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The Impact of Population Ageing on China's GDP-Per-Capita Growth - An Application of the Solow-Model[1]

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Abstract

China's economy has made remarkable achievements since the start of the reform and opening up policy in 1978. However, as the population ages and the size of the labour force declines, China's first demographic dividend is gradually disappearing. The demographic shift creates uncertainty about China's future economic growth and prosperity. This paper aims to quantify the impact of the ageing society on China's GDP-per-capita growth by applying an advanced Solow-model that includes quality and age of human capital as well. The model is tested by using the SYS GMM methodology for dynamic panel models with data from 1995 to 2020 on a provincial level.

It turns out that indeed the ageing population has a negative impact on China's GDP-per-capita growth. It can be shown that the relative decline of the age cohort between '40 to 49' has the strongest negative effect, which indicates the comparative high productivity of this age group.

Another interesting result is that an increase in education attainment – as a measurement of the quality of human capital - is either insignificant for GDP-per-capita growth or even have a slight negative effect if tested for the case that integrates different age groups. This result especially disaccord with the assumption of the so-called 'second demographic dividend' that predicts a positive correlation between the level of education and income through more savings in an overlapping generation model. We explain the surprising result with the phenomenon of 'overeducation' in China.

Finally, it turns out that the depreciation rate of capital is not negative correlated with GDP-per-capital growth as expected. This is possibly the result that in China very often new physical capital is used before the old one is fully written off. Hence, a higher depreciation rate goes hand in hand with the injection of new and better capital that increases productivity.

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1. Introduction

China is a population-rich country. Many researchers have shown that the rapid economic growth during the past 40 years largely depends on sufficient labour supply, the so-called first demographic dividend (Cai, 2010). The transfer of labour from agricultural to manufacturing in combination with the decrease of the dependency ratio – the relationship between the population with an age under 14 and over 65 to the potential workforce between 15 and 64 - contributed to around 26.4 percent of the economic growth (Wang D., Cai F., and Zhang X., 2004). However, China's One-Child Policy that started already in 1980 and was not relaxed until the year 2016, triggered a population shift in favour of the non-working part. The proportion of the working population reaching a high of 74.53 percent in 2010 but gradually decreased since then to 68.55 percent in the year 2020[2].

China has entered a society of an ageing population already since the 1990s when the birth rate started to decline. According to the seventh census in 2020, that shows the lowest population growth ever for China since the start of the reform policy in 1978, the proportion of people over 65 in China reached 13.5 percent, a figure that is higher than the world average (9.3 percent[3]) but still lower than for the average OECD economies (17.32 percent)[4]. Yet, the ageing process is furthermore accelerating. Compared with 2010 the share of people over 65 is up by 4.63 percent in contrast to a 2.72 percent increase over the previous 10 years. According to World Population Prospects published by United Nations[5], it is expected that from the year 2023 onwards China's population will shrink and surpassed by India as the world's most populous country.[6]

The economic consequences of an ageing society are well-known from a variety of advanced economies. Due to the shortage of labour, it challenges the growth rate of a country and simultaneously increases the financial burden for the social security system including pensions funds and health care. The current paper aims to analyse the impact of the demographic change on China's growth rate in terms of GDP-per-capita. To do so, we integrate in an advanced Solow model developed by Mankiw, Romer and Weil (1992) that includes the quality of human capital as well, the approaches from Hu (2012) and Feyrer (2007) that both recognise population age and age groups. Based on the designed model we then test the impact of population ageing in China disaggregated into four distinct age groups based on provincial data between 1995 to 2020.

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[2] All statistics in the paper, if not specifically stated, are retrieved from China's National Bureau of Statistics.
[3] United Nations – World Population Ageing 2020 Highlights. *https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd-2020_world_population_ageing_highlights.pdf*
[4] Data retrieved from OECD website. *https://data.oecd.org/pop/elderly-population.htm*
[5] *https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf*
[6] The just published China's Statistical Yearbook 2022 (https://www.chinayearbooks.com/china-statistical-yearbook-2022.html) shows that China's population grew only by 480,000 to overall 1.4126 billion in the year 2021, the smallest increase since 1962 and already 18.9 percent of the population were aged 60 and above.

The paper starts with a review of recent research on the topic followed by an analysis of the demographic development in China and concludes with the interpretation of the empirical results and an outlook with a focus of policy considerations.

2. Literature Review

2.1 General Research

Early research on the topic was based on theoretical models like the Overlapping Generation Model[7] or the Life-Cycle Hypothesis[8] and mainly focused on how population ageing indirectly affects economic growth by changing the savings rate, investment, and consumption behaviour.

The studies can be classified into three categories. Firstly, studies that show that population ageing has a positive impact on economic growth. According to Fougère and Mérette's (1999), who analysed the effects of the Overlapping Generation Model for seven industrialized nations, population ageing would promote economic growth by giving younger generations a greater opportunity to invest in human capital. Bloom et al. (2007) found that an increase in life expectancy led to an increase in savings rate which boosted economic growth. Fougère et al. (2009) conducted a dynamic Overlapping Generation Model to analyse the impact of population ageing on labour supply and human capital investment in Canada. Long-term population ageing increased opportunities for the younger generation and assisted the society by providing skilled labour which reduced the financial cost of ageing. Prettner (2013) investigated the impact of population ageing on the long-run economic growth by incorporating endogenous and semi-endogenous growth models and found out that the economic growth was positively affected by an increase in longevity and negatively affected by a decrease in fertility, with the positive longevity effect outweighing the negative fertility effect.

Secondly, studies that show that population ageing has a negative impact on economic growth. Many academics concur that increasing labour forces has a favourable impact on economic growth while a rise of the dependency ratio harms the economy (Lindh & Malmberg 1999; Eichengreen et al. 2011). Tabata (2005) investigated the impact of population ageing on long-term economic growth by an Overlapping Generation Model with endogenous growth and reported a negative result. Bloom and Finlay (2009) concentrated on the impact of the demographic transition on Asian economic growth based on a cross-country analysis. They argued that an increase in working-age share positively drove economic growth, thus a prediction on decrease of working-age population would depress economic performance. Choi

[7] The OLG model is a framework to study macroeconomic dynamics, economic growth, and the factors that caused fertility transition (Peter, 1965).

[8] The LCH describes people's savings and spending habits over their lifetime.

and Shin (2015) developed a computable Overlapping Generation Model which made human capital endogenous and investigated the influence of population ageing on economic growth. They claimed that intergenerational transfer of human capital had a significant impact on long-term economic growth and that the main barrier to economic growth was the decline in labour supply brought on by population ageing.

The third category contains research, which show an uncertain impact of population ageing on economic growth. Futagami and Nakajima (2001) developed a general equilibrium model of life cycle savings with endogenous growth. They concluded that demographic change had a variety of effects on the macroeconomy, some of which could cancel out others. It was difficult to determine whether population ageing had a negative impact on economic expansion. An and Jeon (2006) performed a cross-country regression and a non-parametric estimation with panel data from OECD countries between 1960 and 2000. The relationship between demographic changes and economic growth demonstrated an inverted-U shape which meant that with population ageing the output first increased then decreased.

2.2 China Research

In the early stage, Chinese scholars focused on qualitive analysis of the population ageing problem. Zeng (2001) analysed and forecasted the main features of population ageing in China: the proportions of elderly aged (65+) and oldest aged (80+) were predicted to rise sharply in the first half of the twenty-first century. Other features were large quantities, a high dependency ratio and significant geographical variances. Cai (2004) explained how the age structure characteristics brought on by demographic change fuelled economic development. Economic growth was influenced favourably by a low dependency ratio and an adequate labour supply.

Chinese scholars then researched with theoretical models and econometric methods. Ding and Knight (2009) examined China's exceptional economic growth using the Solow model, supplemented by human capital and structural changes, and discovered that the changes in the workforce's composition had an impact.

Some of them stated that population ageing was negatively related to economic growth. Liu (2008) created an econometric model, used several types of statistics yearbook data, and integrated factor analysis and regression analysis techniques to examine the real effects of population dependency ratio on economic growth. The study found that the population dependency ratio and economic growth were moving in opposite directions. Some scholars held the opposite opinions. Qi and Yan (2018) used panel data of 31 Chinese provinces from 2001 to 2015 to build a panel smooth transition regression model. The findings demonstrated a non-linear and significant threshold characteristic in the effect of population ageing on economic growth. The impact was positive based on the time series analysis. Other scholars found it hard to reach a clear conclusion. Wang and Gan (2017) examined the effects of population ageing on the regional economic growth of 31 provinces using panel data collected every five years starting from 1990 and a fixed effect model. They argued that while the growth rates of the labour population ratio, participation rate, the elderly population, and the elderly dependency ratio had positive effects on regional economic growth, the growth rates of the total population and the children's dependency ratio had a statistically significant negative impact on regional economic growth. It seemed to imply that the regional economic growth had not yet been negatively impacted by the current stage of China's population ageing. However, the adverse impact would take centre stage in the future.

In the theoretical studies of population ageing, Chinese scholars take the demographic change as a new factor into Solow’s endogenous growth model and in the Overlapping Generation Model to analyse the impact on economic growth like Hu et al. (2012). Theoretical analysis demonstrated that population increase and ageing both had detrimental effects on economic growth. Sun and Liu (2014) added demographic variables to the Solow Model with the help of provincial data from 1990 to 2008 in order to theoretically examine their effects on economic growth. The outcome showed that demographic shift contributed 15 percent to economic growth. But as China's population ages more rapidly, the country's future economic growth would be negatively impacted by demographic transition. The results of the study by Fang et al. (2014) indicated that during the past 30 years, population ageing, and the savings rate have been positively correlated with economic growth, but population growth rates have been adversely correlated. Wang (2014) ran a dynamic computable Overlapping Generation Model with endogenous labour supply and human capital investment decisions. In the short term, the decline in labour supply of young adults initially lowered productive capacity and exacerbated the financial costs of population ageing. Future middle-aged cohorts, however, will be more skilled and work longer hours, which will eventually increase the labour participation rate and increase productivity while reducing the cost of population ageing.

