THE INFLUENCE OF POPULATION AGEING ON HOUSE PRICES IN CHINA

by

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ABSTRACT

This thesis tries to clarify the issue of the effect of population ageing on the housing market. Existing studies find both positive and negative effects, which may be because they do not distinguish between the effects of population growth and population ageing. I show that both signs are possible using a three-period overlapping generations model. The impact of population ageing is divided into two opposite effects: the size effect and the age composition effect. The static comparative analysis shows that under reasonable assumption, the size effect is positive and the age composition effect is negative. Based on the data from 35 cities during the period of rapid population ageing in China, panel data regressions are used to examine the two opposite effects. The estimates are consistent with the predictions of the theoretical analysis. Regarding the size effect, a 1% increase in population size can push up house prices by 0.41%. Regarding the age composition effect, a 1% increase in the old-age dependence ratio can lead to a 1% drop in house prices.

LIST OF ABBREVIATIONS USED

OLG	Overlapping Generations Model
VIF	Variance Inflation Factors

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CHAPTER 1 INTRODUCTION

Over the past 30 years of high-rates of economic growth, houses in China's main cities have become an expensive asset and make up a significant part of the total wealth for the average family. One result of this high-rate of economic growth is growing house prices. In many Chinese cities, most young workers cannot afford a house. For example, based on the National Bureau of Statistics, the average annual wage in 2019 is 173,205 yuan in Beijing, and the average local house price in 2019 is 38,433 yuan/square meters. If living expense are 60% of the annual wage, they could only afford 1.8 square meters per year. In this case, a young worker may need to work 66.7 years to buy a two-bedroom apartment or work 22 years to pay the down payment of the apartment. Therefore, high house prices provoked widespread discussions among academics (Wang et al., 2018).

At the same time, due to carrying out the "One-child" policy in the last 40 years, in most Chinese cities, the typical family is "4+2+1": four grandparents, two parents and one child, which leads to a rapid population ageing rate. Several early studies show a negative effect of population ageing on house prices because the demand for houses will shrink with fewer young buyers entering the market, and the supply of houses will expand with more older people moving into elderly centers (Mankiw and Weil, 1989, DiPasquale and Wheaton, 1994). This research suggests that the population ageing could impede the growth of house prices in China.

However, studies on the effect of population ageing on China's houses market obtain some unexpected results. Some find a positive effect of population ageing on China's house prices through theoretical and empirical analysis (Wang et al., 2018). On the contrary, some studies indicate that the effect of population ageing is negative but insignificant (Zeng et al., 2019). A similar situation can be found in studies regarding the housing markets of other countries. Some studies indicate a negative impact of population ageing on house prices (Hiller & Lerbs, 2016; Mankiw & Weil, 1989; Martin, 2005; Simo-Kengne, 2018; Takats, 2012). Others conclude a positive, marginal or uncertain effect (Engelhardt & Poterba, 1991; Wang et al., 2018; Singh, 2019; Zeng et al., 2019; Piergallini, 2020). There is no consensus on this effect.

Some studies that reports a positive or uncertain effect of population ageing on house prices have included other factors, such as interest rate and GDP growth rate, to offset or dilute the impact of shrinking demand from the young generation (Engelhardt & Poterba, 1991; Wang et al., 2018; Piergallini, 2020). Li & Shen (2013) indicate that a nonlinear relationship could demonstrate positive and negative effects. They also conclude that the intergenerational transfer of savings from the elderly generation to the young may be critical to explain the positive effect.

This idea is consistent with the "six wallets" theory prevalent in many online forums. The "six-wallets" theory argues that when young workers try to buy a house, they can gain financial support from their four grandparents and two parents—therefore, there are six wallets. With the saving of their parents and grandparents, the young can finally afford a house in a big city, but this increase in demand can also lead to higher prices. In this case, the intergenerational transfer of savings is not a result of higher prices but a reason for higher prices.

If the "six-wallets" theory is true, the overall effect of population ageing on house prices may be uncertain in China. On the one hand, the population ageing should lower the house prices because of the shrinking number of new buyers and more second-hand houses in the market. On the other hand, a larger elderly population equates to more and more funds to pay the higher house prices, which leads to a positive effect.

Two issues need to be addressed to disentangle these two effects. The first issue is under what conditions can the transferred savings generate a higher purchasing power that backs up higher house prices? The second issue is whether these conditions have been met in the past 20 years when house prices kept a high growth rate in China? Only after these two questions are answered can we clarify the impact of population ageing on house prices in the past and obtain reliable conclusions for the future.

To do this, I build and solve a simple housing model featuring intergenerational transfer of wealth. In the demand side of this model, a three-period overlapping generations model is used to formulate the intergenerational transfer of savings from the elderly generation to the young age. In the supply side of this model, a Cobb-Douglas production function is used to develop developers' responses to price fluctuations. In this model, equilibrium house prices depend on both population aging and household savings

The theoretical analysis indicates the conditions under which savings transferred from the elderly generation to the young can push up house prices as the “six-wallets” theory suggested. Further, the model of equilibrium house prices shows that population ageing has two opposite effects: a positive population size effect and a negative age composition effect.

As to the second question, panel data regressions are applied to estimate the effects of population ageing and household savings and examine the predictions of the theoretical model. In the last 20 years, China experienced the fastest population ageing in history, making the effect of population ageing on house prices more evident than in other countries. This makes it an ideal country for the empirical analysis. The results of panel data regressions find that the impact of household savings was relatively insignificant in the last 18 years, which supports the conclusion of theoretical analysis. Meanwhile, the results of panel data regressions support the theoretical predictions on the effects of population ageing on house prices.

The content and structure of this thesis are as follows. Chapter 2 summarizes related literature. Chapter 3 describes the theoretical model of this paper and shows the result of static comparative analysis. Chapter 4 presents the results of panel data regression, which examines the predictions of theoretical analysis. Chapter 5 concludes.

CHAPTER 2 LITERATURE REVIEW

2.1 The Effect of Population Ageing on House Prices

The theoretical link between house prices and demographic factors can be traced to the life-cycle hypothesis (Modigliani and Brumberg, 1954; Ando and Modigliani, 1963). According to this hypothesis, consumption and savings of households vary with age. Based on this hypothesis, the overlapping generations model (OLG) is established and used to study the relationship between the effects of demographic changes on asset prices (Diamond, 1965; Samuelson, 1958). In a typical OLG model, people live for two periods. They work and accumulate wealth in the first period. They retire and consume their savings in the second period.

In the 1960s, the U.S. society was in the early stage of the "baby boom." This OLG model was first used in studying the relationship between demographic changes and the fluctuation of asset prices. Based on the OLG model, Diamond (1965) indicates that improvements in life expectancy can lead to an upward shift in the demand curve for assets. Assuming that the young generation who purchase assets turns greater in size than the old generation who supply assets, the young would bid higher prices for the senior's assets, which drives up the prices. Moreover, shifts in demographic structure may also influence productivity growth, which may boost future asset prices.

In the 1980s, an opposite demographic change showed up with the end of the baby boom. In their seminal paper, Mankiw and Weil (1989) find a strong time-series correlation between demographic variables and real house prices in the postwar period. They further forecast a "market meltdown" in the next two decades since 1987. In this market meltdown scenario, real house prices in the United States may fall by 3% per year, on average, due to both the "baby bust" and "baby boomers" liquidating their housing and financial assets.

This market meltdown scenario motivated more studies since then. However, there is no consensus on the effect of population ageing on house prices. Some studies verified a negative impact of ageing on house prices (Mankiw and Weil, 1989; Martin, 2005; Takats, 2012; Hiller and Lerbs, 2016; Simo-Kengne, 2018). On the contrary, some studies concluded a positive, marginal or uncertain effect of population ageing on house prices

(Engelhardt and Poterba, 1991; Hort, 1998; Wang et al., 2018; Singh, 2019; Zeng et al., 2019; Piergallini, 2020).

2.1.1 Negative Impact

The OLG model Has been the basis of most theoretical analysis since 1989. Abel (2001) develops a rational expectation, general equilibrium OLG model with a bequest motive. In this model, a baby boom increases stock prices. Stock prices are rationally anticipated to fall when the baby boomers retire, even though consumers continue to hold assets throughout retirement. The continued high demand for assets by retired baby boomers does not attenuate the fall in the asset price.

Some studies use national data to examine the impact of population ageing on house prices. Takáts (2010) frames his model on a theoretical OLG model. Using panel regressions on data from 1970 to 2009 in 22 advanced economies, he concludes that the old-age dependency ratio negatively impacts real house prices, and population size positively affects real house prices. These results were consistent across the 22 countries. Guest and Swift (2010) assess the effect of population ageing on housing consumption and house prices in Australia and find that population ageing may cause average real house prices to be between 3 and 27 percent lower than they otherwise would be over the period 2008–2050. Using data from Korea, Park et al. (2017) show that house prices in the regional market are inversely correlated with the dependency ratio but positively correlated with GRDP per capita in each region. They further estimate that the house price will decline by 3–12% in 2020 and more than 20% in 2030.

Instead of the national data, some studies focus on the regional or city level data. Simo-Kengne (2018) examines the collective dynamics between house prices, population ageing and unemployment in South Africa. He uses a provincial-level data set to compare the demographic effects of house prices across different housing segments from 1995 to 2015. In the past 22 years, they find that population ageing has contributed to the decline of the South African house prices by 6.28 and 7.52 basis points in the large and medium housing segments, respectively, while the small housing segment has remained unaffected. Hiller and Lerbs (2016) combine city-level demographic information with detailed housing price data for 87 German cities over 1995–2014. They find that population ageing has heterogeneous effects across housing segments: sales price growth of condominiums and single-family homes is negatively related to the increase in older-age dependency ratio. In contrast, a positive association is found for ageing and real rent growth.

Besides the panel data regression, some studies use time-series data to examine the causal relationship between demography and housing prices. The empirical results of Peng and Tsai (2017) reveal that house prices are cointegrated with the fertility rate and old dependency rate, respectively. In the long run, an increase in fertility rates increases house prices, but an increase in the old dependency rate reduces house prices.

Overall, based on different levels of data or approaches, many studies find o a negative relationship between changes in population structure and house prices. It seems that the negative effects of population ageing have been verified. However, some studies show a positive or insignificant effect of population ageing on house prices.

2.1.2 Positive or Insignificant Effect

Mankiw and Weil's forecasts were undermined by the fact that real house prices in the U.S. increased by approximately 60% between 1987 and 2007 rather than falling 47% as they tentatively predicted. Some scholars also argue that population ageing will not lead to a decline in asset prices.

Studies using cross-section data or panel data regression can also conclude a positive or insignificant effect of population ageing on house prices. Green and Hendershott (1996) assume that real house prices are directly determined by the willingness of households to pay for a house. Using 1980 census data, they find that the demand for housing tends to be flat or rise slightly with age. They believe that partial derivatives more accurately depict the age-demand relationship and thus that the population ageing should not be expected to lower real house prices. Berg (1996) found little demographic impact, while Hort (1998) even found a positive ageing impact. Poterba (2001) examines the historical relationship between demographic structure and real returns on assets, using data from the United States, Canada, and the United Kingdom. He finds that although theoretical models generally suggest that equilibrium returns on assets will vary in response to changes in population age structure, it is difficult to find robust evidence of such relationships in the time series data. Chen et al. (2012) adopt a micro-simulation methodology that combines a macrolevel house price model with a micro-level household model and use panel data from the British Household Panel Survey covering 1999–2008. The main finding from their simulation is that population ageing is not likely an important determinant of house prices, at least in Scotland.

Piergallini (2020) analyzes the effects of demographic changes on the long-run pattern of real house prices in an overlapping generations general equilibrium model with housing-wealth effects. He concludes that declines in the birth rate and population growth, associated with increases in life expectancy, generate disinflation and a fall in the real interest rate, triggering a rise in real house prices over the long run. The positive relationship between contemporary demographic trends and real house price trends in the U.S and other OECD countries is thus not puzzling but perfectly consistent with dynamic macroeconomic theory. In this context, ceteris paribus, falling prices in the housing market are possible only when self-fulfilling boom-bust dynamics, unrelated to demographic fundamentals.

Studies using time series data find an insignificant effect of population ageing on house prices. Engelhardt and Poterba (1991) estimate simple time-series models relating house prices to demographic factors using postwar data for Canada. Unlike previous estimates for the U.S. by Mankiw and Weil (1989), they find a statistically insignificant and negative relationship between demographic demand and house prices, which implies a positive effect of population ageing on house prices.

