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The effects of ageing and urbanisation on China's future rural and urban populations

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ABSTRACT

This paper estimates China's future population and labour force by developing a novel forecasting model for population. It combines information about age-specific parameters on fertility and mortality for both rural and urban areas using information about rural–urban migration and the transformation of rural areas into urban ones. This model takes into account the effects of urbanisation on changes in the age structure of the Chinese population; and provides separate projections on the rural and urban populations. Our findings show that (i) the shares of people aged 65 and over, in China's rural and urban populations, will double between 2010 and 2030; this implies that the ageing problem in rural areas will continue to be more serious than in urban areas; (ii) the rural labour force will shrink by 45 per cent, between 2010 and 2030, while the urban labour force will grow by 34 per cent; and (iii) China's urbanisation rate will increase to 71 per cent by 2030.

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1. Introduction

The ageing of the population will be an important concern for China in the upcoming decades, mainly because the labour force will constitute a considerably smaller proportion of the total population. Three factors explain these phenomena. First, the fertility rate is low. After the one-child policy was launched in the 1980s, China's fertility rate significantly declined (Poston & Gu, 1987). According to the latest national population census data (NBS, 2012), in 2010 China's fertility rate was 1.18. However, this estimate has been broadly considered as being too low to be true. Cai (2013) concludes that China's total fertility rate (TFR) was around 1.50 in 2010, which is still clearly much lower than the 2.10 replacement level. And even though the one-child policy has recently been relaxed, it will take roughly two decades before the resulting increased fertility rates are reflected in the labour force size. Second, China's large baby boom generation, born in the 1960s, will gradually retire over the next two decades. Third, improvements in China's healthcare, and the consequent increased life expectancy, is contributing to the increase in the percentage of the elderly in the total population. These three factors will boost the ageing process in China over the following decades.

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Ageing will affect rural and urban areas to different extents. On the one hand, the fertility and mortality rates are both significantly lower among the urban population. This will increase ageing more quickly in urban areas than in rural areas. On the other hand, ongoing urbanisation should be taken into account. In the past two decades, many people migrated from rural to urban areas and the urban areas expanded. From 1990 to 2010, the urbanisation rate (i.e. the share of the population living in urban areas) increased from 26.4 per cent to 50.0 per cent, which is an annual increase of 1.2 percentage points, on average. Given China's industrialisation process, and the associated employment opportunities, this trend toward rapid urbanisation is expected to continue into the future (United Nations, 2014; Zheng, 2011).

Young people tend to migrate from the countryside to the cities, as is characteristic of urbanisation processes. This trend is likely to cause rural areas to age faster than urban areas. Without careful analysis, it is impossible to determine whether the dominant effect will be rural–urban differences in fertility and mortality rates (resulting in ageing being faster in urban areas), or the tendency toward rural-to-urban migration (resulting in ageing being faster in rural areas).

This paper projects the development of the age structure of the Chinese population to 2030, distinguishing between rural and urban areas and taking urbanisation into full account. Such projections are relevant because many socio-economic issues are directly associated with demographic changes. For instance, the size of the labour force will decrease as the population ages. This may have adverse effects on China's long-run economic growth, which is highly dependent on the input of labour. Consequently, it is important to have a reliable estimate for the future size of the labour force (i.e. the people in the 15–64 age group). We chose 2030 as the projection year because it is anticipated that the full effects of baby boomer retirements will have materialised around that year.

A number of models aimed at addressing similar questions about the ageing population have been previously proposed. The first attempt to model China's rural–urban population growth can be tracked to Wang (1988). However, this model failed to consider the important rural–urban migration component. Subsequent to this, researchers proposed multi-regional population models to study China's rural–urban population growth (Shen, 1991; Zeng & Vaupel, 1989). These models incorporate rural–urban migration, but they ignore the transformation of rural areas into urban ones. This transformation refers to the phenomenon that many rural areas have (both administratively and in reality) become urban areas with the economic development of China. Many rural individuals have thus become urban individuals through the expansion of the urban area. Not taking this phenomenon into account may well lead to an under-projection of the level of urbanisation.

Shen and Spence (1996) constructed a more advanced rural–urban population model, which includes both important components of the ageing population process: rural–urban migration and rural–urban transition. These researchers calibrated a demo-economic model of both rural and urban sectors to account for the long-term trend of urbanisation in China. The model projects the total net rural-to-urban labour population migration and transition. Despite the successful implementation of this advanced model in investigating the consequences of China's population growth and rapid urbanisation (Shen, 1998), the transition from rural to urban areas was modelled in an indirect way. That is, it was defined as the transition of the agricultural employment-related population to the non-agricultural

employment-related population, both populations of which lived in cities and towns. Consequently, the transformation from rural areas to urban ones was not fully modelled. This can have consequences for the population forecasts, since urban and rural fertility and mortality rates are not identical.

Inspired by these previous studies, we develop an age–sex-specific model with a module for the rural population and a module for the urban population. This distinction allows for the demographic heterogeneities between rural and urban areas; it also allows for modelling the urbanisation process by means of tracking both rural–urban migration and the expansion of urban areas. The demographic impacts of the two drivers of urbanisation are not the same. Rural–urban migrants are predominantly of working age, while the expansion of urban areas increases the urban population for a much wider range of ages. Hence, we estimate the age-specific rural–urban transition rates separately. We adopt the NBS's (National Bureau of Statistics, China) latest definition of urban population, which was also used in the 2010 population census. Information on newly created residents' committees (the smallest administrative units of urban areas) is used to estimate urbanisation via the transformation of rural areas into urban ones. We calibrate the model using data from the 2010 population census (NBS, 2012).

The most recent projections for China's future population are found in Mai, Peng, and Chen (2013) and the United Nations (2014; 2015). Both Mai et al. (2013) and the United Nations (2015) projected China's population to the year 2050, using China's 2000 population census data. However, neither model underlying these projections distinguishes between rural and urban populations. The United Nations (2015) projection for China's rural and urban populations used a growth differences method. Here, the totals for both the rural and urban populations are derived from the projected population totals and the projected urbanisation rates. However, age-specific rural and urban populations cannot be projected by using this approach.

The remainder of this paper is organised as follows. Section 2 describes China's current population profile and the rural–urban demographic heterogeneity. The rural–urban population model is presented in Section 3; and Section 4 deals with the assumptions or estimates for the quantification of the parameters. It also tests our model's in-sample validity, by comparing model outcomes for the period 2000–2010 to the actual population statistics for the same period. Section 5 projects China's rural and urban populations for 2030, for several fertility scenarios. Section 6 compares our findings with the other projections in the literature, and Section 7 concludes.

2. A sketch of China's population profile and the rural–urban demographic heterogeneity

According to the population census data for 2010 (NBS, 2012), China's total population was around 1340 million. The share of the population 65 years or older was 8.9 per cent, which was low when compared to developed countries. For example, figures for the same year for the US, Japan and Germany, respectively, were 13.1 per cent, 22.7 per cent and 20.4 per cent. However, when evaluated against the standard ageing trend line of 7 per cent, as set by the United Nations (1956), by 2010 China had already become an ageing country.

Figure 1 depicts the age structure of China's rural and urban populations in 2010. It shows that a relatively large share of the population was in the 35–49 age group, for

Figure 1. The age structure of the rural and urban population in 2010.

Notes: The percentages in Figure 1 refer to the shares of each rural age group in the total rural population (left-hand side) and the shares of each urban age group in the total urban population (right-hand side).

Source: NBS (2012).

both the rural and urban populations. This age group represents the baby boom generation born in the 1960s, when China had just pulled out of the great famine. The 20–24 age group covers a major part of the offspring of the baby boom generation and was also relatively large. A substantial proportion of the baby boom generation will survive over the next two decades and contribute to China's ageing problem toward the end of the 2010–2030 period.

The age structures of the rural and urban populations differed in 2010. The share of young people (i.e. aged 0–14) was larger for the rural than the urban population and the same was true for the share of people aged 65 and over, although to a lesser extent. The opposite held for the share of the population in the younger age group (i.e. aged 15–34) in the labour force, which was smaller for the rural than the urban population. These different age structures are in line with the differences in fertility rates between these two populations and also with rural–urban migration. However, different mortality rates seem to have somewhat dampened these disparities.