Chinese scholars studied how demographic changes affect economic growth in specific ways. Yang and Hou (2011) examined the macro and micro effects of population ageing on economic growth. They discovered that the ageing of the population hampered economic growth in the areas of labour supply, labour productivity, savings rate, and pension load.

Regarding to the first aspect of labour supply mentioned above, according to Wang et al. (2004), China had benefited from its demographic dividend since the middle of the 1960s and would continue to do so until 2015. They recommended taking immediate measures to reduce the shocks associated with population ageing, such as increasing employment. Using a calculable general equilibrium model, Peng (2006) investigated the macroeconomic effects of population ageing between the years 2000 and 2100. The simulation demonstrated that the main impact of population ageing was to decelerate economic growth through the contraction of the rate of physical capital formation and the negative growth of the labour supply. He highlighted that, despite population ageing, productivity development was the primary factor supporting China's economic growth over the 21st century. According to Wang (2007), China's population development has entered a phase of low fertility, and this slow growth will eventually result in a modest increase in the labour supply. The sustainability of Chinese economic growth would be largely dependent on how to accelerate the accumulation of both physical capital and human capital, how to significantly increase labour productivity, and how to alter the pattern of economic growth considering the country's rapidly ageing population and rising labour costs. The effects of population ageing on labour supply and economic growth in China were further studied by Zhu and Wei (2017). They presented a labour supply indicator based on a computable general equilibrium model that considered the variations in labour productivity across age groups and simulated several scenarios with varied labour supply assumptions. The findings indicated that China's total effective labour supply peaked in 2017 and then began to drop. Future economic development might be understated if it was assumed that the dynamics of the working-age population were the only factors affecting labour supply.

The second aspect is human capital. Some studies support the conclusion that population ageing will benefit human capital accumulation. From the perspective of the substitution effect of quantity and quality, Zhai (2013) examined how population ageing affects economic growth in the context of Chinese social development. Low fertility accelerated population ageing, although per capita spending on education and human capital were encouraged. The economy's development was governed by the two opposing driving forces, and China's population control measures have so far been successful in promoting economic progress. Zhang and Zhao (2018) investigated the effects of population age structure on the development of human capital as well as the link between these two factors and economic growth. The findings demonstrated that an increase of education human capital has a considerable impact on economic expansion. Population ageing would consume physical capital and human capital, which would be detrimental to the economy's long-term growth. Other scholars came to different conclusion. Zhao and Han (2015) used a dynamic panel data regression model to examine the effects of ageing on China's economic development and discovered that ageing phenomenon had a negative influence on human capital, working-age population growth, technological advancement, and GDP.

The third aspect is the saving rate. By using a multi-period Overlapping Generation Model, Wang and Ai (2015) investigated the effect of population ageing on savings rate and discovered that while population ageing had a positive impact on savings rate initially, the positive effects would be outweighed by the negative effects of population ageing over time. Using datasets from the China Family Panel Studies, Li and Luo (2018) examined the relationship between the age structure and savings rate of Chinese households. The findings showed that the proactive and preventative savings incurred by ageing population were more than the negative consequences noted by the Life Cycle Consumption Theory, indicating that ageing had a considerably favourable impact on families' savings rate. Other scholars agreed that population ageing hinders savings rate. Wang (2016) used a three-period Overlapping Generation Model including bilateral inter-generational transfer, parents' self-interest, and altruistic motivation, to study how population ageing and changes in family planning policy affect China's household savings, human capital investment, and economic growth. He discovered that population ageing had a detrimental impact on investments in human capital, economic growth, and savings.

There are other aspects affecting economic growth through population ageing. Based on panel data from 31 Chinese provinces and regions from 1997 to 2016, Lu and Wang (2019) analyzed the effect of population ageing on economic vitality and its mechanism of action. They argued that while population ageing had a good impact on economic vitality by modernizing the industrial structure, it had a negative impact on employment and inhibited technological innovation.

2.3 Summary of Current Research

Most of the research is aggregated on the national or cross-national level only. Few analyses investigate the condition in urban and rural regions. Moreover, most of the studies focused on the indirect effects of ageing on economic growth via labour supply, savings, consumption, human capital, and social security. When studying the direct impact of ageing on economic growth, however, many economic theories exclude the population ageing factor, resulting in disagreement in the selection of the variables. Finally, almost all the literature separate people of different age into three categories: young dependents (aged below 15), working-age population (aged at 15-65), and old dependents (aged over 65). This classification neglects the different impact of diverse age group, i.e., young workforce (aged at 15-29) versus elder workforce (aged at 50-60).

Based on these results, the current paper conducts additional research to provide more precise results on the impact of population ageing on economic GDP-per-capita growth in China.

3. Demographics and Economic Growth

Demographics is an important factor in a country's economic growth. Demographic changes profoundly affect social and economic development. China has entered an ageing population society since the turn of the century, and the pace of population ageing has been increasing in line with the gradual ageing of the population structure. Based on population-level statistics, this part analyses the dynamic relationship between demographic transition and economic growth, as well as the current condition and features of China's ageing population. We also discuss the demographic dividend which contributes to economic growth.

3.1 Current situation of China’s demography and economic growth

When it comes to measuring the ageing of a region's population, the consensus is that a country has an ageing population when 10 percent of its total population is 60 years or older, or 7 percent of its total population is 65 years or older. The first aspect of population ageing is an increase in the number of elderly people, and the second is an increase in the proportion of the elderly population to the total population.

Chinese demographics has experienced a huge change since 1970s. China’s total fertility rate has dropped sharply from a high rate of above 5 to only 1.66 in 1995 and stayed at the same level till now. On the economy’s side, China has grown rapidly in the past four decades and has become the world's second largest economy since 2010, and the largest measured in Purchasing-Power-Parity since 2013. The following figure 1 shows the development of GDP per capita in China that demonstrates the rise since the kick-off of the reform process, the strong acceleration at the end of the 1990s and the recent deacceleration. The dash line shows the nature log of GDP per capita, depicting a clear pattern of GDP development.

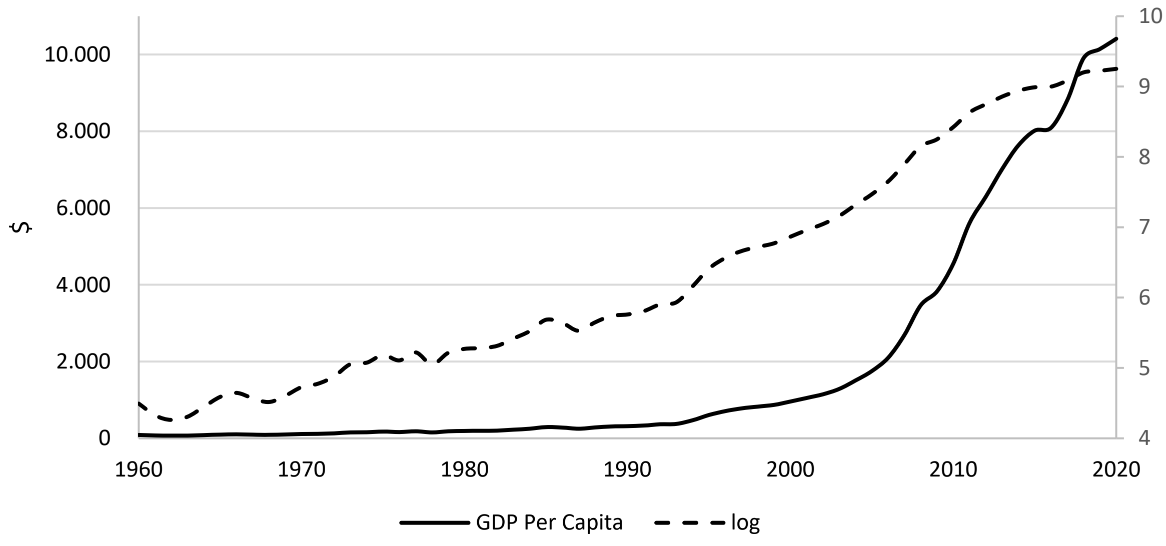

Figure 1: GDP per capita in China
Source: World Bank, World Development Indicators 2021

By exploring the reasons for this change, scholars generally agree that the demographic dividend has had a significant impact on economic growth. The process of demographic transition shows that China's population has been growing steadily and the total population number has continued to climb up to 1.412 billion people reported in the seventh census in 2020. Figure 2 exhibits the changes of population among three age groups over the seven censuses. The number of young populations has been declining year by year and almost halved since 1964, the second population census, while the number of people aged 15-64 in the labour force increasing, reaching the peak at 1.1 billion in 2013. Since then, there has been a year-on-year decline to 0.968 billion in 2020, representing 71.7 percent of the total population. The number of elder populations in 2020 reached 190.6 million, while the portion of people aged 65 and over grew at a rate of 1.39 percent from 1991 to 2000, 1.91 percent from 2000 to 2009, and 4.63 percent from 2010 to 2020, of which the data is calculated from the National Bureau of Statistics. The growth rate of the population of the elderly has accelerated, and the trend towards accelerated ageing appears to be irreversible in the short term.

