IMPACTS OF LTV POLICY ON THE MORTGAGE MARKET VIA HOUSING SPECULATION

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Abstract: We study how loan-to-value (LTV) policy specifically targeting house purchases for speculative investments influences housing and mortgage markets. Using China's administrative data of more than 3 million mortgage originations, we find that such a policy change during 2014Q4-2016Q3 fueled a housing boom by encouraging mortgage demand for primary homes, especially from middle-aged highly educated households. We develop a theoretical model to show that this LTV policy has a quantitatively large impact on house prices and mortgage originations to primary homes as homeowners trade up existing primary homes to larger ones via housing speculation.

There is a widely-held view that housing speculation plays an essential role in driving the fluctuation of house prices. In many countries, a key motivation for macroprudential policy is to regulate speculative activities in the housing market (Crowe et al., 2011; Jácome and Mitra, 2015), and regulations on the loan-to-value (LTV) ratio are the main tool for macroprudential policy on the household leverage.[1] The question of how important LTV policy is in affecting housing speculation and hence the housing and mortgage markets, however, is largely unexplored.[2] An answer to this question is important both for the macro-finance literature and for macroprudential policymaking.

To address this question adequately, one needs to find a clear experiment in which a change in LTV policy targeting exclusively speculative investments in houses. In general, however, changes in LTV policy affect not only speculative investments in houses but also home ownership for housing services, making it difficult to identify the channel through which housing speculation drives the housing and mortgage markets. One notable exception is recent changes in China's LTV policy specifically targeting for speculative investments. Most households in China purchase secondary houses for pure speculative investments.[3] In 2014Q4, China relaxed its LTV policy until 2016Q3 by lowering the requirement of the minimum down payment ratio (MDPR) for secondary (non-primary) houses from 60-70% to 30% (top panel of Figure 1).[4] Associated with this LTV policy change is a boom in the *entire* housing market. As reported by the National Bureau of Statistics (NBS), the annualized growth rate of real house prices in 70 major Chinese cities increased, on average, by 5.94% per annum during the mortgage boom period of 2014Q4-2016Q3 (bottom panel of Figure 1). The annual amount of newly issued mortgages for these cities was, on average, 92% higher

[1]Alam et al. (2019) find that among 134 countries adopting macroprudential policy, LTV limits have been imposed by 60 countries; Cerutti et al. (2017) find that by 2017 LTV limits had been imposed as macroprudential policy by about 60% of advanced economies.

[2]A majority of prior studies on LTV limits as macroprudential policy provide cross-country analyses with aggregate data; these studies are silent on specific channels (such as the housing speculation channel) through which LTV policy affects housing markets. Recent studies by Han et al. (2021), Acharya et al. (2022), and Bekkum et al. (2022) use granular data to study the effects of LTV limits as macroprudential policy on housing markets via channels other than housing speculation.

[3]A secondary house is a non-primary house, which is a house not for housing services but for a speculative investment. It can be a second, third, or even fourth, for example. In this paper, we use the phrases "secondary house" and "non-primary house" interchangeably.

[4]The main purpose of this policy change was to remove hurdles of entering the mortgage market from households with investment incentives. The 2015 Central Economic Work Conference stated the Chinese government's mandate clearly: "It is necessary to encourage natural persons and various institutional investors to purchase inventories of commodity housing, ... to eliminate outdated restrictive measures (`http://finance.people.com.cn/GB/8215/392239/401049/index.html`)."

during 2014Q4-2016Q3 than in 2013 (middle panel of Figure 1). The outstanding mortgage debt nationwide increased from 10.6 trillion RMB in December 2014 to 17.9 trillion RMB in December 2016. Because China has implemented particular LTV policy that specifically targets housing investors, its economy offers a rare and clear experiment for researchers to evaluate the quantitative importance of such policy in influencing the housing and mortgage markets via housing speculation.

In this paper, we exploit administrative loan-level data with more than 3 million loans originated by one of the largest banks in China.[5] We first use research designs of difference-in-differences for identifying the average and distributional effects of a change in the LTV limit for secondary houses on both total mortgages and primary home mortgages (mortgages for primary homes constitute most of the mortgage market). Motivated by our empirical findings, we develop and calibrate a dynamic equilibrium model with housing speculation to assess the quantitative effects of LTV policy on secondary houses in the housing market. Both our empirical and theoretical findings show that LTV policy targeting housing speculators has large impacts on the entire mortgage market as homeowners trade up their primary homes.

By exploiting cross-city variations in ex-ante exposures to a change of the LTV limit on secondary houses, we identify the causal effects of this policy change on mortgages. We measure an exposure to this policy change by the 2011 share of mortgages on secondary houses in total mortgages of each city, and exploit its variations across cities.[6] The rationale for using this exposure as an instrument in our regression analysis is as follows. The nation-wide change in the LTV limit on investment (secondary) houses should have stronger effects in cities with a larger share of mortgages on secondary houses in total mortgages prior to the policy change, because households in these cities are more likely to purchase houses for investment purposes.

During the period when LTV policy for secondary houses was relaxed, we find that a one standard deviation increase in ex ante exposure led to a 22% increase in mortgage amount and a 20.6% increase in mortgage number during the policy period 2014Q4-2016Q3, implying the large impacts of this policy change on total mortgages in both origination amount and number. The impacts of such an policy change on primary home mortgages, moreover,

[5]Appendix A provides validation of this database by comparing the aggregate and cross-sectional moments from this data with those from other data sources. This sample is representative because this bank makes loans in every corner of the Chinese economy.

[6]This empirical approach has been widely used in the literature to isolate the effects of various post-crisis stimulus policies in the United States. See, for example, Mian and Sufi (2012) and Chodorow-Reich, Feiveson, Liscow and Woolston (2012) on fiscal stimulus and Berger, Turner and Zwick (2021) on credit subsidies to first-time homebuyers.

were similar in magnitude to the impacts on total mortgage, as increases in primary home mortgages are the main driver for LTV policy targeting secondary houses to affect the entire mortgage market. We also find that this policy change reallocated primary home mortgages to middle-aged households with high education from other age-education groups. That is, a relaxation of LTV policy for secondary houses had a disproportionate effect on mortgage demand for primary homes by middle-aged households with high education. There is no evidence of a differential pretrend in high and low exposure cities, and the timing of the increase in both total mortgages and primary home mortgages lines up with the timing of the policy loosening.

Disciplined by our empirical findings, we build a life-cycle model with household heterogeneity to explain the mechanism for a relaxation of LTV policy for secondary houses to affect the housing market. The model has two key ingredients. First, there is a distinction between primary homes and secondary houses, where secondary properties are purchased only for speculative investments, not for housing consumption. Resembling actual LTV policies in China, primary homes and secondary houses in the model are subject to different MDPR requirements. Second, there are two stochastic regimes embedded in households' utility of housing services to capture speculative housing demand. The first ingredient helps isolate the impacts of a change in LTV policy for secondary houses only; the second ingredient introduces speculative demand for housing. By holding expectations of future housing demand constant throughout the phase of a policy change, we are able to isolate the effect of the policy change on the housing boom.

We calibrate the model's key parameters to various aggregate and cross-sectional moments in the data. We find that a loosening of the LTV limit on secondary houses can explain more than 80% of the increase in the house price and more than 60% of the increase in mortgage originations observed in the data. Moreover, the model can replicate reasonably well the changes in mortgage shares of various age-income groups, and particularly the increase in the mortgage share of middle-aged households with high education. Apart from its impacts on the housing and mortgage market, this policy relaxation generates an unintended welfare loss (measured by consumption equivalent variation) for the economy. Such welfare loss is disproportionately borne by young households and renters, who find it more difficult to afford owning homes.[7]

[7]There is a strand of literature that highlights the redistributive effects on households of booms and busts in house prices. For instance, Kiyotaki, Michaelides and Nikolov (2011) argue that net house buyers (such as young workers or tenants) lose and net house sellers (such as retired homeowners) gain from a sharp rise of the house price. Along a similar line, Glover, Heathcote, Krueger and Ríos-Rull (2011) show that young households may benefit from a slump in asset values during the downturn by purchasing assets at low prices.

The capital gain channel for the owners of primary homes play a central role for a relaxation of LTV policy on non-primary houses to affect the housing and mortgage markets. A loosening of LTV policy for secondary houses has direct impacts on mortgage demand by speculative investors. Their strong demand raises the house price in the first place. Capital gains from a higher house price, in turn, allow homeowners—especially middle-aged households with high incomes—to overcome the credit constraint and trade up their existing primary homes. The increased demand for primary homes further pushes up the house price, then capital gains of the homeowners, and finally aggregate housing demand. Since middle-aged households with high incomes contribute to a substantial fraction of total housing demand, their trading-up transactions allow a change of LTV policy for secondary houses to generate sizable aggregate impacts on the house price and overall mortgage demand.

Our paper contributes to two strands of literature on housing. First, our paper is related to the extensive empirical literature on housing speculation. Many papers using granular data (e.g., Haughwout et al. (2011), Bhutta (2015), Chinco and Mayer (2016), Albanesi et al. (2017), Defusco et al. (2017), Gao et al. (2020), Bayer et al. (2021), and Mian and Sufi (2022)) have established the important role of speculations in driving housing booms. Our empirical work is closest to Mian and Sufi (2022), who use the rise of the private mortgage securitization market in 2003 as a natural experiment to investigate the causal effects of exogenous increases in mortgage credit supply on housing speculation. Existing studies in this literature focus on the direct effect of housing speculation on house prices and housing markets. To our knowledge, our paper is the first to develop a structural model illustrating that speculation on secondary houses propagates into the entire mortgage market via changes in mortgages on primary homes. With the model calibrated to match both aggregate and cross-sectional moments, we show that speculation on secondary houses can have a large impact on house prices and mortgage loans, and much of the impact is through the indirect channel by encouraging trade-ups of primary homes.[8]

Second, our paper is related to the macro literature on the role of LTV or credit policy on housing booms. A growing number of works use quantitative models to study how changes in the LTV limit affect housing booms and busts.[9] The literature, however, discusses the role of LTV policy in an economic environment without housing as speculative investments. Thus, changes in the LTV limit are more relevant for poor or young households, who are constrained for housing consumption or housing tenure choices. Our paper complements

[8]In a different context, Stein (1995) and Ortalo-Magné and Rady (2006) study how changes in the house price affect trading decisions of homeowners.