What factors underlie these differences? First, rural and urban areas faced different policies for fertility control, which led to different fertility rates. In rural areas, the 'one-and-a-half' children policy was adopted, which meant that if a rural couple's first child was female, they were allowed to have a second child. In urban areas, however, the 'one-child' policy was maintained. Figure 2 gives the age-specific fertility rates for the rural and urban populations in 2000 and 2010. It shows that, for any reproductive age (15–44), the rural fertility rate was higher than the urban fertility rate. This partly explains why the share of young people in the rural population was larger than in the urban population.

Second, many young rural workers migrated to urban areas, in search of employment, during China's industrialisation process. And although the urban fertility rate was lower

Figure 2. Rural and urban age-specific fertility rates in 2000 and 2010.

Source: NBS (2002, 2012).

than the rural fertility rate, the migration of young rural people to urban areas added to the number of young workers in the urban labour force.

In addition to fertility and migration, mortality rates also differed between rural and urban areas. Figure 3 shows that the mortality rate was higher among the rural population, in particular for new-born children (age 0) and for the population aged 65 and over. This has dampened the disparities. That is, if the rural and urban population had the same mortality rates in 2010, then the difference between the share of young people (0–14) in these two populations would have been larger than it actually was. The same holds for the proportion of the populations aged 65 and over.

3. The rural–urban population model

As shown above, China's rural and urban populations behave quite differently with regard to many demographic aspects, such as fertility, mortality and migration. These heterogeneities will play an important role in China's future population growth. In order to

Figure 3. Age-specific mortality rates in 2000 and 2010, for young and old people.

Source: NBS (2002, 2012).

adequately project the dynamics of China's population, these demographic heterogeneities must be included in a rural–urban population model. The structure of our rural–urban population model is similar to a multi-regional type of population projection model (Rogers, 1995; Shen & Spence, 1997; Wilson & Rees, 2005). It generates separate future profiles of the rural and urban populations and provides forecasts of the urbanisation process in China.

The model is age–sex specific and includes two modules, a rural module and an urban module. Suppose the projection interval is one year and we classify the rural and urban populations into the following $h+1$ age groups. Age group 0 (new-borns) includes all individuals who are aged 0 at the end of the year; age group 1 includes all individuals aged 1 at the end of the year; ... age group h includes all individuals aged h or older. In what follows, superscript r represents 'rural' and superscript u represents 'urban'. Italic letters (e.g. x) represent the variables for females, and letters with a tilde (e.g. $\tilde{x}$) represent males.

Definitions:

$n_{it}, \tilde{n}_{it}$ represents the number of female and male individuals aged i at the end of year t ;

f_{it} is the fertility rate of age group i in year t (assuming that birth takes place at the start of year $t+1$);

p_t is the probability that a new birth in year t is female;

$m_{it}, \tilde{m}_{it}$ are the mortality rates of female and male individuals, respectively, in age group i in year t , i.e. the probability that an individual aged $i-1$, at the end of year $t-1$, dies in year t . m_{0t} gives the probability that a baby born at the start of year t dies before the end of the year;

$s_{it} = 1 - m_{it}, \tilde{s}_{it} = 1 - \tilde{m}_{it}$ show the probabilities that a female and male individual, respectively, in age group i survives in year t ;

$k_{it}, \tilde{k}_{it}$ are the rural–urban population transition rates of female and male individuals, respectively, in age group i , in year t (which is assumed to take place at the start of the year).

For each age–sex group, the rural–urban population transition rate equals the ratio of the net number of rural individuals who become urban individuals¹ to the total number of rural individuals. This transition stems from two causes: the first is migration; the second is the result of rural areas becoming urban areas. In the latter case, a rural individual becomes an urban individual through the expansion of the urban area (i.e. the annexation of a rural area by an urban area). With the economic development of China, more and more rural areas have administratively (and thus statistically) become urban areas.

3.1. Rural females

For the rural population, equations are required for age-specific females and males. Female rural babies (who are age 0 at the end of the year $t+1$) are assumed to have been born at the start of the year $t+1$. Some of them will become part of the urban

population (e.g. due to migration) and some of them who stay in the rural area will die.

$$n_{0,t+1}^r = s_{0,t+1}^r(1 - k_{0,t+1})p_{t+1}^r \sum_{i=0}^h f_{it}^r n_{it}^r$$

where $\sum_{i=0}^h f_{it}^r n_{it}^r$ represents the rural babies who are born at the start of year $t+1$.

The number of rural individuals in age group i ($= 1, \dots, h-1$), at time $t+1$, equals the survivors among the rural individuals who were in the previous age group $i-1$, at time t , and who have not become urban:

$$n_{i,t+1}^r = s_{i,t+1}^r(1 - k_{i,t+1})n_{i-1,t}^r, \quad i = 1, 2, \dots, h-1$$

The rural individuals of the last age group at the end of year $t+1$ are the survivors from among those who remained in the rural population and were $h-1$ years of age or older.

$$n_{h,t+1}^r = s_{h,t+1}^r(1 - k_{h,t+1})(n_{h-1,t}^r + n_{ht}^r)$$

3.2. Rural males

The model for the male population is essentially the same as for the female population, with the exception of the first age group, because reproduction is related to females.

$$\tilde{n}_{0,t+1}^r = \tilde{s}_{0,t+1}^r(1 - \tilde{k}_{0,t+1})(1 - p_{t+1}^r) \sum_{i=0}^h \tilde{f}_{it}^r n_{it}^r$$

For the other age groups we have:

$$\tilde{n}_{i,t+1}^r = \tilde{s}_{i,t+1}^r(1 - \tilde{k}_{i,t+1})\tilde{n}_{i-1,t}^r, \quad i = 1, 2, \dots, h-1$$

$$\tilde{n}_{h,t+1}^r = \tilde{s}_{h,t+1}^r(1 - \tilde{k}_{h,t+1})(\tilde{n}_{h-1,t}^r + \tilde{n}_{ht}^r)$$

3.3. Urban females

The model for the urban population is essentially the same as for the rural population model. The difference is that part of the rural population becomes urban through the rural-urban population transition. The urban population receives these rural individuals at the start of the year, after which they may survive (or die) as urban people. The equations are as follows:

$$n_{0,t+1}^u = s_{0,t+1}^u p_{t+1}^u \sum_{i=0}^h f_{it}^u n_{it}^u + s_{0,t+1}^u k_{0,t+1} p_{t+1}^r \sum_{i=0}^h f_{it}^r n_{it}^r$$

$$n_{i,t+1}^u = s_{i,t+1}^u n_{i-1,t}^u + s_{i,t+1}^u k_{i,t+1} n_{i-1,t}^r, \quad i = 1, 2, \dots, h-1$$

$$n_{h,t+1}^u = s_{h,t+1}^u (n_{h-1,t}^u + n_{ht}^u) + s_{h,t+1}^u k_{h,t+1} (n_{h-1,t}^r + n_{ht}^r)$$

3.4. Urban males

$$\tilde{n}_{0,t+1}^u = \tilde{s}_{0,t+1}^u (1 - p_{t+1}^u) \sum_{i=0}^h \tilde{f}_{it}^u n_{it}^u + \tilde{s}_{0,t+1}^u \tilde{k}_{0,t+1} (1 - p_{t+1}^r) \sum_{i=0}^h \tilde{f}_{it}^r n_{it}^r$$

$$\tilde{n}_{i,t+1}^u = \tilde{s}_{i,t+1}^u \tilde{n}_{i-1,t}^u + \tilde{s}_{i,t+1}^u \tilde{k}_{i,t+1} \tilde{n}_{i-1,t}^r, \quad i = 1, 2, \dots, h-1$$

$$\tilde{n}_{h,t+1}^u = \tilde{s}_{h,t+1}^u (\tilde{n}_{h-1,t}^u + \tilde{n}_{ht}^u) + \tilde{s}_{h,t+1}^u \tilde{k}_{h,t+1} (\tilde{n}_{h-1,t}^r + \tilde{n}_{ht}^r)$$