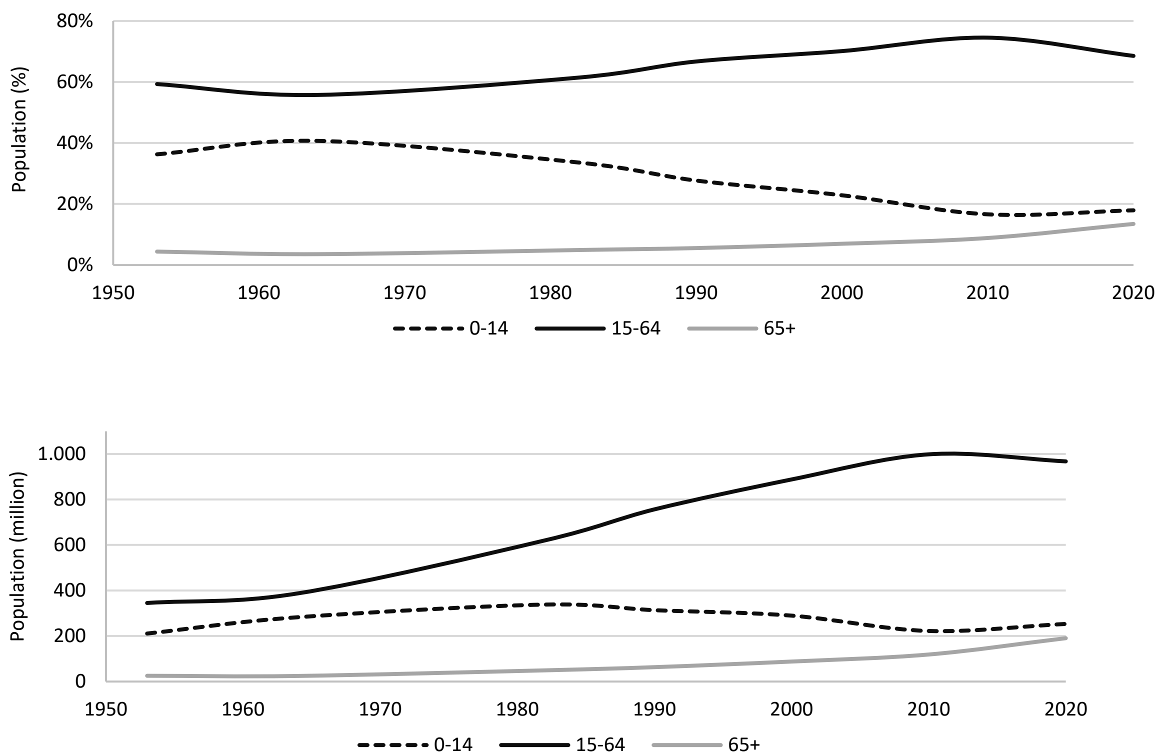

Figure 2: Population changes of three age groups
The figures show the percentage/absolute data of the population of three age groups from seven population censuses. ***Source:* National Bureau of Statistics, PRC National Population Census**

Figure 3: Population pyramids
Figure 3 shows the population pyramids of China's population age structure in percentage in 1990, 2000, 2010 and 2020.
Source: **National Bureau of Statistics, PRC National Population Census**

Figure 3 depicts the population pyramids of the last four censuses. The shape changed from a fat bottom, slim waist in 1990 to a slim bottom, fat waist in 2020. People over 65 account for 7.0 percent of the total population in 2000, while the number increased to 13.5 percent in 2020. On average, the number of people over 65 increased on 4.63 percent between 2010 to 2020.

Figure 4 illustrates the changes of dependency ratios over the seven censuses. Before 2010, the child-age dependency ratio had been decreasing since 1963. The elderly dependency ratio has been increasing year by year, and the total population dependency ratio has been decreasing first then increasing. Prior to 2010, the total population dependency ratio was generally decreasing because the decline in child-age dependency outweighed the increase in elderly-dependency. After 2010, the number of teenagers has increased in recent years because of the national "two-child policy", but the increase is not significant due to the rising cost of raising children. At the same time, as medical care advances, the life expectancy of Chinese people is increasing. The elderly dependency ratio accelerated, resulting in an overall increase in the total population dependency ratio. As a result, China's total population dependency ratio reached its lowest level in 2010, which means that China's demographic dividend is coming to an end, and the future demographic burden will be increasingly heavy.

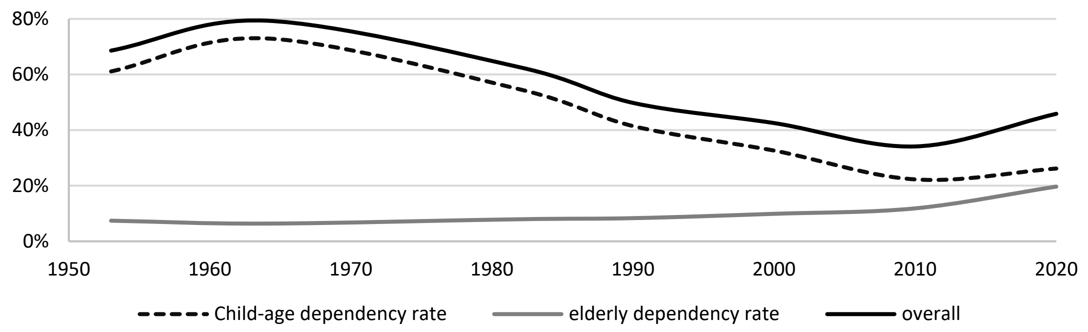

Figure 4: Dependency rate from the seven censuses
The figure shows child-age dependency rate, elderly dependency rate, and overall dependency rate from seven population censuses data. Child-age represents children aged from 0-14. Elderly represents people aged over 65.
Source: **National Bureau of Statistics, PRC National Population Census**

3.2 Characteristics of Chinese demography

Influenced by population policies and traditional concepts, Chinese demography presents some distinctive features. This section focuses on the characteristics of demography from various perspectives, such as large scale and rapid population ageing; unbalanced population ageing; and ageing before getting rich.

3.2.1 Large scale and fast pace

China currently accounts for approximately 20 percent of the world's population. It stepped into a population ageing society in 2000, when the proportion of the elderly people reached 7 percent of the total population (88 million). In 2020, the number of people aged 65 and over has risen to 191 million. Meanwhile, according to the World Population Prospects 2019, China's population of 65 and older will reach 366 million in 2050, with the population ageing rate increasing to 26 percent[9].

China's total population accounted for 22 percent of the world's total population in 1980, and the population aged 65 and over accounted for 18 percent of the world's total elderly population. In 2020, China's total population accounted for 18 percent of the global total, while its elderly population accounted for 24 percent of the global elderly total, which demonstrates that China's population is ageing faster than the global average.

The fertility rate and mortality rate are also strong evidence. The development of Chinese total fertility rate and the comparison to the world and other countries' average rates can be seen in Table 1 below.

[9] The population projections are based on the probabilistic projections of total fertility and life expectancy at birth, which are carried out with a Bayesian Hierarchical Model. The figures display the probabilistic median.

Table 1: Total fertility rate comparison

YEARS	WORLD	DEVELOPED COUNTRIES	LESS DEVELOPED COUNTRIES	ASIA	CHINA
1970-1975	4.47	2.16	5.41	5.06	4.85
1975-1980	3.86	1.92	4.58	4.10	3.01
1980-1985	3.59	1.84	4.16	3.69	2.52
1985-1990	3.44	1.81	3.90	3.50	2.73
1990-1995	3.01	1.67	3.34	2.90	1.83
1995-2000	2.78	1.57	3.04	2.61	1.62
2000-2005	2.65	1.58	2.87	2.45	1.61
2005-2010	2.58	1.68	2.75	2.33	1.62
2010-2015	2.52	1.67	2.66	2.21	1.64
2015-2020	2.47	1.64	2.59	2.15	1.69

Total fertility rate refers to the average number of children that would be born to a woman over her lifetime at the age-specific fertility rate for a given period of five years throughout her reproductive years.
Developed countries comprise Europe, Northern America, Australia, New Zealand, and Japan, while less developed countries comprise all regions of Africa, Asia (except Japan), Latin America and the Caribbean plus Melanesia, Micronesia, and Polynesia.
Source: **United Nations, World Population Prospects 2019**

Table 1 depicts that China had the highest fertility rate in 1972 among all other groups, while its fertility rate today is already below the world average as well as that of East Asia & Pacific countries. The decline in fertility was the most rapid in period 1970-1975.

The same pattern can be found in mortality rate, which attributes to improved healthcare system and innovations in medicines. Both declines in fertility and mortality rate lead to an improvement in life expectancy.

According to the report from United States Bureau of the Census, it took 115 years for the proportion of population aged 65 and over to increase from 7 percent to 14 percent in France, 85 years for Sweden, 75 years for the USA, 70 years for Australia, 45 years for the UK, and 38 years for Germany. From 2000 to 2020, the proportion in China increased from 6.96 percent to 13.5 percent. It takes only half the time of developed countries to reach this stage.

3.2.2 Unbalanced population ageing

Unbalanced population ageing primarily manifested by unbalanced regional population ageing, urban-rural inversion phenomenon, and gender differences.

China has entered a population ageing society since 2000. But of the 31 provinces, only 12 of them had a population ageing rate over 7 percent. Regions with population ageing rates above 8 percent were all in the East. From the latest census, the share of people aged 65 and over of the other 30 provinces are all over 7 percent except Tibet and that of 12 provinces are over

14 percent. Of the 12 provinces with the rates over 14 percent, 4 of them are in the East, 3 in the North-east, 3 in the Middle, and 2 in the West. From table 2, there are significant regional differences in the rate of ageing. Population ageing occurs earlier and faster in the eastern and northern provinces than in the central and western provinces. The accelerated development of population ageing will have profound socioeconomic consequences for the eastern region.

The unbalance is caused by the increase in life expectancy and immigration. With the development of the economy and the improvement of medical system, life expectancy in China reached 74.83 years in 2010 and 76.34 in 2015. The eastern and north-eastern region's population has an average life expectancy of 77.28 years, the central region is 75.02 years, and the western region is 72.18 years[10]. Figure 5 depicts the estimated life expectancy from the World Population Prospects 2019.