[9]See, for example, Kiyotaki, Michaelides and Nikolov (2011), Landvoigt et al. (2015), Favilukis et al. (2017), Kaplan et al. (2020), and Guren et al. (2018).

to this literature by highlighting the role of LTV policy targeting housing speculation in the housing market. We show that with a fraction of houses invested for pure speculative purposes, the capital gain channel for owners of primary homes propagates the effects of loosening the LTV limit for non-primary houses on the entire mortgage market.

The rest of the paper is organized as follows. Section I provides the institutional background of China's LTV policy and its mortgage and housing markets. Section II discusses the databases used for this paper and provides a narrative of the mortgage boom during the period when LTV policy was loosened. Section III estimates the causal effects of a loosening of LTV policy for secondary houses. In Section IV, we build and calibrate a life-cycle equilibrium model with both primary homes and secondary houses. Section V uses the model to quantify the aggregate and distributional impacts of a relaxation of LTV policy for secondary houses on the housing and mortgage markets. Section VI concludes the paper.

I. China's Housing Market and Policy

In this section, we discuss China's housing market and its housing policy that are pertinent to the subsequent empirical analysis as well as the theoretical framework for interpreting our empirical findings.

I.1. **Housing as speculative investment.**

In China, the availability of financial assets for household savings is very limited: stock markets are poorly regulated and dominated by state owned enterprises (SOEs), the national capital account is severely restricted, and the exchange rate is tightly managed. Under these circumstances, houses have become the most important assets with an extremely high concentration of housing wealth among most Chinese households. According to our own calculation from the China Household Finance Survey (CHFS) data for urban China, the housing stock comprised 80.4% of households' wealth in 2013, as compared to about 40% for U.S. households. Within the category of financial assets, the share of bank deposits was 65.21% in 2013, but the share of financial assets in Chinese households' total wealth was only 8.63%, compared to 37.9% in the United States.

The land available for home construction is limited by the "red-line lower limit" imposed by Chinese governments for arable land. According to a law passed by the State Council of China in 2008, the amount of cultivated land was 1.818 billion acres in 2010 and remained at 1.805 billion acres in 2020. This red-line lower limit implies a de facto upper bound for the supply of land for real estate construction. Since 1994, the revenues from selling the land have been important revenue sources for local governments. A combination of revenue sources

and the upper bound of the land for real estate construction has given local governments a strong incentive to limit the supply of land to boost the land price.

The use of housing as investment tools, together with the limited supply of land, has created speculative investment demand for houses. In 2013, for instance, around 15% of urban Chinese households owned a second home as an investment. The ratio of house value to income (price-to-income ratio) is much higher than the developed economies. According to Fang, Gu, Xiong and Zhou (2016), the price-to-income ratio for the bottom income group has been sustainably above 8. For the middle income group, the ratio reached a level above 6 in 2012. By contrast, the price-to-income ratio for the U.S. was only around 3 during and after the housing bubble that peaked in 2006.

In recent years, the vacancy rate of houses of urban homeowners in China has been persistently high. According to our own calculation from the CHFS data, the average housing vacancy rates remained stable around 20% during 2011-2017 among 35 major cities. The housing vacancy rate for secondary houses was even higher (e.g., 42.06% in 2017). Chen and Wen (2017) show that underlying the fast price-to-income growth and the high vacancy rate in urban China were speculative demand of houses.

I.2. **Mortgage market and LTV policy.** Since 1998, China's mortgage markets have developed rapidly. In 2013, for instance, the share of residential mortgage loans in total consumer loans was 69.4% and the share of medium and long term (MLT) consumer loans in total consumer loans was 87.4%. All residential mortgage loans in China are for home purchases. Unlike in the U.S., Chinese households cannot use home equity to obtain a line of credit for consumption and neither can they refinance their original mortgage debts to use a cash-out refinance for consumption. Moreover, there is no secondary market for mortgage loans through securitization (e.g., via mortgage-backed securities).[10] As a result, the maximum LTV ratio that an individual bank can offer closely follows the government's LTV policy.

[10]The reverse mortgage market did not exist until 2014 when the Chinese government launched a two-year pilot program for reverse mortgages introduced by a life insurance company. This pilot program, however, proved to be unpopular in China. By July 2017, only 65 households participated in the program nationwide (Fang and Feng, 2018).

LTV policy has been an effective tool used by the Chinese government to influence housing demand since 2010.[11] It has two separate components: the minimum down payment for financing (1) the primary home and (2) a second house or additional houses. In January 2010, to curtail speculative housing demand, the government reversed its previous LTV policy by raising the MDPR to 30% for financing the primary home that had more than 90 square meters and to 50% for financing a secondary house. In January 2011, the government further increased the MDPR for financing a second house to 60% and prohibited commercial banks from making mortgage loans to any household who would finance houses beyond the first two houses.[12]

To boost housing demand again, China relaxed its LTV policy from 2014Q4 to 2016Q3 by reducing the MDPR for financing secondary houses from 60-70% to 30%. During this period, the down payment requirement for financing the primary house was reduced from 30% to 25% on September 30, 2015. The mortgage interest rates for non-primary homes also continued to decline during this period. For example, the average second-home mortgage interest declined from 6.84% in December 2014 to 5.39% in December 2015. Since 2016Q4, however, LTV policy has been tightened again. In 2016Q4, local governments in 20 cities (most of them were first and second tier cities) tightened their LTV policy by increasing the MDPR for financing a secondary house from 30% to 70%.[13] By June 2017, local governments in 44 cities across China followed suit by tightening their LTV policy, especially on a secondary house.

II. Data and stylized facts about the mortgage boom

In this section, we describe the two databases used in this paper and use the data to document stylized facts about the mortgage boom during 2014Q4-2016Q3.

II.1. **Data description.**

We use two administrative databases for our empirical work. The first is a confidential loan-level database for mortgage originations in one of the largest Chinese commercial banks (we call this data the Bank Loan Data for the rest of this paper). The outstanding mortgage loans issued by this bank have remained around 14% of total

[11]Prior to 2010, there was no government regulation that required banks to collect information about whether a mortgage was for a primary home or a secondary house. In early 2010, the People's Bank of China and the China Banking Regulatory Commission jointly issued a policy that required banks to collect information about whether a mortgage is for a primary home or a secondary house (see https://www.chinanews.com.cn/estate/news/2010/06-05/2325187.shtml).

[12]An alternative regulation policy—the PTI limit—has not been a major policy tool in China. Despite the statutory requirement of a PTI limit enacted by the China Banking Regulatory Commission in 2004, this regulation has been barely enforced, making the PTI limit *de facto* unbinding for individual households.

[13]The MDPR for financing primary houses reverted back to 30%.

outstanding mortgage loans in China since 2011. Our database contains all mortgage loans originated by this bank for new residential properties purchased from 2011Q1 to 2018Q2. It comprises more than 3.2 million mortgage loans, covering 70 cities that correspond to the city sample used by the NBS. The most important information contained in the database relates to whether a particular mortgage is issued for the borrower's primary home or secondary house. This crucial information allows us to distinguish direct and indirect effects of a change in the LTV limit on the demand for mortgage financing of secondary houses.

The database also contains information about each homebuyer's characteristics, including age, gender, occupation, education, self-reported income, number of houses, city, zip code, and credit score.[14] Unfortunately, this database misses crucial information about the exact address of a house, the floor of a building on which a house was located when the house was purchased, and the number of rooms for each transacted house. Such missing information prevents us from constructing a house price index that measures the prices of the same (or at least comparable) house over time in order to obtain comparable *growth rates* of house prices across cities.[15] For regressions that involve *growth rates* of house prices across cities, therefore, we therefore use the data provided by Fang, Gu, Xiong and Zhou (2016), who use the loan-level data from another major Chinese bank to construct a city-level house price index from January 2003 to March 2013.

The second database is the CHFS, conducted by Southwestern University of Finance and Economics every two years since 2011 (Gan, Yin, Jia, Xu, Ma and Zheng, 2014). The inaugural 2011 survey interviewed about 9,000 households; since then, the number of households interviewed has increased steadily in each subsequent survey. The 2013 survey sample, for example, includes 19,181 urban households. This database is the most comprehensive source of household data on wealth, consumption, and income in China. It has a clear advantage over traditional data on household spending in the United States and the United Kingdom, such as Consumer Expenditure Survey (CEX), Survey of Consumer Finance (SCF), and Living Costs and Food Survey (LCFS), because it contains disaggregated information of both household balance sheets (including wealth) and a rich array of household expenditures. Appendix B provides summary statistics for these two databases.

[14]We do not use the information of self-reported incomes as they are very unreliable.

[15]As Fang, Gu, Xiong and Zhou (2016) argue, changes in city-level house prices likely measure not only changes in the prices of similar homes, but also changes in the composition of transacted homes. This problem is likely to be more severe in emerging housing markets than in mature ones, because in emerging housing markets such as cities in China, homes in more central locations are likely to be built and transacted earlier than homes in city outer-rings.

II.2. **Stylized facts.** In this section, we analyze how newly originated mortgage loans changed during the period when LTV policy for secondary houses was loosened. This analysis is provided at both aggregate and disaggregated levels.

II.2.1. *Aggregate facts.* To gauge the extent to which the LTV constraint on households is binding, we calculate the distribution of LTV ratios over time for primary and secondary houses separately (Figure 2). For visual clarity, we report the distribution of LTV ratios across four quantiles of households: the 90th, 75th, 50th, and 25th percentiles. For primary homes, except for households in the bottom 25th percentile of the distribution, the LTV ratios for all households were close to the maximum value allowed by LTV policy.[16] For secondary houses, LTV ratios were below or at the maximum value (40%) allowed by LTV policy prior to its relaxation. Following the loosening of LTV policy for secondary houses in 2014Q4, LTV ratios for all quantiles of households sprang up substantially.[17] A loosening of the LTV constraint on secondary houses allowed households with speculative incentives to borrow more against the value of secondary houses.