The life cycle hypothesis suggests that when the Baby Boomers retire, many are likely to sell their assets to finance their retirement, exerting downward pressure on house prices. Thenuwara et al. (2019) examine whether the increasing proportion of the population in the old age cohort due to the retirement of Baby Boomers will precipitate a dramatic decline in real house prices in Australia. They choose a structural vector autoregressive framework and a time series from 1950 to 2014. Their findings reject the predictions that population ageing will lead to pronounced downward pressure on real house prices in Australia and suggest that macroeconomic shocks could outweigh any effects of future demographic shifts on house prices.

Overall, using similar research approaches, some studies also find a positive, marginal or uncertain effect of population ageing on house prices. Several reasons can be found to explain the different study results:

Firstly, the estimates on the effect of population ageing are influenced by other variables in the regression. With more elements in the regression model, the significance of population ageing is shrinking and sometimes even reversed. For example, both Guest and Swift (2010) and Thenuwara et al. (2019) study the effect of population ageing on house prices in the Australian house market. Guest and Swift confirm the significance of negative impact, but Thenuwara et al. reject the predictions that population ageing will lead to pronounced downward pressure on real house prices. Further, Thenuwara et al. find that macroeconomic shocks and house price-specific shocks explain more of the variation in house prices than the shifts in the population age structure, suggesting that such factors could outweigh any effects of future demographic shifts on house prices.

Singh (2019) finds evidence of the significant positive impact of the working-age population on real housing and stock prices, bolstering the intuition of the life cycle theory. In contrast to the evidence from developed countries, he does not support the negative effect of ageing. He attributes this result to lack of state-funded health and old age safety nets, reliance on family for social insurance, and strong bequeath motives rooted in the social configuration. Green and Lee (2016) argue that the massive demographic shift will not result in a housing crisis on its own because the education and income levels of current and future seniors are still high, leading the Millennial generation to consume more than previous generations.

Secondly, even if the development of a city's age structure is a critical determinant of local house prices, the effects of population ageing are heterogeneous across segments. Hiller and Lerbs (2016) find that real sales price growth of existing condominiums and single-family homes is negatively related to growth in the old-age dependence ratio (with condominium prices being more severely affected than home prices). In contrast, a positive relationship is found between an increase in the old-age dependency ratio and real rent growth. They conclude that a possible reason for this asymmetry is that demand for condominiums and homes as a form of capital investment is declining with ageing populations. In contrast, demand for housing services in the urban rental sector increases with growing population shares of the elderly.

Besides the different preferences, different pricing mechanisms also generate heterogeneity of the effects of population ageing. For U.S. cities, differences in the development of subprime lending, mortgage securitization and home foreclosures have been well documented to considerably affect house price trajectories (Favara and Imbs, 2015). Since the prevalence of subprime lending has been highly correlated with urban demographics with higher shares of young working-age households, empirical estimates of the nexus between demographic changes and house prices based on U.S. data may be severely biased. (Mian et al., 2015).

2.2 Studies on China's House Market and Population Ageing

In the past 20 years, despite various government control policies, including purchase restriction and high banks credit threshold, China's house prices have remained high, encouraging many studies on determinants of house prices.

The OLG model is still the basis for theoretical analysis but includes another factor. Zeng et al. (2019) set up an OLG model. The difference is they consider the household savings in their model. Basing on data from small cities, they find that asset prices are negatively linked with the population dependency ratio and positively linked with household savings. The estimates show that population ageing affects houses prices through savings, and the mediator dilutes and weakens this impact.

As to the empirical analysis, panel data is still the first choice. Wang et al. (2018) aim to investigate how population ageing and mobility affect housing prices at the city level by using a set of two-period panel data of 294 prefecture-level cities in China. Their results show that an increase in the elderly dependency ratio by 1% leads to a rise in housing prices by 0.368%. Furthermore, the policy of purchase limits could weaken the positive impacts of the elderly dependency ratio and inter-regional migration on housing prices and, thus, plays a moderating role in the relationship between demographic structure and housing prices.

Some researchers testify nonlinear relationship between population ageing and house prices. Using an OLG model, Li and Shen (2013) investigate the impact of the demographic transition on housing consumption in China. They find a nonlinear relationship between the elderly dependency ratio and housing consumption. With the deepening population ageing, housing consumption will increase; housing consumption will decrease when the elderly dependency ratio reaches a turning point. Furthermore, the turning point of the nonlinear curve will emerge when China's elderly dependency ratio comes to a value of 32 percent in 2025.

Most studies concerning the relationship between house prices and population ageing in China depend on province-level or city-level data. The difference in the results of empirical analysis is possibly derived from the heterogeneity among different provinces or cities. This heterogeneity may result from different economic structures or different population compositions. For example, the young generation of some small cities in the northeast of China has continuously emigrated from their hometown to some big cities to seek more opportunities. To avoid this bias, only the data of 35 big cities are input into the regression model in this thesis. The heterogeneity among those 35 big cities is much lower than that of 32 provinces or other small cities because they are all the economic centers of their region. They can provide similar opportunities for the young generation. Although the average income of people in those cities is different, those cities share similar income distributions.

Another reason is the questionable statistical data. The annual population statistics of most cities are estimated by using sampling. The sampling result combines with the population of registered residents to evaluate some critical indicators, such as the old-age dependency ratio. However, the size of registered residents is not accurate since many young people who have moved to big cities are still recorded on the register book of their home town. Therefore, neither the population size nor the old-age dependency ratio can correctly reflect the actual change in demography.

On the contrary, the population statistics of some big cities is based on another approach. Municipal governments of big cities require people who move in but cannot register as normal residents to register as temporary residents. Most young people moved from other towns and rural areas are recorded in the temporary resident system to get the social security service. The population sampling result combines the records of both normal and temporary residents to estimate demographic changes. The empirical analysis of this thesis in chapter 4 is based on those big cities' statistics to avoid potential bias

CHAPTER 3 THEORETICAL ANALYSIS

The overlapping generations model (OLG) was first constructed by Maurice Allais in 1947 and enhanced by Samuelson (1958) and Diamond (1965). In a typical OLG model, there are two generations alive at any time, the young and old. They consume part of their first-period income and save the rest for their consumption when old. Mankiw and Weil (1989) establish their OLG models, but it does not consider the effect of household savings and intergenerational transfer.

Abel (2001) expands the use of the OLG model in the capital market. He considers the savings and intergenerational transfer but only includes two generations and excludes the mortgage loan, which is essential for the young generation to buy a house.

Ortalo-Magné and Rady (2006) use the OLG model framework to analyze the trade-up behaviour of representative households in different life cycles and the corresponding housing market dynamics. However, they assumed that the population size is constant and excluded the demographic structure change. Cocco (2005) and Piazzesi et al. (2007) establish a complete OLG model with household savings. However, their models do not consider the interaction between different generations.

Hui and Wang (2016) establish a theoretical model that addresses the specific issues of the inter-generation wealth transfer when purchasing houses in China. They build a four-period OLG model including the altruistic behaviour of buying a house for the younger generation. However, their model does not include the utility of the old age from supporting the young and does not consider the effect of house supply on the house prices.

This chapter presents a theoretical model based on the OLG model under the partial equilibrium framework. The optimal consumption of an average individual is given by solving the utility maximum problem in a three-period OLG model. The market supply is an endogenous variable from the profit maximum problem of real estate firms.

3.1 Individual Behavior

3.1.1 Assumptions on Life-cycle stages

Following Modigliani and Brumberg (1955), I break each life into three stages: childhood, young-age and old-age. The basic assumptions of individuals' behaviour in different life stages are as follows:

i. Childhood (before having labour income): No employment income, no house demand, and consumption depend on their working-age parents.

ii. Young-age (during working age): Individuals gain wage income, raise their children and pay their consumptions and mortgage loans for their houses[1]. Assume that they provide 1 unit of labour in this period. When they buy their houses, their retired parents will finance them to pay the down payment. Individuals only buy one house for their whole life. At the end of this stage, they inherit and sell their parent's houses. The proceed is added to savings.

iii. Old-age (after retirement): No wage income. They do not need the financial support from their young-age but relies on their own savings to pay their consumption[2]. Further, they will transfer part of their savings to their working-age children to pay a portion of the down payment. Their savings will be exhausted, and only their houses will be inherited and sold by their sons and daughters.

The behaviour of individuals in each stage is summarized in the following table 1.

Table 1 Assumptions on the behaviour of each generation

Life stage	Income	House consumption	Savings	Wealth transfer
Childhood	No income	No demand	No savings	Consumption relies on their parents
Young-age	Wage income and inheritance	Buy houses, pay the down payment and pay off the mortgage.	Accumulate, and hold savings	Receive savings from their parent to pay the down payment. Inherit their parent's houses and sell.
Old-age	No income	Hold houses	Hold and expend savings	Fund their children to buy houses. Bequest their houses at the end of life.

To facilitate the empirical analysis, I assume that the ranges of the three life stages are consistent with the statistical data regarding the age composition. According to the definition from the National Bureau of Statistics of China, "children" denotes the population aged 0-14 years old; "working-age population" denotes the population aged 15-

[1] In the presence of borrowing constraints and other frictions, households face obstacles of smoothing housing services consumption over the life cycle and will purchase self-owned housing (which typically requires a down payment and high levels of creditworthiness) in later stages in life (Flavin and Yamashita, 2002).

[2] Considering the good performance of the Chinese social security system and the pension system in urban areas, this model does not consider the possible support of the working-age generation to retired generation. This kind of support is widespread in rural areas, but most old individuals rely on their pension and savings in urban areas.

64 years old; and "elderly population" denotes the population aged 65 years and over[3]. Therefore, the childhood stage is from 0 to 14 years old, the young-age (working-age) is from 15 to 64 years old, and the old-age stage is over 65 years old.[4]

Before April 2018, according to the "*Regulation on the Administration of Housing Accumulation Funds*" issued by the State Council of China, the maximum age for a mortgage loan borrower was 65, which implies that people should pay off their mortgage loan before reaching their old-age stage[5]. Because our data is from 2002 to 2019, I assume that people borrow and repay mortgage loans in the young-age stage and have no loan in their old-age stage.

3.1.2 Utility Function

Assume the utility function of an average individual in period t as:

$$u_t = \alpha_1 \ln c_t + \alpha_2 \ln h_t + \alpha_3 \ln x_t \text{ , } (\alpha_1 + \alpha_2 + \alpha_3 = 1) \quad (1)$$

where c_t represents the consumption of an average individual in the period t, h_t represents the house consumption in the period t, x_t denotes the intergenerational wealth transferred to the next generation, α_1, α_2 and α_3 show the preferences on the regular consumption, house ownership and financial support to the next generation.

Suppose that in period 0, a generation is denoted as "o" in their working age. The generation o give birth to generation y and raise them. In period 1, the generation o is in their old-age stage. They support the working-age generation y to pay the down payment. At the end of period 1, generation o pass away and leave their houses to generation y. Since their houses had reached their design working life at that time, the value of this legacy is only the value of the land.[6]

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[3] This definition is in line with the definition of United Nations. Statistics Canada has different definition: youth population (0 to 19 years), working-age population (20 to 64 years) and senior population (65 or older).

[4] There is a problem in this assumption that the range of young-age stage is almost two times of the range of the old-stage. The potential influence of this difference can be partly offset by longer life expectancy and most young individuals earn their labour income after 20 years old. However, if further divide the young-stage into two parts, then we will lose the convenience from correspondence to the statistical data. Fortunately, the theoretical model maximum the lifetime utility of one generation, the difference in the length of time period only influences the budget constraints. I will change the budget constraints to reflect the short old-age stage.

[5] Since May 2018, this maximum age is increased to 70 years old, which may lead to some change in the trade-up of their houses for some wealthy old-age individuals.

[6] According to China's national standard, "*Unified standard for reliability design of building structure*" (GB50068-2018), the design working life of house is 50 years. Combining with the assumption that individuals only buy one house for their whole life, we can assume that the old-age generation's house have no value. However, the land of the house is not zero. The working-age generation still obtain some proceed. This proceed cannot be measured by the price of new house

For generation y, they are born in period 0. In period 1, generation y reach the working-age stage, raise their children—the generation c, receive the financial support and the legacy from the generation o. The following discussion will focus on generation y.

The life-time utility of an average individual of generation y in period $0, 1$ and 2 can be represented as:

$$MaxE_1\{u_y\} = \sum_{t=1}^{2} \beta^{t-1} E(u_{y,t}) \tag{2}$$

In the above equation, $E_1\{u_y\}$ represents the expected lifetime utility of the individual in period 1 when they are in their working-age stage. β is the discount factor of the utility. According to the previous assumption, individuals of generation y are raised by generation o in period 1, so their utility in period 0 ($u_{y,0}$) is excluded from their lifetime utility[7]. The lifetime utility only includes the utility of the working-age and old-age stages.