Table 2: Comparison of Age Composition in different regions

REGION	CITY	% OF POPULATION AGED 0-14			% OF POPULATION AGED 15-64			% OF POPULATION AGED 65+			TOTAL POPULATION (MILLION)		
		2020	2010	2000	2020	2010	2000	2020	2010	2000	2020	2010	2000
TOTAL	Grand Total	18.0	16.6	22.9	68.6	74.5	70.2	13.5	8.9	7.0	1412	1340	1266
EAST	Beijing	11.8	8.6	13.6	74.9	82.7	78.0	13.3	8.7	8.4	22	20	14
	Tianjin	13.5	9.8	16.8	71.8	81.7	74.9	14.8	8.5	8.3	14	13	10
	Hebei	20.2	16.8	22.8	65.9	74.9	70.3	13.9	8.2	6.9	75	72	67
	Shanghai	9.8	8.6	12.2	73.9	81.3	76.3	16.3	10.1	11.5	25	23	17
	Jiangsu	15.2	13.0	19.7	68.6	76.1	71.6	16.2	10.9	8.8	85	79	74
	Zhejiang	13.5	13.2	18.1	73.3	77.5	73.1	13.3	9.3	8.8	65	54	47
	Fujian	19.3	15.5	23.0	69.6	76.7	70.4	11.1	7.9	6.5	42	37	35
	Shandong	18.8	15.7	20.9	66.1	74.4	71.1	15.1	9.8	8.0	102	96	91
	Hainan	20.0	20.0	27.5	69.6	72.2	66.0	10.4	7.8	6.6	10	9	8
	Guangdong	18.9	16.9	24.2	72.6	76.4	69.8	8.6	6.8	6.1	126	104	86
	Total	17.1	14.7	20.9	69.9	76.4	71.4	13.0	8.8	7.7	564	506	449
NORTH-EAST	Heilongjian	10.3	12.0	18.9	74.1	79.7	75.7	15.6	8.3	5.4	32	38	37
	Liaoning	11.1	11.4	17.7	71.5	78.3	74.5	17.4	10.3	7.8	43	44	42
	Jilin	11.7	12.0	19.0	72.7	79.6	75.2	15.6	8.4	5.9	24	27	27
	Total	11.0	11.8	18.4	72.6	79.1	75.1	16.4	9.1	6.5	99	110	107
MIDDLE	Shanxi	16.4	17.1	25.8	70.7	75.3	68.0	12.9	7.6	6.2	35	36	33
	Anhui	19.2	18.0	25.5	65.8	71.8	67.0	15.0	10.2	7.5	61	60	60
	Jiangxi	22.0	21.9	26.0	66.2	70.5	67.9	11.9	7.6	6.1	45	45	41
	Henan	23.1	21.0	25.9	63.4	70.6	67.1	13.5	8.4	7.0[11]	99	94	93
	Hubei	16.3	13.9	22.9	69.1	77.0	70.8	14.6	9.1	6.3	58	57	60
	Hunan	19.5	17.6	22.2	65.7	72.6	70.5	14.8	9.8	7.3	66	66	64
	Total	19.9	18.5	24.6	66.1	72.7	68.5	13.9	8.9	6.8	365	357	351
WEST	Inner Mongolia	14.0	14.1	21.3	72.9	78.3	73.4	13.1	7.6	5.4	24	25	24
	Guangxi	23.6	21.7	26.2	64.2	69.1	66.6	12.2	9.2	7.1	50	46	45
	Chongqing	15.9	17.0	21.9	67.0	71.5	70.2	17.1	11.6	7.9	32	29	31
	Sichuan	16.1	17.0	22.7	67.0	72.1	69.9	16.9	11.0	7.5	84	80	83
	Guizhou	24.0	25.2	30.3	64.5	66.2	63.9	11.6	8.6	5.8	39	35	35
	Yunnan	19.6	20.7	26.0	69.7	71.6	68.0	10.8	7.6	6.0	47	46	43
	Tibet	24.5	24.4	31.2	69.8	70.5	64.3	5.7	5.1	4.5	4	3	3
	Shaanxi	17.3	14.7	25.0	69.3	76.8	69.1	13.3	8.5	5.9	40	37	36
	Gansu	19.4	18.2	27.0	68.0	73.6	68.0	12.6	8.2	5.0	25	26	26
	Qinghai	20.8	20.9	26.6	70.5	72.8	69.1	8.7	6.3	4.3	6	6	5
	Ningxia	20.4	21.5	28.4	70.0	72.1	67.2	9.6	6.4	4.5	7	6	6
	Xinjiang	22.5	20.8	27.3	69.8	73.0	68.2	7.8	6.2	4.5	26	22	19
	Total	19.2	18.9	25.1	67.7	72.1	68.5	13.1	9.0	6.4	383	360	355

The table shows changes in the proportion of the population of three age groups in all regions and city of China. We follow the classification in the report of the seventh census.
Source: **Major Figures on 2020 Population Census of China**

[10] Data pulled from the Sixth Population Census. No detailed relevant data in the Seventh Population Census

[11] The rate for Henan province is 6.96%

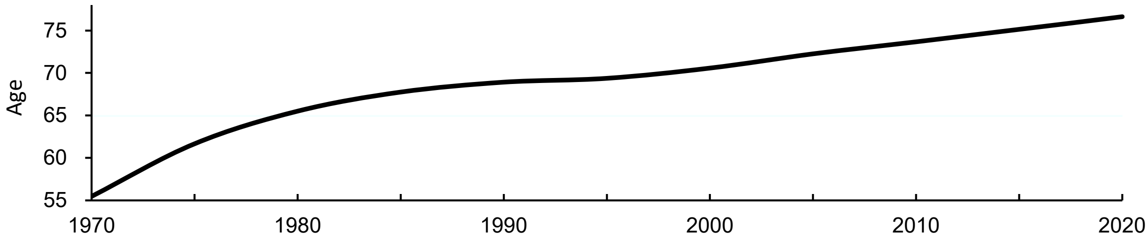

Figure 5: Life expectancy of Chinese people
This figure refers to the average number of years of life expected by a hypothetical cohort of individuals who would be subject during all their lives to the mortality rates of a given period.
Source: **United Nations, World Population Prospects 2019**

China's population ageing problem is not only characterized by regional imbalances, but also by more pronounced urban-rural imbalances. From Table 3, the economic gap between urban and rural China is gradually widening as society develops, and the rural labour force is gradually migrating to cities. Because children and the elderly are unable to work, as well as the higher level of consumption in cities, most rural families have children and the elderly left behind in rural areas. Furthermore, as rural medical care has improved, the rural population's life expectancy has gradually increased. When the aforementioned factors are considered, China's rural ageing is more severe than urban ageing, and the gap between urban and rural ageing is gradually widening.

Table 3: The comparison of ageing level between urban and rural areas

% OF POPULATION		2000 (%)	2010 (%)	2020 (%)
0-14	urban areas	18.43	16.87	17.24
	rural areas	25.49	19.16	19.27
15-64	urban areas	75.27	75.15	71.62
	rural areas	67.16	70.78	63.01
65+	urban areas	6.30	7.98	11.14
	rural areas	7.35	10.06	17.72

The table shows the proportion of different age groups of the total population between urban and rural areas in the latest three population censuses.
Source: **National Bureau of Statistics, PRC National Population Census**

3.2.3 Getting old before getting rich

There is a dynamic relationship between economic growth and population ageing. When the rate of population ageing exceeds the rate of economic development, the phenomenon is known as "ageing before getting rich" (Cai and Wang, 2006). China's demographic transition, achieved through a combination of socioeconomic development and one-child policy, is not a natural developmental process, especially with the latter effect dominating. As a result, China's population ageing differs greatly from that of other countries. That is, China has completed the demographic transition process and has ushered in population ageing prematurely at a still low level of economic development, causing problems not seen in other countries and posing unique policy challenges (see table 4).

Table 4: Comparison of GDP per capita of 4 countries with their ageing population rates

COUNTRY (USD P.C.)	POPULATION AGEING RATE (%)		
	7	10	14
CHINA	949	4,696	8,810
USA	950	7,010	27,813
JAPAN	1,967	11,335	38,555
FRANCE	200	1,135	13,236

When the population ageing rate reached 7 percent in China, GDP per capita is 949 USD, less than that of USA and Japan. We cannot compare the figure with France as it entered an ageing society about one hundred years ago. When the rate reached 14 percent in China, the per capita GDP was far less than that of developed countries in the table.
Source: **World Bank Database**

3.3 Demographic Dividend

Demographic dividend has had a significant impact on economic growth. It’s defined as the economic growth effect that comes with an increase in the labour force share of the total population, and a decrease in dependency rate.

The first demographic dividend is characterized by two main features, a sustained increase in the working-age population and a sustained decline in the dependency ratio. First, a sustained increase in the working-age population will provide an adequate supply of labour for economic growth. Second, according to the Life-Cycle hypothesis, when the dependency ratio decreases, consumption will decrease and savings will increase, which will also facilitate capital formation and thus provide an adequate supply of capital for economic growth.

The One-Child policy that began in 1980 led to a rapid reduction in China's total fertility rate in a short period of time that in short-run declined the dependency ratio because of the decreasing number of peopled people under 15 years but leads in the long-run to a rise of the ratio due to increase of people over 65 years. As a result, the absolute number of working-age people eventually decreased, and the first demographic dividend disappeared.

According to data above referring to the age structure, the number of working-age people aged 15-64 began to decline in 2010, while the population dependency ratio rose accordingly. It can be said that after 2010, the two main features of the first demographic dividend have gradually shifted in a direction that is not conducive to economic growth.

The historical demographic and economic development of other economies shows that during the latter period of the first demographic dividend, they did not suffer a precipitous economic decline or even regression because of paying off the previous demographic debt. This can be explained by the second demographic dividend proposed by Mason and Lee (2006).

They argue that when the first demographic dividend declines, although in the short to medium term the increase in the older population leads to an increased demographic burden and the decline in the birth rate leads to a reduction in the working age population. However, this age structure of the population will also imply a reduction in personal consumption and an increase in the propensity to savings, which in turn has a positive effect on economic growth and thus creates a second demographic dividend due to the model immanent assumption that all savings end up in additional investment.

Furthermore, a higher saving rate of the older generation increases potentially the education spending for the following generation, which in turn increases the quality of human capital that contributes to the second demographic dividend as well. The latter means that young people have a higher level of education than the older one, and the comprehensive quality of the younger generation at retirement will be significantly higher than that of the generation before. This fits with the increasing quality requirements for human capital as the economic development continues from a labour to more capital-intensive production.

4. Methodology

In the following section, the paper will provide a brief theorical background and empirical analysis of population ageing with and without the age structure.

4.1 Background

The Solow (1956) growth model is one of the most fundamental macroeconomic models (see also Solow, R. and Swan, T., 1956). The centre of the model is a typical neoclassical Cobb-Douglass production function with constant returns to scale and diminishing marginal returns. Capital, labour and productivity are the independent variables that determines the growth of GDP-per-capita. The steady state, i. e. the natural growth rate is reached, if capital intensity is constant, which requires proportional changes of capital and labour for any given propensity to save. An increase of the natural growth rate is exogenous to the model and only possible with technological progress, the so-called ‘residuum’ in Solow’s growth model empirically classified and tested as technological factor productivity.

