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Demographic age structure and economic development: Evidence from Chinese provinces

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ABSTRACT

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In this paper, we examine the economic implications of demographic age structure in the context of regional development in China. We extend the development accounting framework by incorporating age structure and apply it to a panel data set of 28 Chinese provinces. We find that changes in age structure, as reflected by shifts in both the size and internal demographic composition of the working-age population, are significantly correlated with provincial economic growth rates. During our study period 1990–2005, the evolution of age structure accounts for nearly one-fifth of the growth in GDP per capita, of which more than half is attributable to shifts in the internal demographic composition of the working-age population. Differences in age structure across provinces also explain more than one-eighth of the persistent inter-provincial income inequality. *Journal of Comparative Economics* **43** (1) (2015) 170–185. Center for Labor Economics and Public Policy and School of Public Affairs, Zhejiang University, China; Department of Economics, The Chinese University of Hong Kong, Hong Kong.

1. Introduction

The role of population demographics in economic development is one of the oldest themes in economics, dating back to Thomas Malthus's Essay on the Principle of Population (1798). Early demographic–economic literature highlights the role of population growth in economic development. On the theoretical front, there are contentious debates over the role of population growth in economic development.[1] On the empirical side, however, more often than not, research has failed to find a significant association between population growth and the pace of economic growth (e.g., Kelly, 1988; Temple, 1999). The lack of a conclusion in the early empirical literature is due in part to its exclusive focus on population growth and common neglect of the underlying demographic components of population dynamics, the critical dimension of which is changes in age structure. Since World War II, almost every country in the world has been undergoing a demographic transition from high to low rates of mortality and fertility (Lee, 2003). The radical changes in age structure accompanying this demographic transition can affect

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[1] Pessimists (e.g., Coale and Hoover, 1958; Forrester, 1971; Meadows et al., 1972) argue that rapid population growth hinders economic development as it exerts unsustainable pressure on capital accumulation, food production, natural resources, and the environment, whereas optimists (e.g., Boserup, 1965; Simon, 1981) see it as a stimulus to technological and institutional innovation that, accordingly, boosts rather than hinders economic growth.

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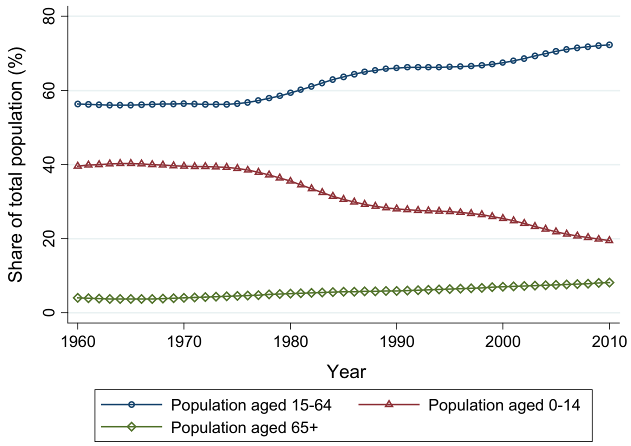

Fig. 1. Population share by age group, 1960–2010. *Source:* World Development Indicators 2012 (World Bank, 2012).

output per capita for several reasons. First, a per capita change in the number of working-age (15–64 years) individuals has an accounting effect on output per capita, as it translates output from per-worker into per-capita terms (Kelly and Schmidt, 2005). Second, as people's human capital, productivity, labor force participation, savings, and consumption are all inherently age-specific, changes in age structure can also affect output per capita through age-specific variations in productivity and behavior (Bloom et al., 2003). Third, the age structure of the workforce may have an effect on the upgrading of industry in an economy through its correlation with industry-specific human capital, and thus affect average worker productivity (Han and Suen, 2011).

Since the late 1990s, a body of empirical literature examining the connection between age structure and economic growth has emerged. One strand of this literature incorporates demographic variables into the convergence growth model (e.g. Barro, 1991; Barro and Sala-i-Martin, 2004) to assess the effects of demographic transition on economic growth. For example, Bloom and Williamson (1998) examine the connection between demographic transition and East Asia's economic miracle during the period 1965–1990 and find that the region's spectacular demographic transition – with the working-age population growing persistently faster than the overall population – can explain about one-third of its growth miracle.[2] The other strand of the literature examines the demographic–economic relationship under the accounting framework and highlights the influences of age structure on different determinants of productivity. For example, in a cross-country study adopting the accounting framework, Kögel (2005) finds the youth dependency ratio to have a negative effect on total factor productivity (TFP) and thus to be detrimental to economic growth.

However, despite the important role that age structure plays in the process of economic development, the majority of the empirical work has focused exclusively on the imbalanced growth between the dependent and working-age population or on changes in the dependency ratio, whereas the internal demographic composition of the working-age population has been relatively neglected. Lindh and Malmberg (1999), Feyrer (2007), and Gómez and Hernánadez de Cos (2008) are a few notable exceptions that give attention to the link between changes in the composition of the working-age population and economic growth.[3] Lindh and Malmberg (1999) examine the effects of age structure on economic growth in the OECD during the period 1950–1990 and find a positive correlation between the initial share of the upper middle-aged group (50–64 years) and the growth rate in the subsequent period.[4] Using a large panel of 87 countries, Feyrer (2007) also finds a strong and significant correlation between changes in workforce age structure and growth in worker productivity, with movement into the 40–49 age group from any other age group being associated with higher worker productivity. Unlike the detailed age group breakdowns used in the two earlier studies, Gómez and Hernánadez de Cos (2008) employ only two demographic variables to measure demographic maturity – the ratio of the working age to the total population and the ratio of the prime age (35–54 years) to the working age – and show that demographic maturation has contributed to nearly half of the evolution in global GDP per capita since 1960.

China's demographic transition over the past three decades has probably been the most pronounced in the world because of its distinct family planning policy (or the so called "One-Child Policy").[5] Fig. 1 illustrates the evolution in the country's proportion of youth (0–14 years), working-age (15–64 years), and elderly (65+ years) population from 1960 to 2010. After remaining stable for nearly two decades, the share of the working-age population began to rise steadily from 0.578 in 1978 to 0.728 in 2010, leading to a concomitant decline in the total dependency ratio,[6] which fell from 72.4 to the historic low of 38.2 over the

[2] See also Bloom et al. (2000), Bloom and Finlay (2009), and Macunovich (2012).

[3] More recently, researchers have extended the line of investigation to examine the effect of age structure on business cycle volatility. Jaimovich and Siu (2009) first connect age structure to the magnitude of the business cycle using a panel data of G7 countries and find a large proportion of youth workers to be associated with periods of greater cyclical volatility. He et al. (2011) and Lugauer (2012) present similar evidence using a panel of Chinese provinces and US states, respectively.

[4] Lindh and Malmberg (2009) extend the investigation to a longer time series from 1950 to 2004 and reconfirm the positive effects of the 50–64 age group.

[5] The total fertility rate in China decreased from 2.91 in 1978 to 1.60 in 2010 (World Bank, 2012).

[6] The total dependency ratio is defined as the number of dependent population younger than 15 or older than 64 per 100 working-age persons.