3.1.3 Budget Constraints

According to the assumption on individual behaviour, we only consider the budget constraints of the young-age and old-age stages.

a. Budget Constraints of the young-age stage (period 1)

Assume that the price of regular consumption is standardized as 1. For individuals of generation y, the budget constraint of period 1 when they are in the young-age stage is:

$$w_{y,1} + n_o x_{o,1} = c_{y,1} + x_{y,1} + d_y p_1 h_y + p_1 h_y (1 - d_y)(1 + r_m) + s_{y,1}(1 + r_1) \tag{3}$$

On the left-hand side of the above equation (3), $w_{y,1} + n_o x_{o,1}$, denotes the total income of an average individual of generation y. $w_{y,1}$ represents the labour income. $x_{o,1}$ represents the financial support transferred from an average individual of generation o to his/her children. For the asset received by the generation y, we should consider the demographic structure change. Let n_o denote the old-age dependence ratio[8], and N_o and

at the same period. Since the old houses is near its designed useful life and the banks will not issue mortgage loan to those old houses in China, so the sale proceed of the inherited houses could be measured by the value of land.

[7] Although the utility of the young generation in their childhood is not counted in their life-time utility, but the expense of this utility is included in the budget constraints of their parents. Therefore, I keep this utility in theoretical model.

8 In this model, the term "old-age dependence ratio" seems improper because the elderly generation do not depend on the support from the young generation. On the contrary, they fund the young generation to buy houses. However, use other term will be inconvenient when using to statistic data and comparing with other studies. Moreover, no matter where

N_y represent the population of generation o (the old-age) and y (the young-age), respectively. Then the old-age dependency ratio is

$$n_o = {}^{N_o}\!/_{N_y} \quad (4)$$

Then, $n_o x_{o,1}$ represents the financial support received by an average individual of generation y.

On the right-hand side of the above equation (3), $c_{y,1} + x_{y,1} + d_y p_1 h_y + p_1 h_y(1 - d_y)(1 + r_m) + s_{y,1}(1 + r_1)$, denotes the total outlay and savings of an average individual of generation y. $c_{y,1}$ represents the regular consumption of an average individual of generation y. $x_{y,1}$ represents the expenditure of raising the generation c. p_1 denotes the house price in period 1 and h_y denotes the house consumption. d_y is the ratio of down payment to the total house price. $d_y p_1 h_y$ is the down payment of the house of generation y. $d_y p_1 h_y$ represents the down payment of the house purchased. $p_1 h_y(1 - d_y)$ is the principal of a mortgage loan. r_m is the interest rate of the mortgage loan. Then, $p_1 h_y(1 - d_y)(1 + r_m)$ is the total payment of the mortgage loan. At the end of the young-age stage, generation y will pay off their loans.

$s_{y,1}$ is the savings of an average individual of generation y in period 1. $s_{y,1}$ comes from the labour income and may include a part of savings transferred from generation o. Let r_1 represent the average rate of return in the economy in period 1. $s_{y,1}(1 + r_1)$ is the total amount of savings owned by generation y at the end of period 2.

Rearranging equation (3), we have a short-expression:

$$s_{y,1}(1 + r_1) = w_{y,1} + n_o x_{o,1} - c_{y,1} - x_{y,1} - p_1 h_y(1 + r_m - d_y r_m) \quad (5)$$

b. Budget Constraints of the old-age stage (period 2)

The budget constraint of period 2 when an individual of generation y is in his old-age stage is:

$$s_{y,1}(1 + r_1) + n_o l_o \tau_2 = c_{y,2} + x_{y,2} + s_{y,2} \quad (6)$$

Similarly, the left-hand side is the total asset, and the right-hand side is the total outlay. Since the length of the old-age stage is uncertain and may be less than the length of the

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the elderly generation's savings is (the savings can in their social security accounts or invested in other asset), the young generation's work is the key to run the social security system and the key to preserve the value of their investment. From this perspective, the term "old-age dependence ratio" is reasonable.

young-age stage, I assume that all values in equation (6) are discounted to the beginning of this period.

$l_o \tau_2$ represents the bequest value of an average individual of generation o. The generation y will inherit and sell the houses of generation o after they pass away. Since those houses have reached the end of design working life, the proceed equates to land value. let l_o denote the land of the generation o's house and τ_2 represent the land price in period 1. Then $l_o \tau_2$ is the land value of the generation o's house. For this legacy received by the generation y, we should consider the demographic structure change. $n_o l_o \tau_2$ is the legacy received by an average individual of generation y.

Assume an individual of generation y passes away at the end of period 2 with no saving left. We have $s_{y,2} = 0$.

3.1.4 Utility Maximization

The utility maximum problem of an average individual of the generation y is,

$$max\{u_y\} = \sum_{t=0}^{2} \beta^{t-1} u_{y,t}$$

$$s.t. \begin{array}{c} s_{y,1}(1+r_1) = w_{y,1} + n_o x_{o,1} - c_{y,1} - x_{y,1} - p_1 h_y (1 + r_m - d_y r_m) \\ s_{y,2} = s_{y,1}(1+r_1) + n_o l_o \tau_2 - c_{y,2} - x_{y,2} \end{array} \tag{7}$$

The optimization problem of the utility of the generation y individuals can be solved by constructing the Bellman equation. The control variables are: $c_{y,1}$, $x_{y,1}$, h_y, $c_{y,2}$, and $x_{y,2}$.

The Bellman equation of period 2 for an average individual of generation y is:

$$\begin{array}{c} V_2(s_{y,1}) = \max_{c_{y,2}, x_{y,2}, s_{y,2}} \left[(\alpha_1 ln\, c_{y,2} + \alpha_2 ln\, h_y + \alpha_3 ln\, x_{y,2}) + \beta V_3(s_{y,2}) \right] \\ s.t \quad s_{y,2} = s_{y,1}(1+r_1) + n_o l_o \tau_2 - c_{y,2} - x_{y,2} \end{array} \tag{8}$$

where $s_{y,2} = 0$, therefore $V_3(s_{y,2}) = 0$.

Because the generation y pass away and transfer their houses to the next generation at the end of period 2, the first-order conditions can solve the optimal solution of the above equation.

$$x_{y,2}^* = \frac{\alpha_3}{\alpha_1 + \alpha_3} (s_{y,1}(1+r_1) + n_o l_o \tau_2) \tag{9}$$

$$c_{y,2}^{*} = \frac{\alpha_1}{\alpha_1 + \alpha_3}\left(s_{y,1}(1 + r_1) + n_o l_o \tau_2\right) \tag{10}$$

The correspondent value function is,

$$V_2(s_{y,1}) = \alpha_1 ln\, c_{y,2}^{*} + \alpha_2\, ln\, h_y + \alpha_3 \ln x_{y,2}^{*} \tag{11}$$

In period 1, the Bellman equation of the generation y is,

$$\begin{aligned} V_1 = & \max_{c_{y,1}, x_{y,1}, h_y} \left[\left(\alpha_1 ln\, c_{y,1} + \alpha_2 ln\, h_y + \alpha_3 \ln x_{y,1}\right) + \beta V_2(s_{y,1})\right] \\ s.t.\ \ & s_{y,1}(1 + r_1) = w_{y,1} + n_o x_{o,1} - c_{y,1} - x_{y,1} - p_1 h_y (1 + r_m - d_y r_m) \end{aligned} \tag{12}$$

Solve the first-order condition: $\frac{\partial V}{\partial c_{y,1}} = 0$, $\frac{\partial V}{\partial h_y} = 0$ and $\frac{\partial V}{\partial x_{y,1}} = 0$. We can get:

$$h_y^{*} = \frac{\alpha_2 (w_{y,1} + n_o x_{o,1} - s_{y,1}(1 + r_1))}{(1 + r_m - d_y r_m) p_1} \tag{13}$$

$$x_{y,1}^{*} = \alpha_3 (w_{y,1} + n_o x_{o,1} - s_{y,1}(1 + r_1)) \tag{14}$$

$$c_{y,1}^{*} = \alpha_1 (w_{y,1} + n_o x_{o,1} - s_{y,1}(1 + r_1)) \tag{15}$$

Equation (13) gives the optimal house consumption for an average individual of generation y. For individuals of generation o, their financial support to pay the generation y's down payment can be deduced from the equation (9):

$$x_{o,1}^{*} = \frac{\alpha_3}{\alpha_1 + \alpha_3}\left(s_{o,1}(1 + r_0) + n_{o-1} l_{o-1} \tau_1\right) \tag{16}$$

where $s_{o,1}$ represent the savings of generation o in period 1; $n_{o-1} l_{o-1}$ represents the land inherited from the parent of the generation o; τ_1 represent the price of land in period 1; $n_{o-1} l_{o-1} \tau_1$ is the income from selling the houses of generation o's parents.

Substituting the equation (16) into (13), we have,

$$h_y^{*} = \frac{\alpha_2 \left[w_{y,1} + \frac{\alpha_3 n_o}{\alpha_1 + \alpha_3}\left(s_{o,1}(1 + r_0) + n_{o-1} l_{o-1} \tau_1\right) - s_{y,1}(1 + r_1)\right]}{(1 + r_m - d_y r_m) p_1} \tag{17}$$

This is the optimal house demand for the generation y in period 1.

3.2 Real Estate Developers

3.2.1 Assumptions on House Supply

The goal of real estate developers is to maximize profits by providing houses for each generation. In this housing market equilibrium analysis, the main assumptions of house supply are as follows:

i. There is one developer in a regional house market. A typical developer considers two inputs—capital and land—in their production. The production function for all real estate developers is,

$$q = Ak^{\rho}l^{1-\rho} \tag{18}$$

where k is the capital input, l is the land used to build houses, and A is workers' productivity[9]. Assume that the developer hires one unit of labour inelastically. The change in A reflects the technical development in the real estate industry. Let ρ be the output elasticities of capital and $1-\rho$ the output elasticities of land ($\rho < 1$). Doubling the usage of capital k and labour l will also double output q.

ii. The partial elasticity of housing supply is realized by assuming the complete elasticity of capital for housing production and the inelasticity of land.[10] Land is owned and auctioned by the local government in China. Let L denote the total land supply in a given period.

iii. Since all developers are homogeneous, they will equally share land in equilibrium, that is, $L = m * l$. The price of land τ_t is determined by the value of the marginal output of land:

$$\tau_t = p_t(1-\rho)Ak^{\rho}l^{-\rho} \tag{19}$$

iv. The cost of capital k is represented by r, assuming that r is exogenous in the house market[11]. It is the average rate of return in the economy. The capital income comes from the savings of the young and the elderly generation and comes from bank credit or government savings. Given the production function, the capital input k can be represented as,

---

[9] For most Chinese developers, they can find enough workers at any time with the average wage, since China's economy is still a dual economy where the rural area can supply enough workers to the urban area and the wage in the urban area is higher than that of rural area. To same extent, given the productivity, which is decided by the technology level, the cost of labour input is a fixed amount changing with the total production, which is the house supply. Assume this fixed amount is standardized as 1. Then, the labour input could be reflected by the productivity A.

[10] House development is restricted by land. Unlike capital that can be continuously accumulated through investment, there is no effective way to increase the land. The supply of land suitable for building houses is quite inelastic, which may be due to the natural geographical and geological conditions, or may be due to factors such as government control. In fact, limited land supply is often the main reason for the inelastic housing supply, especially in those high-density cities where there is only a very limited land supply in urban areas (Gyourko et al., 2006; Glaeser et al., 2008).

[11] The rate of return for capital input is decided by the general equilibrium of the economy. Since this model is based on the partial equilibrium in the housing market, I assume that the rate of return is exogenous for the developers. This rate of return (r) is different from the mortgage interest rate (r_m). The former is the price of capital input into the house production. The latter is the price of mortgage loan which limited the purchasing power of the young generation.

$$k = \quad (qA^{-1}l^{\rho-1})^{\frac{1}{\rho}} \tag{20}$$

The above equation reflects that most developers borrow capital k according to their expectations of sales.