As with any model, the model in this study has some limitations. First, for the sake of simplicity, we use forward demographic rates instead of the classical occurrence-exposure rates. The forward demographic rates are fixed parameters that are in line with the characteristics of the population at the start of the period under review. More precise parameters could be obtained using so-called occurrence-exposure rates.² Given that we use short time periods (years) and low average frequencies in a year of events – for example, births and deaths – we do not think that such corrections will be so large that they will compensate for the required increase in model complexity. Second, due to lack of detailed migration information, we use the net rural–urban transition rates. Ideally, it would be more accurate to use separate rural and urban out-migration rates to derive the net migration rates, because the pace of the out-migration of rural and urban populations could be different. A possible solution could be to use a demo-economic model to model the bilateral rural–urban migrations (Shen & Spence, 1996). Unfortunately, we do not have separate rural and urban out-migration data. Third, we assume that rural immigrants newly arriving in urban areas have the same fertility propensities as the urban population. These are much lower than for the rural population. This assumption may thus imply a risk of overstating the negative effect of urbanisation on fertility, since one might think that migrants do not behave like long-time urban dwellers upon arriving in a city. For a long time, institutional arrangements did not force migrants to adopt the stricter rules for urban people. Large numbers of rural immigrants could not register in the cities (i.e. could not obtain the *hukou* - registered permanent residence) and were therefore allowed to have more children. In recent years, the Chinese government has been loosening its restrictions on registration in cities.³ A more important reason why we believe the negative impact of migration on fertility is not overstated is that migrants are often uncertain about life in urban areas and will postpone important decisions on child-bearing until they have clear ideas about their future. This implies that they do not attain the high fertility rates of rural people, and that their fertility patterns are much closer to those of people who grew up in cities.

4. Estimation of the parameters and model validation

The rural–urban population model contains variables (n_{it} , $\tilde{n}_{it}$) and parameters (f_{it} , p_t , s_{it} , $\tilde{s}_{it}$, k_{it} and $\tilde{k}_{it}$). The relationships between these variables are fairly simple: given the values for the variables n_{it} and $\tilde{n}_{it}$ in $t = 2010$ and given the estimates for the parameters, the population in $t = 2011$ can be projected, and so forth. This section describes how the estimates were obtained and what assumptions were made. We mainly focus on the estimation of age-specific rural–urban transition rates, which are the core parameters of our model. The assumptions for fertility rates, mortality rates and the probability that a new birth is female are discussed in Appendix 1.

4.1. Corrections for the 2010 population

Due to China's strict policy on fertility control, underreporting new births has become an issue in China. Many demographers argue that the TFR is underestimated in the Chinese population statistics (see Goodkind, 2011; Guo, 2004; Zeng, 2007; Zhai & Chen, 2007; Zhang & Zhao, 2006). Primary school registration files are believed to have a complete

coverage of school-age children, since primary school education is compulsory and free in China. A cohort size comparison between age–sex-specific student data (Ministry of Education of China [ME], various years) and census data shows that around 30 million children aged 0–9 were missing from China’s 2000 census and that, based on this data, China’s 2000 total fertility rate could have been around 1.68 (Mai et al., 2013; Zhai & Chen, 2007). We used the same approach based on primary school enrolment data to correct the age–sex-specific populations under age 10 in the 2010 census as well. The corrected 2010 population will be used as the starting population for our projections. Hereafter, the 2000 and 2010 census data refers to the adjusted 2000 and 2010 census data.

4.2. Rural–urban transition rates

Data on the age-specific transition rates of the rural population becoming urban (through migration and urban expansion) are not available and need to be estimated. The age-specific impacts of these two factors are different. Whereas rural migrants are mainly represented in the younger age groups, the transition that takes place due to urban expansion plays a role in a much wider range of ages.

We estimate the age-specific rural–urban population transition in three steps. First, we estimate the aggregate rural–urban population transition. Second, we split this into the transition that is due to urban expansion and the transition that is the result of migration. Third, we estimate the age structures for the two types of rural–urban population transitions. The estimated aggregate rural–urban population transition that results from urban expansion is then distributed over the age groups, according to the corresponding estimated age structure; the same is done for the transition due to migration, after which the rates are determined. Summarised, this yields the following assumption:

Assumption 1: $k_{it} = k_i$ and $\tilde{k}_{it} = \tilde{k}_i$ for $t = 2011, \dots, 2030$,

$$k_i = \frac{q_i^e e + q_i^g g}{n_i^f} \text{ and } \tilde{k}_i = \frac{\tilde{q}_i^e e + \tilde{q}_i^g g}{\tilde{n}_i^f}$$

Here, k_i and $\tilde{k}_i$ are the female and male rural–urban population transition rates of age group i ; n_i^f and $\tilde{n}_i^f$ are the numbers of rural females and males in age group i ; e and g are the aggregate rural–urban population transitions due to urban expansion and migration, respectively; q_i^e and $\tilde{q}_i^e$ are the percentage of females and males in age group i as a share of the aggregate rural–urban population transition due to urban expansion; and q_i^g and $\tilde{q}_i^g$ are the percentage of females and males in age group i as a share of the aggregate rural–urban population transition due to migration.

The first step is to estimate the aggregate rural–urban transition. This is accomplished by employing the decomposition approach of Zhang and Song (2003). The idea is that the actual growth of the urban population (for which data are available) is caused by both natural growth and the net rural–urban population transition. The natural urban growth can be estimated using both the fertility and mortality rates of the urban population. The aggregate rural–urban population transition can thus be estimated by subtracting the natural number for the growth in the urban population (i.e. taking into account births and deaths) from the actual urban population growth.⁴ The NBS only includes, in its urban population statistics, persons who have lived in urban areas for six months or

more. Therefore, the present study does not include temporary rural migrants to urban areas. Table 1 presents the results. They show, for example, that the urban population increased from 645.1 million persons in 2009, to 669.8 million persons in 2010. Thus, the actual urban population grew by 24.7 million persons. The natural growth of the urban population, as calculated according to the 2010 urban fertility and mortality rates, was 3.3 million persons. The aggregate rural–urban population transition is, therefore, estimated as $24.7 - 3.3 = 21.4$ million persons.

The second step splits the aggregate rural–urban population transition into the part due to urban expansion and the part due to migration. To this end, we estimate the urban population growth that is due to urban expansion. Due to the availability of the relevant data, this number is easier to estimate than the change in the urban population from migration. The transition from migration is obtained as a residual, by deducting the estimated transition due to expansion from the estimated aggregate rural–urban population transition.

The statistical standard that determines whether an area is rural or urban has changed several times in China (Zhou & Ma, 2003), the most recent change occurring in 2006. According to this standard, the rural–urban division takes place on the basis of residents’ and villagers’ committees. These are the smallest administrative units and are the basic autonomous organisations for urban and rural areas. That is, both types of committees consist of administrators and all the (urban or rural) households in their respective administrative areas. Due to urban expansion, many villagers’ committees are administratively replaced by residents’ committees, for example, because most of the workers in a villagers’ committee are employed in non-agricultural industries. Thus, the rural–urban population transition that results from urban expansion is basically captured by the population in the newly created residents’ committees, which can be calculated on the basis of information in the *China Civil Affairs Statistical Yearbook* (MCA, 2011).⁵ Continuing the example above, during 2009–2010 the aggregate rural–urban population transition was 21.4 million persons, of which 13.7 million persons transited from rural to urban areas due to urban expansion. Therefore, the estimated (net) migration amounts to $21.4 - 13.7 = 7.7$ million persons.

Table 1 gives the results for the period 2006–2010, i.e. the years after the last change in the statistical standard used to determine the rural and urban populations. The table shows that the growth in the urban population was mainly caused by a rural–urban population transition and that both migration and urban expansion are important factors here. On average, the urban expansion and migration effects have been equal in size, but the results have fluctuated over the years (and in no particular direction). To eliminate the effect of these fluctuations, Assumption 1 uses the average values over the 2006–2010

Table 1. The decomposition of urban population growth (unit: million persons).