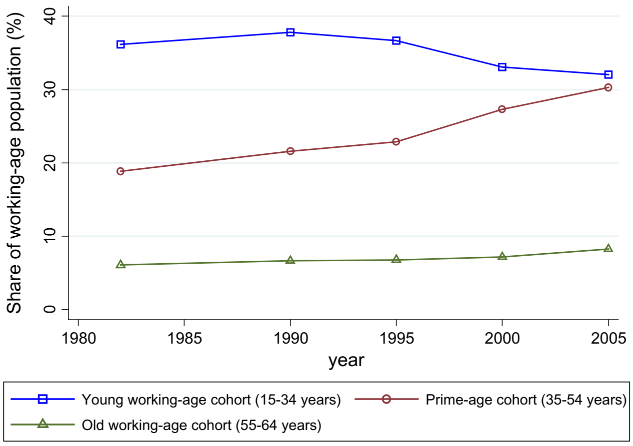

Fig. 2. Internal demographic composition of the working-age population, 1982–2005. *Source:* Authors' calculations using census (mini-census) microdata from 1982 to 2005.

same period. Several studies have paid attention to the connection between China's dramatic demographic transition and its concurrent growth miracle. For example, Li and Zhang (2007) investigate the causal relationship between birth rate and economic growth across provinces in China by exploiting differences in the enforcement of the One-Child Policy between *han* Chinese and ethnic minorities, and find that birth rate has a negative impact on economic growth. Cai and Wang (2005) incorporate the total dependency ratio into the convergence growth model to examine the demographic effect on China's provincial economic growth during the period 1982–2000, and find that the decline in the total dependency ratio contributes 2.3 percentage points, or more than one-quarter, to the observed 8.4% annualized per capita GDP growth rate during that period.[7] Wei and Hao (2010) also employ the convergence model to examine the effect of demographic transition on economic growth in China but distinguish between the effects in terms of the youth and elderly dependency ratios. They find that changes in age structure, particularly the large decline in the youth dependency ratio, account for about one-sixth of the provincial per capita GDP growth rate between 1989 and 2004.

However, changes in birth rate or dependency ratio may be insufficient to account for the effect of demographic transition on economic growth in China over the past three decades as shifts in the internal demographic composition of the working-age population, which are not reflected in either birth rate or dependency ratio, were also extraordinary during this period. Fig. 2 illustrates the evolution in the internal demographic composition of the working-age population from 1982 to 2005 based on data from three population censuses (1982, 1990, and 2000) and two mini-censuses (1995 and 2005)[8] – the only available sources that contain detailed information on the age distribution of the population. The demographic transition patterns of the working-age population are very similar to those of the overall population: the share of the young working-age cohort (15–34 years) saw a 13.8 percentage point decline over the period (from 0.592 in 1982 to 0.454 in 2005), accompanied by a 12.0 percentage point increase (from 0.309 to 0.429) in the share of the prime-age cohort (35–54 years) and a 1.8 percentage point increase (from 0.099 to 0.117) in the share of the old working-age cohort (55–64 years). This paper extends the investigation on the demographic–economic connection in the Chinese context by providing the first assessment of the role played by the internal demographic composition of the working-age population in economic development. In addition to taking a closer look at the demographic age structure, this paper also differs from prior work on the demographic–economic connection in China in several other important ways. First, we employ the development accounting framework (see, e.g., Klenow and Rodríguez-Clare, 1997; Hall and Jones, 1999) to examine the underlying mechanisms through which age structure can affect output per capita, and decompose the overall effect into those on capital-output ratio, average human capital, employment–population ratio, and TFP. Second, we allow the age structure of the workforce to be correlated with average human capital through age-specific variations in schooling and experience. Third, we use projected demographic variables – predicted using the lagged provincial age structure and the contemporaneous province-year-specific birth rates and province-age-specific survival rates – as instruments for the observed demographic variables to address the potential endogeneity that may arise from cross-province migration.

In this paper, we examine the impact of demographic age structure on economic development using a panel of Chinese provinces for the period 1990–2005.[9] We describe the age structure of a population using two key demographic variables – the number of working-age individuals per capita (hereafter the *working-age ratio*) and the prime-age cohort's share in the

[7] Using the national data for the same period (i.e., 1982–2000) but measuring the change in the demographic structure by the change in the ratio of effective consumers to producers, Wang and Mason (2008) also show that the change in the demographic structure contributes the equivalent of 1.3 percentage points, or about 15%, to the observed annual growth in GDP per capita.

[8] The 1995 and 2005 mini-censuses are based on the 1% population surveys.

[9] A number of previous studies have examined China's economic growth from perspectives other than demographics, including foreign direct investment (e.g., Ran et al., 2007; Yao and Wei, 2007), infrastructure (e.g., Démurger, 2001), human capital (e.g., Fleisher et al., 2010), fiscal decentralization (e.g., Zhang, 2006), and entrepreneurship (e.g., Li et al., 2012).

working-age population (hereafter the *prime-age share*) – to capture both the size and composition effects of the working-age population on output per capita. We find shifts in the internal demographic composition of the working-age population, which have been completely ignored in prior research in the Chinese context, to be at least as important as changes in the working-age ratio in affecting China's provincial economic growth. In our preferred fixed-effect estimation, a 1% increase in the size of the working-age population over the total population is associated with a 1.57% increase in output per capita, whereas a one-percentage-point shift in the working-age population from non-prime age to prime age is associated with a 1.43% increase in output per capita. The coefficients are robust to the inclusion of the share of the elderly in the dependent population to further account for the internal demographic composition of the dependent population (which is found to have a positive though insignificant effect on output per capita) as well as the use of projected demographic variables as instruments. Given these estimates, it can be concluded that the evolution of age structure contributes 1.68 percentage points, or more than 19%, to China's observed 8.80% annualized per capita GDP growth rate during the study period 1990–2005, of which more than half (or 0.97 percentage points) results from shifts in the internal demographic composition of the working-age population. We also find demographic factors to play a significant role in shaping China's inter-provincial income inequality, with inter-provincial differences in age structure accounting for more than one-eighth of the observed inter-provincial income inequality, regardless of the inequality index used. To further explore the channels through which age structure affects output, we conduct a decomposition analysis that breaks down the overall effect of age structure on output per capita into those on capital-output ratio, average human capital, employment–population ratio, and TFP. The decomposition results show that changes in age structure, particularly shifts in the internal demographic composition of the working-age population, appear to affect all four components, with the TFP channel being the most important driving force.

The remainder of the paper is organized as follows. Section 2 introduces our theoretical framework and empirical strategy. Section 3 illustrates the data and provides some summary statistics. Section 4 presents the main results for the effect of age structure on output per capita. Section 5 conducts a further decomposition analysis to explore the channels through which age structure affects output per capita, and Section 6 concludes.

2. Methodology

As mentioned, there are two empirical frameworks to examine the demographic–economic relationship: the *growth regression framework* (Barro, 1991) and the *development accounting framework* (Hall and Jones, 1999; Caselli, 2005; Hsieh and Klenow, 2010). In the former, the *initial* demographic structure is included as a factor determining the *growth* of output per capita (e.g., Lindh and Malmberg, 1999; Li and Zhang, 2007); in the latter, the *current* demographic structure is included as a determinant of the *level* of output per capita (e.g., Feyrer, 2007). In this paper, we examine the demographic–economic relationship under the development accounting framework, which has the advantage of allowing the further decomposition of the overall effect of demographics on output per capita into different channels (see Section 5 for a more detailed discussion of the decomposition).

The development accounting literature attempts to explain the differences in output levels across economies by their differences in factor quantities and the efficiency with which production factors are used (for surveys, see Caselli, 2005; Hsieh and Klenow, 2010). The central hypothesis of this paper is that demographic age structure is a kind of fundamental determinant of output per capita through both factor accumulation and efficiency.[10] There are a number of theoretical channels through which demographic age structure could affect the level of output per capita through factor accumulation/efficiency. For example, first, the life-cycle theory suggests that individual savings behavior varies across stages of his/her life because of the motivation for consumption smoothing over lifetime. The existence of an empirical relationship between savings rate and age has also been proved in the household savings literature.[11] Second, the employment–population ratio also reflects the age structure of the population: on the one hand, the working-age ratio has an accounting effect on output per capita; on the other hand, labor supply also varies considerably across age groups within the working-age population. Third, average human capital of the workforce is correlated with age structure as both schooling and experience exhibit age-specific variations.[12] Last, but not least, age structure can also affect the efficiency of the use of production factors through innovations and externalities. In fact, Kögel (2005) and Feyrer (2007) both demonstrate that TFP is the main channel through which age structure affect output per worker.

To quantify the demographic–economic relationship through both factor accumulation and efficiency implied by the development accounting framework, we adopt the following reduced-form model,

[10] The conceptual logic here is somewhat similar to Hall and Jones (1999), in which social infrastructure is deemed as a fundamental determinant of factor accumulation and efficiency.