Mankiw N.G., Romer, D., and Weil, D. (1992) improved the Solow growth model by including human capital in terms of quality as an additional variable to test the hypothesis that the lack of Foreign Direct Investments to developing economies is due to comparative lower quality of human capital, which in turn explains that there is no significant rise in GDP-per-capital in these countries in the long run. In principle, the integration of the quality of human capital into the Solow model, leads to an amplified impact of the saving rate on the steady-state and hence on the growth rate.

In this paper, we extend the model of Mankiw et al. by integrating distinct age groups as well. The so redesigned model predicts that the level of education attainment, the savings rate and the labour force participation rate have a positive impact on the growth rate of GDP-per- per capita, whereas the initial level of GDP-per-capita, the population growth rate, and the level of population ageing have a negative effect on the growth rate of GDP-per-capita.

4.2 Model of population ageing

The data for the model mainly consists of balanced panel data of 31 Chinese provinces from the China Statistical Yearbook which contain age structure, education level, and GDP from 1995 to 2020. Data about the savings rate are pulled from World Bank (2022). A special case is the city Chongqing that was part of Sichuan province until 1997 and is since then a separate municipality. For the years 1995 and 1996, we therefore used the data from the Sichuan provinces to estimate the respective data for Chongqing by allocating the population based on the proportion of Sichuan and Chongqing in 1997.

For the analysis we are using the following model to quantify the impact of population ageing on economic growth in China:

$$lny_{it} = a_0 + a_1 lny_{i,t-1} + a_2 lnpcgdp_{it} + a_3 lnpop_{it} + a_4 lnH_{it}$$
$$+a_5 lns_t + a_6 ln(\delta_t + n_{it}) + \varepsilon_{it} \quad (4.1)$$

In the model above, the dependent variable is economic growth. Since economic growth tends to exhibit significant lagged effects, we use five-years moving averages of output growth per capita to represent economic growth. $y_{i,t}$ means the economic growth in province i at time t. We also introduce a lagged variable $y_{i,t-1}$ to better simulate the real-time economic growth. The intercept a_0 is the regional fixed effect. a_1 shows how relevant the growth at time $t-1$ with time t. $pcgdp_{it}$ is the GDP per capita[12] in province i at time t.

$pop_{i,t}$ reflects the impact of age structure on economic growth, which includes the share of the working-age population in the total population that appears in the theoretical model $(1-u-v)$ and the dependency ratio of the aged people $\left(\frac{u}{1-u-v}\right)$. The former variable, the so-called labour force, is inversely related to population ageing; when the proportion of the young population remains constant, the proportion of the working-age population decreases as the population ages. Correspondently, the coefficient of $(1-u-v)$ is expected to be positive. Meanwhile, the dependency ratio is positively correlated with population ageing, and when the proportion of the young population remains constant, the dependency ratio rises as the population ages. Theoretically, the coefficient of $\left(\frac{u}{1-u-v}\right)$ should be negative. We will also

[12] We use 2015 as the base year for all GDP related data, 2015=100.

examine the productivity by dividing the population into different age groups as the more skilled middle-aged people are the main contributors to economic growth (Feyrer, 2007 & Wang, 2014).

H_{it} represents human capital. The previous literature contains a wide range of selection criteria. We follow most researchers by estimating the stock of human capital using a segmentation function of years of education per capita:

$$H = \frac{Primary \times 6 + Junior \times 9 + Senior \times 12 + Higher\ Education \times 16}{total\ number\ of\ people\ aged\ over\ 6}$$

s_t is the savings rate. $(\delta_t + n_{it})$ represents the sum of the depreciation ratio and the population growth rate. According to the past literature, the depreciation ratio ranges from 5 percent to 17 percent. We assume a constant of 10 percent in this paper following the methodology by Hu, et al. (2012). Table 5 exhibits the descriptive statistics of variables, which we are going to use in the regressions in the following chapters: 'pcgdp' is in terms of Renminbi and H is on yearly basis. The other variables are shown as a percentage.

Table 5: Descriptive statistics of variables

VARIABLE	OBS.	MEAN	STD. DEV.	MIN	MAX
y	806	8.94	4.20	-5.98	28.38
$pcgdp$	806	16,616	12,823	1,924	83,835
$1\text{-}u\text{-}v$	806	71.60	4.15	59.72	83.85
H	806	8.24	1.44	2.34	12.68
s	26	44.48	4.30	36.43	51.09
n	806	0.85	1.35	-7.6	9.1
p	26	73.12	3.09	68.25	78.02

4.3 Model of Workforce Age Structure

On the other side, population ageing is only one of China's demographic characteristics. Given the idea from Feyrer (2007), this part focuses on the age structure of the workforce, rather than the entire population, and concentrates on the direct effects of workers on economic growth.

All the data are extracted from the China Statistical Yearbook at the national level. With certain data process we get the age structure at the provincial level. Since we have the exact provincial data of the proportion of people aged under 15, 15-64, over 65, and the national data of the proportion of people aged under 15, 15-29, 30-39, 40-49, 50-64, over 65, we allocate the difference of national and provincial data of people under 15 and over 65 among other age groups with the assumption that the difference is evenly distributed.

Compared to the previous chapter, this chapter uses the proportion of the workforce by age groups as regressors and the overall dependency ratio as an additional control. The sum of all the proportions of different age groups equals to one and thus one group is excluded to avoid multicollinearity. To investigate the performance of each age group, we provide four regressions with each excluding one of the age groups. Based on Feyrer (2007), the economic growth is a function of changes in the workforce demographics, so we use the changes instead:

$$lny_{it} = a_0 + a_1 lnpcgdp_{it} + a_2 \Delta W1_{it} + a_3 \Delta W2_{it} + a_4 \Delta W3_{it} + a_5 \Delta W4_{it} + a_6 lnalldepen_{it} + a_7 lnH_{it} + a_8 lns_t + a_9 ln(\delta_t + n_{it}) + \varepsilon_{it} \quad (4.2)$$

The workforce is split into 4 age groups: $W1$ is for people aged from 16 to 29, $W2$ is for people aged from 30 to 39, $W3$ is for people aged from 40 to 49, and $W4$ is for people aged from 50 to 64. $alldepen_{it}$ is the overall dependency ratio for people aged under 15 and over 65. Here we split the age structure into these 4 age groups rather than in five-year groups since fewer groups would increase the likelihood of significance in the results.

5. Results and Discussion

5.1 Model Estimates on Population ageing

In equation (4.1), the independent variable of GDP-per-capita growth with one period lag is included in the explanatory variables. In this case, it arises the endogeneity problem in the model certainly. Since endogeneity is one of the most common sources of skewed parameter estimations, instrumental variables (IVs) should be used to overcome explanatory variable endogeneity. It is critical to select the suitable instrumental variables in order to obtain consistent parameter estimations. Choosing instrumental variables should meet two criteria: first, it should be exogenous, which means, it should be determined by factors other than the model system as a whole; and second, it should be significantly correlated with the proxy variables.

Arellano and Bond (1991) introduced the first difference generalized method of moments (FD GMM) estimate approach to address the endogeneity problem in dynamic panel models induced by lagged explained factors as explanatory variables. The main idea is to employ the level quantities of the lagged explanatory and explained variables as instrumental variables for the corresponding variables in the difference equation after first order differentiation of the variables in equation (4.1). However, this method also has drawbacks that after differencing, the explanatory variable becomes almost a random walk variable, and the lagged term as an instrumental variable is prone to the problem of weak instrumental variables due to insufficient transmission of future information.

Arellano and Bover (1995), Blundell and Bond (1998) suggested an alternative and more effective method, the system generalized moments estimate method (SYS GMM), to tackle the problem of weak instrumental variables. On the one hand, this estimation method eliminates fixed effects by using the first difference method and the lagged level term of the explanatory variables as the difference term's instrumental variables; on the other hand, it overcomes the explanatory variables' weak instrumental variables by increasing the number of instrumental variables by introducing moment constraints in the horizontal equation. Under small sample conditions, the system GMM approach's estimation results are more effective than the first difference GMM approach because it uses a combination of level and differential variation information. The results of the system GMM method are mostly used in the study of our paper study. The findings of mixed ordinary least squares (OLS), fixed effects (FE), and first difference GMM approach for panel data are also shown as a control. The empirical results are presented in Table 6.

The validity test values of the instrumental variables are listed in the last three rows of Table 6. There are two main categories of validity test for the instrumental variables in system GMM method: The first is the Arellano-Bond test for autoregressive (AR), which is used to see if the residual term $\varepsilon_{i,t}$ in differential regression and level regression is serially correlated. Second, the Sargan test, also known as the over-identification constraint test for instrumental variables, is used to determine whether the moment-conditional instrumental variables employed in the estimate process are generally valid. The original hypothesis (H_0) in the Arellano-Bond test for AR is that there is no serial correlation, and the residual terms can have first differential serial correlation but not second differential serial correlation, while H_0 in the Sargan test is that the instrumental variables are valid. The AR (2) and Sargan test values for both the first difference GMM estimation and the system GMM estimation are above 0.01, indicating that the instrumental variables employed in this paper are valid, according to the test results.

We choose two alternative variables to represent the population ageing variable $lnpop_{it}$, column (1) to (4) are calculated with the dependency ratio $lndepend$, while column (5) to (8) are calculated using the proportion of the working age population $ln(1\text{-}u\text{-}v)$. As have been shown in Table 6, the system GMM estimation performs most effective among all four methods with the best significance of the variables, e.g., the working age population is insignificant until implemented in system GMM model. In column (3) and (4), we dropped the variable output per capita in our regressions since it will reduce the significance of other variables. The reason behind could be the multicollinearity between the output per capita and the lagged GDP growth rate per capita.

The parameter estimates in Table 6 are generally consistent with the previous theoretical analysis. In column (4), the coefficient of the dependency ratio is negative and can pass the statistical significance test under the 5 percent confidential level, which means it has a negative influence on the GDP growth per capita. Since the population ageing is positively correlated to the dependency ratio when the share of child population remains constant, it also proves the negative effect of population ageing on per capita GDP. Meanwhile, in column (8), where working population is our explanatory variable for population ageing, it has a positive coefficient and pass the statistical significance test under 10 percent confidential level. This result supports the hypothesis, that population ageing will drive GDP growth per capita down.