3.2.2 Optimal Production

The profit maximum problem for an average developer is,

$$\max_{q} \pi = p_t q - rk - \tau_t l - Aw \tag{21}$$

Substituting equations (19) and (20) into the above equation, we have,

$$\max_{q} \pi = p_t q - r(qA^{-1}l^{\rho-1})^{\frac{1}{\rho}} \ - p_t(1-\rho)Ak^{\rho}l^{1-\rho} - Aw \tag{22}$$

Since $q = Ak^{\rho}l^{1-\rho}$, the above equation can be simplified as,

$$\max_{q} \pi = \rho p_t q - r(qA^{-1}l^{\rho-1})^{\frac{1}{\rho}} - Aw \tag{23}$$

Solve the first-order condition: $\frac{\partial \pi}{\partial q} = 0$. We can get:

$$q^* = \rho^{\frac{2\rho}{1-\rho}} A^{\frac{1}{1-\rho}} r^{\frac{-\rho}{1-\rho}} p_t^{\frac{\rho}{1-\rho}} l \tag{24}$$

3.3 Static Comparative Analysis

3.3.1 Partial Equilibrium Price

Let H_1^D denote the total amount of house demand in period 1. We have $H_1^D = N_y h_y^*$. Let H_1^S denote the total number of house supply in period 1. We have $H_1^S = q^*$. The housing market-clearing condition $H_i^S = H_i^D$ can be rewritten as

$$q^* = N_y h_y^* \tag{25}$$

Combing equation (17), (23) with the above equilibrium condition, we have,

$$\rho^{\frac{2\rho}{1-\rho}} A^{\frac{1}{1-\rho}} r^{\frac{-\rho}{1-\rho}} p_1^{\frac{\rho}{1-\rho}} l = N_y \frac{\alpha_2 \left[w_{y,1} + \frac{\alpha_3 n_o}{\alpha_1 + \alpha_3} (s_{0,1}(1+r_0) + F\tau_1) \ - s_{y,1}(1+r_1) \right]}{(1 + r_m - d_y r_m) p_1} \tag{26}$$

To simplify our following analysis, we take the logarithm of both sides of the above equation.

$$lnp_1^* = -2\rho ln\rho - lnA - \rho lnr + (1-\rho)lnN_y - (1-\rho)ln(1 + r_m - d_y r_m) - (1-\rho)lnL + (1-\rho)ln\alpha_2 + (1-\rho)ln\left[w_{y,1} + \frac{\alpha_3 n_o}{\alpha_1 + \alpha_3}\left(s_{0,1}(1+r_0) + F\tau_1\right) - s_{y,1}(1+r_1)\right] \quad (27)$$

Based on equation (27), we can deduce how the equilibrium house prices in period 1 will change because of the shifts in the variables of the right-end.

3.3.1 Size effect

Population ageing is not a stationary statistic phenomenon but a dynamic process driven by increasing longevity and declining fertility. Because of these two driving factors, population ageing results in changes in the population size and the age composition at the same time. Those two changes affect house prices differently. We discuss the changes in the population size and its effect at first.

Regarding the long-run population size, the increasing longevity postpones the mortality of the elderly generation, which increases the total population. Meanwhile, the declining fertility decreases the size of the childhood generation. Figure 1 shows the theoretical trend of population size in the process of population ageing.

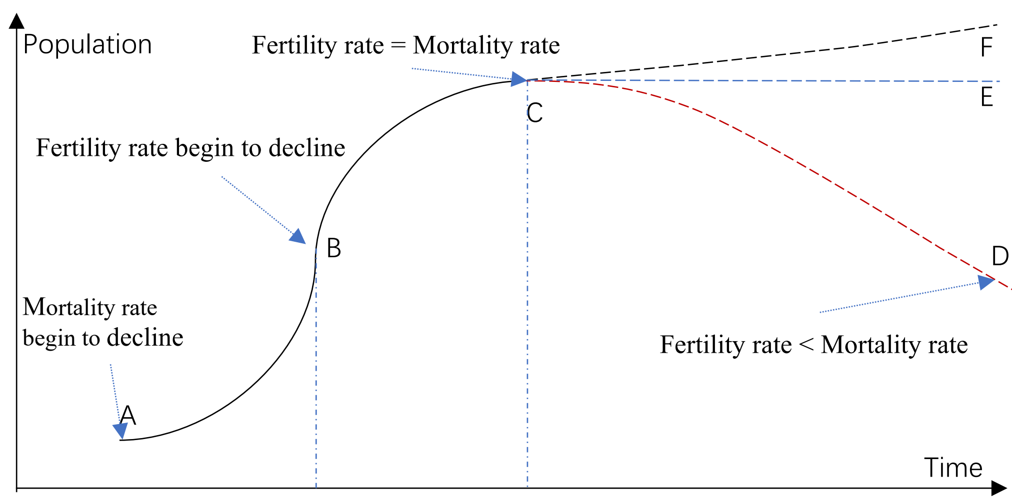

Figure 1 The long-run trend of population size due to population ageing

Population ageing starts from point A in Figure 1. Increasing longevity, which results from economic development, equates to a decline in mortality rate and renders the total population increase. At the same time, the fertility rate remains at least unchanged. From point A to B, the population size increases at the highest growth rate. At point B, the fertility rate begins to decline. This dropping fertility rate reduces the growth rate of the total population. The population size still increases but at a decreasing rate. The population size reaches its peak at point C. The net increase of population stops at point C because the fertility rate decreases to the same level of mortality rate[12]. If the fertility rate holds unchanged after that, the population size will keep its peak scale at point C. The blue straight-line CE shows this trend. If the fertility rate continues to decrease, the population size will decline after point C. The red curve CE shows this trend. If the fertility rate turns higher, the population size will increase after point C. The black curve CE shows this trend. From point A to point C, population ageing generates a continuous increase in the population size.

A change in the house price level due to the population shift from point A to point C without changing the age composition can be labelled as a size or scale effect. Whether the size effect on the house prices is positive or negative can be deduced from the first-order partial derivatives of p_1^*or lnp_1^* with respect to N_o.The first-order partial derivatives of lnp_1^* with respect to N_0 is

$$\frac{\partial lnp_1^*}{\partial N_o} = \frac{1-\rho}{N_y} \frac{\frac{\alpha_3}{\alpha_1+\alpha_3}\left(s_{0,1}(1+r_0)+F\tau_1\right)}{\left[w_{y,1}-s_{y,1}(1+r_1)\right]+\frac{\alpha_3 n_o}{\alpha_1+\alpha_3}\left(s_{0,1}(1+r_0)+F\tau_1\right)} \tag{28}$$

Since ρ denotes the output elasticities of capital, we have $\rho < 1$. Then, whether the first-order partial derivatives of lnp_1^* with respect to N_o, $\frac{\partial lnp_1^*}{\partial N_o}$, is positive or negative depends on the following conditions:

1. If $w_{y,1} - s_{y,1}(1 + r_1) > 0$, which implies the total wage of the young generation is more than their savings when their retirement, we have $\frac{\partial lnp_1^*}{\partial N_o} > 0$, and the size effect is positive.
2. If $w_{y,1} - s_{y,1}(1 + r_1) < 0$, which implies the total wage is less than their savings, but $\frac{\alpha_3 n_o}{\alpha_1+\alpha_3}\left(s_{0,1}(1+r_0)+F\tau_1\right) > \left|w_{y,1}-s_{y,1}(1+r_1)\right|$, we still have $\frac{\partial lnp_1^*}{\partial N_o} > 0$, and the size effect is positive.

[12] In this theoretical analysis, the effect of immigration is not taken into account, because the scale of immigration is relatively insignificant at the national level, and regarding the data of the 35 big cities, the city level demographic statistic data already includes the immigration from small cities and rural areas.

3. If $w_{y,1} - s_{y,1}(1 + r_1) > 0$ and $\frac{\alpha_3 n_o}{\alpha_1+\alpha_3}\left(s_{0,1}(1 + r_0) + F\tau_1\right) < \left|w_{y,1} - s_{y,1}(1 + r_1)\right|$, then $\frac{\partial lnp_1^*}{\partial N_o} < 0$, and the size effect is negative.

Moreover, only the following two extreme criteria are met, we have $w_{y,1} - s_{y,1}(1 + r_1) < 0$.[13] The first is, $d_y p_1 h_y < n_o x_{o,1}$, which means the financial support from parents is larger than the down payment; the second is $c_{y,1} + x_{y,1} + p_1 h_y\left(1 - d_y\right)(1 + r_m) + d_y p_1 h_y < n_o x_{o,1}$, which means the financial support from parents not only covers the total value of the young's house ($p_1 h_y\left(1 - d_y\right)(1 + r_m) + d_y p_1 h_y$), but also paid the young's entire living expense ($c_{y,1} + x_{y,1}$). The savings of generation y consists the entire wages and a part of their parents' financial support. This condition may be met for some richest families, but is hardly met for most ordinary families.

Therefore, in most cases, we can assume that $w_{y,1} - s_{y,1}(1 + r_1) > 0$ holds and have $\frac{\partial lnp_1^*}{\partial N_o} > 0$, which implies that the size or scale effect is positive. With the population ageing, the increase in the population size will generate more demand for houses which will push the house prices up.

3.3.2 Age Composition Effect

Besides the shifts in the population size and the age composition is also changed

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[13] Combining the budget constraint of the young -age stage (equation (5)):

$$w_{y,1} - s_{y,1}(1 + r_1) = c_{y,1} + x_{y,1} + \left(d_y p_1 h_y - n_o x_{o,1}\right) + p_1 h_y\left(1 - d_y\right)(1 + r_m)$$

Since the down payment is just a portion of the whole price, we have $d_y \leq 1$.

If $d_y p_1 h_y > n_o x_{o,1}$, which means that a part of down payment is paid by the wages of the young genration,then we have $w_{y,1} - s_{y,1}(1 + r_1) > 0$;

If $d_y p_1 h_y < n_o x_{o,1}$, which means that the savings transferred from the elderly generation is used to not only pay the entire down payment but also pay some part of living expense of the young, then only when $c_{y,1} + x_{y,1} + p_1 h_y\left(1 - d_y\right)(1 + r_m) > n_o x_{o,1} - d_y p_1 h_y$, we have $w_{y,1} - s_{y,1}(1 + r_1) > 0$

Therefore, only when the following conditions are met at the same time, we have $w_{y,1} - s_{y,1} < 0$:

(1) $d_y p_1 h_y < n_o x_{o,1}$, that means the financial support from parents is larger than the down payment;

(2) $c_{y,1} + x_{y,1} + p_1 h_y\left(1 - d_y\right)(1 + r_m) + d_y p_1 h_y < n_o x_{o,1}$, that means the financial support from parents not only covers the total value of the young's house ($p_1 h_y\left(1 - d_y\right)(1 + r_m) + d_y p_1 h_y$), but also paid the young's entire living expense ($c_{y,1} + x_{y,1}$). The savings of generation y consists the entire wages and a part of their parents' financial support. This condition may be met for some richest families, but is hardly met for most ordinary families.

because of population ageing. Similar to the shifts in population size, increasing longevity and declining fertility shift the old-age dependency ratio. Figure 2 shows the theoretical trend of the old-age dependency ratio in the process of population ageing.

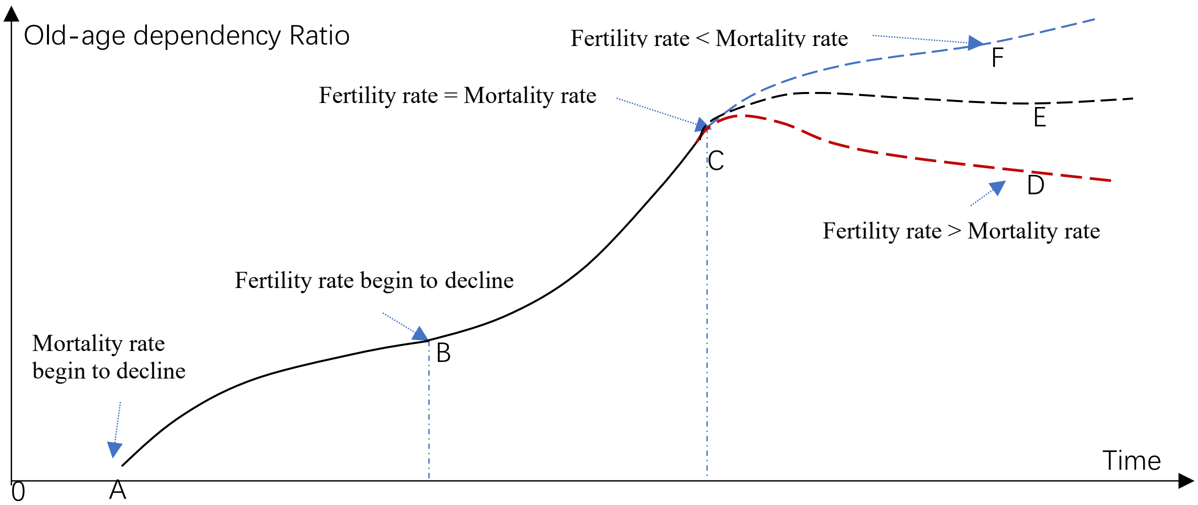

Figure 2 The long-run trend of old-age dependency ratio due to population ageing

Population ageing starts from point A in Figure 2. Increasing longevity increases the population of the elderly generation At the same time, the fertility rate remains at least unchanged. The old-age dependency ratio rises at a relatively low rate from point A to point B. At point B, the fertility rate begins to decline. This dropping fertility rate reduces the population of the young generation in the future, which causes the old-age dependency ratio to rise at a higher rate and reaching its peak at point C. The growth of the old-age dependency ratio stops at point C because the fertility rate decreases to the same level as the mortality rate. From point A to point C, population ageing generates a continuous growth in the old-age dependency ratio.