[11] The household savings literature typically finds a hump-shaped age-savings profile in which the savings rate peaks in the middle aged population (e.g., Mason, 1988; Higgins and Williamson, 1997; Higgins, 1998; Lee et al., 2000). However, a recent paper by Ge et al. (2012) shows a U-shaped age-savings profile in China, where both younger and older households have higher savings rates than their middle-aged counterparts. Nonetheless, regardless of the pattern that the age-savings profile exhibits, the demographic age structure is always correlated with the aggregate savings rate.

[12] Since the seminal work of Barro (1991) and Mankiw et al. (1992), a large body of empirical research investigates the role of human capital in economic development by exploring cross-country data. In general, these studies have found human capital to have a positive effect on the output growth (for surveys, see, e.g., Krueger and Lindahl (2001) and Caselli (2005)). However, the underlying content of human capital in this literature focuses exclusively on the formal schooling of the workforce, ignoring years of experience. A notable exception is Bils and Klenow (2000), who incorporate both schooling and experience in calibrating human capital and quantifying its effect on growth.

$$\log y_{it} = D_{it}\beta + \mu_i + \tau_t + \varepsilon_{it}, \tag{1}$$

where y_{it} is the output per capita, D_{it} is a set of variables measuring age structure, μ_i is the unobserved time-invariant province-specific effect, τ_t is the unobserved time-specific effect common to all provinces, and ε_{it} is the idiosyncratic time-varying province-specific error term.

A practical challenge in the empirical estimation of the effect of age structure on output per capita is choosing appropriate demographic measures to characterize high-dimensional age structure. If a large number of age groups are used to characterize the age structure of a population, the strong collinearity across age groups may result in very poorly estimated age structure coefficients. To achieve precision in the coefficient estimates without losing too much information, it is desirable to characterize the age structure of a population using only a few key demographic variables. In the benchmark empirical specification of this paper, we adopt the strategy used by Gómez and Hernánadez de Cos (2008) and characterize the age structure of a population using only two key demographic measures: the *working-age ratio* and *prime-age share*. The former accounts for the (relative) size effect of the working-age population, whereas the latter captures the composition effect of the working-age population using a single indicator of its internal composition. With the choice of these two key demographic variables, Eq. (2) below becomes the benchmark empirical specification that we estimate in this paper:

$$\log y_{it} = \rho \log W_{it} + \theta P_{it} + \mu_i + \tau_t + \varepsilon_{it}, \tag{2}$$

where W_{it} is the working-age ratio in the total population and P_{it} is the prime-age share in the working-age population.

It is worth noting that different functional forms are used for W and P in Eq. (2), but there are good reasons for this. First, as noted in the introduction, working-age ratio (W) has an accounting effect on output per capita (y). This accounting effect alone would indicate unit elasticity of y to W, thus suggesting a double-log relationship between them, although the coefficient ρ may differ from unity if the effect of the relative size of the working-age population goes beyond the accounting channel. Second, a semi-log functional form, which implies a constant effect on output per capita of one-percentage-point substitution of prime age for non-prime age within the working-age population, is used for the relationship between y and P. In contrast, a double-log functional form would indicate the effect of such a substitution to depend inversely on the initial prime-age share.[13] As there is no *a priori* reason for such an inverse relationship between the effect size and the initial prime-age share, we adopt a semi-log functional form for P here, which is also favored by the Davidson and Mackinnon (1981) J test for model specification comparing the semi-log and double-log functional form between y and P.

While we only account for the size effect (through $\log W$) and the composition effect (through P) of the working-age population on output per capita in the benchmark specification in Eq. (2), one may also be concerned about the possible impact of the internal composition of the dependent population. For example, if the elderly could offer child care and household production and thus enable some working-age individuals to participate in the labor force or become more productive, they may contribute to the production indirectly relative to the youth. Therefore, for the same reasoning as the inclusion of the prime-age share in the working-age population to account for the internal composition of the working-age population in Eq. (2), we further include in some specifications the elderly share in the dependent population to account for the internal composition of the dependent population to investigate the possible heterogeneity in the impact of the youth and the elderly. Moreover, as an alternative specification to account for the composition effect of the working-age population, we further breakdown the non-prime working-age population into the young (15–34 years) and old working-age cohorts (55–64 years) and include their separate shares in the working-age population as robustness checks.

Depending on one's belief about the correlation between the unobserved time-invariant province-specific effect and the demographic age structure, μ_i in Eq. (2) can be treated as either a random effect or a fixed effect. However, there are at least two reasons for us to believe that such a correlation may exist. First, cross-province migration may depend on persistent provincial differences in the unobserved productivity, thus leading to endogenous shifts in the provincial age structure. Second, a province's age structure is in part shaped by the local enforcement of the One-Child Policy. To the extent that the intensity of the local population control enforcement is endogenous to the local economic development level, a correlation may arise between a province's age structure and its unobserved time-persistent determinants of output. Moreover, when Eq. (2) is estimated by both the random-effect and fixed-effect models, the Hausman test statistics always reject the exogeneity of the province fixed effects and favor the fixed-effect model. We therefore only report the fixed-effect estimations of Eq. (2).

While the inclusion of province fixed effects (μ_i) eliminates any correlation between age structure and provincial-level time-invariant determinants of output per capita, we should still be cautious about the consistency of the fixed-effect estimators as the temporal changes in the age structure of a province may be endogenous to the temporal changes in the unobserved time-varying, province-specific determinants of output per capita ε_{it}, i.e., $cov(\log W_{it}, \varepsilon_{it}|\mu_i) \neq 0$ and/or $cov(P_{it}, \varepsilon_{it}|\mu_i) \neq 0$. This may materialize from the pervasive cross-province migration that takes place in China. For example, a province with a positive (negative) productivity shock, i.e., $\varepsilon_{it} > 0$ ($\varepsilon_{it} < 0$), may experience a net inflow (outflow) of migrants. To the extent that the age structure of the migrants differs from that of the incumbent population, which is quite likely given that individual mobility varies across age groups, a net inflow (outflow) of migrants will shift the age structure of the current population in ways that are correlated with ε_{it}. We deal with this potential endogeneity using the instrumental

[13] Consider two shifts of the prime-age share, one from 0.40 to 0.41 and the other from 0.20 to 0.21. A semi-log functional form indicates equal effect on output per capita of the two changes, whereas a double-log functional form indicates that the effect of the former change is only one-half that of the latter.

Table 1
Variable definition and summary statistics.

Variables	Definitions	1990	1995	2000	2005	Δ1990–2005
A. Age-cohort ratio to total population						
0–14 years	Pop. aged 0–14/total pop.	0.242	0.266	0.227	0.193	−0.049
15–34 years	Pop. aged 15–34/total pop.	0.394	0.354	0.359	0.304	−0.090
35–54 years	Pop. aged 35–54/total pop.	0.224	0.243	0.275	0.325	0.101
55–64 years	Pop. aged 55–64/total pop.	0.068	0.073	0.070	0.090	0.022
65+ years	Pop. aged 65+/total pop.	0.072	0.064	0.069	0.088	0.016
B. Demographic variables						
Working-age ratio	Pop. aged 15–64/total pop.	0.686	0.670	0.704	0.719	0.033
Prime-age share	Pop. aged 35–54/pop. aged 15–64	0.326	0.361	0.402	0.451	0.126
Young working-age share	Pop. aged 15–34/pop. aged 15–64	0.575	0.530	0.494	0.423	−0.152
Old working-age share	Pop. aged 55–64/pop. aged 15–64	0.099	0.109	0.104	0.125	0.026
Elderly share	Pop. aged 65+/(pop. aged 0–14 + pop. aged 65+)	0.175	0.198	0.239	0.323	0.147
C. Economic variables						
Output per capita (in 1000 RMB)	Real gross regional product/total pop.	1.858	3.186	4.912	8.213	0.097#
Gini coefficient	–	0.269	0.295	0.291	0.301	0.032
Trade openness	(Export + import)/gross regional product	0.171	0.249	0.290	0.391	0.221
Road density	Road mileage/provincial area	0.015	0.028	0.054	0.095	0.080