Figure 3 reports the time series of mortgages on primary versus secondary houses and of household leverages. During the policy period, especially in 2014Q4-2015Q3 when only the LTV limit for secondary houses was relaxed, mortgages on both secondary houses and primary homes increased significantly from the pre-policy period, and the absolute increase in mortgages on primary homes was significantly larger than that on secondary houses. The sharp increase in aggregate mortgage loans during the policy period was mainly attributable to the increase of mortgages on primary homes. These facts imply that a loosening of LTV policy for secondary houses had large spillover effects on mortgage demand for primary houses. After 2015Q3, while secondary house mortgages leveled off, mortgages on primary homes continued to increase until LTV policy was tightened again after 2016Q3.

[16]The maximum LTV allowed was 70% prior to the change in LTV policy and 75% after the policy change with some exceptions. The most important exception applied to households who owned primary homes that had less than 90 square meters. These households were qualified for the "Housing Provident Fund Loans" program provided by the Chinese government to help low-income households to meet their housing needs; they were allowed to have the MDPR lower than 25%.

[17]The maximum LTV allowed for secondary houses was 70% with one exception. Homeowners who had paid in full the mortgages on their primary homes qualified for mortgage loans with the MDPR below 30%. After 2016Q3, local governments tightened LTV policy, especially for secondary houses. There was, however, no uniform policy change mandated by the central government, and there were varying degrees and timings of tightening across cities. Nonetheless, LTV ratios for primary homes and especially for secondary houses fell gradually after 2016Q3 (Figure 2).

II.2.2. *Mortgage loans across age-education groups.* Figure 4 reports the age profile of average LTV ratios across years when mortgage loans were originated (at origination). The three years, 2011, 2013 and 2015, are chosen to highlight changes of the age profile that were potentially attributable to the change in LTV policy. The first two years are prior to the policy change and the third year is during the period when LTV policy was relaxed. The LTV ratio for primary homes in three years peaked at age 30 (left panel). More important, LTV ratios for primary homes across these three years were close to one another, consistent with the fact that the loosening of LTV policy had most of the impact on the leverage of secondary houses during the mortgage boom.[18] The age profile of LTV ratios for secondary houses differs considerably from that for primary homes in several respects (right panel). First, the levels of LTV ratios were smaller in magnitude than those for primary homes in all three years, and were close in magnitude to the maximum value stipulated by LTV policy in these years. Second, the age profile of LTV ratios sprang up from a level below 40% in 2013 to a level above 55% in 2015, as the MDPR for secondary houses was reduced from 60-70% to 40% in March 2015 (and further to 30% in February 2016). The loosening of LTV policy allowed homeowners who purchased secondary houses to increase their leverage substantially.

Another important stylized fact relates to the distribution of mortgage loans across ages. We calculate the age profile of mortgage loans in 2011, 2013, and 2015 for both the amount of mortgage loans and the number of mortgage originations. Top panels of Figure 5 report the share of mortgage loans for each age group in the total loan amount as well as the total number of originations for all ages. The age profiles of these shares were hump-shaped. The age profiles for 2011 and 2013 were very similar, and households of ages 25-30 had the highest share (more than 20%). In 2015, the age profile shifted to the right: the share for households of ages 30-40 (middle-age households) increased significantly, whereas the share for households of ages 20-30 (young households) declined. This distributional shift holds for both the amount of mortgage loans and the number of mortgage originations.

To understand the role of extensive margins in household indebtedness, we calculate the age profile of the debt-to-income (DTI) ratio and a fraction of households within each age group with positive mortgage debts in all households including those without mortgages (a mortgage participation rate).[19] The age profiles for 2011 and 2013 were similar and hump-shaped with peaks at age 30 (bottom left panel of Figure 5). The peak age is consistent

[18]Recent empirical studies on the U.S. housing boom and bust find very small changes in the LTV ratio at origination over the boom and bust cycle across the whole distribution of LTV ratios. See, for example, Adelino, Schoar and Severino (2018).

[19]In this paper, DTI is mortgage DTI unless stated otherwise.

with the top panels of the figure. From 2013 to 2015, however, the DTI ratio for households of ages 30-65 increased significantly. This increase was attributable to a combination of increases in the mortgage participation rate (extensive margin) and higher DTI ratios for those households who had outstanding mortgage debt prior to the housing boom (intensive margin). As the bottom panels show, the age profile of mortgage participation rates was similar to the age profile of DTI ratios. Extensive margins in the age profile of DTI ratios for households of ages 30-50 were important as the mortgage participation rate for these households increased most (bottom right panel).

We classify households into a high-education group and a low-education group: those with college degree and above as a proxy for a high-income group and those with high school diploma and below as a proxy for a low-income group. Figure 6 reports the age profile of the average value of newly purchased houses financed by mortgages in 2011, 2013 and 2015. The average house value of each household in a given year is deflated by the constant-quality house price index of the city in which the household resided at the time during that year when the mortgage was originated. For a given age of households, therefore, a change in the average house value captures an increase in the average house size or the quality of the average house for households of that age.

Between 2011 and 2013, the average house value increased across households of different ages with low education in similar magnitude (left panel of Figure 6). This similarity holds true for the increase of the average house value for households with high education (right panel of Figure 6). Between 2013 and 2015 after the loosening of LTV policy, however, the average house value for households of age 30-55 with high education increased by about 20%, significantly higher than the increase of the average house value for young households with high education and those whose age was 60 and above. This asymmetric increase of the average house value between 2013 and 2015 does not hold for households with low education, implying that a disproportionate fraction of middle-aged households with high education traded up to larger primary homes during the mortgage boom. In Section IV, we build a life-cycle equilibrium model to help interpret these stylized facts uncovered from our granular data.

To summarize, we find that during the period when LTV policy for secondary houses was loosened, mortgage loans for both primary homes and secondary houses increased significantly. The share of mortgages on primary homes of middle-aged households with high education in total mortgages on primary homes increased significantly. Underlying this increase of mortgage demand by middle-aged households with high education was the fact that these households traded up to larger primary homes with an increased burden of mortgage debt.

III. The estimated effects of LTV policy for secondary houses

The aforementioned facts reveal a potentially critical role of loosening LTV policy specifically for secondary houses in its aggregate and distributional effects on the entire mortgage market. In this section, we identify the causal effects of such a policy, which are consistent with the narrative. We first estimate the average effect of this policy change on the mortgage origination amount and number. We then provide further evidence that such policy had a disproportionate effect on primary home mortgages of middle-aged households with high education.

III.1. **Research design.** In this section, we discuss a research design for estimating the causal effects of LTV policy. Our empirical strategy exploits cross-city variation in ex-ante exposure to the relaxation of the LTV limit on secondary houses to isolate the effects of this policy change from those of other policy changes and aggregate macroeconomic shocks. Cities with few potential buyers of secondary houses serve as a "control group." The difference between the average response of secondary mortgages to households in the treatment and control groups of cities provides an estimate of the causal effects of a relaxation of secondary house LTV policy.

We measure the exposure to a loosening of secondary house LTV policy by the number of mortgage originations for secondary houses in a city in 2011, divided by the number of total mortgage originations in the city in 2011. Since this LTV policy targets buyers of secondary houses, we expect the policy impact to be larger in cities where, historically, households tend to buy secondary houses prior to the policy change. One concern about identification is a difficulty of disentangling the effects of policy from those of fundamental economic variables to which the policy reacts. For instance, the bottom panel of Figure 1 shows that a loosening of LTV policy was implemented after a slowdown in growth of house prices. Thus, the 2014Q4-2016Q3 housing boom might have been influenced by factors that propelled and then slowed the previous boom in 2013-2014. To mitigate this concern, we use the 2011 measure as an instrument to take into account the possibility that a loosening of LTV policy was partially in response to the slowdown of the housing market in 2013-2014.

Our exposure measure is not about the difference between small and large cities as there is considerable variation of exposure to the LTV policy across cities. The exposure varies from 2.4% at the 10^{th} percentile to 14.5% at the 90^{th} percentile and the standard deviation is 5%, while mean exposure is 7% and median is 4.7%. High exposure cities include not only large cities such as Beijing, Shanghai, Guangzhou, and Shenzhen (tier-one cities in China) but also medium and small (tier-two and tier-three) cities such as Beihai, Haikou, Wenzhou.

All of these high-exposure medium and small cities have exposures about 20%, reflecting the speculative motive of investing in secondary houses in these areas.

The change of LTV policy for secondary houses is represented by a policy dummy equal to one from 2014Q4 to 2016Q3 and zero otherwise. There are two concerns about our policy instrument and LTV policy measure. The first concern is that our policy exposure may be correlated with certain characteristics of the treatment cities that are unrelated to the LTV policy.[20] For example, second home purchases might be more popular in cities in which house prices are more sensitive to the national house variations, as households in these cities may have larger increase in expectation about house price appreciation.

To mitigate the concern about potential effects of these correlates, we estimate in Section III.2 a regression that includes the interaction of potential correlates of policy exposure with our LTV policy measure as additional controls. Specifically, we estimate the following city-level regression for the average effect of loosening LTV policy on mortgage loans to secondary houses:

$$y_{ct} = \beta Exposure_c \times Policy_t + \Gamma X_c \times Policy_t + \Psi Z_{ct} + \alpha_c + \delta_t + \varepsilon_{ct}, \tag{1}$$

where y_{ct} represents the variables of interest, including the log of the amount and number of mortgage loan originated in quarter t (normalized by the city's house price index) for homes located in city c, or the share of primary home mortgages by the middle-aged households of high education; $Exposure_c$ is the share of mortgage originations for secondary houses in city c in 2011 (defined as the number of mortgage originations for secondary houses in city c in 2011, divided by the number of total mortgage originations in the same city in 2011); $Policy_t$ is a policy dummy equal to one from 2014Q4 to 2016Q3 and zero otherwise; the vector X_c includes city characteristics as listed in Table C.1 of Appendix C; the vector Z_{ct} includes a number of city-level time-varying controls, such as lagged city income and its growth, lagged city population and its growth, lagged city unemployment rate and its change, lagged city median mortgage rates for primary houses; α_c captures city fixed effects; and δ_t captures year-quarter fixed effects. The inclusion of city fixed effects absorbs any permanent differences in secondary house mortgages across households in different cities due to unobservable characteristics. The inclusion of year-quarter fixed effects absorbs any unobserved macroeconomic shocks at the quarterly frequency. To aid interpretation, we normalize the exposure measure by its cross-sectional standard deviation.