Optimal housing consumption varies with different life cycle stages (Flavin and Yamashita, 2002). A change in the house price level due to the change in age composition from point A to point C can be labelled as an age composition effect, independent of the size effect. The age composition effect could be estimated by the first-order partial derivatives of p_1^* with respect to n_0. Based on the equation (27), we have,

$$\frac{\partial lnp_1^*}{\partial n_o} = (1-\rho)\left[\frac{1}{\frac{(w_{y,1} - s_{y,1}(1+r_1))(\alpha_1+\alpha_3)}{2\alpha_3\left(s_{0,1}(1+r_0)+F\tau_1\right)} + n_o} - \frac{1}{n_o}\right] \tag{30}$$

As mentioned previously, we can assume that $w_{y,1} - s_{y,1}(1 + r_1) > 0$ holds in most circumstances. Therefore, we have $\frac{(w_{y,1} - s_{y,1}(1+r_1))(\alpha_1 + \alpha_3)}{2\alpha_3(s_{0,1}(1+r_0) + F\tau_1)} > 0$. Substituting this condition into the equation (30), we have,

$$\frac{\partial lnp_1^*}{\partial n_o} = (1-\rho)\left[\frac{1}{\frac{(w_{y,1} - s_{y,1}(1+r_1))(\alpha_1+\alpha_3)}{2\alpha_3(s_{0,1}(1+r_0)+F\tau_1)} + n_o} - \frac{1}{n_o}\right] < 0 \tag{31}$$

Therefore, except for a few extreme circumstances where $w_{y,1} - s_{y,1}(1 + r_1) < 0$, as previously mentioned, we can assume $\frac{\partial lnp_1^*}{\partial n_o} < 0$ in most circumstances, which implies that the age composition effect of population ageing on house prices growth is negative. With the population ageing, an increase in the old-age dependency ratio has a negative impact on the growth of house prices.

In the next chapter, I will build a panel data regression model based on the theoretical model of this chapter and examine the size effect and the age composition effect.

CHAPTER 4 EMPIRICAL ANALYSIS

The theoretical analysis gives the benchmark model of house prices and the hypotheses on the size effect and the age composition effect of population ageing. This chapter conducts an empirical study to estimate and examine those hypotheses using data of 35 Chinese cities from 2002 to 2019 (see Appendix A for city list).

4.1 Regression Model

Based on the equation (27), the econometric regression model of house prices is,

$$ln\,Price_{i,t} = \alpha + \beta_1 lnpop_{i,t} + \beta_2 old_{i,t} + \gamma_1 lnLand_{i,t} + \gamma_2 mortgage_{i,t} + \gamma_3\, ln\,saving_{i,t} + \gamma_4\, ln\,wage_{i,t} + u_i + \lambda_t t + \varepsilon_{i,t} \qquad (32)$$

In the above model, subscript i denotes different cities, and t represents different years. The explained variable $ln\,Price_{i,t}$ is the logarithm of house prices of city i in year t; The explanatory variable $lnpop_{i,t}$ denotes the logarithm of population size of city i in year t ; and $old_{i,t}$ denotes the old-age dependence ratio for city i in year t.

There are four other explanatory variables in the regression model. $lnLand_{i,t}$ represents the logarithm of the total amount of land used to build houses in the city i in year t. As mentioned in Chapter 3, it is a critical input in house development. $mortgage_{i,t}$ denotes the mortgage loan rate in city i in year t. The mortgage rate is an exogenous variable. The central bank sets the bottom of mortgage rate. $ln\,saving_{i,t}$ denotes the logarithm of household savings of people in city i in year t. The household savings is a critical control variable when solving the optimal consumption for an average individual in Chapter 3. $ln\,wage_{i,t}$ denotes the logarithm of the annual wage for an average individual in city i in year t. The two control variables, $ln\,wage_{i,t}$ and $ln\,saving_{i,t}$, can indirectly reflect the change in the budget constraints of buyers.

Many other control variables are not contained in the regression model because the data are not available. Some change with different cities, such as land price (τ_1), the down payment ratio (d) and the property-purchasing limitations set by different local governments. Some change with time, such as the technical development in the real estate industry (A), the elasticity of capital input for real estate developers (ρ), the return of capital input for real estate developers (r).

I try to include the influence of those variables by using this panel data regression model. u_i is the entity fixed effects estimator and λ_t is the time fixed effects estimator. Based on the theoretical analysis, β_1 , the coefficient of $lnpop_{i,t}$, is expected to be positive since it reflects the size effect, and, β_2, the coefficient of $old_{i,t}$, is expected to be negative because it estimates the age composition effect.

Table 2 gives the specific definition of statistic indicators used in the variables of the econometric model.

Table 2 Definition of Regression Variables

Variable Name	Symbol	Source Sample Data	Description (Source: National Bureau of Statistics of China)
Explained Variable			
The logarithm of house prices	$ln\,Price$	House annual average selling price	The annual average selling price of commercialized residential buildings for a given city
Explanatory Variables			
The logarithm of population size	$lnpop$	Total Population (year-end)	Total Population (year-end) is the figure of household registration from the Ministry of Public Security at year-end.
Old-age dependence ratio	old	Old-age dependence ratio	Old-age dependency ratio= (population aged over 64 years old)/ (population aged 15–64 years old)
Control Variables			
The logarithm of the total amount of land	$lnLand$	Floor Space of Residential Buildings for Real Estate Development	The floor space of residential buildings completed in the reference period
Mortgage loan rate	$mortgage$	Lending Rate	Lending rate for individual housing provident fund loan
The logarithm of household savings	$lnsaving$	Savings Deposit of Urban Households, Balance at Year-end	Household Savings Deposits refer to the total savings of urban residents at a certain point in time on banks and other financial institutions.
The logarithm of annual wage	$lnwage$	Average Wage of Staff and Workers	The average wage of staff and workers = total wages of on-the-job workers /the average number of workers

In China's housing market, lands are auctioned by a local government with a specific "floor area ratio"[14]. Only after knowing this ratio can developers calculate the floor space they are allowed to build. They estimate their profit according to the floor area and then bid on the land. As the floor area ratio is different across lands, I take the floor space—the

[14] Floor area ratio (FAR) is the ratio of a building's total floor area (gross floor area) to the size of the piece of land upon which it is built. It is often used as one of the regulations in city planning along with the building-to-land ratio.

product of land area and the ratio—as the source data of land.

4.2 Data

The data used in the empirical study are all collected from the China Regional Statistical Yearbook published by the National Bureau of Statistics of China, which covers 35 cities from 2002 to 2019. One important reason for using the data of the 35 cities rather than using the province data or including more data from medium or small cities is to avoid the heterogeneity between different regional housing markets[15].

The data is balanced, with no missing values. Table 3 shows the descriptive statistics of the source sample data. The source sample data's standard deviations and means are different for different indicators. Some data need to be transferred into the logarithm for further analysis.

Table 3 Summary Statistics of Source Data

	Mean	SD	Min	Max	Median
House average price	7299.228	6653.254	1202.000	55769	5610.255
Total Population	710.458	545.154	132.960	3416.29	650.9
Old-age dependence ratio	.132	.03	0.070	.238	.129
Floor Space	658.793	573.676	41.100	3400.08	478.02
Average Wage (yuan)	43004.546	26327.619	9174.000	173205	38655.5
Household savings (100 million yuan)	4100.713	4893.457	88.650	37309.68	2508.25
Lending Rate	4.123	.566	3.250	5	4.15

Source: National Bureau of Statistics of China.

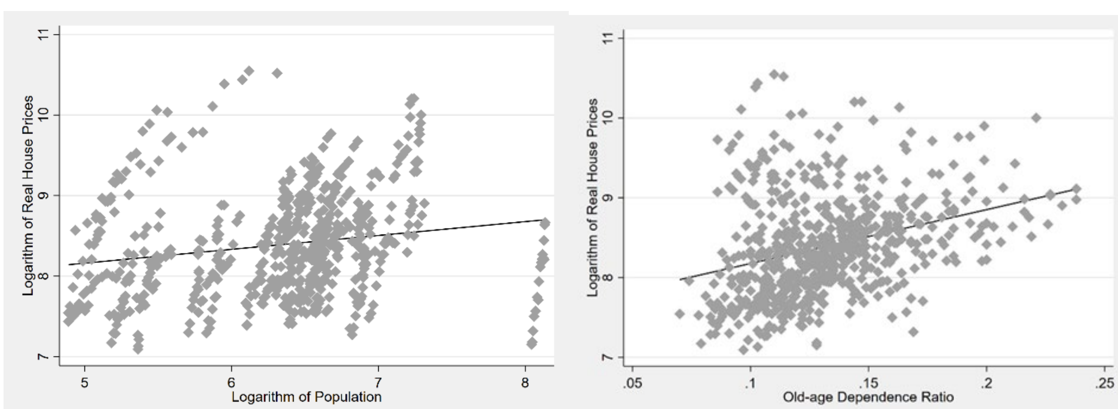

Figure 3 Scatter plots of the explained variable and explanatory variables

Figure 3 shows several uphill patterns for a different level of the logarithm of the

[15] All 35 big cities are the economic centers. Among them, 31 cities are also the political centers. These 35 cities are treated specially in the statistical data of the National Bureau of Statistics of China.

population. There is no apparent relationship between the logarithm of house prices and the old-age dependence ratio, which may be influenced by the panel data's fixed and random effects.

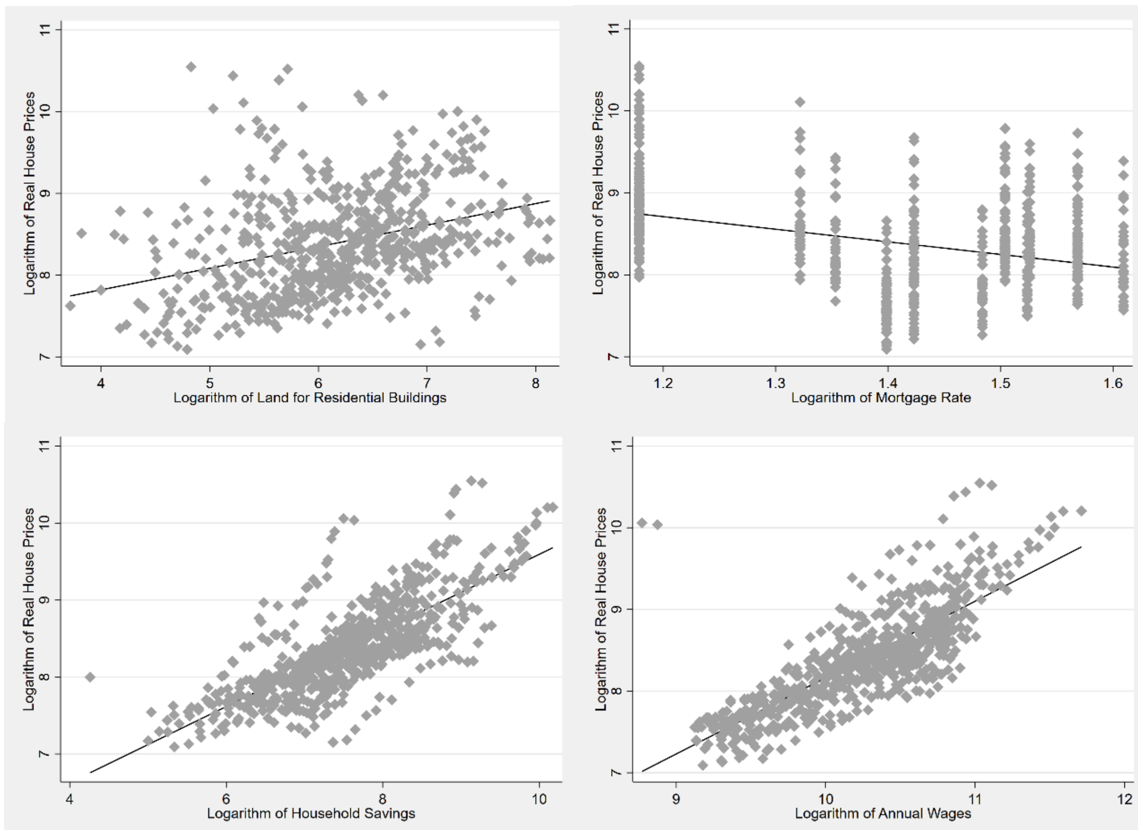

Figure 4 Scatter plots of the explained variable and control variables

The scatter plot of the logarithm of mortgage rate shows the fixed time effect, which corresponds to China's mortgage market, where the central bank sets and adjusts the bottom of the mortgage loan's interest rate. The scatter plot of land for residential buildings shows a similar uphill pattern as the scatter plot of the old-age dependence ratio. This unclear pattern may be affected by the panel data's fixed effects and random effect.