Notes: Columns 1–4 report the means of each variable indicated by the row headings across the 28 provinces by census year, and column 5 reports the means of the change for each variable across the 28 provinces from 1990 to 2005, except for output per capita (#), for which the mean of annualized provincial growth rates are reported.

variables (IV) approach; that is, we construct and employ instruments that are correlated with the age structure of the current population but unrelated to the unobserved time-varying, province-specific determinants of output per capita. Our instruments are the projected age structure in the absence of migration, predicted using the lagged age structure, the contemporaneous province-year-specific birth rates, and the contemporaneous province-age-specific survival rates. The projected measures of age structure are likely to satisfy the two conditions for valid instruments. First, they reflect the age structure of the incumbent population, which are highly correlated with that of the current population by construction. Actually, these two measures differ only to the extent that the age structure of the migrants differs from that of the incumbent population. Second, the projection is conducted by applying the contemporary province-specific birth rates and province-age-specific survival rates to the lagged age structure. Given that the lagged age structure is predetermined and therefore should be orthogonal to the realization of ε_{it}, we also do not expect the projected age structure to have any relationship with ε_{it}.[14] Note that if the age structure of the current population is indeed endogenous to the time-varying, province-specific determinants of productivity, the fixed-effect IV estimation is preferred for its consistency; otherwise, the fixed-effect estimation would be preferred for the sake of efficiency. In the empirical analysis, we conduct the Hausman test for the hypothesis of the equality between the two estimations to guide our choice of the preferred estimation.

3. Data

Our data consists of a panel data set of the demographic and economic variables of 28 Chinese provinces[15] for four census (or mini-census) years: 1990, 1995, 2000, and 2005. The demographic variables are calculated using the microdata from the censuses, whereas the economic variables are obtained from the *China Compendium of Statistics 1949–2008* and various issues of *China Statistical Yearbooks* compiled by the National Bureau of Statistics of China.

Table 1 reports the summary statistics of the demographic and economic variables by census year. Panel A summarizes the means in the ratio of each of the five age cohorts (i.e., 0–14, 15–34, 35–54, 55–64, and 65+) to total population across the 28 provinces by census year. Shifts in the age structure in the population during our study period are characterized by declines in the ratios of the younger cohorts and rises in the ratios of the older cohorts. While the youth (0–14 years) and the young working-age cohort (15–34 years) saw declines in their ratios to total population of 0.049 (from 0.242 to 0.193) and 0.090 (from 0.394 to 0.304), respectively, the ratio of the prime-age cohort (35–54 years) to total population increased by 0.101, a more than 45% increase from its initial level of 0.224 in the base year. The ratios of the old working-age cohort (55–64 years) and the elderly (65+ years) to total population also increased, but much more modestly: 0.022 for the former and 0.016 for the latter.

Panel B reports the statistics of the five demographic variables we construct and employ in different specifications. First, the working-age ratio, defined as the ratio of the working-age to total population, is used to measure the size of the working-

[14] While some migrants could have been included in the calculation of the contemporary province-specific birth rate and province-age specific survival rates used in the projection, we believe that the impact of their inclusion on birth rates and survival rates, if any, would be ignorable.

[15] We dropped three provinces – Tibet, Hainan, and Chongqing – from our data set. Tibet's economic situation is very different from that of the other provinces in China. Hainan was combined with Guangdong and Chongqing was combined with Sichuan because Hainan and Chongqing were once part of Guangdong and Sichuan, respectively.

age population relative to total population. Second, the prime-age share, young working-age share, and old working-age share, defined as the respective proportional shares of the prime-age, young working-age, and old working-age cohorts in the working-age population, are utilized to measure the internal composition of the working-age population. Third, the elderly share, defined as the proportional share of the elderly in the dependent population (i.e., 0–14 years and 65+ years), is employed to measure the internal composition of the dependent population. Taking the two key demographic variables used in this paper, i.e., the working-age ratio and the prime-age share, as examples: while both measures increased during the study period, the rise in the prime-age share (from 0.326 to 0.451) is much more pronounced than that in the working-age ratio (from 0.686 to 0.719), thus giving changes in demographic age structure greater potential to affect economic development through shifts in the internal composition rather than the relative size the working-age population.

In Panel C, we summarize the economic variables used in our empirical analysis. The main dependent variable of interest, output per capita, is calculated by dividing the real gross regional product (GRP) – measured in 1990 constant prices – by the regional population. During the period 1990–2005, output per capita – averaged across provinces – more than quadrupled, increasing from RMB 1858 to RMB 8213. At the same time, the Gini coefficient also grew from 0.269 to 0.301, indicating a worsening of income disparities across provinces. We also report the statistics for trade openness and road density, which are used as control variables in some of our empirical specifications. During our study period, trade openness (the sum of imports and exports divided by GRP) more than doubled, rising from 0.171 to 0.391; and road density (measured as the ratio of total road mileage [in km] over provincial area [in km^2]) increased more than fivefold, from 0.015 to 0.095.

Before turning to the formal empirical analysis, we first present in Fig. 3 a visual illustration of the relationship between log output per capita and age structure employing the 112 province-year cells (28×4) in the data. Specifically, each panel of Fig. 3 plots the partial relationship between log output per capita and the ratio of an age cohort (denoted in the panel title) to total population implied in Eq. (1). The omitted default age cohort is 35–54 years. Taking Fig. 3A as an example, it plots the residual of log output per capita and the residual of the ratio of 0–14 years to total population after removing the province fixed effects, year fixed effects, as well as the effects of the ratios of other age cohorts (i.e., 15–34, 35–54, and 65+) to total population except for the omitted default age cohort of 35–54 years. Therefore, the slope of the fitted line in Fig. 3A reflects the relationship between log output per capita and the shift of the population from the 35–54 years to 0–14 years, holding constant the ratios of other age cohorts. The slope coefficients are negative in all four panels of Fig. 3, suggesting that the shift of the population from the 35–54 years to any other age cohort is detrimental to economic development.

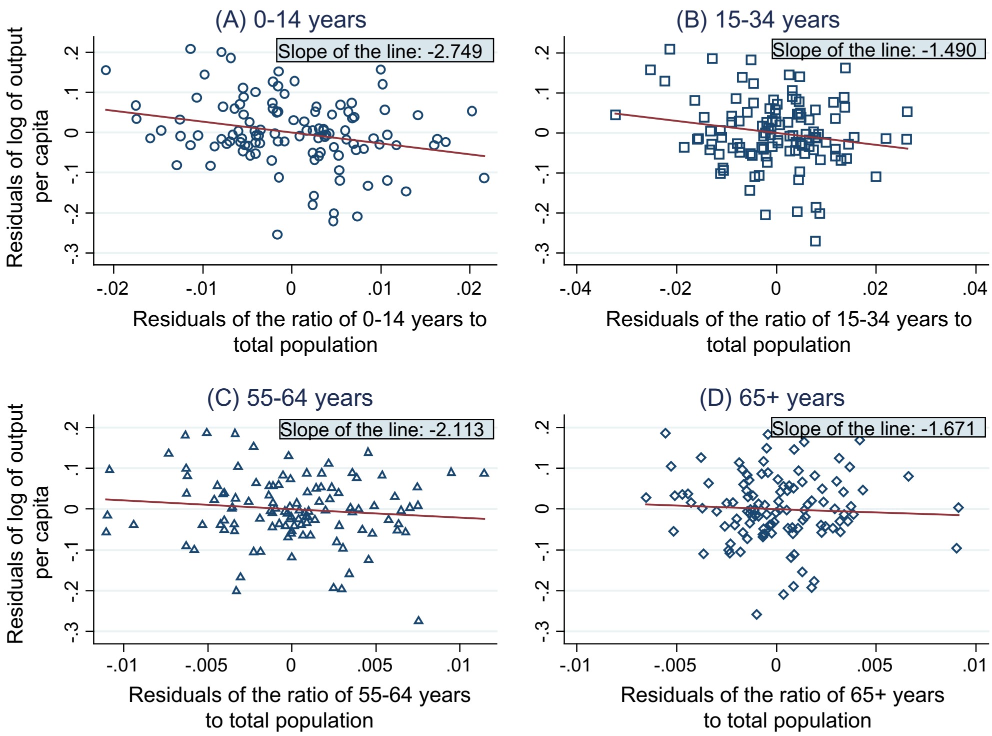

Fig. 3. Partial relationships between output per capita and ratios of different age cohorts to total population. *Notes:* Each panel plots the residual of log output per capita and the residual of the ratio of a particular age cohort (denoted in the panel title) to total population after removing the province fixed effects, year fixed effects, as well as the effects of the ratios of the other three age cohorts. The omitted age cohort is 35–54 years.