[20]See Table C.1 of Appendix C for the results of bi-variate regressions of policy exposure on various city-level characteristics that may correlate with demand of secondary houses for investments.

The coefficient of interest is β, which captures the average city-level policy effect of the LTV limit on secondary houses during the period 2014Q4-2016Q3. Note that our identified cross-city evidence is not directly informative about aggregates. This is because the estimated coefficients measure only differences across cities, so any common aggregate effects across all cities are necessarily differenced out.

The second concern is about city-time trends and potential confounders introduced by the change of the LTV limit on primary homes during the policy period. For example, one challenge to our empirical design is a contemporaneous change in the LTV limit on primary homes in the late part of the policy period: the LTV limit on primary homes was loosened on September 30, 2015 until 2016Q3. This contemporaneous change might confound the effects of a loosening of the LTV limit on secondary houses. We overcome this challenge by estimating a regression with quarterly coefficients of the LTV policy and test explicitly for parallel trends in the pre-policy period and for the effects of LTV policy for secondary houses prior to the relaxation of LTV policy for primary homes.[21] Specifically, we run the following dynamic regression:

$$y_{ct} = \beta_t Exposure_c + \Gamma_t X_c + \Psi Z_{ct} + \alpha_c + \delta_t + \varepsilon_{ct}, \tag{2}$$

where y_{ct} represents the variables of interest same as those in (1), β_t and Γ_t are time-varying coefficients for each year-quarter.

III.2. **Average Effects.** The regression results for mortgage origination amounts and numbers are reported in Table 1a. In both column (1) and (2), the estimated policy effect, β, is positive and statistically significant. This result indicates that a relaxation of LTV policy for secondary houses increases mortgage loans in the entire market. When we include all potential correlates of exposure in the regression (column 2), the estimated β changes little in magnitude in comparison to the estimate without potential correlates of exposure as controls (column 1). This is despite the fact that some of these controls are correlated with our exposure measure. The estimated average quarterly policy effect remains statistically significant at the 0.01 level. The estimated coefficient, $\beta = 0.220$, implies that a one-standard-deviation increase in policy exposure raises, on average, the mortgage loan to a city's primary homes by 22% during the period of policy relaxation. Column (3) and (4) show that similar to the effects on mortgage origination amount, the estimated policy effect on mortgage origination numbers is positive and significant at 1% level. The estimated coefficients for mortgage numbers, are close, though somewhat smaller, in magnitude to their counterparts in column (1) and (2). This suggests that an increase in mortgage origination

[21] In all our regressions, we include lagged city-level interest rates of mortgages on primary homes as a control for the effects of changes in mortgage interest rates.

numbers are a key channel for a relaxation of LTV policy on secondary houses to increase mortgage origination amounts.

The top panels of Figure 7 display the time-varying coefficients of exposure for mortgage origination amounts (top left panel) and numbers (top right panel). Both panels exhibit similar time-varying patterns. In the pre-policy period (before 2014Q4), the estimated β is all statistically insignificant, implying a parallel pre-trend. The statistical insignificance of coefficients in the pre-policy period supports our empirical design that low-exposure cities are a control group and high-exposure cities are a treatment group for studying the impact of LTV policy for secondary houses on their mortgages. The policy relaxation period (2014Q4-2016Q3) shows a significantly positive average effect on primary home mortgages; and this effect is most pronounced during the first policy window (2014Q4-2015Q3) in which only LTV policy for secondary houses was loosened. After this period, the estimated β began to decline and eventually become statistically insignificant again in the post-policy period (after 2016Q4).

Table 1b reports the estimated effect of this policy change on primary homes mortgage originations. The estimated coefficients are all positive and significant with the magnitude close to their counterparts for the total mortgages. For example, column (2) shows that a one-standard deviation increase in ex ante exposure increases the primary mortgage origination amount by 22.5%, close to its counterpart for the total mortgage amount (22%). The middle panels of Figure 7 exhibit a similar pattern as the top panels: (i) the estimated coefficients are statistically insignificant in the pre-policy period, which suggests a parallel pre-policy trend, (ii) the estimated policy impact was most pronounced during the policy window of 2014Q4-2015Q3, in which only the LTV limit on secondary houses was loosened, and (iii) the estimated coefficients are statistically insignificant in the post-policy period.

In summary, by controlling for potential correlates of policy exposure in our regressions, we find that a relaxation of LTV policy for secondary houses has positive effects on the mortgage loans for the entire housing market. The corresponding impacts on the primary home mortgages, moreover, are close in magnitude to that of total mortgages, which suggests a propagation of the impact of LTV policy on secondary houses into demand for primary home mortgage. Our findings of a parallel pre-trend, a sharp rise in mortgage originations in high-exposure cities during the policy relaxation period, and a reversal of this effect in the post-policy period support our empirical design and help isolate the causal effect of LTV policy for secondary houses.

III.3. **Distributional effects across age-education groups.** During the policy relaxation period, we observe that middle-aged households with high education, on average, increased the size of their primary homes. A relevant question is how a relaxation of the LTV limit on secondary houses affected mortgage demand for primary homes across households. In this section, we show that a relaxation of LTV policy for secondary houses increased the share of primary home mortgages held by middle-aged households with high education in total mortgages on primary homes.

We classify households into three age groups: those of ages below 30 (young households), of ages 30-49 (middle-aged households), and of ages 50 and above (old households). This classification is consistent with the age profile of mortgage loans prior to the relaxation of LTV policy, which peaked at age 30. Households who are middle-aged and have a college degree or above are classified as middle-aged households with high education.

Table 1c reports the regression results on the share taken by middle-aged high-income households in a city's total primary-home mortgage origination amounts and numbers. For mortgage amount shares, the estimated coefficient of policy exposure, β, is positive and statistically significant at the 1% level (column 1 and 2). When we include all potential correlates of exposure in the regression, a one-standard-deviation increase in policy exposure would raise the amount share of primary home mortgages to middle-aged households with high education by 2.9 percentage points (column 2). Similarly, column (4) shows that a one-standard-deviation increase in policy exposure would raise the number share of primary home mortgages to middle-aged households with high education by 2.6 percentage points. This suggests, again, that increase in mortgage origination numbers is an important channel for the policy relaxation to increase the total mortgage amount share by the middle-aged high-educated households.[22]

The bottom two panels of Figure 7 displays the dynamics of these quarterly coefficients. As one can see, there is no sign of differential trend between treatment and control cities in the pre-policy period. Similarly, the coefficients are statistically insignificant in the post-policy period. During the policy-relaxation period, however, the estimated coefficients of policy exposure are positive and statistically significant. This result holds true particularly for the period 2014Q4-2015Q3 when only a relaxation of LTV policy for secondary houses took place.

In summary, our findings show that a loosening of LTV policy for secondary houses has a positive effect disproportionately on mortgage loans to middle-aged households with high

[22]Our findings are robust to a loan-level regression in which the dependent variable is a dummy variable that equals one if the mortgage loan goes to a middle-aged household with high education and zero otherwise. The results are available upon request.

education that are used to finance their primary homes. Although only a small share of total mortgages were used for financing secondary houses, a relaxation on the LTV limit on secondary houses during 2014Q4-2016Q3 fueled a housing boom via mortgage loans to primary homes, especially for middle-aged households with high education who owned a large share of wealth in the economy.

IV. A model with the LTV constraint on secondary houses

Our empirical work focuses on causal effects of loosening LTV policy for secondary houses on housing and mortgage demand. What is the transmission mechanism for a relaxation of LTV limits on secondary houses to fuel a housing boom via mortgage demand for primary homes? What's the welfare implications of this policy relaxation on households of different ages and income levels?

To address these questions, we develop a theoretical model disciplined by our empirical findings in preceding sections. The model incorporates two unique ingredients of China's housing market. First, there is a distinction between primary homes and secondary houses. Secondary houses provide no housing services, while primary homes do. Primary homes and secondary houses are subject to different MDPR requirements. Second, households' utility of housing services has two stochastic regimes to capture housing demand for speculative investments. This ingredient introduces an investment motive for purchasing a secondary house, which allows a change in LTV policy to target housing speculators exclusively. Together with the first ingredient, we use the model to compare aggregate, distributional, and welfare effects of a relaxation of LTV policy for secondary houses.

We begin with the household's problem and then introduce the rental and production sectors into the model economy. The model is calibrated to match both aggregate and cross-sectional moments of the Chinese economy. The technical details of how to formulate the household problem recursively, as well as the definition of the equilibrium, are contained in Appendix D. Appendix E provides details of how to solve the model numerically.

IV.1. **Households.**

We first describe the economic environment for households in our model and then specify the household decision in each period.

IV.1.1. *The environment.*

The economy is populated by a continuum of overlapping generations of households whose life cycle is divided between work and retirement. Each household lives multiple periods, age is indexed by $j = 1, 2, \ldots, J$, and the household retires at age J^{ret}. All households die with certainty after age J.