Year	Urban population	Growth in persons	Natural growth in persons	Rural–urban population transition	
				Urban expansion in persons	Net immigration in persons
2006	582.88				
2007	606.33	23.45	3.12	7.46	12.87
2008	624.03	17.70	3.40	8.15	6.16
2009	645.12	21.09	3.23	7.39	10.47
2010	669.78	24.66	3.27	13.71	7.68
Average		21.73	3.25	9.18	9.30

Source: Authors’ calculations based on MCA (2011).

period that are presented in Table 1. That is, $e = 9.2$ million persons per year and $g = 9.3$ million persons per year.

For the age-specific numbers of the rural population, we use the 2010 population census data, the most recent year for which data show the state of the Chinese population. That is, $n_i^r = n_{i,2010}^r$ and $\tilde{n}_i^r = \tilde{n}_{i,2010}^r$. The third step estimates the age structures. The sex-specific age structure of the 2010 rural population is used as an approximation for the age structure of the rural–urban population transition due to urban expansion. Rural population shares are used because rural areas become urban areas. We have $q_i^e = n_{i,2010}^r / \sum_{i=0}^h (n_{i,2010}^r + \tilde{n}_{i,2010}^r)$ and $\tilde{q}_i^e = \tilde{n}_{i,2010}^r / \sum_{i=0}^h (n_{i,2010}^r + \tilde{n}_{i,2010}^r)$.

There are no detailed data on the age structure of China's rural–urban migrants. China's population census data only report the age structure of all migrants, which also includes both urban–urban and rural–rural migrants. The age structure for the all migrants (as reported in the 2010 population census) is used (after correction) as an approximation for the age structure of the rural–urban migrants (i.e. q_i^g and $\tilde{q}_i^g$). This treatment is also used by other researchers in their studies on rural–urban migration issues in China (see e.g. Zeng & Vaupel, 1989). We exclude migrants who relocate for marriage from the total number of migrants, because it is difficult for rural people to migrate to an urban area just for marriage (Sun & Fan, 2011). The share of young people will be smaller after this correction since the migrants who are excluded because they relocated for marriage are generally young.

Figure 4 shows the estimated age-specific rural–urban population transition rates. The pattern is hump-shaped, indicating greater mobility among the younger members of the labour force (aged 15–49). Furthermore, the male population appears to be more mobile than the female population.

Historical data show that the speed of the urbanisation process has been steady in recent decades. Over the 2000–2010 period, the annual increase in the urbanisation rate was always around 1.4 per cent. China's twelfth five-year plan (2011–2015) sets a target of a further four percentage points increase. This is the same as the target set in the eleventh five-year plan (2006–2010), which was actually exceeded. As a result, we expect that the

Figure 4. Age-specific rural–urban population transition rates (2010).

Source: Authors' calculations based on MCA (2011).

current fast urbanisation process will continue over a number of years. For simplicity, we use the assumption of fixed rural–urban population transition rates (Assumption 1). This is not in line with the expectation that the rural–urban transition rates will increase as a consequence of a shrinking rural population base. However, it is difficult to predict the exact level of future transition rates. If the current pace of urbanisation continues, our assumption could slightly underestimate China’s future urbanisation rate.

4.3. Model validation test

To test the validity of our projection model, we assume the fixed fertility rate scenario and use our rural–urban population model and the 2000 population census data to project China’s population to 2010. We then compare the results with the actual statistics reported in China’s 2010 population census data and also with those projected by using an aggregate population model with parameter values that are obtained by appropriately weighting the parameters of the disaggregated model in the initial period. (The assumptions and formulas of the aggregate model are introduced in Appendix 2.) We divide the population into 91 age groups: 0, 1, 2 ... and 90+.

Figure 5 compares the projected Chinese population in 2010 with that reported in the 2010 census. For the groups above age 10, we find that the projected results fit the census data very well and that both our rural–urban population model and the aggregate population model yield very similar results. This is due to the fact that our findings for the 10-year validation period imply that differences between rural and urban fertility rates do not play a role for these age groups, since they were born before 2000. Hence, differences could only be due to differences between urban and rural mortality rates, but these are very low for these age groups. For the population aged 0–9, however, Figure 5 shows that our model’s projected results and those of the aggregate model are quite different, but our projection results are closer to the actual statistics. This is because our rural–urban population model captures the negative effect of urbanisation on China’s fertility rate. In the 10-year projection span (2000–2010), for the 0–9 age group, our projection results are much lower than those of the aggregate model. The results from our model also show that as the urbanisation effect increases over time, the difference between the results of our

Figure 5. The Chinese population in 2010, by age.

Notes: The number of inhabitants aged 0–9 reported in the 2010 census data has been corrected by using educational statistics (ME, various years).

model and those of the aggregate would become even larger. Hence, the major advantage of our projection, over the 2010–2030 period, will be a more accurate estimation for the population in the 0–19 age groups. For the relatively young age groups (7–17 years of age), Figure 5 shows that our projection results are significantly higher than those reported in the 2010 census. Both models seem to have over-predicted the number of persons in the 11–17 age group. One of the reasons is probably that large numbers of people who were in the 1–7 age group and underreported in the 2000 population census were still underreported in the 2010 population census. It is generally thought that the underreporting problem is mainly confined to children in the age group 0–9, but our results suggest that there are also reporting issues related to somewhat older children.

The validation test shows that the urbanisation effect, captured in our rural–urban population model, can yield more realistic results than the general aggregate population models for the young population. The validation test implies that our model might well yield more accurate projections than the aggregate model for the 0–19 age groups in 2030.

5. The projections

Taking as a starting point the corrected 2010 population census data, we have projected China's population from 2010 to 2030, using the rural–urban population model and the two fertility scenarios. The detailed results are reported in Table 2 (for the constant fertility rate scenario, i.e. Assumption A1.2A) and in Table 3 (for the 'two-children' policy scenario, i.e. Assumption A1.2B).

Table 2. The Chinese population projection results for the constant fertility rate scenario (% of total rural, urban and aggregate population).

Age group	2010			2020 (Projected)			2030 (Projected)		
	Rural	Urban	Aggregate	Rural	Urban	Aggregate	Rural	Urban	Aggregate
0–4	7.5	5.1	6.3	5.9	4.9	5.3	5.1	3.4	3.9
5–9	6.6	4.9	5.7	6.6	5.1	5.7	5.4	4.0	4.4
10–14	6.3	4.8	5.5	7.5	5.0	5.9	6.1	4.7	5.1
15–19	6.9	7.9	7.4	6.4	4.9	5.4	6.6	5.1	5.5
20–24	8.4	10.6	9.5	5.6	5.0	5.2	6.9	5.3	5.8
25–29	6.4	8.6	7.5	5.8	7.6	6.9	5.4	5.3	5.3
30–34	6.1	8.3	7.2	7.1	9.9	8.9	4.8	5.2	5.1
35–39	7.9	9.6	8.7	5.4	8.1	7.1	5.1	7.4	6.7
40–44	9.1	9.4	9.2	5.5	7.6	6.8	6.5	9.4	8.6
45–49	7.7	7.9	7.8	7.3	8.5	8.1	5.1	7.6	6.9
50–54	5.9	5.8	5.8	8.5	8.5	8.5	5.3	7.0	6.5
55–59	6.5	5.5	6.0	7.1	7.2	7.1	7.2	7.8	7.7
60–64	4.9	3.8	4.3	5.7	5.0	5.2	8.4	7.9	8.1
65–69	3.5	2.6	3.0	6.0	4.8	5.2	6.6	6.6	6.6
70–74	2.7	2.2	2.4	4.2	3.3	3.6	5.3	4.4	4.7
75–79	2.0	1.6	1.8	2.6	2.1	2.3	5.0	4.1	4.4
80–84	1.1	0.8	1.0	1.7	1.4	1.5	2.9	2.5	2.6
85–89	0.5	0.4	0.4	0.9	0.8	0.8	1.4	1.3	1.3
90+	0.2	0.1	0.1	0.4	0.4	0.4	0.8	1.0	0.9
0–14	20.3	14.9	17.6	20.0	15.0	16.9	16.5	12.1	13.4
15–64	69.8	77.4	73.6	64.3	72.3	69.3	61.4	68.0	66.1
65+	9.9	7.7	8.8	15.6	12.8	13.9	22.1	19.9	20.5
Total	100	100	100	100	100	100	100	100	100
Urbanisation rate			50			62			71

Source: The data for 2010 is calculated based on China's 2010 population census data (the population aged 0–9 has been adjusted by using educational statistics). The data for 2020 and 2030 are projected using our rural–urban population model.