Table 2
Fixed effect estimates of the effects of age structure on output, 1990–2005.

	Dependent variable: log output per capita					
	(1)	(2)	(3)	(4)	(5)	(6)
Log(working-age ratio)	1.214**	1.572**	1.301**	1.073	1.444**	1.237*
	(0.527)	(0.495)	(0.494)	(0.637)	(0.648)	(0.667)
Prime-age share	1.071*	1.427**	1.242**	–	–	–
	(0.611)	(0.591)	(0.558)			
Young working-age share	–	–	–	−1.120*	-1.473**	−1.272**
				(0.634)	(0.606)	(0.552)
Old working-age share	–	–	–	−1.696	−1.994	−1.560
				(1.800)	(1.641)	(1.639)
Elderly share	–	–	0.664	–	–	0.647
			(0.625)			(0.626)
Control variables included	No	Yes	Yes	No	Yes	Yes
R-squared	0.649	0.862	0.869	0.642	0.859	0.868
N	112	112	112	112	112	112

Notes: All regressions include province and year fixed effects. Control variables include log trade openness and log road density. Standard errors clustered at the province level are reported in parentheses.
* Significant at the 10% level.
** Significant at the 5% level.

4. Empirical results

In this section, we empirically estimate the effects of demographic age structure on output per capita using a panel data set of 28 Chinese provinces for the period 1990–2005. We begin with the fixed effects estimation in Section 4.1. We then incorporate the IV approach into the fixed-effect model in Section 4.2 to address the potential endogeneity of temporal changes in provincial age structure. Based on our empirical estimates, in Section 4.3, we quantify the extent to which shifts in age structure contribute to China's economic growth and the extent to which inter-provincial differences in age structure account for provincial income inequality.

4.1. Fixed-effect estimation

Column 1 of Table 2 presents the fixed-effect estimate of our benchmark specification, Eq. (2), which includes only the two key demographic variables of interest (log working-age ratio and prime-age share), province fixed effects, and year fixed effects. The coefficients on both demographic variables are positive and highly significant, indicating that both the working-age ratio and prime-age share are positively associated with output per capita. In column 2, we further include trade openness and road density as control variables to examine whether estimates of the coefficients on the demographic variables are sensitive to their inclusion.[16] The results suggest that the coefficients on the demographic variables are robust to the inclusion of additional control variables. The point estimates of the demographic coefficients in column 2 indicate that a 1% increase in the working-age ratio can increase the per capita output level by 1.57%, whereas a one-percentage-point shift in the working-age population from non-prime age to prime age can lead to a 1.43% increase in output per capita. In column 3, we further include the share of the elderly in the dependent population to account for the possible impact of the internal composition of the dependent population. The coefficients on log working-age ratio (1.30) and prime-age share (1.24) decline slightly with the inclusion of the elderly share in the dependent population, but both remain significant. While the coefficient on the elderly share is positive in sign, consistent with the hypothesis that the elderly contribute to economic development relative to the youth, it is insignificant and the magnitude (0.664) is also much smaller compared with the coefficients on the two key demographic variables.

Columns 4–6 of Table 2 replicate the regressions in columns 1–3 with the further breakdown of the non-prime working-age population into the young and old working-age cohorts. Specifically, for each specification, we omit the prime-age share but control, separately, the share of the young working-age cohort (15–34 years) and the old working-age cohort (55–64 years) in the working-age population. The results are qualitatively the same as those from a simple division of the working-age population into prime and non-prime age groups. The coefficients on both the young and old working-age shares are of similar magnitude but of the opposite sign to the corresponding coefficients on the prime-age share in columns 1–3. The cost associated with the expansion of the dimension to characterize the internal composition of the working-age population is a loss in the precision of the demographic coefficients, especially for those on the old working-age share, which

[16] The effects of the inclusion of additional control variables are two folded: on the one hand, it can mitigate the potential bias in the demographic coefficients due to the *spurious* association between these control variables and age structure (if any); on the other hand, it would eliminate the effects of demographics on output working through the channels reflected in these control variables.

becomes insignificant. Nonetheless, we cannot reject the equality of the coefficients on the young and old working-age shares. We thus prefer the specifications in columns 1–3, which use only the prime-age share to measure the internal composition of the working-age population. The coefficients on other demographic variables, i.e., log working-age ratio and elderly share in the dependent population (when included), remain largely unchanged with the use of alternative measures of the internal composition of the working-age population.

4.2. Fixed-effect IV estimations

As discussed in Section 2, the inclusion of province fixed effects mitigates, but does not fully eliminate, concerns over the endogeneity of the demographic variables. The fixed-effect estimates may still be biased if changes in age structure are correlated with changes in the unobserved time-varying, provincial-level determinants of output per capita. Such correlations may arise, for example, if cross-province migration responds to time-varying, province-specific productivity shocks and leads to endogenous shifts in provincial age structure. In this subsection, we employ an IV approach to address such possible endogeneity in the fixed-effect model. Our instruments are the projected demographic variables, which are predicted using the lagged provincial age structure from the previous census, the contemporaneous province-year-specific birth rates between the two census years, and the contemporaneous province-age-specific survival rates between the two census years, assuming that there is no cross-province migration. Taking year 1990 as an example, the projected number of 25-year-olds in a province in that year is the product of the number of 17-year-olds in 1982 and the province-specific 8-year survival rate for 17-year-olds. The projected number of 5-year-olds is the product of the projected number of people in 1985, the province-specific birth rate in 1985, and the province-specific 5-year survival rate for newborns in 1985. Based on the projected number of people in each age year in a province in 1990, we can then use the projected age structure to construct the projected demographic measures as IVs for the observed demographic measures. However, in practice, the province-age-specific mortality rates (i.e., one minus the survival rates) are available only for census year 2000; for the other census years only national age-specific mortality rates are available. To overcome this data deficiency, we interpolate the province-age-specific mortality rates for the other census and inter-census years assuming that the age-specific mortality rates for all provinces decline at the same (exponential) rates as the corresponding national age-specific mortality rates. Appendix A provides further details of our province-age-specific mortality rate interpolations.

Table 3 reports our IV estimation results using the projected demographic measures as instruments for the observed demographic measures in the fixed-effect model. For every specification, the IV estimates of the demographic coefficients are similar to those obtained from the fixed-effect estimation in Table 2, and the Hausman test statistics cannot reject the null hypothesis of no difference between the fixed-effect and fixed-effect IV estimates. However, the employment of the IV approach in Table 3 always leads larger standard errors and sometimes even changes the estimates of the demographic coefficients from significant to insignificant. As our concerns over the endogeneity of the demographic variables in the fixed-effect model are not substantiated by the Hausman test statistics, we prefer the more precise fixed-effect

Table 3
Fixed-effect IV estimates of the effects of age structure on output, 1990–2005.

	Dependent variable: log output per capita					
	(1)	(2)	(3)	(4)	(5)	(6)
Log(working-age ratio)	1.073 (1.242)	1.735** (0.710)	1.301* (0.770)	0.740 (1.475)	1.466* (0.887)	1.109 (0.979)
Prime-age share	1.358 (0.860)	1.451* (0.761)	1.096* (0.606)	–	–	–
Young working-age share	–	–	–	−1.231 (0.799)	−1.352* (0.702)	−1.048* (0.586)
Old working-age share	–	–	–	−2.458 (1.845)	−2.246 (1.645)	−1.853 (1.614)
Elderly share	–	–	0.511 (0.684)	–	–	0.452 (0.714)
Control variables included	No	Yes	Yes	No	Yes	Yes
Hauman test statistics	0.49 (p = 0.99)	0.04 (p = 1.00)	1.20 (p = 0.99)	1.25 (p = 0.97)	0.89 (p = 0.99)	8.79 (p = 0.46)
N	112	112	112	112	112	112

Notes: All regressions include province and year fixed effects. Columns 1–3 instrument the log working-age ratio, the prime-age share in the working-age population, and the elderly share in the dependent population (when included) using their projected values, whereas columns 4–6 instrument the log working-age ratio, the young and old working-age shares in the working-age population, and the elderly share in the dependent population (when included) using their projected values. Control variables include log trade openness and log road density. Standard errors clustered at the province level are reported in parentheses. The Hausman test statistics report the F-test statistics and p-values of the Hausman test of the null hypothesis of equality between the fixed-effect and fixed-effect IV estimates.