For further analysis, I examine the correlation between different variables. Some pairs of explanatory variables show significant correlations (see Appendix B). I also examine the potential multicollinearity by variance inflation factors (VIF) among explanatory and control variables (see Appendix B).

4.3 Regression Analysis

4.3.1 Regression results

I run different panel data regressions. The results are shown in the following Table 4.

Table 4 Estimation of Regression

VARIABLES	(1) OLS	(2) FE	(3) FE-T	(4) FE-Year	(5) RE	(6) RE-Trend	(7) RE-Year
$lnpop$	-0.446***	0.683***	0.431***	0.410***	0.062	0.166***	0.208***
	(-3.05)	(2.86)	(3.52)	(3.37)	(1.11)	(2.74)	(4.17)
old	1.399	-0.288	-1.214**	-1.006	-0.836*	-0.771*	-1.358***
	(1.15)	(-0.51)	(-2.63)	(-1.51)	(-1.94)	(-1.82)	(-3.45)
$lnsavings$	0.635***	0.419*	0.083	-0.002	0.464***	0.449***	0.135***
	(5.75)	(1.92)	(1.20)	(-0.04)	(13.25)	(12.81)	(3.81)
$lnLand$	-0.083	-0.091***	-0.070***	-0.069***	-0.118***	-0.113***	-0.073***
	(-1.37)	(-3.40)	(-3.00)	(-2.81)	(-6.68)	(-6.49)	(-5.01)
$lnwage$	0.251*	0.315	0.001	-0.067	0.371***	0.363***	-0.037
	(1.85)	(1.24)	(0.01)	(-1.55)	(9.79)	(9.61)	(-0.95)
$mortgage$	0.044	0.001	0.064***	-1.854***	-0.004	-0.004	-1.581***
	(1.57)	(0.07)	(3.80)	(-12.62)	(-0.27)	(-0.24)	(-15.71)
2003.year				0.072***			0.048
2004.year				0.328***			0.260***
2005.year				0.966***			0.810***
2006.year				1.422***			1.201***
2007.year				2.335***			2.002***
2008.year				1.984***			1.691***
2009.year				0.430***			0.353***
2010.year				1.105***			0.932***
2011.year				2.329***			1.971***
2012.year				1.998***			1.678***
2013.year				1.853***			1.550***
2014.year				1.870***			1.564***
2015.year				0.543***			0.429***
2016.year				-0.298***			-0.279***
2017.year				-0.176***			-0.165***
2018.year				-0.056***			-0.049
t			0.075***			0.001**	
			(8.92)			(2.56)	
Constant	3.989***	-1.747	-18.165***	13.770***	1.537***	0.831*	12.802***
	(2.85)	(-1.30)	(-8.49)	(8.87)	(3.86)	(1.94)	(16.06)
R-squared	0.811	0.885	0.914	0.934	0.873	0.877	0.931
City FE		YES	YES	YES			
Year FE				YES			
RE					YES	YES	YES
Year RE							YES
Trend RE						YES	

Robust t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The regression in Column (4) has the following interesting results.

1. The effect of population size is positive, the same as the prediction of theoretical

analysis. The coefficient on the logarithm of the population is 0.410, which implies that a 1% increase in population size pushes real house prices by 0.41%.

2. The age composition effect is negative, the same as the prediction of theoretical analysis. The coefficient on the logarithm of the old-age dependency ratio is -1.006, which implies that a 1% increase in the old-age dependency ratio can lead to a 1% drop in real house prices.
3. The mortgage rate has a significant influence on house prices growth. The coefficient is -1.854, implying that a 1% increase in the mortgage rate can lower real house prices by 1.854%. The mortgage rate is set and adjusted by the central bank. This estimate suggests that the central bank has the most influence on house prices.
4. The effects of household savings, wage and land supply are estimated to have a negligible impact on house prices. The coefficient on the logarithm of land is precisely estimated as -0.069, which means a 1% increase in the land supply can only decrease the real house prices by 0.069%. A 1% decrease in land supply only leads to a 0.069% increase in the real house prices, which implies land supply is not a good choice for controlling house prices.

Column (2) in Table 4 presents panel data regression results with city fixed effect. Comparing this result with the pooled OLS regression results in Column (1), we can find that the positive coefficient estimates of the pooled OLS result from omitting the city fixed effects. The regression R^2 jumps from 0.811 to 0.885 when fixed effects are included. More importantly, after considering the city fixed effect, the coefficient on the logarithm of the population is positive, and on the old-age dependency ratio is negative, which is inverse to the results of pooled OLS regression but in line with the theoretical analysis result and most other studies. The regression in Column (2) shows that the 94.8% total variance could be attributed to the fixed city effect (see Appendix C for the detailed regression results).

Estimates change when time effects are added, as reported in Column (3). The estimates of coefficients of population size and old-age dependency ratio shift significantly. The regression R^2 jumps from 0.885 to 0.914, and the coefficient on the old-age dependency ratio is now estimated more precisely. The regression in Column (3) also shows that the 99% total variance could be attributed to both the city fixed effect and time fixed effect (see Appendix C for the detailed regression results).

However, the regression in Column (3) assumes that every sample period has an equal time fixed effect. The coefficient of the time variables t is 0.075, which implies that every year the time fixed effect generates a 0.075% increase in house prices. This assumption may not hold. For example, the property-purchasing limitations set by local governments is changed a lot in the sample period.

Therefore, the regression in Column (4) set different dummy times every year. All of the time effects are strongly significant, and some are positive while others are negative. since they don't appear to follow a linear trend at all, that might be stronger evidence of this specification. The coefficient of the logarithm of mortgage rate changes from 0.064 in Column (3) to -1.854 in Column (4) with a similar significance. The former implies that a higher mortgage rate encourages a higher house price. The latter shows that a higher mortgage rate negatively impacts house prices than the other five variables. A slight increase in the mortgage rate could largely increase the total purchase cost because the interest is compounded.

The results in columns (1) through (4) omits some fixed factors—the land price, the down payment ratio, the property-purchasing limitations set by different local governments, the technical development in the real estate industry, the elasticity of capital input of developers, the return of capital, and so forth. Those variables are important determinants of the variation in house prices across cities.

Fixed effects regression is run under the assumption that these variables are related to two explanatory variables and four control variables, at the cost of relatively less precise estimates on the coefficients.

The next four regressions in Table 4 replace the former three fixed effect regression with three random effect regressions. The random effects assumptions include all of the fixed effects assumptions plus the additional requirement that unobserved effect is independent of all explanatory variables in all periods. Tighter constraints may lead to more accurate estimates.

The regression in Column (5) does not include time dummy variables. We can see that both the explanatory ability of the whole regression model and the accuracy of estimate on coefficients are lower than the fixed effect regressions. The regression in Column (6) includes a time variable t. The meaning of the coefficient of the time variable differs from the similar coefficient in the regression in Column (3). This coefficient of the time variable can be explained as the average growth rate of house prices. However, the regression R^2 of this model is worse than any fixed effect model. The regression in Column (7) replaces the unchanged time trend with different dummy time variables for every year as the regression in Column (4). The regression R^2 jumps from 0.8775 in Column (6) to 0.9315 in Column (7), and the accuracy of most coefficients are improved.

I run several tests to find which is better between the regressions in columns (4) and (7). The result of the Breusch-Pagan LM test shows the random effect is significant. However, results of the Hausman test, Mundlak formulation test and modified Wald test show that the fixed effect regression is better. Moreover, the omitted factors—the land auction price, the down payment ratio, the property-purchasing limitations, the elasticity of capital, the return of capital, and so forth—may relate to the explanatory variables and control variables, which means the assumption of random regression cannot be met. Therefore, the regression in Column (4) provides more reliable estimates. Moreover, the estimates in Column (7) fall in the 95% confidence interval of Column (4) estimates.

4.3.2 Prediction

The Department of Economic and Social Affairs of the United Nations Secretariat produces estimates of population demographics for China and other countries from 2025 to 2100 (United Nations, 2020). Population sizes are forecasted yearly, and the age-dependency ratios are predicted every five years (see Appendix D for detailed estimates). I use these estimates to evaluate the expected effect of population ageing based on the projections of the UN.

It is worth noting that the expected effect of population ageing may include bias but can still display the long-run trend. Since the estimated coefficients of the panel data regression are based on the 35 big cities in China to avoid heterogeneity, the coefficients only evaluate the reaction of house prices in those 35 big cities. The housing markets of medium and small cities are not considered in the theoretical or regression models.[16]

[16] As mentioned in Chapter 2, the young generation of some small cities in the northeast of China has continuously emigrated from their hometown to some big cities to seek more opportunities. This is one of the reasons that generate

I use the estimates from the regression in column (4) to calculate the expected size effects of the population ageing on house prices. The size effect is derived from the change in the population size because of population ageing. This trend is shown in Figure 1 of Chapter 3 and Figure 5.

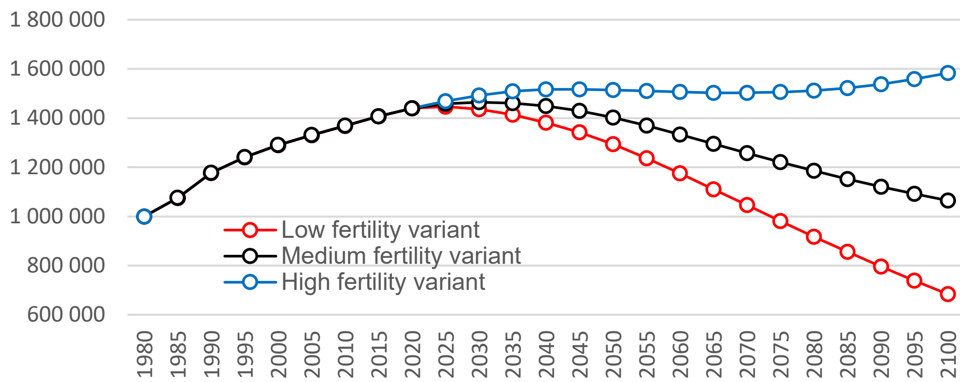

Figure 5 Projections of population size of China from 2020 to 2100

Figure 5 shows the trend of population size of China from 2020 to 2100 forecasted by the Department of Economic and Social Affairs, United Nations. The data from 1980 to 2020 is the actual statistic numbers. The predicted data is from 2020 to 2100. The actual trend from 1980 to 2020 shows an increase in population size, which verifies the theoretical trend in Figure 1 of Chapter 3.

After 2020, the forecasted data is divided into three projections: low fertility variant projection (red line), medium fertility variant projection (black line), and high fertility variant projection (blue line). The medium fertility variant projection is based on median probabilistic total fertility (United Nations, 2020). [17] In the high variant, total fertility is projected to reach a fertility level that is 0.5 births above the total fertility in the medium variant. In the low variant, total fertility is projected to remain 0.5 births below the total

heterogenicity among the housing markets of big cities and of other cities. Besides this, the savings of elderly generations may not enough to pay their own retired lives, which make they are dependent on the financial support from their grown children. The land supply may not inelasticity as in big cities. Therefore, if we try to model the relationship between the population ageing and house prices in the medium and small cities, we should build a different model and a different regression equation.

[17] According to the definition part of "World Population Prospects 2019", probabilistic methods were used to reflect the uncertainty of the projections based on the historical variability of changes in each variable. The method takes into account the past experience of each country, while also reflecting uncertainty about future changes based on the past experience of other countries under similar conditions. The medium-variant projection corresponds to the median of several thousand distinct trajectories of each demographic component derived using the probabilistic model of the variability in changes over time. Prediction intervals reflect the spread in the distribution of outcomes across the projected trajectories and thus provide an assessment of the uncertainty inherent in the medium-variant projection (United Nations, 2020).

fertility in the medium variant (United Nations, 2020). The trends of the three projections are in line with the theoretical projection of population size under the condition of population ageing in the statistic comparative analysis section of Chapter 3.

To estimate the expected future size effect, I calculate the change in the logarithm of population size and then multiply those percentage changes with the estimated coefficient $\beta_1 = 0.410$. The result of this prediction is shown in Figure 6.