Table 3. The Chinese population projection results for the two-children policy scenario (% of total rural, urban and aggregate population).

Age group	2010			2020 (Projected)			2030 (Projected)		
	Rural	Urban	Aggregate	Rural	Urban	Aggregate	Rural	Urban	Aggregate
0–4	7.5	5.1	6.3	6.2	5.3	5.7	6.1	4.7	5.1
5–9	6.6	4.9	5.7	6.7	5.1	5.7	6.5	4.7	5.2
10–14	6.3	4.8	5.5	7.5	5.0	5.9	6.3	5.0	5.4
15–19	6.9	7.9	7.4	6.3	4.8	5.4	6.5	5.0	5.4
20–24	8.4	10.6	9.5	5.5	5.0	5.2	6.7	5.2	5.6
25–29	6.4	8.6	7.5	5.8	7.6	6.9	5.2	5.1	5.2
30–34	6.1	8.3	7.2	7.1	9.9	8.8	4.7	5.0	4.9
35–39	7.9	9.6	8.7	5.4	8.0	7.0	5.0	7.2	6.6
40–44	9.1	9.4	9.2	5.4	7.5	6.7	6.3	9.1	8.3
45–49	7.7	7.9	7.8	7.3	8.5	8.0	4.9	7.4	6.7
50–54	5.9	5.8	5.8	8.5	8.5	8.5	5.2	6.8	6.4
55–59	6.5	5.5	6.0	7.0	7.2	7.1	7.0	7.6	7.4
60–64	4.9	3.8	4.3	5.6	4.9	5.2	8.2	7.7	7.8
65–69	3.5	2.6	3.0	5.9	4.8	5.2	6.4	6.5	6.4
70–74	2.7	2.2	2.4	4.1	3.3	3.6	5.2	4.2	4.5
75–79	2.0	1.6	1.8	2.6	2.1	2.3	4.8	4.0	4.2
80–84	1.1	0.8	1.0	1.6	1.4	1.5	2.8	2.5	2.6
85–89	0.5	0.4	0.4	0.9	0.8	0.8	1.4	1.3	1.3
90+	0.2	0.1	0.1	0.4	0.4	0.4	0.8	0.9	0.9
0–14	20.3	14.9	17.6	20.4	15.3	17.2	18.8	14.5	15.8
15–64	69.8	77.4	73.6	64.0	71.9	69.0	59.7	66.1	64.3
65+	9.9	7.7	8.8	15.6	12.7	13.8	21.5	19.4	20.0
Total	100	100	100	100	100	100	100	100	100
Urbanisation rate			50			62			71

Source: The data for 2010 is calculated based on China's 2010 population census data (The population aged 0–9 has been adjusted by using educational statistics). The data for 2020 and 2030 are projected by using our rural–urban population model.

Figure 6 depicts the specific rural–urban population projections for the two scenarios. It shows that the rural population will continue to shrink over the entire 2011–2030 period and, at the same time, the urban population will continue to expand. This pattern is found for both scenarios. Although the ‘two-children’ policy can increase the number of rural births to some extent, it cannot fully compensate for the huge number of rural–urban migrants.

Figure 6. China's rural and urban populations (2010–2050).

In addition, to investigate the peak of China's total population, we extend our projections to 2050. For the constant fertility rate scenario, we find that before 2035 the decrease in the rural population will be smaller than the growth of the urban population, but after 2035 this pattern will be reversed. Again, assuming the constant fertility rate scenario, the results will be that, first, China's total population will grow, and then it will gradually shrink (as shown in Figure 7). At its peak, around 2035, the total population will be approximately 1460 million people.

In the 'two-children' policy scenario (i.e. the rural and urban TFRs in 2011–2013 are fixed at the level of 2010 and then linearly increase to 2.27 and 1.80 by 2020. Afterwards, the TFRs are fixed at the level of 2020, see Appendix 1 for details), the rural population will decrease to 431 million in 2030, which is 12 million more than the projection in the constant fertility rate scenario; in the latter case, the urban population will reach 1070 million, which exceeds the projection for the constant fertility rate scenario by 30 million people. China's total population will continue to grow over the entire 2011–2050 period. In 2030, the total population is projected to reach 1500 million, which is 2.9 per cent more than the projection under the constant fertility rate scenario.

Figure 8 gives the projections for the total labour force and shows a decreasing pattern over the next two decades. From 2025 onwards, in particular, the size of China's labour force will experience a steep decline. This is because the Chinese baby boom generation, born in the 1960s, will begin retiring in 2025. The total labour force will decrease, between 2010 and 2030, with approximately 4 per cent (from 1000 million persons to approximately 940 million persons, in both scenarios). Figure 9 presents separate projections for the rural and urban labour forces. The rural labour force is projected to show an obvious decreasing pattern, between 2010 and 2030, wherein it will shrink by approximately 45 per cent (from about 470 million to about 257 million). In addition to the retirement of the baby boom generation, urbanisation will play an important role in the substantial shrinkage of the rural labour force. Urbanisation will continue to absorb a large number of rural workers who seek employment in the urban areas. This will support the continuing growth of the urban labour force over the period (by approximately 34 per cent – from 526 million to 707 million).

We observe that the projections for the labour force are exactly the same for both fertility scenarios over the years 2011–2028. The reason is that the labour force in this study is

Figure 7. Total population (2010–2050).

Figure 8. Total labour force (aged 15–64, 2010–2050).

defined as the population aged 15–64 and the total fertility rate under the ‘two-children’ policy scenario starts to increase in 2014. This policy adjustment starts to affect the labour force only when the first babies under the ‘two-children’ policy enter the labour force at age 15, which is in 2029. To gain some insight on the different effects of both scenarios on the labour force, we extend our projections to 2050. Figures 8 and 9 show that the labour force will continue to decrease, despite the effects of a rising total fertility rate from 2029. The ‘two-children’ policy cannot reverse this decreasing labour force trend over the next 40 years; however, it does slow its decline. As Figures 8 and 9 show, the gap between the results of the two fertility scenarios widens from 2029 onward.

Table 2 gives the projections for each age group, assuming that the fertility rates are fixed at the 2010 level. Over the next two decades, China will experience a rather fast ageing process. The share of China’s population that is 65 years of age and over will increase from 8.8 per cent in 2010, to 13.9 per cent in 2020, and 20.5 per cent in 2030. In 2010, there were almost twice as many people in the youngest age group (aged 0–14) in China as there were old people (aged 65 and over). In 2030, however, there

Figure 9. China’s rural and urban labour force (aged 15–64, 2010–2050).

will be almost 1.5 times the number of people in the oldest age group as there will be in the youngest age group. Meanwhile, the share of the labour force (aged 15–64) in China's total population will decrease from 73.6 per cent in 2010, to 69.3 per cent in 2020, and 66.1 per cent in 2030.

For the rural population, the share of the population aged 65+ will increase from 9.9 per cent in 2010, to 15.6 per cent in 2020, and to 22.1 per cent in 2030. The gap between the rural and urban populations will increase from 2.2 percentage points in 2010, to 2.8 percentage points in 2020, after which it will shrink somewhat, to 2.2 percentage points in 2030. This indicates that the problem of an ageing population in China will continue to be more serious in rural areas over the next two decades. Many young rural people will move to urban areas during the process of fast urbanisation and industrialisation. And if we look at the number of persons aged 65 and over, we find that the urban areas will have more old people than the rural areas will over the same period. Initially, the number of old people (aged 65 and over) in rural areas will be around 67 million, which will be 1.3 times those in urban areas (52 million). In 2030, however, the number of old people in urban areas will soar to 207 million, which will be more than twice the number in rural areas (93 million). The decrease in urban mortality rates and the expansion of urban areas are both important factors for the increasing number of urban old people.