* Significant at the 10% level.

** Significant at the 5% level.

estimates in Table 2. In Table A1, we also present the results of the first-stage regressions of the observed demographic measures on the projected demographic measures corresponding to the fixed-effect IV estimations in columns 3 and 6 of Table 3. Our instruments are found to have strong explanatory powers in the first-stage regressions: the coefficients on the relevant instruments are all significant at the 1% level and the first-stage *F*-statistics (adjusted for multiple endogenous variables) range from 14 to 354.

4.3. The roles of age structure in economic growth and provincial income inequality

All of the estimates discussed in Sections 4.1 and 4.2 show that age structure plays a significant role in output per capita. In this subsection, we consider the contribution of changes in age structure to China's economic growth and the link between inter-provincial differences in age structure and income inequality.

At the national level, China experienced remarkable changes in its age structure during our study period 1990–2005, featuring increases in both the working-age ratio (from 0.660 to 0.706) and prime-age share (from 0.327 to 0.429). Table 4 illustrates the contribution of temporal changes in age structure to the country's growth in GDP per capita based on the coefficients of our preferred fixed-effect estimation in column 2 of Table 2, i.e., 1.572 for $\log W$ and 1.427 for P. During the 1990–2005 period, changes in age structure contribute 1.68 percentage points, or 19.1%, to China's observed 8.80% annualized per capita GDP growth rate, of which 57.7% (or 0.97 percentage points) stems from shifts in the internal composition of the working-age population as reflected by the increase in the prime-age share. We also make several out-of-sample predictions concerning the contribution of the changes in age structure to economic growth in both the pre- and post-study periods. In the pre-study period 1982–1990, changes in age structure contribute 1.55 percentage points, or 19.6%, to the observed 7.9% annualized per capital GDP growth rate. Using the age structure predicted by the United Nations Population Division (2011), which assumes fertility to remain constant at the current level, we also estimate the effect of the predicted changes in age structure on China's per capita GDP growth for the 2005–2020 and 2020–2050 periods. Given the current fertility level, the working-age ratio and prime-age share will both remain at their 2005 levels in 2020 and decline thereafter. Consequently, the window for the demographic dividend will close in the period 2005–2020 and the country will eventually move into a period of demographic deficit. The estimate in the bottom row of Table 4 shows that the predicted changes in age structure will have a negative effect of 1.2 percentage point on annual per capita GDP growth between 2020 and 2050.

China's inter-provincial inequality has attracted considerable scholarly and general media attention.[17] In 2005, the country's richest province, Shanghai, reports per capita GRP (RMB 23,807) that is more than eight times greater than its poorest province, Guizhou (RMB 2612). Prior literature attributes such inter-provincial inequality to a number of factors, such as physical capital investment, human capital input, foreign direct investment, TFP, and coastal location (e.g., Tsui, 1993, 2007; Chen and Fleisher, 1996). Our results suggest that age structure may also play a significant role in such inequality. The startling income gap between Shanghai and Guizhou is in part attributable to Shanghai's more economically favorable age structure compared to Guizhou.[18] Had Guizhou's age structure been the same as Shanghai's in 2005, its per capita GRP would have been more than one-third higher, and the income ratio between the two provinces would have declined by over one-quarter, falling from 9.1 to 6.7. Following the prior literature on inequality decomposition (e.g., Shorrocks, 1982; Cancian and Reed, 1998), we use the extent to which an inequality index would fall if inter-provincial differences in age structure were eliminated to measure the effects of age structure on inter-provincial income inequality. Table 5 presents the results of a comparison between the observed and counterfactual levels of three inequality indexes – coefficient of variation, Gini coefficient, and Theil index – in 2005. The results in the bottom row of the table show inter-provincial differences in age structure to account for more than one-eighth of the observed inter-provincial income inequality, regardless of the inequality index used. For instance, the Gini coefficient of provincial per capita GRP would decline by 13.0% from 0.301 to 0.262 if all provinces had the same age structure as the national average.

5. Decomposition analysis

The foregoing estimations show that movements in age structure, as captured by changes in the working-age ratio and prime-age share, have significant effects on per capita output growth. In this section, we further explore the channels through which age structure can affect output. To do so, we begin with the following augmented neoclassical production function with constant returns to scale,

$$Y_{it} = K_{it}^{\alpha}(A_{it}H_{it})^{1-\alpha}, \quad \text{with } 0 < \alpha < 1, \tag{3}$$

where Y is the output level, K is the physical capital stock, A is the labor-augmenting TFP, H is the efficiency unit of labor employed in production, and subscripts i and t denote province and time, respectively. As illustrated in Appendix B, Eq. (3) can be transformed into per-capita terms to the following equation

[17] See Hao and Wei (2009) for an up-to-date and comprehensive discussion of the various measures of inter-provincial inequality in China.

[18] In 2005, Shanghai had a working-age ratio of 0.790 and a prime-age sharer of 0.444, whereas Guizhou had a working-age ratio of 0.635 and a prime-age share of 0.426.

Table 4
Contributions of age structure changes to growth, 1982–2050.

Period	(1) Period range (T)	(2) Starting prime-age share (P_0)	(3) Ending prime-age share (P_1)	(4) Starting working-age ratio (W_0)	(5) Ending working-age ratio (W_1)	(6) $\frac{\Delta P \times \hat{\theta} \times 100}{T}$	(7) $\frac{\Delta \log(W) \times \hat{\rho} \times 100}{T}$	(8) Predicted annualized growth rate (6) + (7)	(9) Actual annualized growth rate
Study period									
1990–2005	15	0.327	0.429	0.660	0.706	0.970	0.713	1.683	8.800
Pre-study period									
1982–1990	8	0.309	0.327	0.611	0.660	0.321	1.512	1.552	7.890
Post-study period									
2005–2020	15	0.429	0.429	0.706	0.707	−0.000	0.015	0.015	–
2020–2050	30	0.429	0.408	0.707	0.573	−0.100	−1.100	−1.200	–

Notes: $\hat{\rho} = 1.572$ and $\hat{\theta} = 1.427$, both obtained from the estimates in column 2 of Table 2. The prime-age share and working-age ratio in 2020 and 2050 come from the projections in *World Population Prospects* (United Nations Population Division, 2011), which assumes fertility to remain constant at the current level.

$$\frac{Y_{it}}{N_{it}} = \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{(1-\alpha)}} A_{it} \frac{H_{it}}{L_{it}} \frac{L_{it}}{N_{it}}, \tag{4}$$

where L is the number of workers and N is the population size. Let y_{it} denote output per capita (Y_{it}/N_{it}), k_{it} denote the capital-output ratio (K_{it}/Y_{it}),[19] h_{it} denote the number of efficiency units of labor per worker (H_{it}/L_{it}), and m_{it} denote the employment–population ratio (L_{it}/N_{it}). In turn, Eq. (4) can be written as

$$y_{it} = (k_{it})^{\frac{\alpha}{(1-\alpha)}} A_{it} h_{it} m_{it}. \tag{5}$$

Taking logarithms of both sides of Eq. (5), we obtain

$$\log y_{it} = \frac{\alpha}{1-\alpha} \log k_{it} + \log A_{it} + \log h_{it} + \log m_{it}. \tag{6}$$

Eq. (6) suggests that differences in output per capita must come from differences in the four channels indicated by its right-hand-side variables: capital-output ratio, TFP, average human capital, and employment–population ratio. As discussed in Section 2, all of these four channels are potentially affected by demographic age structure. Assuming that the empirical relationship between the demographic variables and output per capita in Eq. (2) applies to every channel, we follow Feyrer (2007) to decompose the overall output effect of age structure by separately regressing each right-hand-side variable in Eq. (6) on the demographic variables.