One surprising observation from the table is the insignificant coefficient of educational attainment. Human capital investment is expected as a driver of economic growth and not the other way around. Normally, a positive correlation is consistent with the usual economic intuition since many scholars' studies have proven the importance of human capital investment in long-term economic success. Increasing human capital investment during the initial stages of population ageing can help to mitigate its impact through making individual labour more efficient and is used as a key strategy for dealing with population ageing in the future.

The reason of the insignificant coefficient of educational attainment in both regressions may be contributed to the so-called overeducation phenomenon, i. e. that more education does not transform in higher payments that increased GDP-per-capital at least not in China. Over the past two decades, China’s higher education sector has grown by 10 times and the graduate labor market has been under increasing strain in recent years due to the continues supply of new graduates, which has exceeded 7 million annually, according to a Ministry of Education report from 2019. As a result, the supply of qualified labour still exceeds the respective demand even with the high growth rate of China’s economy.[13] Moreover, due to the declining growth rate in recent years youth unemployment has reached 20 percent today most of them are graduates from universities (Zhang, Ziyu 2022).

Zheng et al. (2021) investigated the issue of overeducation in China over the previous two decades and created a method employing textual analysis based on the most recent information obtained directly from a significant recruiting platform in China. They discovered that over 50 percent of Chinese internet job candidates have two or more years of excess education, equivalent to a 5.1 percent lower than expected salary.

Besides the educational attainment, another interest finding is the variable $ln(\delta+n)$. According to the common understand in the relevant literature as well in the model used in this paper, the sum of the depreciation rate and the population growth should negatively affect the economic growth. But our finding shows the opposite direction, i. e. depreciation has a positive effect on GDP-per-capita growth. This implies a high level of technological iteration by replacing old machines which are not used until the end of their life with new more advanced machines. As

[13] A detailed explanation for the case of China’s banking industry can be found in Funke, Li, Löchel (2016).

shorter the use of the existing capital, as higher the depreciation rate and as sooner new and better technology that increases productivity is used is used.

Despite of these two variables, the estimates of the other explanatory variables are substantially compatible with the theoretical derivations:

Firstly, the savings rate has a strong beneficial impact on economic growth and meets the 1 percent significance test in most circumstances. Demographic shifts can also explain some of the fluctuations in China's savings rate during the reform, as savings rise when a person's labour output exceeds consumption and fall when he or she stops working and becomes a pure consumer in old age. When the proportion of working-age people grows and the society turns to population ageing, the propensity to save will increase to ensure the future life after retirement. Secondly, the coefficients of GDP per capita in the previous period are negative and pass the 1 percent significance test in our estimates. When all other factors are equal, the lagging regions' economic growth rate is higher than the developed regions', resulting in a "catch-up" situation, suggesting that China's regional economic development meets the "conditional convergence" predicted by neoclassical economics. In fact, in China, a trend toward shrinking the per capita GDP difference between regions began in 2004, and by 2010, the coefficient of variation of per capita GDP between regions had declined to 0.56 and is estimated to fall to 0.40 by 2020.

As mentioned above, we are interested in whether the positive coefficients of $ln(\delta+n)$ are contributed to the inappropriate assumption on the depreciation rate of 10 percent. The 10 percent depreciation rate has been chosen at a moderate level since it does not have a uniform standard. In order to obtain a robust regression result and to keep the arbitrary behavior of depreciation rate from affecting the main model's parameter estimates, we run the regression again and research the influence of population ageing on China's economic growth under both low (8 percent) and high (15 percent) depreciation rates.

Table 6: Empirical results of population ageing on GDP growth

	OLS (1)	FE (2)	FD GMM (3)	SYS GMM (4)	OLS (5)	FE (6)	FD GMM (7)	SYS GMM (8)
lny L1.			0.3067	0.4636			0.2175	0.3597
			(0.1029)***	(0.0808)***			(0.0992)**	(0.0831)***
lnpcgdp	-0.0347	-0.0576			-0.0354	-0.4763	-0.0352	-0.0216
	(0.0036)***	(0.0062)***			(0.0034)***	(0.0051)***	(0.0058)***	(0.0036)***
lndepend	0.0095	0.0201	-0.0253	-0.0136				
	(0.0067)	(0.0094)**	(0.0124)***	(0.0062)**				
ln(1-u-v)					0.0880	0.0511	0.0549	0.0688
					(0.0332)***	(0.0427)	(0.0618)	(0.0402)*
lnH	0.0102	0.0504	-0.1071	-0.0378	0.0009	0.0245	-0.0047	-0.0047
	(0.0123)	(0.2380)**	(0.0253)***	(0.0152)**	(0.0145)	(0.0255)	(0.0223)	(0.007)
lns	0.1862	0.2389	0.1414	0.0683	0.1798	0.2201	0.1746	0.1090
	(0.0145)***	(0.1579)***	(0.0305)***	(0.0235)***	(0.0154)	(0.0178)***	(0.0341)***	(0.0321)**
ln(delta+n)	0.0444	0.1262	0.0127	0.0155	0.0344	0.0114	0.0101	0.0329
	(0.0091)***	(0.0095)	(0.0127)	(0.0142)	(0.0090)***	(0.0095)	(0.0102)	(0.0132)**
constant	4.1617	4.1430		2.3313	3.8837	4.0086		2.4307
	(0.0533)***	(0.0526)***		(0.3526)***	(0.1225)***	(0.1488)***		(0.3680)***
F-Test		0.000				0.000		
Obs.	806	806	744	775	806	806	744	775
R-Square	0.2453	0.2064			0.2446	0.2196		
Abond test for AR(1)			0.020	0.000			0.003	0.010
Abond test for AR(2)			0.824	0.515			0.566	0.882
Sargan test			1.000	1.000			1.000	1.000

Table 6 exhibits the empirical result based on four different estimations. All figures in the parentheses are standard errors. *, **, *** represent to reject the null hypothesis under the 10%, 5%, 1% confidential level. *lny L1.* is the GDP growth lagged in one year.

In Table 6, column (1) and (2) refer to the model with a depreciation rate of 8 percent while column (3) and (4) use a rate of 15 percent. Here we choose 8 percent as the lower bound to make sure the sum of population growth and deprecation rate to be positive. Given that the estimation results for the OLS, FE and first difference the GMM models are reported in Table 8, the robustness tests in this part focus on regression using system GMM approach, which is the most effective. Table 7 presents the estimation findings, with the diagnostic test values for the validity of the instrumental variables listed in the last three rows. Both the AR (2) and Sargan test values have a concomitant probability above 0.05, indicating that the instrumental variables are valid.

Table 7: Robustness test of population ageing on GDP growth

	(1)	(2)	(3)	(4)
lny L1.	0.4636	0.3597	0.4626	0.3577
	(0.0800)***	(0.0820)***	(0.0809)***	(0.0845)***
lnpcgdp		-0.0211		-0.0218
		(0.0035)***		(0.0037)***
lndepend	-0.0143		-0.0133	
	(0.0062)**		(0.0062)**	
ln(1-u-v)		0.0757		0.0685
		(0.0403)*		(0.0389)*
lnH	-0.0375	-0.0068	-0.0381	-0.0037
	(0.0147)**	(0.0064)	(0.0154)**	(0.0068)
lns	0.0679	0.1077	0.0681	0.1089
	(0.0235)***	(0.0300)***	(0.0235)***	(0.0319)***
ln(delta+n)	0.0085	0.0178	0.0286	0.0579
	(0.0092)	(0.0101)*	(0.0251)	(0.0235)**
constant	2.3524	2.4456	2.2945	2.3598
	(0.3504)***	(0.3608)***	(0.3513)***	(0.3643)***
Obs.	775	775	775	775
Abond test for AR (1)	0.020	0.001	0.000	0.010
Abond test for AR (2)	0.531	0.936	0.510	0.857
Sargan test	1.000	1.000	1.000	1.000

Table 7 exhibits the robustness test result based on system GMM. All figures in the parentheses are standard errors. *, **, *** represent to reject the null hypothesis under the 10%, 5%, 1% confidential level. *lny L1.* is the GDP growth lagged in one year.

When different capital depreciation rates are chosen, the estimations in Table 7 reveal that the impact of the dependency ratio on economic growth remains negative and both corresponding coefficients pass the significance test at the 5 percent level. The impact of the working-age population on economic growth is also still beneficial in the significance level of 10 percent.

The other variables in Table 7 are broadly in line with the theoretical model's derivation. For example, the coefficient of per capita GDP in previous period is still negative while the one of savings is positive, and they pass the significance test of 1 percent in both scenarios. However, the quality of human capital measured in years of overall education still negatively affects the GDP growth per capita, with only the level of significance is influenced in some way.

Overall, the coefficient estimates in Table 7 are generally consistent with those in Table 6, with minor differences in the significant levels for a few variables. The results of the robustness test confirm that China's long-term economic growth potential will be harmed by population ageing and the foreseeable slowdown in population growth will to some extent worsen the negative effects of an ageing population on China's economic growth.

5.2 Model Estimates on Workforce Age Structure

Column (1) in table 8 describes the results of estimating the model for economic growth with people of age 16 to 29 excluded. Both negative and positive coefficients for different age groups appear in column (1), (2) and (4) with different significant level, leading to ambiguous interpretations. What all the columns have in common is that the coefficients of age group 2 are all significantly negative, whereas those of age group 3 are all significantly positive, implying that people in their 40s ageing to 50s will lead to an increase in economic growth. Furthermore, as people reach their fifties, economic growth slows significantly.

All coefficients of different age groups in column 3 are significantly negative, indicating that a larger excluded group, where people aged from 40 to 49, is associated with a higher output. A five percent decrease in age group 1 (16-29) leads to a 2 percent increase in economic growth, which means that 5 percent people aged 16 to 29 growing up to the next age group stimulating the economy to increase by 2 percent. Similarly, a five percent decrease in age group 2 (30-39) leads to a 6.5 percent increase in economic growth, which means that 5 percent people aged 30 to 39 ageing to the next age group supporting the economy to increase by 6.5 percent, far more than the jump from age group 1 to age group 2. But differences among the age groups are very large. In column 1, 2, and 3, the coefficients of age group 3, people aged from 40 to 49, are all significantly positively, which means that a decrease in the population of this age group will lead to a decrease in economic growth.