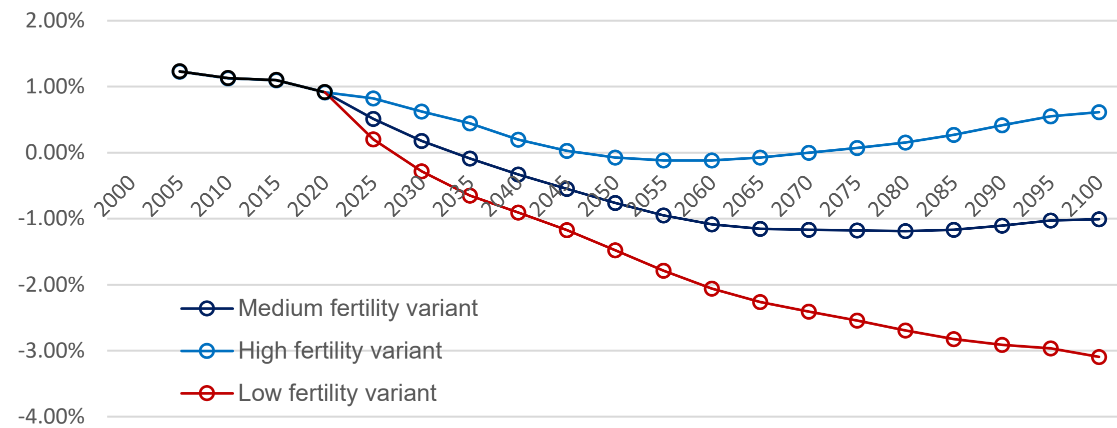

Figure 6 The expected size effect of population ageing from 2020 to 2100

The black line in Figure 6 is the expected size effects of population ageing assuming the median probabilistic total fertility. It shows that the size effect remains positive before 2025, but becomes negative after 2030. From 2025 to 2030, the total population in China will reach its largest scale, according to the projection of the UN. Compared the black line with the red lines, a lower fertility rate accelerates the coming of negative size effect. On the contrary, a higher fertility rate will postpone the negative effect to 2050, and soon return to the positive effect because of the high fertility rate. Overall, the size effect of population ageing displays downward trends from 2020 to 2055, from the highest positive effect in 2020 to the negative effect in 2055. From 2055 to 2100, if the fertility rate holds a high level, the size effect returns to positive because of a net increase in population size. However, if the fertility rate keeps unchanged or falls to a lower level, the size effect will continue to be negative because of the net reduction in population size.

Figure 7 shows the trend of the old-age dependency ratio of China from 2020 to 2100 forecasted by the Department of Economic and Social Affairs, United Nations. The old-age dependency ratio shows a long-run growth from 2020 to 2100. If the fertility rate keeps at a high level after 2030, this ratio may decrease because of more young generations.

Similarly, this projection also verified the theoretical trend of the old-age dependency ratio in Figure 2 of Chapter 3. To estimate the expected age composition effect, I calculate the changes in the old-age dependency ratio and multiply those changes with the estimated coefficient $\beta_2 = -0.1006$. The result of this prediction is shown in Figure 8.

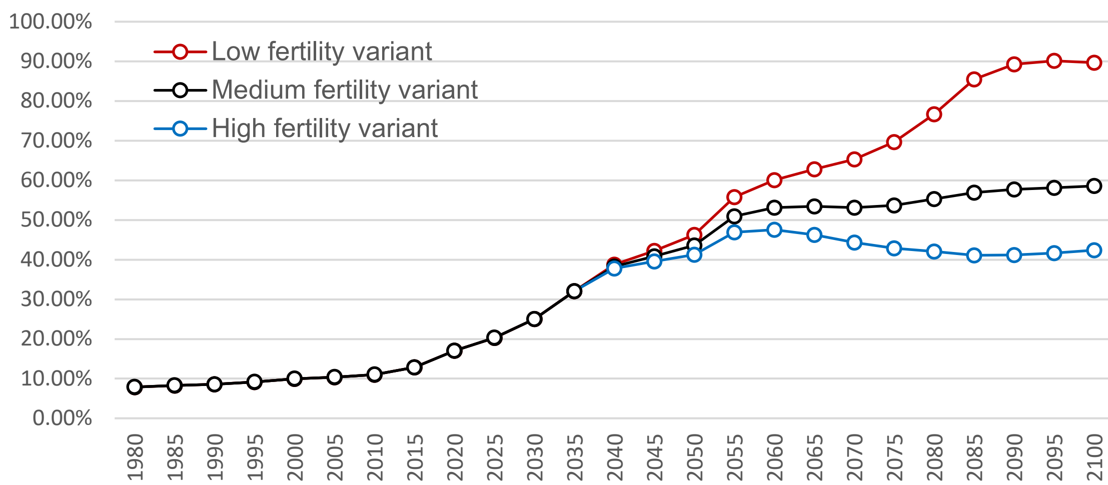

Figure 7 Projections of old-age dependency ratio from 2020 to 2100

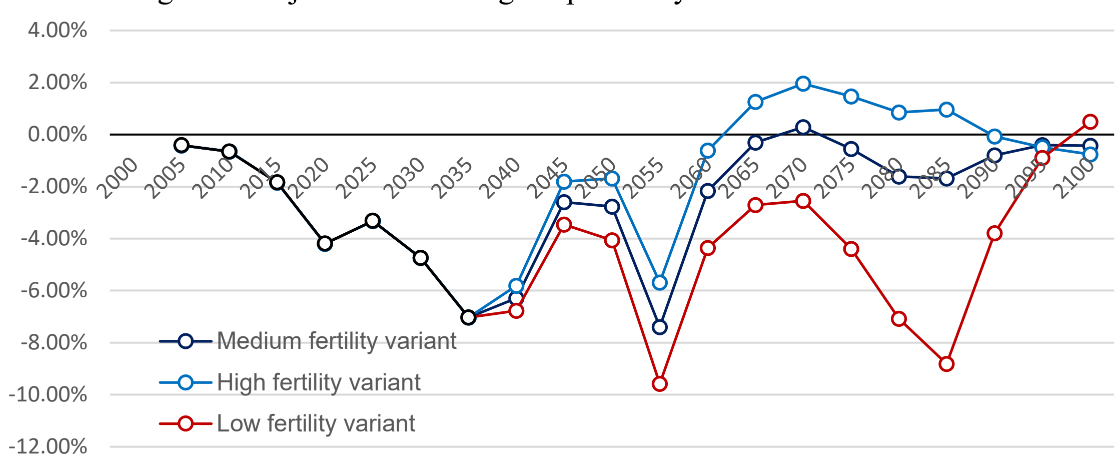

Figure 8 The expected age composition effect of population ageing from 2020 to 2100

The trend of age composition effects in Figure 8 shows that this effect remains negative for most of the period from 2005 to 2100. Around 2070, this effect turns positive because of a decline in the old-age dependency ratio. Another feature is the fluctuations in the age composition effects on house prices, determined by the changes in the old-age dependency ratio.

To evaluate the total expected effect of the population ageing on house prices from 2020 to 2100, the size effect and the age composition effect are summed in every year the result is shown in Figure 9. Before 2035, adding a positive and decreasing size effect to a negative and increasing age composition effect generates a total negative effect. From 2035 to 2065, the size and age composition effects are negative, and the fluctuation in this period is derived from the change in the old-age dependency ratio. After 2065, if the fertility rate can keep a high level, the total effect may return to positive because of growth in population size; however, if the fertility rate keeps unchanged or even declines, the total effect of population ageing on house prices is still negative.

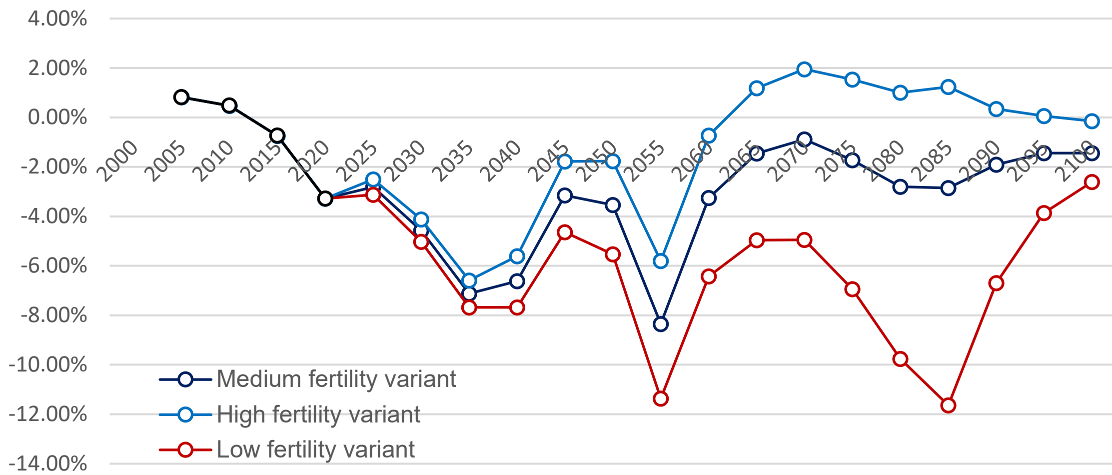

Figure 9 The total expected effect of population ageing from 2020 to 2100

The prediction for the long-run trend of the total effect shows both negative and positive impacts. However, this situation is not a result of a nonlinear relationship between the changes in population ageing and changes in house prices. Figure 9 shows that the sum of two different effects—the population size effect and the age composition effect—can also generate a fluctuation trend in the long run.

CHAPTER 5 CONCLUSION

Many recent papers have studied the link between population aging and house prices. However, the term "population aging" can be misleading because it represents two different factors: growth in the overall population and changes in the age distribution.

Those two changes may generate opposite effects. For example, some papers find the impact of population ageing on house prices is negative, while others conclude a positive effect.

This thesis distinguishes between the two different effects: the size effect and the age composition effect. Chapter 3 builds a partial equilibrium model to show that the size effect is positive and the age composition effect is negative in most circumstances. In chapter 4, based on the data of 35 cities from 2002 to 2019, panel data regressions are used to examine the actual effect of population ageing. The results of the empirical analysis are correspondent to the predictions of the theoretical analysis. For the positive population size effect, a 1% increase in population size can push house prices by 0.41%. Based on the negative age composition effect, a 1% increase in the old-age dependence ratio can lead to house prices dropping by 1%.

The empirical analysis also shows that either the size effect or the age decomposition effect is more influential than the effect of wage or household savings on house prices. The mortgage loan rate has the greatest influence on house prices—a 1% increase in mortgage loan rate can lower the house prices by 6.74%. This result suggests that bank credit drives China's house market. Although population ageing has a moderate effect on house prices, its influence can be accumulated in the long run. Labour income and household savings have little impact on the house prices.

Overall, a positive size effect and a negative age composition effect of population ageing on house prices are shown and examined by using panel data regressions. This result can help to clarify the discussion on the effect of population ageing on the housing market. Further, the effect of population ageing on other markets could also be studied following the same approach.

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Appendix A City List

City	Population 10000 persons	Old-age dependency ratio	Average Selling Price of Residential Buildings(yuan/sq.m)
Beijing	1397.4	16.3	38433
Tianjin	1108.18	15.6	15423
Shijiazhuang	1052.39	19.3	9234
Taiyuan	383.5	14.9	11136
Hohhot	248.74	13.3	10029
Shenyang	756.4	21.6	10251
Dalian	598.69	21.6	12041
Changchun	753.8	17.7	8731
Harbin	951.34	18.1	9780
Shanghai	1469.3	22.1	32926
Nanking	709.82	21.2	19428
Hangzhou	795.37	19.3	26522
Ningbo	608.47	19.3	15956
Hefei	770.44	20.7	14086
Fuzhou	710.09	13.7	14186
Xiamen	261.1	13.7	33830
Nanchang	536	14.6	9355
Jinan	796.74	23.8	11947
Qingdao	831.07	23.8	13674
Zhengzhou	881.6	17.2	9332
Wuhan	906.4	18.3	13834
Changsha	738.24	19.7	8227
Guangzhou	953.72	11.4	24015
Shenzhen	550.71	11.4	55769
Nanning	781.97	14.9	8574
Haikou	182.89	13.1	15562
Chongqing	3416.29	22.6	8657
Chengdu	1500.07	23.2	11729
Guiyang	427.83	17.5	9799
Kunming	578.46	13.7	12123
Sian	956.74	16.4	11627
Lanzhou	331.92	16.1	7332
Xining	209.37	11.8	8731
Yinchuan	199.57	13.6	6440
Urumchi	226.82	11.9	8728

Appendix B Pairwise Correlations and VIF

Table 5 shows the correlation matrix of the dataset. Some pairs of explanatory variables show significant correlations. Those correlations could be explained. For example, people with higher wages may also have higher savings, so there is a positive correlation between the logarithms of the wage and the savings. Municipalities supply land according to the population size, so there is a positive correlation between logarithms of the population and the land, which partly supports the assumption of inelasticity of land in respect to house prices.