The household's expected lifetime utility is

$$E_0\left[\sum_{j=1}^{J}\beta^{j-1}u_j\left(c_j,s_j;\phi\right)+\beta^J v(\mathfrak{b})\right],$$

where $\beta>0$ is the discount factor, c_j is non-housing consumption, s_j is consumption of housing services. Each period, the household has a constant elasticity of substitution (CES) utility over non-housing consumption and housing services in the form of

$$u(c,s;\phi)=\frac{\left[(1-\phi)c^{1-\gamma}+\phi s^{1-\gamma}\right]^{\frac{1-\sigma}{1-\gamma}}}{1-\sigma},$$

where γ determines the elasticity of substitution between non-housing consumption and housing services and σ determines the relative risk aversion. The housing utility weight ϕ determines the share of housing services in total consumption. It is a stochastic variable common for all households, capturing the common belief about aggregate housing demand in the future. We assume a two-state Markov process for $\phi\in\{\phi^L,\phi^H\}$ with the transition probability matrix

$$\Pi=\begin{bmatrix}1-\Pi_{lh} & \Pi_{lh}\\ 0 & 1\end{bmatrix}.$$

From the state of a low housing preference, there is a probability Π_{lh} that the low housing preference moves into the state of a high housing preference and stays in that state.[23] The stochastic belief about future housing demand can be interpreted as anticipated higher future demand for urban housing due to the relaxation of China's urban policy known as the "Hukou" restriction.[24] A high housing preference is an absorbing state because it captures the institutional fact that once the Hukou restriction was eased, the relaxation would not be reversed.

To evaluate the impact of a policy change, we assume that each household is endowed with a low housing preference (ϕ_L) in the initial state and stays in that state after housing policy is relaxed. The stochastic housing preference captures a belief about higher housing demand in the future. This modeling approach shares some key features of a rational bubble, but unlike the rational bubble literature it allows for the utility of housing services. In the stochastic steady state in which the house price is constant, households always demand speculative

[23]Our belief modeling follows Kaplan, Mitman and Violante (2020). Unlike their paper, however, the trigger for the housing boom in our model is a change in mortgage policy instead of an exogenous change in belief about future housing demand.

[24]According to Wu, Gyourko and Deng (2012), the urbanization rate grew on average by 1.4% per year between 1996 and 2015. Even with a slightly slower growth rate of urbanization since 2015, there have been about 15 million new people entering urban areas every year.

investment in houses because of a positive probability of switching to the state of higher housing demand with higher house prices.

We introduce a warm-glow bequest motive into the model to capture the reality in China that old people tend to give houses to their children or grandchildren as a bequest. This bequest takes the functional form

$$v(\mathfrak{b}) = \varphi \frac{\mathfrak{b}^{1-\sigma}}{1-\sigma},$$

where the parameter φ reflects the strength of a bequest motive.

At birth, households are ex-ante heterogeneous in their endowment of permanent (lifetime) labor ability, denoted by a binary variable η_k with $k \in \{L, H\}$, where L stands for low ability and H high ability. Working age households are subject to uninsurable idiosyncratic shocks to their efficiency of labor, denoted by ϵ that follows a first-order Markov process. The total labor income for each household is given by $y = w\varepsilon_j \eta_k \epsilon$, where w is the wage rate per efficiency unit of labor and ε_j is the deterministic efficiency profile determined by age.[25] When a household retires, it receives a pension benefit each period equal to a fraction ξ of the income in the last period of working age, denoted as $y = \xi y^{\text{ret}}$.

The household enjoys housing services by either renting a house at the rental rate ρ_h or buying a house at the price p_h. The size of a purchased or rented house is modeled discretely. For a purchased house, the size h belongs to a set $\mathcal{H}$; for a rented house, the size $\tilde{h}$ belongs to a set $\widetilde{\mathcal{H}}$.[26]

To capture these rental market frictions in our model in a tractable way, we assume that renting generates services less than the size of the rented house, i.e. $s = \omega \tilde{h}'$ with $0 < \omega < 1$.[27] Both rented and owned houses depreciate at a rate of δ_h. When a household sells its home, it incurs a transaction cost $\kappa_h p_h h$, which is proportional to the house value. When a household sells its home or purchases a new house, there is a fixed cost κ_j that is age-dependent, where j denotes the household's age (i.e., the age of the head of the household in the CHFS). This age-dependent cost reflects two factors in China: the reluctance for the old people to move

[25]Since our model abstracts from the government budget, a household's labor income in our model should be interpreted as labor income after tax payments and government transfers.

[26]Although our databases do not have information about the quality of a house financed by a mortgage, we do have information about the house value. After controlling for an increase of the house price, an increase of the house value captures an increase of size or quality or both. In the model, therefore, we assume that different house sizes reflect differences not only in physical size but also in quality. For tractability, we do not distinguish physical size and quality in the model.

[27]Following the standard notation, the superscript prime in $\tilde{h}'$ indicates the current period and $\tilde{h}$ without the superscript prime indicates the last period. This notational convention applies to other housing-related variables as well.

to a new neighborhood (the cultural factor) and the difficulty of obtaining mortgage loans by the old people (the legal factor).[28]

Households can purchase multiple houses with the total housing size h. There is an upper bound on the size of the first house, denoted by $\hat{h}$, such that $s = \min\{h, \hat{h}\}$. The rest of h, $\max\{0, h - \hat{h}\}$, is the size of a secondary house. A secondary house provides no utility. Homeowners do not rent out their secondary houses but hold them purely for the speculative purpose of possible capital gains in the future. This assumption is consistent with China's institutional facts. China does not have a credit score system for individual households such as FICO and Equifax in the U.S. As a result, it is difficult for the landlord to identify potentially good tenants and effectively protect the landlord against defaults on rental payments. In addition, there is lack of laws to penalize the tenant for the delay or delinquency of rental payments, and there is no property tax. More important is the fact that the rent-to-price ratio has long remained low. In 2013, for instance, the average rent-to-price ratio for residential housing in first tier cities was around 2.4%, while the benchmark deposit rate was 3% and the benchmark lending rate was 6% during the same period. Such a low rent-to-price ratio discourages homeowners from leasing their secondary houses and encourages them to hold these empty houses for investment purposes.

Households can finance the purchase of both primary and secondary houses by mortgage if their age is less than J^M (corresponding to age 65 in China).[29] The maximum LTV ratios at origination for these two types of houses, denoted as λ_1 and λ_2, are different. At the time of origination, the borrower is subject to the maximum LTV ratio constraint $m' \leq \lambda_m(h')p_h h'$, where m' is the amount of mortgage in the current period and $\lambda_m(h')$ is defined as

$$\lambda_m(h')p_h h' = \begin{cases} \lambda_1 p_h h' & \text{if } h' \leq \hat{h} \text{ and } j \leq J^M \\ \lambda_1 p_h \hat{h} + \lambda_2 p_h (h' - \hat{h}) & \text{if } h' > \hat{h} \text{ and } j \leq J^M \\ 0 & \text{if } j > J^M \end{cases}.$$

All mortgages are subject to a fixed origination cost, denoted by κ_m. The minimum mortgage payment in each period, denoted by π_m, follows a constant amortization schedule during the remaining lifetime such that

$$\pi \geq \pi_m = \frac{r_m(1 + r_m)^{J+1-j}}{(1 + r_m)^{J+1-j} - 1} m,$$

where r_m is the mortgage interest rate and π is an actual mortgage payment. The outstanding principle evolves according to $m' = (1 + r_m)m - \pi$. Consistent with China's institutional

[28]The longest mortgage term in China is 30 years. A borrower of age 50, for example, is not permitted to obtain a 30-year mortgage loan and must pay a high cost to get a shorter term mortgage loan.

[29]In China, mortgage borrowers are required to be between 18 and 65 years of age.

facts, we assume that the mortgage, once originated, cannot be refinanced and there is no mortgage default.

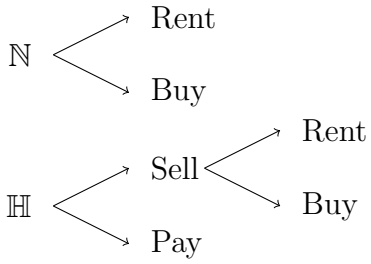
In addition to houses, the household can own a one-period risk-free government bond, denoted by b, at an exogenous price q_b. The interest rate is $r_b = 1/q_b - 1$. The household cannot borrow by short selling its houses. That is, homeowners have no access to a home equity line of credit in our model (another institutional fact of China).

In each period, a household's idiosyncratic state is represented by the vector $\chi = (b, m, h, y)$. Let $\mu \equiv \mu(\chi)$ be a probability measure of households indexed by the idiosyncratic state χ and let $\Omega = (\phi, \mu)$ represent the aggregate state. We solve the household problem in two steps. First, we solve for the household tenure decision (e.g., buying or renting a house). Second, conditional on this decision, the household chooses the size of a house to purchase or rent, along with its choice of consumption and savings in non-housing financial assets.

IV.1.2. *The household decision.* At the beginning of each period, a household with no house chooses between renting and buying a house, and a household that owns a house chooses between selling its house and keeping it while making mortgage payments. If the household sells the house, it then needs to choose between buying and renting a new house. Diagram 1, below, summarizes the housing state at the beginning of the period and the housing tenure decision choice during the period.

Diagram 1: Initial state and housing tenure decision during the period[30]

State at beginning of the period		Housing tenure decision			
With house	Without house	Sell	Pay	Rent	Buy
$\mathbb{H}$	$\mathbb{N}$	$\mathbb{S}$	$\mathbb{P}$	$\mathbb{R}$	$\mathbb{B}$



In the decision tree, we rule out the possibility that a household purchases a house and at the same time rents another house, as the housing decision is lumpy. The housing decision depends on the costs and benefits of owning a house. The cost is a down payment. There are at least two benefits: (a) it generates more utility from housing services than renting a

[30]The symbols $\mathbb{S}$, $\mathbb{P}$, $\mathbb{R}$, $\mathbb{B}$ are used as superscripts for various value functions in the recursive household problem described in Appendix D.

house and (b) it allows the household to enjoy potential capital gains with expected returns much higher than investing in risk-free assets.

Homeowners have the option of keeping their houses or changing their housing positions. In the model, a homeowner with an idiosyncratic shock that leads to high labor incomes is likely to trade up her house for investment purposes, while a homeowner with an idiosyncratic shock that leads to low labor incomes is likely to downsize her house or become a renter to smooth consumption. In the stochastic steady state, therefore, there is always demand for newly originated mortgages with a positive fraction of households trading up their primary houses.