Table 8: The impact of different age groups on economic growth

	(1)	(2)	(3)	(4)
lnpcgdp	-0.0368	-0.0368	-0.0368	-0.0368
	(0.0061)***	(0.0061)***	(0.0061)***	(0.0061)***
Δ age 16-29		0.6652	-0.4723	0.1373
		(0.2808)	(0.2559)*	(0.1332)
Δ age 30-39	-0.6652		-1.1375	-0.5279
	(0.2808)**		(0.3582)***	(0.2526)*
Δ age 40-49	0.4723	1.1375		0.6096
	(0.2559)*	(0.3582)***		(0.3251)*
Δ age 50-64	-0.1373	0.5279	-0.6096	
	(0.1332)	(0.2526)	(0.3250)*	
lnalldepen	0.0066	0.0066	0.0066	0.0066
	(0.0127)	(0.0127)	(0.0127)	(0.0127)
lnh	0.0192	0.0192	0.0192	0.0192
	(0.0272)	(0.0272)	(0.0272)	(0.0272)
lns	0.1615	0.1615	0.1615	0.1615
	(0.0303)***	(0.0303)***	(0.0303)***	(0.0303)***
lndeltan	0.0163	0.0163	0.0163	0.0163
	(0.0097)*	(0.0097)*	(0.0097)*	(0.0097)*
constant	4.3227	4.3227	4.3227	4.3227
	(0.1134)***	(0.1134)***	(0.1134)***	(0.1134)***

Table 8 shows the regression results with each excluding one age group. All figures in the parentheses are standard errors. *, **, *** represent to reject the null hypothesis under the 10%, 5%, 1% confidential level.

Figure 6 exhibits the change of proportions of the three age groups over the last 25 years. The number of people in age group 2 (aged from 30-39) starts to decrease since 2002 and shifts to age group 3, which is one of the intrinsic reasons for the increasing economic growth before 2007. Since 2012, the number of people in age group 3 (aged 40-49) has been decreasing and there is an overall upward trend in the number of people older than 50 years old.

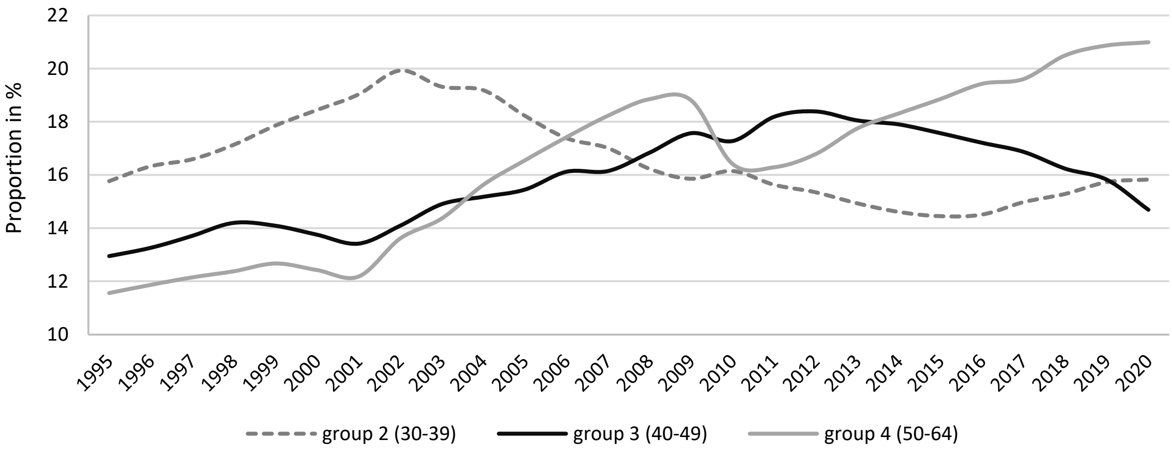

Figure 6: Changes of 3 age groups over 25 years
The figure shows the changes of proportion of the 3 age groups over the last 25 years. It's the proportion over the workforce age group rather than the whole population
Source: **National Bureau of Statistics, PRC National Population Census**

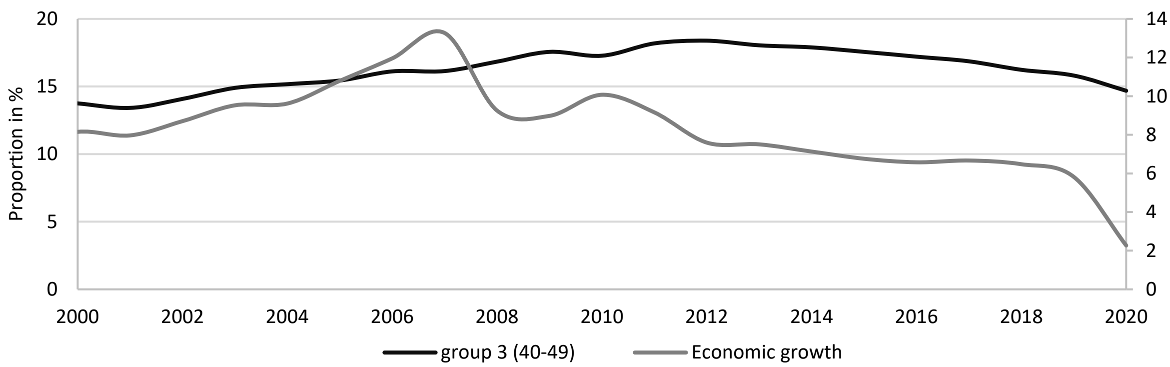

Figure 7: Changes of age group 3 versus economic growth
The figure shows the relationship between age group 3 and economic growth over the last 20 years. The axis on the left is the proportion of the people aged 40 to 49 over the workforce population. The axis on the right shows the natural log of economic growth in percent. We use fixed currency for economic growth (2015=100).
Source: **National Bureau of Statistics, PRC National Population Census**

Figure 7 depicts the relationship between economic growth and the proportion of people aged from 40 to 49. There is a clear positive correlation between the two excluding the global financial crisis and the pandemic periods.

We can conclude from the figure above that people aged from 40-49 are the main contributors to China's GDP growth per capita. People in this age are at their career peak. They are more productive and experienced than the younger cohorts while more energetic than the older ones. From the perspective of age structure, while the number of people aged from 40 to 49 decreases and the dependency ratio goes up, China's economic outlook is not optimistic.

5.3 Demographic Changes and General Government Expenditure

The acceleration of population ageing is the main trend of China's demographic evolution in recent years. The total dependency ratio in 2020 was 44.8 percent and in 2040 it will exceed 60 percent (Ciuriak, 2022). The dependency burden will have a profound impact on China's economic and social development, with the visible changes at three levels: labour supply, consumption, and public welfare, all of which are related to government finance.

A portion of the government's revenue comes from personal income tax, and as people age, more people leave the labour market. This portion of tax revenue shrinks accordingly. The growing number of elderly people has increased public welfare expenditures such as social security expenditure and health expenditure, putting the government under increasing financial burden, with debt financing becoming the government's primary means of bridging the fiscal gap.

In the past 20 years, the overall growth of government health expenditure was higher than GDP growth. In 2000, the expenditure was 71 billion Renminbi and in 2014 it exceeded 1 trillion ¥[14]. In 2020 health spending already increased to 2.2 trillion ¥.[15]

The National Standards for Basic Public Services (2021 version) provides two aspects of "care for the elderly". One is the provision of elderly assistance services, and the other is the provision of pension insurance services. The latter is aimed at eligible retirees, which has no direct relation with government financial support. The former, however, is concerned with health management and welfare for the elderly, both of which involve health condition assessments and allowance for those aged over 65. This part of expenditure must come from general public expenditure.

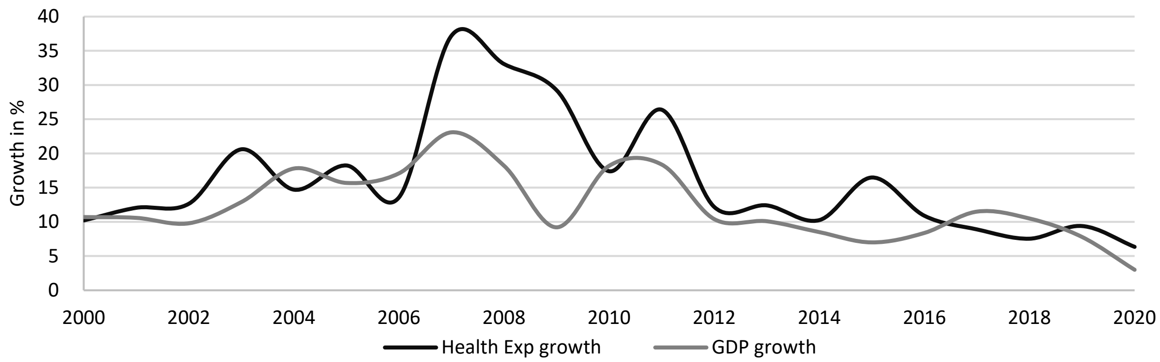

Figure 8: The growth of health expenditure and GDP
The figure shows the comparison of GDP growth and health expenditure growth over the last 20 month. We use current currency for both lines.
Source: **Yearbook of Health in the PRC**

As a result, as the population ages, more resources will be directed toward elderly assistance services. In addition to the increasing pressure on public expenditure in healthcare and social security, the potential impact on the expenditure in elderly care industry cannot be overlooked. There is a significant difference in the level of old-age security services between urban and rural areas. At present, there are far fewer institutions for the elderly, and even fewer in rural areas. The cost of providing the same elderly services to the rural elderly is higher than that of the urban elderly. The higher costs require additional public expenditure to cover. The potential impact from the additional costs should be noticed.

