecondary	78.0	81.4	86.0
Immigration (5-year)		97,101	121,965	145,975
Emigration (5-year)				
	TFR=1.0	1,036,089	969,884	593,224
	TFR=1.7	1,036,089	1,050,639	853,027
Mean age at birth		27.9	30.9	31.7
Educational attainment (age 20-39)				
Women	No education	0.8%	0.0%	0.0%
	Primary incomplete	3.0%	0.2%	0.0%
	Primary	6.3%	0.2%	0.0%
	Lower secondary	47.4%	18.8%	1.3%
	Upper secondary	21.2%	40.0%	29.3%
	Postsecondary	21.4%	40.8%	69.3%
Men	No education	0.5%	0.0%	0.0%
	Primary incomplete	1.9%	0.3%	0.0%
	Primary	4.9%	0.2%	0.0%
	Lower secondary	48.3%	23.1%	3.0%
	Upper secondary	23.0%	41.4%	37.2%
	Postsecondary	21.3%	35.0%	59.8%

SI Appendix

Supplementary Information Text

Appendix 1 – Data, methods, assumptions, and scenarios

The microsimulation model

The projection model developed for this research uses a microsimulation approach (1). A microsimulation model starts from a baseline population that consists of individual actors whose characteristics represent the composition of a given population across chosen dimensions. These individual actors are exposed to the risk of a set of events relevant to their state and specific to their own characteristics – death, births of a child (which generates a new actor inside the model), moving to a different region in a country, leaving the country, achieving the next level of education, entering or exiting the labour market, and so on. Transitions between the particular states are determined stochastically with a random experiment (the Monte Carlo method). Microsimulation thus allows to not only include a larger set of dimensions than the standard multistate population projection models, but also to easily handle competing risks.

Microsimulation methods are particularly useful when heterogeneity is of significance in the projection modelling or in the projection outcomes (2). A multistate cohort-component method can only handle a limited number of dimensions, because the number of cells for the transition matrices corresponds to the multiplication of the number of categories of each dimensions. In microsimulation, each additional dimension only adds one new column in the dataset. Furthermore, microsimulation can more easily model events for which behaviours can be better understood at the micro–level than at the aggregated level. For instance, having had a child in the past few years could be a major predictor for female labour force participation. At the micro-level, this predictor can easily be taken into account as it only requires to add one column recording the time since the last birth occurred and what value is incremented every year, without any complex modelling. The variable can then be used in the modelling of other events, using for instance relative risks or logit regression parameters.

<u>Model properties</u>

The microsimulation model projects the population of China by ages (5-year age groups), sex, education, and labor force status from 2015 to 2070. It is built with the Statistical Analysis System (SAS) and has the following proprieties:

- Time-based. It simulates the life of all individuals from time t to t+a, then repeats from t+a to t+2*a and so on up to the end of the time span.
- Discrete time. The model only considers the population at specific points in time (by 5-year steps), without considering what could be happening between those points.
- Stochastic. Events are modelled stochastically using random experiments (the Monte Carlo approach), which involves comparing probability with a random linear number from 0 to 1 in order to determine whether or not the event occurs.

The base population is synthetically built from the WIC estimates of 2015 by age, sex and level of education (3). The number of individuals generated represents 0.05% of the population size corresponding subgroups, with an oversampling for subgroups with population size lower than 10,000 in order to minimize the Monte Carlo error for smaller populations. The resulting dataset for the starting population in 2015 has 700,000 cases. Since the model allows for immigration, some individuals representing immigrants are added throughout the projection, which are generated following the same statistical rules as the base population, according to their characteristics and numbers established a priori in assumptions. For our projections, about 505,000 cases for immigrants are added throughout the projection from 2015 and 2070. When a woman gives birth, a new individual with the same weight is added to the dataset. The number of new individuals thus added from the fertility event varies according to fertility assumptions.

Events are ordered as follows:

1. The mortality from t to t+5 is first applied with survival ratios by age, sex and, education;
2. Education transition rates by age, sex, and education are then used for educational shifts. From 0 to 14, the education variable is not applied. At the age of 15-19, the cohort is broken down according to the education level reached at this age. Transition rates are then applied and the final educational attainment is reached at the age of 30-34.;
3. For those who survive, emigrants are removed using emigration rates by age and sex;
4. Immigrants, for whose numbers and characteristics are set a priori, are then added;
5. Births are generated with fertility rates by age applied to the exposed population;
6. The labor force status is finally established from age-, sex-, and education-specific rates calculated from regression parameters.

Demographic assumptions

Two scenarios are built concerning the total fertility rates, either 1.0 and 1.7 starting from 2015 and constant until 2070. All other parameters are the same between the two scenarios. However, giving the fertility impacts the population size, the number of emigrants, which are calculated from emigration rates by age and sex, also differs among these scenarios. In Table 1 of the main manuscript, we summarize those assumptions.

For the mortality, the migration, the fertility schedule, and the education progress, assumptions are those from the medium scenario (SSP2) of the WIC multistate projections (3). Those assumptions were established from statistical modelling of past trends and expert judgments, for which detailed explanations can be found in Lutz, Butz, and KC (4) and Lutz et al. (5). This allows to use already validated long-term assumptions for those components of the projection instead of having to build them from scratch. The life expectancy is thus assumed to continue its progression, while keeping differences by educational attainment. The mean age at birth is also expected to increase, while the immigration is assumed to stay low volume, thus yielding in a negative net migration.