Regarding the 'two-children' policy scenario, [Table 3](#) shows that the share of the population aged 65 and older will reach 20.0 per cent of the total population in 2030. This is only 0.5 percentage points lower than the projection using the constant fertility rate scenario (based on the situation in 2010, with a one-child policy in urban areas and a 'two-children' policy in rural areas). Both fertility scenarios yield very close projections for the 65+ age group. This finding implies that, at least over the next two decades, the 'two-children' policy as recommended by several researchers cannot alleviate China's upcoming ageing problem by very much.

[Tables 2](#) and [3](#) show that the projected urbanisation rates in the two fertility scenarios are also very close. For the 'two-children' policy, the increase in the total fertility rates for the rural and urban populations are essentially the same, which leads to very similar effects on the growth of the rural and urban populations. Because the rural–urban population transition rate is small for the infant age group (see [Figure 4](#)) and because infants compose a small share of the total rural population, the rural–urban transition only leads to a very minor increase in the urban population. Therefore, the fertility rate changes in our scenarios do not affect China's urbanisation process. If the estimated rural–urban transition rates for 2010 are fixed for the next two decades, the projections show that China's fast urbanisation process will continue. That is, China's urbanisation rate will reach 62 per cent in 2020 and 71 per cent in 2030. For developed countries, the current urbanisation rate is around 80 per cent.⁶ Our results show that even if China continues its current fast urbanisation process, it will still lag behind the urbanisation rate of developed countries over the next two decades.

6. A comparison of the projections

The United Nations (2015) recently revised its projections for the Chinese population on the basis of China's 2010 population census data. According to the UN's results, using the constant fertility rate scenario, the share of the population aged 65+ will

reach 12.1 per cent in 2020 and 17.3 per cent in 2030.⁷ This is considerably lower than our projections. Three methodological differences lead to these different results. First, the UN also adjusted the number of age-specific populations in China's 2010 census data because of the underreporting issues, but the adjusted 2010 population data are different from ours. According to the United Nations (2015), the share of the population in the labour force (aged 15–64) is 0.7 percentage points higher than in the data we use, and the share of old people (aged 65+) is 0.7 percentage points lower in the UN data than in ours. This difference in the starting point will obviously affect the projections in later years. Second, the UN projections for China's future mortality pattern are obtained using data from developed countries. In view of China's expected continued socio-economic advancement over future decades, this might be a justifiable choice. Our projections need information on China's specific mortality rates for both rural and urban areas. Thus, we adopt the Lee and Carter (1992) model and base our estimates on the changes in China's mortality rates between 2000 and 2010. We believe that it is more realistic to model China's mortality rates using the country's own data. Third, our model distinguishes between the rural and urban populations; it also takes urbanisation into account. As previously mentioned, the demographic features of the two population groups are very different in terms of fertility, mortality and migration. The fertility and the mortality rates of the urban population are both significantly smaller than those of the rural population. At the same time, a fast urbanisation process will take place over the next two decades. If urbanisation is taken into account, then the share of the urban population is greater than in the case where urbanisation is neglected. The average fertility and mortality rate of China's population, as a whole (using the share of urban and rural population as weights), are thus smaller when urbanisation is accounted for than when it is neglected. In the projections, the smaller fertility and mortality rates obtained when urbanisation is implemented in the model yield a larger share of the population in the older age group. That is, not taking urbanisation into account will lead to a smaller share of people aged 65+ than when urbanisation is accounted for in the model.

To quantify the effect of separating the rural and urban populations, we have also made age-specific population projections with a version of the model in which the rural/urban distinction is not incorporated (i.e. the aggregate model used in the validation test). In the constant fertility rate scenario, the share of the population aged 65+ in 2030 will be 20.0 per cent. This is 0.5 percentage points less than the results we found using our full rural–urban population model (see Table 2). The difference is comparable to the effect caused by the 'two-children' policy (0.5 percentage points less than in the baseline scenario with a constant fertility rate). In view of this difference, it is advisable to model the rural and urban populations separately when projecting the Chinese population. The effect of modelling them separately is of the same order as the effect one would like to investigate (i.e. one that incorporates the change in fertility control policy).

Mai et al. (2013) presented another recent population projection for China. Their projection is for the period up to 2050, and they use 2000 population census data adjusted for the issues of underreporting (the 2010 population census data had not yet been published when they made their projections). Their model does not distinguish between the rural and urban populations. With a total fertility rate of 1.50 and a medium pace of mortality improvement, their projections for the share of the population aged 65 and over are around 12 per cent in 2020 and 17 per cent in 2030, which are clearly lower than ours.

The different approaches for modelling future mortality rates, the different base-year data, and neglecting rural–urban demographic heterogeneity have all contributed to the differences in the projections.

Furthermore, forecasts for China's urbanisation rate in 2020 and 2030 have already been published. For instance, the forecasts by the United Nations (2014) are 61 per cent in 2020 and 69 per cent in 2030, which are close to our own forecasts. This also holds for the forecasts by Zheng (2011), i.e. 60 per cent in 2020 and 70 per cent in 2030, which are obtained from a direct extrapolation of the time series of past urbanisation rates. As the transformation of rural areas into urban ones was not fully modelled in Shen and Spence (1996), their forecasts are lower than ours (57% in 2020 and 64% in 2030).

To summarise, forecasts for the age-specific population shares (and thus for ageing) appear to be sensitive to the underlying assumptions for fertility and mortality rates and to the inclusion of rural–urban demographic heterogeneities. The forecasts for urbanisation appear to be more robust.

7. Conclusions

Over the next two decades, China is expected to experience rapid ageing and urbanisation. We investigated the effects of ageing and urbanisation on China's future population and labour force. As China's rural and urban populations have large demographic disparities, in terms of fertility, mortality and migration, it is necessary to further investigate the specific rural–urban dynamics of the Chinese population. In order to make our projections, we developed a rural–urban population model which takes into account that fertility and mortality rates differ between the rural and urban populations, and that China's urbanisation process reflects changes in the relative sizes of these two sub-populations.

We conducted our projections for two fertility scenarios. First, the constant fertility rate scenario assumes that the fertility-control policy will not change. The total fertility rates and the age-specific fertility rates are fixed at their 2010 levels during the projection period. Second, the 'two-children' policy scenario reflects the recent adjustment to the fertility policy wherein the Chinese government now allows all couples to have a second child. For the period 2011–2013, the total fertility rates are fixed at the 2010 levels, after which they increase linearly over the period 2014–2020, to 2.27 for the rural population and 1.80 for the urban population, which are the levels assumed for the period 2021–2030.

These population projections show that, in the fixed fertility scenario, the peak of China's total population will occur around 2035, with 1463 million people (and 1458 million in 2030). In the other scenario, the population will continue to grow and there will be an additional 43 million people in 2030. For specific rural–urban population, in both scenarios China's rural population will continue to shrink and China's urban population will continue to expand during the entire 2011–2030 period. Further, the following findings held for both scenarios: (1) China will experience a fast ageing process over the next two decades; the population aged 65+, as a share of China's total population, will be around 20 per cent in 2030; and (2) the problem of an ageing population will continue to be more serious in rural areas than in urban ones due to rural–urban migration (which is an important factor in the urbanisation process), mainly by young people. In 2030, the share of the population aged 65+ will be more than 2 percentage points larger for the rural population than for the urban one. If we look at the population aged 65+, by size

instead of by share, we will see that urban areas will gain more old people than rural areas will. In 2030, the number of old people living in the urban areas will soar to around 207 million, which is 2.2 times those in the rural areas; and (3) China will experience a fast urbanisation process over the next two decades. The urbanisation rate will increase from 50 per cent in 2010 to 71 per cent in 2030.

Our projections also show that the size of China's total labour force will continue to decrease by 4 per cent between 2010 and 2030. Changes in the rural–urban-specific labour force show different patterns. The rural labour force will shrink by approximately 45 per cent (from 470 million to 257 million) between 2010 and 2030, while the urban labour force will grow by approximately 34 per cent (from 526 million to 707 million). This means that rural areas will continue to supply a large number of workers to urban areas. The projection for 2010–2050 further shows that the decline of the total labour force over the next 40 years cannot be reversed by loosening the fertility-control policy. The decreasing labour force size may negatively affect China's long-run economic growth. This certainly indicates the importance of increasing labour productivity for China's future economic development.