5.4 The Three-Child Policy and the Pandemic

Two critical demographic events occurred in May 2021. The National Bureau of Statistics released the seventh population census. According to the census, China has the lowest fertility rate in its history, with a total fertility rate of 1.3. As a reaction China's government decided that

[14] 2020 Yearbook of Health in the People's Republic of China, Page 93. http://www.nhc.gov.cn/mohwsbwstjxxzx/tjtjnj/202112/dcd39654d66c4e6abf4d7b1389becd01.shtml
[15] 2021 Statistical Bulletin on the Development of Health Care. http://www.gov.cn/xinwen/2022-07/12/content_5700670.htm

each household could have three children China after the switch to the Two-Child policy took already place in the year 2016. But it is hard to imagine that the new policy will result in a significant higher fertility rate at least not in the short run. One factor for this the outbreak of the pandemic and the ongoing strict Covid-19 policy. However, more important in the long run is the insufficient income of most of Chinese households to raise more than one child accompanied with the lack of a proper infrastructure (Olcott, 2022). Implementing a three-child policy is no longer just about promoting fertility; it also aims to improve family welfare, promote personal development, advance gender equality, and reduce work-family conflict.

Nevertheless, the sudden outbreak of Covid-19 not only affects human mortality levels and life expectancy, but also has a significant impact on fertility. Zhang and Li et al. (2021) conducted research based on the data from National Health Commission of the PRC and concluded that the pandemic's suppressive impact on marriage is comprehensive and widespread, resulting in a 45 percent decline in the number of registered marriage couples in the first quarter of 2020 and a sharp decline in the number of births in the fourth quarter of 2020. This fits with the long-term trend, that the average age of Chinese women at their first marriage has continually increased in the past (Chen, 2021).

6. Concluding Remarks

In this paper we explore the impact of the demographic development on China's GDP-per-capita growth by using an advanced version of the Solow model that integrates the quality of human capital and distinct age groups as independent variables as well. The model implies in line with the general assumptions of economic theory, that the savings rate, education attainment and the labour force participation rate will boost the growth rate of GDP-per-capita, whereas the initial output per capita, the population growth rate, and the level of population ageing will drag down the growth rate of GDP per capita down.

Based on the model design, we collect the provincial data of China from 1995 to 2020 and test the impact of population ageing on GDP-per-capital growth through the system GMM estimates. Most of the explanatory variables are consistent with the theoretical assumptions in the model. Most important, population ageing will drive GDP growth per capita down but the simultaneously increasing saving rate will promote economic growth, The empirical analysis shows that especially for the age group of 41 to 49 years the former effect is strong, which indicates the comparative high productivity of this age group.

However, there are some interesting deviations from the model assumptions as well. One is that years of education per capita as a proxy for the quality of human capital is either insignificant or even slightly negatively affects the depending variable. We explain this result with the phenomenon of overeducating in China, which implies that more education does not automatically lead to higher income, which contradicts at least partly the so-called second demographic dividend.

Furthermore, it turns out that the depreciation rate is positive and not – as expected - negative correlated with GDP-per-capita growth, i. e. as higher the depreciation rate as higher ceteris paribus GDP-per-capital growth. The reason for this surprising result could be the fast replacement of the existing capital by new and better capital in China's industry that leads to a higher depreciation rate and higher productivity simultaneously, which in turn correlates the depreciation rate and GDP-per-growth positively.

In a second step, we investigate how different age groups of working population affect GDP-per-capita growth, rather than taking the whole population into consideration as in the first model. Our study shows that people aged from 40 to 49 are associated with a higher output when compared to other age groups. The causes of this could include the highest dependency ratio and the highest productivity coming from the working experience of the age group 40 to 49 among all groups. With the gradual acceleration of the ageing process in China, the number of people aged from 40 to 49 will keep decreasing.

Overall, our empirical model has passed the robustness test, demonstrating the validity of our model and results.

In terms of policy, China is under way to development a 'population strategy' that tries to exploit the potential of the second demographic dividend after the first one disappeared not at least due to the One-Child policy. A turnaround in the fertility rate requires an income policy that benefits private households combined with an extension of the social security system and the upgrade of the infrastructure to raise children.

Moreover, the use of more advanced production technology is a key factor that could compensate at least to a certain extent population ageing by increasing the productivity per unit of labour. Therefore, a successful implementation of the intended industrial policy in areas such as automatization, robotics and AI could counter the limitation of labour supply in China's economic future.

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Appendix

Theoretical Model Validation

We use L for the total population, u for the share of the population aged 65 and above in the total population, and v for the youth population, i.e., the share of the population aged 0 to 14, so that the proportion of the working age population aged 15 to 64 is $1-u-v$ and the total working age population is $L\,(1-u-v)$. The production function takes the following form under this assumption:

$$Y = K^{\alpha}[Hp(1-u-v)AL]^{1-\alpha} \tag{3.1}$$

Where Y stands for total output, A for productivity, K for physical capital, and H for years of schooling per capita, which is a measure of human capital. Here we assumed human capital is an exogenous variable instead of an endogenous variable like in the Mankiw-Romer-Weil version of model to simplify the model, and it has a strong correlation with the effective labour. $(1-u-v)L$ is denoted the working age population. p indicates the proportion of the total labour force stock that is invested in economic production, i.e., the labour force participation rate which is the ratio of employed individuals to the working age population. p is supposed to be a parameter between 0 and 1 because of issues such as unemployment. $[Hp(1-u-v)AL]^{1-\alpha}$ represents the total human capital generated by the working age population.

Let:

$$k = \frac{K}{p(1-u-v)AL} \tag{3.2}$$

Then we have:

$$y = \frac{Y}{AL} = k^{\alpha}H^{1-\alpha}p(1-u-v) \tag{3.3}$$

Equation (3.2) denotes physical capital per effective labour, while equation (3.3) represents output per capita. A simple interpretation of equation (3.2) and (3.3) reveals that, on the one hand, population ageing u increases physical capital per effective labour, resulting in higher output per capita. While, on the other hand, diminishes the proportion of the working population in the overall population, lowering output per capita. When we take the first derivative of population ageing u, $\frac{\partial y}{\partial u} = -k^{\alpha}H^{1-\alpha}p < 0$,which reflects the fact that population ageing has a negative impact on the output per capita.

The combined effect of population ageing on GDP per capita is negative, as shown in the previous brief theoretical study, and we turn to the effect of population ageing on the savings rate and GDP per capita on the equilibrium growth path.

According to the Solow growth model, we assume labour and productivity are exogenous variables and grow at constant rates: $L^{\cdot}/L = n, A^{\cdot}/A = g$, and try to find out the accumulation of physical capital through the following equation:

$$\dot{K} = I - \delta \cdot K = s \cdot Y - \delta \cdot K \tag{3.4}$$

Regarding to the steady state of savings rate, if we assume Y_u is the proportion of output used in aged dependency while Y_v is in child dependency, resulting in the fraction of total output committed to the working-age population $Y - Y_u - Y_v$. Then we define the level of aged dependency is $t_u = \frac{Y_u/uL}{Y/L}$,which is the ratio of the aged population's income per capita to the total population's output per capita, and similarly define the level of child dependency as $t_v = \frac{Y_v/vL}{Y/L}$. Assuming that the savings rate of the working population is s_L, and the youth and aged populations only consume and do not save, then we obtain $sY = s_L(Y - Y_u - Y_v)$. Substituting Y_u and Y_v for further sorting we get $s = s_L(1 - t_u u - t_v v)$. When the savings rate s_L of the working-age population remains constant, the bigger the ageing population percentage u, the lower the savings rate s and thus the smaller the portion of GDP devoted to investment, which inevitably has a negative impact on the long-term economic growth potential.

After inserting equation (3.2) and (3.3) into (3.4) we can calculate:

$$\begin{aligned} \dot{k} &= \frac{s}{p(1-u-v)} \cdot y - (n + g + \delta) \cdot k \\ &= s \cdot k^{\alpha} \cdot H^{1-\alpha} - (n + g + \delta) \cdot k \end{aligned} \tag{3.5}$$

When it approaches the equilibrium growth path, the steady state capital per effective labor and output per capita are:

$$k^* = H\left(\frac{s}{n + g + \delta}\right)^{\frac{1}{1-\alpha}} \tag{3.6}$$

$$y^* = H[p(1 - u - v)]\left(\frac{s}{n + g + \delta}\right)^{\frac{\alpha}{1-\alpha}} \tag{3.7}$$

It can be seen from expressions (3.6) and (3.7), when the economy reaches equilibrium growth path, the savings rate has a positive impact on equilibrium physical capital per effective labor and output per capita, while population ageing is negatively related to output per capita.

When it comes to the relationship between the growth rate of output per capita and population ageing y^*/y, we can derive the following equation from (3.7) by taking the logarithm on both sides of the equation:

$$lny^* - lny = lnH + lnp + \ln(1-u-v) + \frac{\alpha}{1-\alpha} ln \frac{s}{n+g+\delta} - lny \qquad (3.8)$$

We can obtain from equation (3.5) that $\frac{s}{n+g+\delta} = \frac{p(1-u-v)}{y} \cdot \left(\frac{\dot{k}}{n+g+\delta} + k\right)$; then, when it is substituted into equation (3.8):

$$lny^* - lny = \frac{\alpha}{1-\alpha} \ln\left[\frac{\dot{k}}{(n+g+\delta)k} + 1\right] \approx \frac{\alpha}{1-\alpha} \cdot \frac{\dot{k}}{(n+g+\delta)k} \qquad (3.9)$$

From equation (3.3), we can derive $\frac{dlny}{dt} = \alpha \frac{\dot{k}}{k}$, so we can plug it in equation (3.9) to get:

$$\frac{dlny}{dt} = (1-\alpha)(n+g+\delta)(lny^* - lny) \qquad (3.10)$$

So, we can have the growth rate of the output per capita by substituting expression (3.8) into (3.10):

$$\frac{dlny}{dt} = (1-\alpha)(n+g+\delta)(lnH + lnp + ln(1-u-v) - lny)$$

$$+(n+g+\delta)(\alpha lns - \alpha\, ln(n+g+\delta)) \qquad (3.11)$$

As shown in by the equation (3.11), on one side, the level of education attainment H, the savings rate s and the labour force participation rate p all have a positive impact on the growth rate of output per capita; on the other side, the initial output per capita y, the population growth rate n, and the level of population ageing u have a negative effect on the growth rate of GDP per capita.