IV.2. **The rental sector.** In each period, the representative rental company purchases houses and rents them to renters with an operating cost ψ for each housing unit. The problem of the representative rental company is

$$J(\tilde{H};\Omega) = \max_{\tilde{H}'} \ [\rho_h(\Omega) - \psi]\tilde{H}' - p_h(\Omega)[\tilde{H}' - (1-\delta_h)\tilde{H}] + \frac{1}{1+r_b} E_{\Omega'|\Omega} J(\tilde{H}';\Omega'),$$

where $\rho_h(\Omega)$ is the rental price. The zero profit condition gives the equilibrium rental rate as

$$\rho_h(\Omega) = \psi + p_h(\Omega) - \frac{1-\delta_h}{1+r_b} E_{\Omega'}[p_h(\Omega')|\Omega].$$

In equilibrium, the rent is the sum of the operating cost and the user cost.

IV.3. **Production sectors.** Following Kaplan, Mitman and Violante (2020), there are two production sectors in the economy: a non-housing consumption goods sector and a construction sector that produces new houses. Labor is perfectly mobile between the two sectors. Competitive firms in the non-housing sector are endowed with a technology with constant returns to scale in labor:

$$Y = \Theta N_c \,,$$

where Y is aggregate output, Θ the aggregate labor productivity, and N_c aggregate efficiency labor employed in the non-housing sector. The first-order condition for labor determines the wage rate as $w = \Theta$.

In the construction sector, the government issues new permits equivalent to $\bar{L}$ units of land each period, and these permits are sold in a competitive market to real estate developers. The government collects all rents from its land ownership. After acquiring a land permit, a competitive real estate developer combines labor and land to produce new houses according to a Cobb-Douglas production technology

$$\max_{N_h} \ p_h I_h - w N_h$$

$$s.t. \ I_h = (\Theta N_h)^{\alpha} (\bar{L})^{1-\alpha},$$

where I_h represents new houses and N_h aggregate efficiency labor employed in the construction sector. The Cobb-Douglas technology implies that the developer makes zero profit in equilibrium. The investment function follows from the first-order condition with respect to N_h and the equilibrium condition $w = \Theta$:

$$I_h = (\alpha p_h)^{\frac{\alpha}{1-\alpha}} \bar{L}. \tag{3}$$

Equation (3) captures the supply curve of new housing as a function of housing prices. Accordingly, the price elasticity of (new) housing supply is $\frac{\alpha}{1-\alpha}$. As we will show later, how much a change in housing demand driven by the change in second-home LTV policy translates into housing price depends crucially on the price elasticity of housing supply.

IV.4. **Calibration.** We calibrate the model to match the key aggregate and cross-sectional moments prior to the loosening of LTV policy in 2014Q4. Since the CHFS is conducted every two years, we use the year 2013 to calculate these moments for the initial steady state of the model, which corresponds to the Chinese economy prior to a change of LTV policy in 2014Q4.[31] The calibrated values of parameters are summarized in Table 2 and a comparison of the targeted moments between the model and the data is reported in Table 3.

There are two sets of parameters in our model. A first set of parameters is assigned externally, whose values are taken from the existing literature. The other set of parameters is calibrated to the key moments in the data.

Demography. A period in the model corresponds to a two-year horizon in the data. Households enter the economy at age 20, work until age 55 (corresponding to $J^{\text{ret}} = 19$), and live until age 76—the average life expectancy in China (corresponding to $J = 29$). Households with high (low) labor ability in our model correspond to households with college degree and above (high school diploma and below) in the data. The fraction of households with high labor ability is calibrated to match the fraction of households with college degree and above in the CHFS. In the rest of the paper, we refer to households with high labor ability in our model as households with high incomes or high education to be compatible with the data.

Preference. In the model, the transition probability Π_{lh} governs the magnitude of speculation incentives. We choose its value to target the average value (5%), across 70 cities in China, of the shares of the mortgage amount of secondary houses in total mortgage amount in 2013. A higher value of Π_{lh} would lead to a higher steady-state share of the mortgage amount of secondary houses in the total mortgage amount. The housing preference parameter in the low state, ϕ_L, is chosen so that the average share of housing services in total

[31] When some data for 2013 are unavailable, we use the data in 2012 or earlier.

expenditures is 0.2 in the steady state, consistent with the weight used in the official consumer price index (CPI) basket in China. We choose ϕ_H to target the homeownership rate (14.6%) of secondary houses in 2013.

We follow Piazzesi, Schneider and Tuzel (2007) and set $1/\gamma$, the elasticity of substitution between non-housing consumption and housing services, at 1.25. The risk aversion parameter, σ, is set to 2, which is also standard in the literature. The utility discount factor β is calibrated to target the average ratio of wealth to labor income in 2012, which is 10.21 as estimated in Xie and Jin (2015) with the China Family Panel Studies data. The utility discount parameter for renting, ω, is calibrated as 0.90 to target the average homeownership rate of China in 2013 (86%). The parameter for bequest motives, φ, is calibrated to target the ratio of net worth of households of age 75 to net worth of those of age 55.

Labor endowment. The age profile of labor efficiency units is the same as He, Ning and Zhu (2017), who estimate the profile using the data in the China Health and Nutrition Survey. The process of an idiosyncratic labor income shock, ϵ, is specified as an AR(1) process in log with the same values of ρ_ϵ and σ_ϵ as in İmrohoroğlu and Zhao (2018). We normalize the low labor ability η_L to 1 and set the high labor ability $\eta_H = 2.4$ to match the the college premium as estimated by Wang (2012) who use the data from China Household Income Project. The social security replacement rate is set to 0.4, which is the average national replacement rate in 2010-2013.

Housing. We follow the strategy of Kaplan, Mitman and Violante (2020) to choose three parameters for the house size set $\mathcal{H}$ among homeowners: the minimum size of owner-occupied housing units, the number of discretized house sizes in $\mathcal{H}$, and the interval between two adjacent house sizes. We target three moments of the distribution of the ratio of net housing wealth to total net wealth among homeowners: the 10th percentile, median, and the 90th percentile. Total net wealth is defined as the sum of housing wealth and net financial wealth, and we refer to total net wealth as "net worth." We use "total net wealth" and "net worth" interchangeably throughout this paper. The distribution of housing wealth in the initial steady state is crucial for the quantitative impacts of a change in LTV policy at both the household and the aggregate levels. We normalize the moving cost for young households at zero and calibrate the moving costs for middle-aged and old households to target the corresponding shares of their mortgage origination numbers in 2013. We choose the threshold value of secondary houses, $\hat{h}$, to target the share of the mortgage origination number for secondary houses in the total number of mortgage originations in 2013, which is around 5%.

The house depreciation rate, δ_h, is set to 2%, the same as the depreciation rate for China's urban owner-occupied houses estimated by the Organisation for Economic Co-operation and

Development. The transaction cost for selling a house, κ_h, equals 3% of the value of house. The rental company operating cost is chosen to match the homeownership rate of households under age 30. The value of a new land permit $\bar{L}$ is calibrated to target the ratio of the house price to income.[32]

One crucial moment to estimate is the price elasticity of (new) housing supply, which governs the value of construction technology parameter α. To estimate the housing supply elasticity, we exploit variations in housing demand that are exogenous to changes in house prices. We use the policy exposure measure to construct the instrument for housing demand during 2013-2018, and then estimate the effect of (exogenous) changes in housing demand on house prices, which gives the inverse of the housing supply elasticity. Appendix F provides the details of our estimation procedure. Our estimated house supply elasticity is 4 (=1/0.250), which implies $\alpha = 0.8$.

Financial variables. The risk-fee interest rate, r_b, is set to 3% per annum, which equals the average benchmark deposit rate in 2010-2013. The mortgage interest rate, r_m, is set to 4.94%, which is the average mortgage interest rate for households in 2013 according to the CHFS. The mortgage origination cost, κ_m, is calibrated to target the average ratio of homeowners' outstanding mortgage debt to their income in 2013, which is 3.38.

LTV Policy. We calibrate the minimum down payment ratio for the first and secondary houses in the model to match actual LTV policies prior to 2014Q4 for these two types of houses. Accordingly, $\lambda_1 = 0.7$ and $\lambda_2 = 0.4$.

IV.5. **Distribution in the steady state.** To understand the distributional impacts of a loosening of LTV policy, we first discuss a set of model predictions in the steady state that are not calibrated to the data. The impact of a policy change on housing demand depends on both the distribution of LTV ratios and the distribution of housing wealth across age-income groups in the steady state. The LTV distribution captures how tight the LTV constraints are across age-income groups, and the distribution of housing wealth determines which age-income group enjoys capital gains most when the house price rises. We show how the model predicts the LTV distribution and the life-cycle profile, as well as cross-sectional moments, of housing wealth and net worth across age-education groups in the data.

LTV distribution. We compute the model distribution of LTV ratios for homebuyers with positive mortgages and compare them to the empirical distribution from the Bank Loan Data.[33] Figure 8 displays the distribution of LTV ratios for mortgages on primary houses at

[32]According to E-House China (`http://www.ehousechina.com/index`), for the 35 major cities in China, the average ratio of the house price to income is 7.3 in 2012.

[33]Our granular mortgage data contains homebuyers with only positive LTV ratios at origination.

origination in four age-education groups (the results from both the model and the data for comparison). Consistent with Figure 2, the empirical LTV distribution peaked at the value of 0.7 (the LTV limit on primary houses in 2013) for all age-education groups. In particular, the LTV ratios for more than 70% of middle-aged households with high education were at the LTV policy limit. This fact is explained by benchmark economy, in which these households are constrained to invest in secondary houses. Indeed, the model's steady state results replicate reasonably well the empirical LTV distributions for the four age-education groups, especially for middle-aged households with high education.