Finally, we would like to point out that our projections also suffer from limitations. One of them is the exogeneity of the total fertility rates in our model, for which the two scenarios were used. Future work might be devoted to endogenising the total fertility rates. Economic growth, for example, has been proved to be an important determinant of age-specific fertility rates. Another limitation is that our forecasts for mortality rates do not take into account recent and future medical, social and economic progress. Endogenising the fertility and mortality rates in our model would be an interesting future step. A similar line of reasoning applies to our treatment of rural–urban migration rates. We consider these to be constant over time for each age. However, it is well known that rural–urban migration rates are dependent on the relative income levels in rural and urban areas (see, for example, Zhang, 2012; Zhu, 2002). For example, the differences between rural and urban income levels can vary over time as a consequence of the positive agglomeration effects and the negative congestion effects of urban economic activity. We do not have reliable indicators for future relative income levels, but our analysis could be enriched by endogenising rural–urban migration for multiple scenarios with differential rates of economic growth in rural and urban areas.

Notes

1. For a specific age group, the number of rural individuals who become urban individuals minus the number of urban individuals who become rural individuals yields the net number of rural individuals who become urban individuals.
2. Occurrence-exposure rates correct for the fact that changes in the demographic composition of a population are not discrete events (taking place all at once, between the end of a period and the start of the next one), rather they are continuous processes. For instance, the occurrence-exposure rate approach corrects for the fact that the rural fertility rate is relevant for just a part of the year, assuming that females migrating to a city behave like the average urban female. Shen (1994) investigated the empirical differences between forward demographic rates and occurrence-exposure demographic rates.
3. For instance, the Chinese government plans to help 13 million (1% of the total population) rural immigrants per year to register in cities during the period 2016–2020 (http://www.gov.cn/zhengce/content/2016-10/11/content_5117442.htm).

4. The rural–urban population transition can also be estimated from the rural population growth. We find that the two results are almost the same.
5. A similar approach was used by Hu (2003) to estimate the rural–urban population transition caused by urban expansion. In that study, data (from *China Civil Affairs' Statistical Yearbook*) on newly created towns were used. Our study uses data on newly created residents' committees because of a more recent statistical standard to determine rural and urban areas.
6. In 2011, the urbanisation rates were 82 per cent in the US, 91 per cent in Japan, 74 per cent in Germany, 86 per cent in France, and 80 per cent in Great Britain.
7. In the projection result for the UN's medium fertility rate scenario, the share of population aged 65+ in 2020 and 2030 are 12.1 per cent and 17.2 per cent, respectively, very close to the projection results for the constant fertility rate scenario. For the high fertility rate scenario, the share of population aged 65+ in 2020 and 2030 are 12.0 per cent and 16.6 per cent, 0.1 and 0.7 percentage points less than for the constant fertility rate scenario. For the low fertility rate scenario, the share of population aged 65+ in 2020 and 2030 are 12.2 per cent and 17.8 per cent, 0.1 and 0.5 percentage points higher for than the constant fertility rate scenario.
8. For a specific age group i , the second-child fertility rate is defined as the ratio between the number of females in age group i that give birth to a second child and the total number of females in age group i .
9. Reversal of the rank order means that the mortality rate of group i is greater than the mortality rate of age group j in time period t , whereas it is forecast to be smaller in period k .

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Appendix 1. The assumptions of fertility rates, mortality rates and the probabilities that a new birth is female

The probabilities that a new birth is female

For the probability that a new birth is female, we use the proportion of females among the number of new-born babies. In 2010, this proportion for rural new-born females was 45.6 per cent and for urban new-born females it was 46.3 per cent. Looking back to the year 2000, the proportions were almost the same (i.e. 45.6% and 46.5%, respectively). Therefore, for our projections, we can safely assume that the probability that a new birth is female is fixed at the 2010 level.

Assumption A1.1: $p_t^r = p_{2010}^r = 0.456$ and $p_t^u = p_{2010}^u = 0.463$, for $t = 2011, \dots, 2030$.

The fertility rates

In 1980, the Chinese government launched its so-called one-child policy to control the country's rapid population growth. This strict policy of fertility control led to rather low and stable fertility rates over the ensuing decades. According to China's population census data (NBS, 2002, 2012), the total fertility rate (TFR) of the rural population was 1.43 in 2000 and 1.44 in 2010, and the TFR of the urban population was 0.94 in 2000 and 0.98 in 2010. It seems obvious that the urban TFR was lower than the rural TFR because the fertility control policy was much tighter for the urban population. In recent years, the Chinese government has loosened its fertility policy. In 2014, it allowed couples to have a second child, but only if one (or both) of the parents was an only child. And in 2016, it implemented the two-children policy, thereby allowing all couples to have a second child.

For our projections we use two fertility scenarios so as to take into account China's fertility-control policy. The baseline scenario assumes a constant fertility rate. We assume that China's fertility rate will not change during the projection period (i.e. 2011–2030). The TFRs for both the rural and the urban populations are fixed at the 2010 level. Nevertheless, one adjustment is made to the TFRs reported in the 2010 population census data, to account for the underreporting issues discussed in Section 4.

By comparing the different estimates of China's TFR, Cai (2013) concludes that this was around 1.5 in 2010, or 27 per cent higher than the TFR reported in the 2010 census. This estimate is also close to the United Nations (2015) estimate of 1.55. We use the underreporting rate of 27 per cent to adjust the 2010 TFR from 1.44 to 1.83 for the rural population, and from 0.98 to 1.24 for the urban population. Thus, the age-specific fertility rates are increased by the same proportions.

Assumption A1.2A: $f_{it}^r = 1.83/1.44f_{i,2010}^r$ and $f_{it}^u = 1.24/0.98f_{i,2010}^u$, for $t = 2011, \dots, 2030$.

The second scenario reflects the much looser fertility-control policies that were adopted in recent years. This gradual policy relaxation is largely in line with Zeng's (2006, 2007) proposal for a so-called 'two children with late childbearing soft landing'. Zeng (2006) estimated the rural TFR to be 2.27 and the urban TFR to be 1.80, after the 2014 transition toward the 'two-children' policy and the resulting behavioural changes by families have been completed.

For our projections, we adopt Zeng's scenario and assume that, for the years 2011–2013, the rural and urban TFRs are fixed at the adjusted 2010 level (i.e. 1.83 for the rural TFR and 1.24 for the urban TFR). The 'two-children' policy was implemented in 2014, and we assume that the TFR's increase will be linear over the seven years until they reach their 2020 levels. These rates are projected to be 2.27 for the rural population and 1.80 for the urban population. For the distribution of the increases in the TFR over the age-specific fertility rates, it should be noted that the increased fertility is only due to an increase in the number of second children. Here, the implicit assumption is that family planning, and thus the first-child fertility rate, is not affected by the implementation of the two-children policy. For the distribution, we use proportions that are based on the age-specific second-child fertility rate in 2010.⁸ The proportion for age group i (denoted by w_i^r for rural rates and w_i^u for urban rates) is

calculated by dividing the second-child fertility rate in age group i by the sum of the second-child fertility rates across all age groups. The information on the age-specific second-child fertility rates can be obtained from the population census data. After 2020, the rural and urban TFRs are assumed to remain fixed.

Assumption A1.2B:

$$f_{it}^r = \begin{cases} \frac{1.83}{1.44} f_{i,2010}^r & t = 2011, \dots, 2013 \\ \frac{1.83}{1.44} f_{i,2010}^r + \frac{2.27 - 1.83}{7} (t - 2013) w_i^r & t = 2014, \dots, 2020 \\ \frac{1.83}{1.44} f_{i,2010}^r + (2.27 - 1.83) w_i^r & t = 2021, \dots, 2030 \end{cases}$$

$$f_{it}^u = \begin{cases} \frac{1.24}{0.98} f_{i,2010}^u & t = 2011, \dots, 2013 \\ \frac{1.24}{0.98} f_{i,2010}^u + \frac{1.80 - 1.24}{7} (t - 2013) w_i^u & t = 2014, \dots, 2020 \\ \frac{1.24}{0.98} f_{i,2010}^u + (1.80 - 1.24) w_i^u & t = 2021, \dots, 2030 \end{cases}$$

Note that $TFR_t^r = \sum_i f_{it}^r = 2.27$ for $t = 2020, \dots, 2030$, because $\sum_i f_{i,2010}^r = TFR_{2010}^r = 1.44$ and $\sum_i w_i^r = 1$. In the same way, $TFR_t^u = 1.80$ for $t = 2020, \dots, 2030$.