The labor force participation module

Labor force participation rates (P) are calculated from a logit regression parameters estimated with data from the Chinese General Social Survey 2010 to 2017 (population aged 15 to 74; n=57,411). The model is described in Equation S1:

Eq. 1

$$\text{logit}(P) = \beta_{s,0} + \beta_{s,1}AGEGR + \beta_{s,2}AGEGR^2 + \beta_{s,3}EDU + \beta_{s,4}EDU * AGEGR + \beta_{s,5}EDU * AGEGR^2$$

The logit of a probability corresponds to the natural logarithm of its odds. Therefore, the logit of the participation rate (P) be calculated from the parameters, such as:

Eq. 2

$$P = \frac{\exp\left(\beta_{S,0}+\beta_{S,1}AGEGR+\beta_{S,2}AGEGR^2+\beta_{S,3}EDU+\beta_{S,4}EDU*AGEGR+\beta_{S,5}EDU*AGEGR^2\right)}{1+\exp\left(\beta_{S,0}+\beta_{S,1}AGEGR+\beta_{S,2}AGEGR^2+\beta_{S,3}EDU+\beta_{S,4}EDU*AGEGR+\beta_{S,5}EDU*AGEGR^2\right)}$$

Each sex has its own set of parameters and its own intercept. The education includes 5 categories, either “No education” (which includes primary incomplete), “Primary”, “Lower Secondary”, Upper Secondary” and “Postsecondary”. The age group is included with a quadratic function, allowing it to be modeled with a reverse U-shape with lower participation rates for younger adults still in school and the elderly. The interaction of age and education allows the model to take into account that the age pattern in labor force participation varies by educational attainment. The max-rescaled R-Square is 0.365 for the males’ model (c-statistic=0.840) and 0.271 for the females’ one (c-statistic=0.758).

Predicted rates from the model show that in general, labor force participation rates for women are 10% to 15% lower than those of men. Women in their 30’s with postsecondary education indeed have rates that are close to those of men. The gender gap exists mainly for individuals with lower education as well as for older adults, as the legal retirement age is lower for women than for men. For both males and females, rates are lower for the populations with no education or primary education for most of adulthood, but become higher past the age of 60, implying that the retirement also comes later for the low educated population.

In the microsimulation model, those parameters are used to calculated individual’s probabilities of being in the labor force. The labor force status (in or out of the labor force) is then determined with a Monte Carlo experiment following formulate presented in Eq 3.

Eq. 3

$$P\begin{cases}1 & F_{t+1} < Z\sim([0,1]) \\ 0 & F_{t+1} \geq Z\sim([0,1])\end{cases}$$

where $Z\sim([0,1])$ is a random number uniformly distributed between 0 and 1.

Productivity-weighted labor force dependency ratio

The productivity weighted labor force dependency ratio (PWLFDR), introduced by Marois et al. (6), divides the number of inactives (the population out the labor force irrespectively of their age) by the number of people in the labor force weighted by a productivity factor associated to their educational attainment. Equation 4 depicts this indicator.

Eq.4 $$\mathrm{PWLFDR} = \frac{I}{\sum_{e=1}^{k} W_e * A_e}$$

Where:

I is the inactive population;

A is active population with education level e, e=e1 (no education),..., e6 (postsecondary);

W is the productivity factor associated to the education level e;

The calculation of productivity factors relies on the assumption that in a competitive market, at an aggregated level, the average salary is good proxy of productivity once a statistical control is performed for demographic variables (7, 8). They are estimated from Poisson regression parameters on the salary variable of the Chinese General Social Survey 2010-2017, excluding the population out of the labor force and controlling for age, sex, and year, as expressed by equation 5.

Eq.5 $$\ln(WAGE) = \beta_0 + \beta_1 EDU + \beta_2 AGE\_GR + \beta_3 SEX + \beta_4 YEAR$$

Productivity factors associated to education levels are estimated with the natural exponent of β_1 and are:

- No education: 0.357
- Primary: 0.458
- Lower secondary: 0.694
- Upper secondary: 1
- Postsecondary: 2.031

The reference category (W=1) is set for the category upper secondary. Therefore, a ratio of 1 would indicate there is 1 inactive per productivity-equivalent-to-upper-secondary-worker.

References

1. E. Van Imhoff, W. Post, Microsimulation methods for population projection. *Popul* **10**, 97–138 (1998).

2. M. Spielauer, What is Social Science Microsimulation? *Social Science Computer Review* **29**, 9–20 (2010).

3. WIC, Wittgenstein Centre Data Explorer Version 2.0 (2019) (March 26, 2019).

4. W. Lutz, W. P. Butz, S. KC, Eds., *World Population and Human Capital in the Twenty-First Century* (Oxford University Press, 2014).

5. W. Lutz, A. V. Goujon, S. KC, M. Stonawski, N. Stilianakis, “Demographic and human capital scenarios for the 21st century: 2018 assessment for 201 countries” (Publications Office of the European Union, 2018) https:/doi.org/10.2760/41776.

6. G. Marois, A. Bélanger, W. Lutz, Population aging, migration, and productivity in Europe. *PNAS* **117**, 7690–7695 (2020).

7. J. Van Biesebroeck, Wages Equal Productivity. Fact or Fiction? Evidence from Sub Saharan Africa. *World Development* **39**, 1333–1346 (2011).

8. P. Carneiro, J. J. Heckman, E. J. Vytlacil, “Estimating marginal returns to education” (National Bureau of Economic Research, 2010).