By contrast, these empirical distributions cannot be explained by the standard life-cycle model, in which the LTV constraint on middle-aged households with high education is largely unbinding without speculative motives for purchasing secondary houses. To show this point, we turn off the stochastic regime in the utility of housing services by setting $\Pi_{lh} = 0$. As shown by the dash line in Figure 8, except for low-income young households, who are constrained for consumption of housing services, the fraction of households whose borrowing constraints are binding is much smaller in the counterfactual economy than in the calibrated benchmark economy. The difference is more pronounced for middle-aged households with high incomes than other groups. For middle-aged households with high incomes, the peak of the LTV distribution shifts to the left end. Nearly 30% of homebuyers borrow with LTV ratios between 0.05 and 0.15, and only about 10% of homebuyers borrow to the LTV limit on primary houses. By contrast, in the benchmark economy, a vast majority of middle-aged homebuyers with high incomes borrow to the LTV limit for investment purposes.

Life-cycle profile of wealth. Figure 9 demonstrates how much the model is capable of accounting for the empirical life-cycle profile of wealth. In the data, both net worth and housing wealth of households with high incomes (education) are higher than those of households with low incomes (education) at the initial level, and increase with age at a much faster rate than those of households with low incomes (education). The top two panels report net worth across ages for both low-income and high-income households. The model matches the empirical life-cycle profile of net worth for households with low education and high education, which was hump-shaped and peaked around age 55. Net worth of households of age 40 with high education was about three times that of households of age 40 with low education and twice that of young households with high education.

The bottom panels show that the model replicates, reasonably well, the empirical age profile of housing wealth of households with high education. Housing wealth of high-income households of age 40, for instance, is about twice that of low-income households of age 40 and about three times the housing wealth of high-income households of age 20. These results imply that middle-aged households with high incomes enjoy much larger capital gains

from increases of the house price than middle-aged households with low incomes or young households with high incomes. [34]

Cross-sectional moments. To see how well the model can match various empirical cross-sectional moments, we begin with the Gini coefficients for housing wealth and net worth (top portion of Table 4). The Gini coefficient for housing wealth produced by the model is close to the empirical Gini coefficient. The model's results are also close to the empirical shares of households' net worth in different quintiles (middle portion of the table). The model matches the data reasonably well for the ratio of housing wealth to income for median households, but fail to predict well this wealth-to-income ratio for households in the 10th and 90th percentiles (bottom portion of the table).

Summary. Our model predicts, reasonably well, the empirical distribution of LTV ratios for various age-education groups, the life-cycle profile of wealth, and other cross-sectional distributions of wealth. Since the LTV distribution for various age-education groups and the distribution of housing wealth in the initial steady state are crucial for how housing demand responds to a change of LTV policy, our theoretical framework is well positioned for exploring the quantitative impacts of alternative LTV policy instruments applied to mortgages on secondary houses as well as primary homes.

V. Impacts of LTV policy for secondary houses

This section provides a quantitative assessment of impacts of LTV policy for secondary houses on the mortgage market. To replicate the actual change of LTV policy for secondary houses during the period 2014Q4-2016Q3, we model a relaxation of the LTV limit on secondary houses to match the duration and magnitude of this actual change. We explore, in Section V.1, the impacts of this policy change on the housing and mortgage markets as well as the household welfare. To understand the key channel through which this policy relaxation affects mortgage markets and welfare, we conduct several counterfactual experiments in Section V.2.

V.1. **A relaxation of LTV policy for secondary houses.**

Our benchmark policy experiment is to reduce the MDPR for secondary houses. In period 0, the model economy is at the steady state. In the beginning of period 1, the LTV limit for secondary houses increases from

[34] To capture determinants of trade-up decision by existing homeowners, in Appendix G, we develop a simple model with linear utility. We show that households with higher income and larger housing net worth (housing wealth minus outstanding mortgage debt) are more likely to trade up their primary homes when a relaxation of LTV policy for secondary houses increase house prices via housing speculation.

0.4 to 0.65.[35] Since a period in our model corresponds to two years in the data, the relaxation of LTV policy lasts for one period to be consistent with the two-year period 2014Q4-2016Q3 when LTV policy was relaxed. During this period, however, households expect that the new LTV limit ($\lambda_2 = 0.65$) will last forever. In period 2, the LTV limit is reversed unexpectedly to the initial steady state value of $\lambda_2 = 0.4$. Throughout this policy experiment, we keep unchanged the MDPR for primary homes and other parameters such as mortgage interest rates. In particular, the parameter Π_{lh} is kept at its steady state value to help isolate the effects of LTV policy for secondary houses.

V.1.1. *Aggregate and distributional effects.* Table 5a reports the changes of annualized growth rates of various key variables in response to the relaxation of the LTV limit on secondary houses. The house price increases by 4.91% (per annum) during the policy period, indicating that this LTV policy change alone accounts for about 82.7% of the observed increase in the housing price from the period 2011Q1-2014Q3 to the policy period 2014Q4-2016Q3.[36] The total amount of newly issued mortgage loans is 67.87% higher than that in the initial state, accounting for almost three-fourths of the observed increase in newly issued mortgages. The number of mortgage originations increases from the initial state by 28.41%, accounting for about 61% of the increase observed in the data. For primary houses, the mortgage amount increases by 48%, accounting for 61% of the observed increase; the number of mortgage originations increases by 21.81%, explaining 52% of the observed increase. The increase in mortgages on secondary houses replicates the data reasonably well for both amount and number of originations. These model results indicate that a relaxation of LTV policy for secondary houses is a main driving force of the observed boom in the housing and mortgage markets.

In our empirical analysis, we find that a relaxation of the LTV limit on secondary houses had significant effects on mortgage loans to primary homes owned by middle-aged households with high education. These households also owned a large share of wealth in the economy. Table 5b reports the percentage changes in the mortgage share of an age-income group in total mortgages on primary homes, where the classification of income group corresponds to the permanent labor ability in the model. For comparison, we report in parentheses the corresponding data on the percentage changes in mortgage shares of various age-education groups

[35]Actual LTV policy in China allowed a household who owned a primary home with the mortgage fully paid to purchase a second house with the MDPR as low as 30%. For a household who owned a primary home with a positive mortgage, however, the MDPR is 40%. We take the midpoint 35% as the MDPR for secondary houses, which corresponds to the LTV limit of 0.65.

[36]Note that our model abstracts from house price growth at the steady state. Therefore, a percetange increase in the house price in the model corresponds to a change in house price growth in the data.

from 2013 to 2015. In our model, across age-income groups, only the high-income middle-aged group of households experiences significant increases in the shares of their mortgage origination amount (11.8%) and number (6.89%) in total mortgages on primary homes; these increases are close in magnitude to the data (11.78% and 7.26%). By contrast, the shares of mortgage origination amount for both low-income and high-income young households in total origination amount of primary home mortgages decline. Out of the total number of originations for mortgages on primary homes, the share of low-income young households declines by 2.45%, while the share of high-income young households increases but by only 0.60%, consistent with the data (−2.46% and 0.52%). The consistency of these results between model and data reinforces our finding that a relaxation of LTV policy for secondary houses is a key driver of the housing and mortgage booms.

In our model, an increase in mortgage demand following a change in LTV policy on secondary houses is influenced mainly by two factors: (i) an increase in housing demand by existing homeowners who choose to trade up their primary homes and (i) an increase of households who switch from renters to homeowners.[37] The literature emphasizes the second factor, which is the conventional channel for how a change in the credit condition influences mortgage demand. By contrast, both empirical and theoretical findings on the distributional effects of LTV policy for secondary houses shed light on the importance of the first factor via the price appreciation. That is, an increase in the house price encourages homeowners to trade up their existing homes with the help of capital gains; these homeowners would otherwise keep their existing homes because of the fixed costs involved in moving and mortgage origination.

We find, through the lenses of our model, that the first factor is the key for a relaxation of the LTV limit on secondary houses to affect the aggregate demand for mortgages. As Table 6a shows, an increase in the number of households who trade up their existing homes contributes to 57.86% of the increase in the origination amount of total mortgages, 78.04% of the increase in the origination number, and 61.56% of the increase in housing demand.[38] Table 6b decomposes the increase in mortgage originations and housing demand attributable to trade-up by existing homeowners into age-education groups. Middle-aged households with high incomes contribute to a majority of the increase in mortgage originations (over 63%), as well as in housing demand, due to trading up existing homes. Thus, a relaxation of the LTV

[37]The first factor is driven by both an increase in the number of existing homeowners who choose to trade up their primary homes, and an increase in the size of homes purchased by these homeowners.

[38]In our model, housing demand is measured as the sum of housing demands by homeowners and by the rental company (see Appendix D.2).

limit on secondary houses influences, disproportionally, high-income middle-aged households who trade up their existing homes with the help of rising house prices.

V.1.2. *Welfare effects.* We now explore the effects of a change in LTV policy for secondary houses on welfare. Following the literature, we measure a change of welfare by the consumption equivalent variation (CEV)

$$\Delta\tilde{c}_j = \left[\left(V_j^{TR}/V_j^{SS}\right)^{\frac{1}{1-\sigma}} - 1\right] \times 100\%,$$

where V_j^{SS} is the utility value of household j in the steady state and V_j^{TR} is the utility value of household j in the transition state (the policy period). CEV captures a percentage increase of (composite) consumption in the steady state such that household j is indifferent between the steady state and the transition state induced by a change in LTV policy.

Column 1 of Table 7a reports the welfare effects of a relaxation LTV policy for secondary houses on different age groups. Households as a whole suffer, on average, a welfare loss of 0.49% in terms of consumption equivalent variation. This loss, however, is unevenly distributed across different age groups. Both young and old households suffer a welfare loss while middle-aged households have a welfare gain. Young households, in particular, suffer a welfare loss of 1.42%. Columns 2 and 3 report the welfare effects of this policy change by households' housing status prior to the policy change. As we can see, the welfare loss is entirely borne by the renters, i.e, those who do not own a home prior to the policy relaxation. An average renter, for instance, suffers a welfare loss of 5.24%. By contrast, all existing homeowners, especially middle-aged households, achieve a welfare gain.

Table 7b shows the welfare effects of such a policy change on different age-income groups. Among young households, the policy change leads to a welfare loss for both low-income and high-income households (columns 1 and 2). Low-income young households suffer a 1.02% welfare loss, while high-income young households suffer a loss of 2.03%. Columns 3 and 4 show that both high-income and low-income renters suffer a welfare loss. By contrast, all existing homeowners except for the low-income young households benefit from welfare gains (columns 5 and 6).