The mortality rates

Improvements in living conditions and progress in medical technology have considerably increased the life expectancy, at birth, of the Chinese population, from 71.4 years in 2000 to 74.8 in 2010. Figure 3 shows that the decreases in the mortality rates between 2000 and 2010 were significant, in particular for new-born children and the elderly. Given that the current life expectancy at birth in developed countries is around 80 years, China's mortality rate is expected to continue to decrease over the next two decades.

We use the Lee–Carter model (Lee & Carter, 1992) to forecast China's future age-specific mortality rates. This is a leading statistical model for mid-term (around 50 years) forecasts of mortality rates and it has been successfully applied to almost all countries that have reliable data and are under normal socio-economic conditions (Booth, 2006; Li, Lee, & Gerland, 2013). The model's main underlying assumption is that the future annual rate of decline of the age-specific mortality rates equals the average rate of decline during the most recent period for which the data are available.

The Lee–Carter model has two characteristics that make it appropriate for our case. First, only two years of historical data are sufficient to apply the model, which is attractive for countries with limited data availability, such as China. Second, the forecasts for age-specific mortality rates, obtained from the Lee–Carter model, always satisfy the desirable property that they are positive.

Nevertheless, the Lee–Carter model also suffers from some limitations. It assumes that the historical average rate of decline in age-specific mortality rates will continue into the future. As Girosi and King (2008) point out, it may be reasonable to assume that the historical pattern will continue over the short run. Over a longer time period, however, the model's forecasts may diverge from the empirical patterns. For instance, if the Lee–Carter model is used for a forecast period that is very long, then reversion in the rank order of the age-specific mortality rates may occur.⁹ In this respect, Li et al. (2013) conclude that, for projections for most countries, a reversal of the rank orders makes little or no difference; the exception is for countries with life expectancies above 80 years. The life expectancy in China is still far lower than this, so we believe it is plausible to assume that China's historical pattern of changes in age-specific mortality rates during 2000–2010 will continue over the next two decades. In addition, the forecasts (which are shown later, in Figure A1) based on this assumption do

not show serious problems in terms of the reverted rank orders of the age-specific mortality rates. Therefore, we feel it is reasonable to use the Lee–Carter model to forecast these mortality rates for China. The model assumes an exponential change in the age-specific mortality rates, which is specified as

$$\ln m_{it} = \alpha_i + \beta_i v_t + \varepsilon_{it} \quad (i = 0, 1, \dots, h; t = 1, 2, \dots, T) \quad (\text{A1})$$

α_i , β_i and v_t are parameters to be estimated and ε_{it} are random disturbances with mean 0 and variance σ^2 ; v_t represents the combined effects of the exogenous factors (such as medical technology and economic growth) that have a systematic impact on the mortality rates of all age groups. Although v_t has an impact on the mortality rates of all age groups, its magnitude varies across age groups. Some age groups benefit more than others and this difference is captured by β_i , which represents the effect of v_t on age group i . Equation (A1) is estimated by using the singular value decomposition (SVD) approach (see Girosi & King, 2008). This yields $\hat{\alpha}_i = \overline{\ln m_i} = \sum_{t=1}^T \ln m_{it} / T$, the average of $\ln m_{it}$ over time, and estimates $\hat{\beta}_i$ ($i = 1, \dots, h$) and $\hat{v}_t$ ($t = 1, \dots, T$).

In the forecasting procedure, we want to calculate $\hat{m}_{i,T+\tau}$. As Equation (A1) indicates, the forecast depends on (i) the estimated parameters $\hat{\alpha}_i$ and $\hat{\beta}_i$, both of which are fixed over time, and (ii) the parameter $\hat{v}_{T+\tau}$, which is time varying. The forecast yields $\ln \hat{m}_{i,T+\tau} = \hat{\alpha}_i + \hat{\beta}_i \hat{v}_{T+\tau}$. Because the parameters $\hat{v}_{T+\tau}$ are time varying, they are obtained by specifying the following random walk with drift model.

$$\hat{v}_t = \theta + \hat{v}_{t-1} + \mu_t, \quad \mu_t \sim N(0, \sigma_\mu^2)$$

In practice, this specification is used almost exclusively (Girosi & King, 2008). The maximum likelihood estimate of θ is given by $\hat{\theta} = (\hat{v}_T - \hat{v}_1) / (T - 1)$. Note that the estimate depends only on the values in the initial and final years. This implies that data for two years are sufficient to forecast the age-specific mortality rates using the Lee–Carter model. The forecast for the parameter v now becomes $\hat{v}_{T+\tau} = \hat{v}_T + \hat{\theta}\tau$, for $\tau = 1, 2, \dots$. Collecting all the pieces of information, and noting that, in our case, we only have census data for two years (2000 and 2010), yields the following:

Assumption A1.3: The forecast for the mortality rate is given by

$$\begin{aligned} \hat{m}_{i,2010+\tau} &= e^{\hat{\alpha}_i + \hat{\beta}_i \hat{v}_{2010+\tau}} = e^{\overline{\ln m_i} + \hat{\beta}_i (\hat{v}_{2010} + (\hat{v}_{2010} - \hat{v}_{2000}) / 10 \tau)} \\ &= e^{(\ln m_{i,2000} + \ln m_{i,2010}) / 2 + \hat{\beta}_i (\hat{v}_{2010} + (\hat{v}_{2010} - \hat{v}_{2000}) / 10 \tau)} \end{aligned}$$

for $\tau = 1, \dots, 20$, where $\hat{\beta}_i$, $\hat{v}_{2000}$ and $\hat{v}_{2010}$ are parameters estimated using the singular value decomposition.

We decided to estimate the Lee–Carter parameters based on Chinese census data for 2000 and 2010 only. A one per cent sample survey is conducted halfway between the two census years (i.e. in 2005); for the other years, a one per cent sample survey is conducted. In these limited sample surveys, the mortality rates of the older (age 65+) population show large variations, because the number of surveyed people in this age group is relatively small. Hence, there is no time series that has sufficient survey coverage for China's age-specific mortality rates. The 2000 and 2010 population census data are representative and obtained in a consistent way.

The annual forecasts up to 2030 for the age-specific mortality rates using the Lee–Carter model are given in Figure 4. Note that $\overline{\ln m_i} = (\ln m_{i,2000} + \ln m_{i,2010}) / 2$ in our case.

Figure A1. Age-specific mortality rates in 2000, 2010, 2020 (projected) and 2030 (projected).

Appendix 2. The aggregate population model used in the validation test

The aggregate population model used in the validation test is briefly introduced as follows. The definitions of the parameters are the same as those shown in Section 3.

Females

$$n_{0,t+1} = s_{0,t+1}p_{t+1} \sum_{i=0}^h f_{it}n_{it}$$

$$n_{i,t+1} = s_{i,t+1}n_{i-1,t}, \quad i = 1, 2, \dots, h-1$$

$$n_{h,t+1} = s_{h,t+1}(n_{h-1,t} + n_{h,t})$$

Males

$$\tilde{n}_{0,t+1} = \tilde{s}_{0,t+1}\tilde{p}_{t+1} \sum_{i=0}^h f_{it}n_{it}$$

$$\tilde{n}_{i,t+1} = \tilde{s}_{i,t+1}\tilde{n}_{i-1,t}, \quad i = 1, 2, \dots, h-1$$

$$\tilde{n}_{h,t+1} = \tilde{s}_{h,t+1}(\tilde{n}_{h-1,t} + \tilde{n}_{h,t})$$

The aggregate population model does not distinguish the rural from the urban population; hence the aggregate model does not show the rural–urban population transition. In the validation test, we also assume a fixed fertility rate in the aggregate population model. TFR = 1.50 is used, which is in line with both the rural and urban fertility rates used in the rural–urban population model. The mortality rate is assumed to change over the period 2000–2010 and is also estimated by using the Lee–Carter model based on the 2000 and 2010 population census data.