Performing such regressions requires data on estimates of physical capital stock, average human capital, and employment–population ratio. The employment–population ratio is calculated by dividing total employment in each province by its total population. Our time-series provincial capital stock data are drawn from Fleisher et al. (2010), who estimate China's annual provincial capital stock of the period 1981–2003 using the cumulative investment approach proposed by Holz (2006). We obtain their formula and extend the data coverage to 2005. For average human capital, we adopt a similar approach to that of Bils and Klenow (2000) and take into account the effects of both schooling and experience. Assuming that market wages fully reflect human capital, we calculate the average human capital of workers with schooling s and age a, h_{sa}, according to the most widely used version of the Mincer equation:

$$h_{sa} = e^{\rho s + r_1 * (a-s-6) - r_2 * (a-s-6)^2},$$

where $(a - s - 6)$ is the potential labor market experience, and ρ, r_1, and r_2 are the parameters of the Mincer equation estimated using microdata. Zhang et al. (2005) estimate the Mincer equation using Chinese Urban Household Survey data for the period 1988–2001 and find steady increases in returns to schooling over the period. We extend their analysis by estimating the same specification of the Mincer equation using 2005 Chinese Urban Household Survey data, and find the trend of rising returns to schooling to continue. Table A2 reports the estimates of Zhang et al. (2005) for 1990, 1995, and 2000 (columns 1–3), and our estimates for 2005 (column 4). Because of the noticeable changes in Mincer equation's coefficients over time, we allow the parameters (ρ, r_1, r_2) to vary across years during our study period and set them equal to the

[19] We use the capital-output ratio instead of the conventional capital per worker in the right-hand side of Eq. (4) because changes in the latter are more subject to productivity shocks (Hall and Jones, 1999; Feyrer, 2007). In addition, as Hall and Jones (1999) note, along a balanced growth path, capital-output ratio is proportional to savings rate. To see this, the evolution of capital per worker can be written as $\dot{k} = sy - (n + g + \delta)k$, where s is the savings rate, n is the growth rate of workers, g is the exogenous technology growth rate, and $\delta$is the depreciation rate. Thus, the capital-output ratio at the steady state can be written as $\frac{k^*}{y^*} = s/(n + g + \delta)$, which is proportional to the savings rate.

Table 5
Impact of age structure on provincial inequality in output per capita, 2005.

	Coefficient of variation	Gini coefficient	Theil index
(i) Actual per capita output inequality level	0.601	0.301	0.150
(ii) Counterfactual per capita output inequality level in the absence of provincial demographic differences	0.525	0.262	0.116
(iii) Impact of demographics on inequality [(i) – (ii)]/(i)	12.65%	12.96%	22.67%

Notes: The counterfactual inequality measures in row (ii) are calculated using counterfactual provincial output per capita assuming that all provinces have the same age structure as the national average. In particular, the counterfactual output per capita of province i, denoted as $\tilde{y}_1$, is calculated using the formula $\tilde{y}_1 = y_i * \exp[\hat{\theta}(\overline{P} - P_i) + \hat{\rho}(\ln \overline{W} - \ln W_i)]$, where y_i denotes the actual output per capita of province i, P_i is the actual prime-age share of province i, W_i is the actual working-age ratio of province i, $\overline{P}$ is the national average prime-age share, $\overline{W}$ is the national average working-age ratio, $\hat{\rho}$ and $\hat{\theta}$ equal to 1.572 and 1.427, respectively, both of which are obtained from the estimates in column 2 of Table 2.

corresponding coefficients in Table A2. With h_{sa} constructed for each schooling-age cell, we can then calculate the average human capital of the workforce according to the following formula:

$$h = \frac{\iint h_{sa} L_{sa} d_s d_a}{\iint L_{sa} d_s d_a}$$

where L_{sa} is the number of workers aged a years with s years of schooling. Finally, TFP can be calculated as a Solow residual of Eq. (6) by setting an appropriate capital share when data on employment–population ratio, capital-output ratio, and average human capital are available. Although a capital share of 1/3 is often used in cross-country studies, the prior literature on China suggests that capital makes a larger contribution to output in the Chinese context (e.g., Bai et al., 2006). Following this literature, we set α equal to 0.45. As robustness checks, we also calculate alternative estimates of the productivity residual with the capital share set to 1/3 and 1/2, respectively. However, the coefficients on the demographic variables in the TFP regression change little when alternative estimates of the productivity residuals are used.[20]

Table 6 presents the decomposition results. Column 1 replicates the estimates of our preferred empirical specification for output per capita in column 2 of Table 2. Columns 2–5 report separate regressions of each component of output per capita – i.e., TFP, capital-output ratio, average human capital, and employment–population ratio – on the working-age ratio, prime-age share, full set of control variables, and province and year fixed effects. Note that we can consider the magnitude of the coefficients on the demographic variables in each regression as indicators of the importance of the particular channel by which age structure affects output per capita. The coefficients on both demographic variables are of the greatest magnitude for the TFP regression, indicating that TFP is the most important force driving age structure's effect on output per capita. In the capital-output ratio regression, the coefficient on the prime-age share is negative and significant, which is consistent with the U-shaped age-savings profile of China's working-age households documented by Ge et al. (2012). Because human capital is calculated as a hump-shaped function of age, both the working-age ratio and prime-age share are, by construction, positively associated with the average human capital of the workforce, as reflected by their positive and statistically significant coefficients in the human capital regression. It is worth noting that the coefficient on the prime-age share is negative and significant in the employment–population ratio regression. This result is to a large extent attributable to the lower labor force participation rate for the upper prime-age cohort (45–54 years) relative to the young adults as illustrated in the age-profile of the labor force participation rates shown in Fig. A1.

6. Conclusion

China has achieved rapid and sustained economic growth over the past three decades with an annualized rate of more than 9%. The determinants of this remarkable growth have attracted considerable attention from academics, policy makers, and the general public. In this paper, we investigate China's spectacular economic growth from the perspective of changes in age structure. Exploring variations in the temporal changes in age structure across provinces for the period 1990–2005, we establish a strong connection between age structure and economic development. While prior research on the demographic–economic relationship in the Chinese context has focused exclusively on changes in the dependency ratios, our analysis shows that shifts in the internal demographic composition of the working-age population play at least an equally important role. During our study period 1990–2005, the remarkable changes seen in the country's age structure have accounted for more than 19% of the observed growth in GDP per capita, more than half of which is attributable to shifts in the internal composition of the working-age population. We also find demographic factors to play a significant role in shaping China's persistent inter-provincial income inequality and cross-province differences in age structure to explain more than one-eighth of the observed inter-provincial income disparity.

Looking forward, the window for the demographic dividend is closing for China, and the pronounced contribution of demographic changes to economic growth is likely to reverse in the near future owning to predicted declines in both the working-age ratio and prime-age share. While China just announced the amendment of its One-Child Policy to allow couples

[20] These regression results are available upon request.

Table 6
Decomposition analysis.