Table 5 Pairwise Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) lnp	1.000						
(2) lnpop	0.184*	1.000					
(3) old	0.321*	0.541*	1.000				
(4) lnL	0.346*	0.709*	0.493*	1.000			
(5) lnwage	0.793*	0.202*	0.428*	0.403*	1.000		
(6) lnsavings	0.769*	0.670*	0.497*	0.683*	0.718*	1.000	
(7) lnR	-0.349*	-0.056	-0.405*	-0.005	-0.456*	-0.293*	1.000

*** *p<0.01*, ** *p<0.05*, * *p<0.1*

The above correlations remind us to examine the potential multicollinearity. Table 6 shows the variance inflation factors (VIF) among explanatory variables and control variables. The mean VIF is 3.176, and the highest VIF is 5.437, implying that the potential multicollinearity may not significantly impact our regression.

Table 6 Variance Inflation Factors

	VIF	1/VIF
lnsavings	5.437	.184
lnpop	3.809	.263
lnwage	3.57	.28
lnL	2.688	.372
old	1.984	.504
lnR	1.568	.638
Mean VIF	3.176	.

Appendix C Detail Regression Results

Linear regression: Pooled OLS of Column (1)

lnp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnpop	-.446	.146	-3.05	.004	-.742	-.149	***
old	1.399	1.211	1.15	.256	-1.063	3.86	
lnland	-.083	.061	-1.37	.18	-.207	.04	
mortgage	.044	.028	1.57	.126	-.013	.1	
lnsavings	.635	.111	5.75	0	.411	.86	***
lnwage	.251	.136	1.85	.073	-.025	.527	*
Constant	3.989	1.4	2.85	.007	1.143	6.834	***

Mean dependent var	8.392	SD dependent var	0.628
R-squared	0.811	Number of obs	630
F-test	116.246	Prob > F	0.000
Akaike crit. (AIC)	163.996	Bayesian crit. (BIC)	195.116

**** p<.01, ** p<.05, * p<.1*

Regression results: City fixed effect model of Column (2)

lnp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnpop	.683	.238	2.86	.007	.198	1.168	***
old	-.288	.563	-0.51	.613	-1.432	.857	
lnland	-.091	.027	-3.40	.002	-.145	-.037	***
mortgage	.001	.017	0.07	.942	-.032	.035	
lnsavings	.419	.218	1.92	.064	-.025	.863	*
lnwage	.315	.254	1.24	.223	-.2	.83	
Constant	-1.747	1.346	-1.30	.203	-4.482	.989	

Mean dependent var	8.392	SD dependent var	0.628
R-squared	0.885	Number of obs	630
F-test	141.636	Prob > F	0.000
Akaike crit. (AIC)	-602.720	Bayesian crit. (BIC)	-576.046

**** p<.01, ** p<.05, * p<.1*

Regression results: City fixed effect and time fixed effect model of Column (3)

lnp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnpop	.431	.122	3.52	.001	.182	.679	***
old	-1.214	.461	-2.63	.013	-2.151	-.277	**
lnland	-.07	.023	-3.00	.005	-.118	-.023	***
mortgage	.064	.017	3.80	.001	.03	.098	***
lnsavings	.083	.069	1.20	.237	-.057	.222	
lnwage	.001	.083	0.01	.993	-.168	.17	
t	.075	.008	8.92	0	.058	.092	***
Constant	-18.165	2.139	-8.49	0	-22.511	-13.819	***

Mean dependent var	8.392	SD dependent var	0.628
R-squared	0.914	Number of obs	630
F-test	268.471	Prob > F	0.000
Akaike crit. (AIC)	-785.262	Bayesian crit. (BIC)	-754.141
Rho (fraction of variance due to u_i)	.99990497		

**** p<.01, ** p<.05, * p<.1*

Regression results: City fixed effect and time fixed effect model of Column (4)

lnp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnpop	.41	.122	3.37	.002	.163	.658	***
old	-1.006	.666	-1.51	.14	-2.358	.347	
lnland	-.069	.025	-2.81	.008	-.119	-.019	***
mortgage	-1.854	.147	-12.62	0	-2.153	-1.556	***
lnsavings	-.002	.054	-0.04	.967	-.111	.107	
lnwage	-.067	.044	-1.55	.131	-.156	.021	
2002b	0	.	.	.	.	.	
2003	.072	.018	3.95	0	.035	.11	***
2004	.328	.044	7.53	0	.239	.416	***
2005	.966	.093	10.37	0	.777	1.156	***
2006	1.422	.13	10.92	0	1.157	1.687	***
2007	2.335	.194	12.01	0	1.939	2.73	***
2008	1.984	.17	11.66	0	1.638	2.329	***
2009	.43	.058	7.47	0	.313	.546	***
2010	1.105	.107	10.37	0	.889	1.321	***
2011	2.329	.207	11.23	0	1.908	2.75	***
2012	1.998	.185	10.79	0	1.622	2.375	***
2013	1.853	.174	10.64	0	1.499	2.207	***
2014	1.87	.174	10.73	0	1.516	2.224	***
2015	.543	.073	7.39	0	.394	.692	***
2016	-.298	.03	-9.98	0	-.359	-.237	***
2017	-.176	.025	-7.00	0	-.227	-.125	***
2018	-.056	.017	-3.33	.002	-.09	-.022	***
2019o	0	.	.	.	.	.	
Constant	13.77	1.552	8.87	0	10.616	16.924	***

Mean dependent var	8.392	SD dependent var	0.628
R-squared	0.934	Number of obs	630
F-test	200.944	Prob > F	0.000
Akaike crit. (AIC)	-920.045	Bayesian crit. (BIC)	-822.239

*** *p<.01, *** *p<.05, * *p<.1*

Regression results: Random effect model of Column (5)

lnp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnpop	.062	.056	1.11	.268	-.048	.172	
old	-.836	.43	-1.94	.052	-1.678	.007	*
lnland	-.118	.018	-6.68	0	-.153	-.083	***
mortgage	-.004	.015	-0.27	.79	-.034	.026	
lnsavings	.464	.035	13.25	0	.396	.533	***
lnwage	.371	.038	9.79	0	.297	.446	***
Constant	1.537	.399	3.86	0	.756	2.318	***

Mean dependent var	8.392	SD dependent var	0.628
Overall r-squared	0.699	Number of obs	630
Chi-square	3929.285	Prob > chi2	0.000
R-squared within	0.873	R-squared between	0.541

*** *p<.01, *** *p<.05, * *p<.1*

Regression results: Random effect model of Column (6)

lnp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnpop	.166	.061	2.74	.006	.047	.284	***
old	-.771	.424	-1.82	.069	-1.602	.06	*
lnland	-.113	.017	-6.49	0	-.147	-.079	***
mortgage	-.004	.015	-0.24	.814	-.033	.026	
lnsavings	.449	.035	12.81	0	.38	.518	***
lnwage	.363	.038	9.61	0	.289	.437	***
t	.001	0	2.56	.01	0	.001	**
Constant	.831	.428	1.94	.052	-.007	1.67	*

Mean dependent var	8.392	SD dependent var	0.628
Overall r-squared	0.661	Number of obs	630
Chi-square	4078.634	Prob > chi2	0.000
R-squared within	0.877	R-squared between	0.490

**** p<.01, ** p<.05, * p<.1*

Regression results: Random effect model of Column (7)

lnp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnpop	.208	.05	4.17	0	.11	.307	***
old	-1.358	.394	-3.45	.001	-2.13	-.585	***
lnsavings	.135	.035	3.81	0	.066	.205	***
lnland	-.073	.015	-5.01	0	-.102	-.045	***
lnwage	-.037	.04	-0.95	.344	-.115	.04	
mortgage	-1.581	.101	-15.71	0	-1.778	-1.384	***
2002b	0	.	.	.	.	.	
2003	.048	.032	1.53	.127	-.014	.11	
2004	.26	.039	6.71	0	.184	.336	***
2005	.81	.064	12.61	0	.684	.936	***
2006	1.201	.085	14.05	0	1.033	1.368	***
2007	2.002	.128	15.69	0	1.752	2.252	***
2008	1.691	.112	15.07	0	1.471	1.911	***
2009	.353	.036	9.73	0	.282	.424	***
2010	.932	.063	14.86	0	.809	1.054	***
2011	1.971	.127	15.50	0	1.721	2.22	***
2012	1.678	.112	14.99	0	1.459	1.898	***
2013	1.55	.106	14.67	0	1.343	1.757	***
2014	1.564	.108	14.51	0	1.353	1.775	***
2015	.429	.044	9.75	0	.343	.515	***
2016	-.279	.034	-8.19	0	-.346	-.213	***
2017	-.165	.032	-5.12	0	-.229	-.102	***
2018	-.049	.031	-1.56	.12	-.11	.013	
2019o	0	.	.	.	.	.	
Constant	12.802	.797	16.06	0	11.24	14.365	***

Mean dependent var	8.392	SD dependent var	0.628
Overall r-squared	0.532	Number of obs	630
Chi-square	6791.256	Prob > chi2	0.000
R-squared within	0.931	R-squared between	0.149

**** p<.01, ** p<.05, * p<.1*

Appendix D Projections on Demographic Data and Population Ageing Effects

Demographic Projections from World Population Prospects

Year	Old-age dependency ratio (%)			Population (thousands)		
	Fertility variant			Fertility variant		
	Medium	High	Low	Medium	High	Low
2025	20.3	20.3	20.3	1 457 908	1 469 113	1 446 703
2030	25.0	25.0	25.0	1 464 340	1 492 094	1 436 586
2035	32.0	32.0	32.0	1 461 083	1 508 694	1 413 473
2040	38.3	37.8	38.8	1 449 031	1 516 205	1 381 915
2045	40.9	39.6	42.2	1 429 312	1 517 332	1 342 146
2050	43.6	41.3	46.2	1 402 405	1 514 606	1 293 619
2055	51.0	46.9	55.8	1 369 594	1 510 224	1 237 153
2060	53.1	47.5	60.1	1 333 031	1 505 820	1 175 180
2065	53.4	46.3	62.8	1 295 285	1 503 119	1 110 745
2070	53.1	44.3	65.3	1 258 054	1 503 092	1 046 063
2075	53.7	42.9	69.7	1 221 580	1 505 726	981 785
2080	55.3	42.0	76.7	1 185 891	1 511 519	918 005
2085	56.9	41.1	85.5	1 151 799	1 521 771	855 541
2090	57.7	41.2	89.2	1 120 467	1 537 679	795 668
2095	58.2	41.7	90.1	1 092 115	1 558 934	738 919
2100	58.6	42.4	89.6	1 064 993	1 582 986	684 050

Predictions of Population Ageing Effects

	Population Size Effect			Age Composition Effect			Total Effect		
Year	Fertility Variant			Fertility Variant			Fertility Variant		
	Medium	High	Low	Medium	High	Low	Medium	High	Low
2020	0.92%	0.92%	0.92%	-4.19%	-4.19%	-4.19%	-3.28%	-3.28%	-3.28%
2025	0.51%	0.82%	0.21%	-3.32%	-3.32%	-3.32%	-2.81%	-2.50%	-3.12%
2030	0.18%	0.62%	-0.28%	-4.74%	-4.74%	-4.74%	-4.57%	-4.12%	-5.02%
2035	-0.09%	0.44%	-0.65%	-7.03%	-7.03%	-7.03%	-7.12%	-6.59%	-7.68%
2040	-0.33%	0.20%	-0.91%	-6.28%	-5.81%	-6.77%	-6.62%	-5.61%	-7.67%
2045	-0.55%	0.03%	-1.17%	-2.60%	-1.81%	-3.46%	-3.15%	-1.78%	-4.63%
2050	-0.76%	-0.07%	-1.48%	-2.77%	-1.69%	-4.06%	-3.54%	-1.76%	-5.54%
2055	-0.95%	-0.12%	-1.79%	-7.40%	-5.69%	-9.58%	-8.35%	-5.81%	-11.37%
2060	-1.09%	-0.12%	-2.06%	-2.16%	-0.61%	-4.36%	-3.25%	-0.73%	-6.42%
2065	-1.15%	-0.07%	-2.26%	-0.30%	1.26%	-2.70%	-1.45%	1.18%	-4.97%
2070	-1.17%	0.00%	-2.41%	0.29%	1.95%	-2.54%	-0.88%	1.95%	-4.95%
2075	-1.18%	0.07%	-2.54%	-0.55%	1.46%	-4.40%	-1.73%	1.53%	-6.94%
2080	-1.19%	0.15%	-2.69%	-1.61%	0.86%	-7.07%	-2.80%	1.01%	-9.77%
2085	-1.17%	0.27%	-2.83%	-1.68%	0.96%	-8.81%	-2.85%	1.23%	-11.64%
2090	-1.11%	0.42%	-2.91%	-0.80%	-0.07%	-3.79%	-1.91%	0.35%	-6.70%
2095	-1.03%	0.55%	-2.97%	-0.41%	-0.49%	-0.90%	-1.44%	0.06%	-3.87%
2100	-1.01%	0.61%	-3.09%	-0.43%	-0.76%	0.49%	-1.43%	-0.15%	-2.60%