	Dependent variables				
	$\log(y)$	$\log(A)$	$\frac{\alpha}{1-\alpha}\log(K/Y)$	$\log(h)$	$\log(m)$
	(1)	(2)	(3)	(4)	(5)
Log(working-age ratio)	1.572***	1.280	−0.568	0.533***	0.224
	(0.495)	(0.783)	(0.643)	(0.107)	(0.262)
Prime-age share	1.427**	2.504**	−1.390	0.496***	−0.436*
	(0.591)	(0.957)	(0.871)	(0.138)	(0.246)
R^2	0.862	0.812	0.065	0.900	0.046
N	112	112	112	112	112

Notes: All regressions include log trade openness, log road density, province fixed effects, and year fixed effects. Standard errors clustered at the province level are reported in parentheses.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

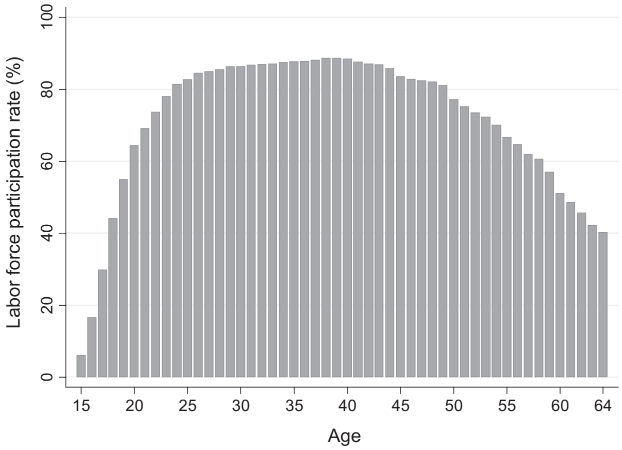

Fig. A1. Labor force participation rates of the working-age population, 2005. *Source:* Authors' calculation using microdata from mini-census 2005.

to have two children if one spouse is the only child, its transition toward the ageing society may still be more accelerated compared with other countries at a similar development level, which will result in extraordinary economic and welfare losses within a shortened transition period. Further relaxation of population control may need to be considered in order to improve the economic prospects of its future demographic age structure and smooth the transition into an ageing society.

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Appendix A. Estimation of province-age-specific mortality rates

Let M_t^c denote the national mortality rate of age cohort c in year t and $m_{i,t}^c$ the mortality rate of age cohort c at province i in year t. During our study period 1982–2005, M_t^c is available for every census year (i.e., $t = 1982$, 1990, 1995, 2000, and 2005), whereas $m_{i,t}^c$ is available for census year 2000 only. In this appendix, we present our procedures to estimate $m_{i,t}^c$ for $t \neq 2000$.

Assuming that $m_{i,t}^c$ of every province declines at the same rate as the corresponding national age-specific mortality rate, M_t^c, between any two census years, we can estimate $m_{i,t}^c$ for any census year other than 2000 as follows.

$$\hat{m}_{i,t}^c = \frac{M_t^c}{M_{2000}^c} * m_{i,2000}^c, \quad \text{for } t = 1982, 1990, 1995, \text{ and } 2005.$$

Next, we consider the estimation of $m^c_{i,t}$ for the inter-census years in our study period. Let $r^c_{T_k,T_{k+1}}$ denote the annualized national exponential rate of mortality decline for age cohort c between two adjacent census years T_k and T_{k+1}. Note that the national age-specific mortality rates of the adjacent census years, $M^c_{T_k}$ and $M^c_{T_{k+1}}$, both of which are available, can be linked by $r^c_{T_k,T_{k+1}}$ via the following relationship:

$$M^c_{T_{k+1}} = M^c_{T_k} * e^{-r^c_{T_k,T_{k+1}}(T_{k+1}-T_k)}$$

Thus, $r^c_{T_k,T_{k+1}}$ can be calculated as

$$r^c_{T_k,T_{k+1}} = \frac{\ln M^c_{T_k} - \ln M^c_{T_{k+1}}}{T_{k+1} - T_k}$$

Under the additional assumption that the national exponential rate of mortality decline for age cohort $c - r^c_{T_k,T_{k+1}}$ – applies to the same age cohort for all provinces for the inter-census years between T_k and T_{k+1}, we can then estimate the province-age-specific mortality rate for any inter-census year as

$$\hat{m}^c_{i,t} = \hat{m}^c_{i,T_k} * e^{-r^c_{T_k,T_{k+1}}(t-T_k)}, \quad \text{for } T_k < t < T_{k+1}$$

Appendix B. Derivation of Eq. (4) from Eq. (3)

Dividing both sides of Eq. (3) by Y^{α}_{it} yields

$$Y^{1-\alpha}_{it} = \left(\frac{K_{it}}{Y_{it}}\right)^{\alpha} (A_{it}H_{it})^{1-\alpha}, \tag{A1}$$

Further dividing both sides of Eq. (A1) by $N^{1-\alpha}_{it}$, where N_{it} denotes the population size, we get

$$\left(\frac{Y_{it}}{N_{it}}\right)^{1-\alpha} = \left(\frac{K_{it}}{Y_{it}}\right)^{\alpha} \left(A_{it}\frac{H_{it}}{N_{it}}\right)^{1-\alpha}, \tag{A2}$$

Taking root of Eq. (A2) yields

$$\frac{Y_{it}}{N_{it}} = \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{(1-\alpha)}} A_{it}\frac{H_{it}}{N_{it}}, \tag{A3}$$

Eq. (4) can be obtained by replacing $\frac{H_{it}}{N_{it}}$ with $\frac{H_{it}}{L_{it}}\frac{L_{it}}{N_{it}}$ (where L_{it} is the number of workers):

$$\frac{Y_{it}}{N_{it}} = \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{(1-\alpha)}} A_{it}\frac{H_{it}}{L_{it}}\frac{L_{it}}{N_{it}}. \tag{4}$$

Table A1
First-stage results of the fixed-effect IV estimations, 1990–2005.

	Dependent variables						
	Log working-age ratio (1)	Prime-wage share (2)	Elderly share (3)	log working-age ratio (4)	Young working-age share (5)	Old working-age share (6)	Elderly share (7)
Log(projected working-age ratio)	0.578***	0.120	0.077	0.479***	−0.228*	0.014	0.041
	(0.145)	(0.083)	(0.067)	(0.148)	(0.127)	(0.054)	(0.061)
Projected prime-age share	−0.202*	0.911***	−0.050	–	–	–	–
	(0.109)	(0.059)	(0.103)				
Projected elderly share	0.088	−0.258**	0.821***	0.081	0.303***	−0.052	0.818***
	(0.087)	(0.93)	(0.053)	(0.095)	(0.104)	(0.030)	(0.046)
Projected young working-age share	–	–	–	0.218*	0.950***	−0.024	0.056
				(0.118)	(0.110)	(0.046)	(0.098)
Projected old working-age share	–	–	–	−0.405	−0.680**	1.014***	−0.166
				(0.299)	(0.278)	(0.105)	(0.145)
First-stage F statistics	16.57	185.08	349.33	14.34	48.66	73.36	353.85
	($p < 0.01$)	($p < 0.01$)	($p < 0.01$)	($p < 0.01$)	($p < 0.01$)	($p < 0.01$)	($p < 0.01$)
R^2	0.792	0.964	0.982	0.809	0.961	0.895	0.982
N	112	112	112	112	112	112	112

Notes: Columns 1–3 correspond to column 3 of Table 3 and columns 4–7 correspond to column 6 of Table 3. All regressions include log trade openness, log road density, province fixed effects, and year fixed effects. The first-stage F statistics report the Angrist and Pischke (2009) first-stage F statistics of each first-stage regression taking into account the multiple endogenous variables. Standard errors clustered at the province level are reported in parentheses.
* Significant at the 10%.
** Significant at the 5% level.
*** Significant at the 1% level.

Table A2
Estimates of returns to schooling and experience, 1990–2005.

	Dependent variable: log annual earnings			
	1990 (1)	1995 (2)	2000 (3)	2005 (4)
Years of schooling	0.0468***	0.0672***	0.1008***	0.0929***
	(0.0019)	(0.0027)	(0.0035)	(0.0016)
Potential experience	0.0480***	0.0321***	0.0241***	0.0336***
	(0.0019)	(0.0026)	(0.0031)	(0.0015)
Potential experience squared	−0.0007***	−0.0004***	−0.0003***	−0.0005***
	(0.0000)	(0.0001)	(0.0001)	(0.0000)
N	6194	6830	6197	20191
R^2	0.4373	0.5169	0.4591	0.3733

Notes: Columns 1–3 are taken directly from the estimates in Appendix Table A1 of Zhang et al. (2005). Column 4 is the authors' estimates using 2005 Chinese Urban Household Survey. All regressions include sex and city dummies. Standard errors are reported in parentheses.
*** Significant at the 1% level.

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