To summarize, an increase of the LTV limit on secondary houses generates a welfare loss for the economy as a whole; the welfare loss is disproportionately borne by those who do not own a house.

V.2. **Counterfactual analysis.** In this section, we conduct several counterfactual exercises to deepen our understanding of the role of LTV policy for secondary houses in influencing the housing market. We begin with a first counterfactual exercise by increasing the parameter of the housing supply elasticity in our model to explore the sensitivity of the house price

to a change in the value of this key parameter (Section V.2.1). We then impose a 100% capital gain tax in the model to quantify the role of capital gains generated by increases of house prices (Section V.2.2). Our third counterfactual exercise is to explore the importance of house prices in our welfare analysis by holding the house price constant when LTV policy changes (Section V.2.3). Last, we explore the effectiveness of a counterfactual tightening of LTV policy for secondary houses in taming housing speculation and the consequence of such a policy tightening on welfare (Section V.2.4).

V.2.1. *The elasticity of housing supply.* A relaxation of LTV policy on secondary houses has a direct impact on aggregate housing demand. Whether this impact will in turn raise the house price and by how much depends on the key parameter for the price elasticity of housing supply. To quantify the role of the housing supply elasticity in the transmission of LTV policy for secondary houses to house prices and mortgages on primary homes, we change the price elasticity of housing supply to 15, but keep the policy experiment and other parameter values the same as in Section V.1. This changed value of the elasticity of housing supply is substantially larger than the value estimated from the data, which is only 4.

When the price elasticity of housing supply is set to 15, a relaxation of LTV policy for secondary houses increases the house price by only 0.67% annually (column 1 of Table 8), much smaller than our benchmark result (4.91%, column 3). As mortgage originations to primary homes decline, the aggregate amount and total number of mortgage originations increase by only 17.85% and 0.98%.[39] By contrast, mortgage originations for secondary houses increase more than the benchmark results (comparing columns 1 and 3) because of the stronger direct effects of LTV policy on mortgage originations to secondary houses with the larger elasticity of housing supply.

Our finding of a large quantitative effect of a relaxation of LTV limits for secondary houses is in contrast with Kaplan et al. (2020), which find that a relaxation in LTV limits has little impact on house prices. The crucial difference between our model and the model of Kaplan et al. (2020) is that our model incorporates secondary houses that are purchased for speculative investments. In Kaplan et al. (2020), households do not have speculative motives for housing investment as LTV limits changes. As a result, a change in general LTV policy in Kaplan et al. (2020), as in the conventional channel of LTV policy, affects the demand for owner-occupied homes through housing tenure decisions of credit-constrained households. The response of house prices, as discussed in Greenwald and Guren (2019),

[39]Mortgages on primary homes decline because the small increase in house prices is insufficient to generate enough capital gains for existing homeowners to trade up to larger homes while paying a fixed cost of mortgage originations. At the same time, the higher house price discourages renters from becoming first-time homebuyers.

depends on how costly it is for the landlord (the rental company in our model) to convert rental homes to owner-occupied homes. In Kaplan et al. (2020), it is costless to convert between rental housing and owner-occupied housing. Hence, without speculative incentive, the strong rental conversion causes little price increase in response to increase in LTV limits.

In our model, landlords can still convert rental housing costlessly into owner-occupied housing. This mechanism, however, is not the main channel for a change in the LTV limit on secondary houses to drive housing demand and thus the house price. When incorporating secondary houses as speculative investments in our model, a relaxation of LTV policy for these houses directly increases the housing demand by speculative investors. Since they are existing homeowners, an increase of their housing demand can only be met by newly built houses, rather than by conversations from rental housing to owner-occupied housing. Hence, the response of house prices to a change in LTV policy for secondary houses depends crucially on the supply elasticity of newly-built houses.

V.2.2. *Capital gains via increases in house prices.* In Section V.1, we show that a *significant* increase in the house price is crucial for a relaxation of LTV policy for secondary houses to drive up households' mortgage demand for primary houses, as it allows existing homeowners to trade up their primary homes. Capital gains are the key channel for the price increase to enable existing homeowners to trade up to larger houses: an increase of the house price enables existing homeowners to take advantage of capital gains when they sell their houses.[40] The larger the existing house, the larger the capital gains. Because middle-aged households with high incomes tend to have large homes, the wealth effect of an increase in house prices on trade-ups of existing homes is strong for this group of households.[41]

To quantify the importance of this capital gain channel, we experiment with a counterfactual exercise in which a 100% tax rate is imposed on capital gains while keeping the increase of the LTV limit on secondary houses the same as in our benchmark model (Section V.1). As column 2 of Table 8 shows, the housing price with a tax rate of 100% on capital gains rises by only 0.53%, much lower than our benchmark result and the data (columns 3 and 4). An increase in the aggregate amount of mortgage originations is only 5.37%, as compared to

[40]Note that the effects of house price appreciation on LTV constraints of existing homeowners differ from Greenwald (2018), who shows that a relaxation in the payment-to-income (PTI) ratio eventually increases housing demand via an increase of the house price and thus housing collateral values.

[41]Using the NBS data, we find that during 2011Q1-2018Q1, the year-over-year growth rates of prices for houses of three size categories (i.e., less than 90 square meters, between 90 and 144 square meters, and above 144 square meters) are quantitatively very close to one another. This evidence is consistent with our model's prediction that different magnitudes of capital gains for homeowners are driven by different sizes of their existing homes.

a 67.87% increase when there is no capital gains tax (columns 2 and 3). Moreover, the total number of originations declines by 4.16%. Declines in mortgage originations for primary houses (18.47% in amount and 12.10% in number, column 2) dampen much of the overall mortgage originations. These declines are in sharp contrast to large increases produced by the benchmark model and shown in the data (columns 3 and 4). Without capital gains from house prices, therefore, existing homeowners would be seriously discouraged from trading up their primary homes.[42]

To summarize, when LTV policy for secondary houses is loosened, capital gains are the key factor for understanding increases in house prices and mortgage demand, especially for primary houses. With speculative incentives for housing investments, a significant fraction of middle-aged households with high incomes face binding LTV constraints for investment purposes. An appreciation in values of primary homes driven by the spillover effect allows these homeowners to overcome the LTV constraint and trade up to larger homes. Since middle-aged households with high incomes represent a sizable share of housing demand in the economy, an increase of their mortgages and housing demand plays a quantitatively important role for an increase in total demand for mortgages when the LTV constraint is loosened.

V.2.3. *The role of the house price increase in welfare.* In this section, we highlight the role of house price increases in the negative welfare impacts of relaxing LTV policy on young renters by considering a counterfactual economy in which the house price is held constant throughout the transitional path when LTV policy on secondary houses is loosened. In this counterfactual economy, a relaxation of LTV policy would generate a welfare gain of 0.04% for all households (Table C.2 of Appendix C), in contrast to a welfare loss when house prices are allowed to respond.

Young households receive a welfare gain of 0.05%, in contrast to a welfare loss in the benchmark economy (column 1 of Table C.2 in Appendix C). The welfare gain of middle-aged households is much smaller than the gain in the benchmark economy (0.08% versus 0.46%). Unlike the benchmark result, renters no longer suffer welfare loss (column 2).[43] These results indicate that higher house prices due to a relaxation of LTV policy for secondary houses is key to the welfare loss for renters in our benchmark model, because higher house prices prevent these households from entering the housing market and force them to stay in the rental market in which a rental house yields a lower utility of housing services than the ownership of a house.

[42]Our numerical results indicate that essentially no household trades up their existing homes.

[43]A similar result holds for renters with both high and low incomes (not displayed in the table).

V.2.4. *Macroprudential policy counterfactual.* Our theoretical model demonstrates that a relaxation of LTV policy for secondary houses fuels a housing boom via housing speculation. To rein in speculation, how effective are LTV policy instruments when applied to secondary houses, and what are the implications on welfare?

To answer these questions, we recalibrate the initial state of the economy such that at the beginning of period 0, the LTV limit is 0.65 on secondary houses and 0.8 on primary homes, which correspond to their actual 2016Q3 levels. In period 1, we conduct a counterfactual exercise by lowering the LTV limit from 0.65 to 0.4 on secondary houses. During the period of policy tightening, households expect that the new LTV policy for secondary houses will last forever. In period 2, the LTV policy is reversed unexpectedly to its initial steady state value.

Following a tightening of LTV policy for secondary houses, the house price falls by 3.38% and the aggregate amount of mortgage originations falls by 44.67%. This fall in the aggregate mortgage amount is attributable to the responses of mortgages on both secondary houses and primary homes. A tightening of LTV policy for secondary houses causes not only a fall in the amount of mortgages on secondary houses by 90.51% as a direct effect, but also a significant decline in the amount of mortgages on primary homes (-36.87%) as a propagation effect via the decrease of the house price.[44] These results indicate that a tightening of LTV policy for secondary houses is an effective macroprudential policy tool in taming speculation.

Table C.3 of Appendix C reports the welfare effects of a tightening of LTV policy for secondary houses. Column (1) shows that a tightening of the LTV limit on secondary houses improves welfare by 0.51% on average. To the opposite of a relaxation of LTV policy for secondary houses, both young and old households benefit from this policy change, while middle-aged households suffer. The young households, for example, enjoy a gain of equivalent consumption by 1.98%. As column 2 and 3 show, welfare gains are concentrated in renters, while homeowners suffer a welfare loss. A fall in the equilibrium house price makes housing more affordable for renters to become homeowners.

In summary, our counterfactual analysis shows that a tightening of LTV policy for secondary houses is not only effective in reining in housing speculation as a macroprudential instrument, but also significantly improves welfare of young households and renters. The welfare improvement from a tightening of LTV policy for secondary houses stems from its effectiveness in taming housing speculation.

[44]All these findings hold true for the number of mortgage originations.

VI. Conclusion

This paper studies the role of LTV policy on housing speculation in driving the boom of the housing and mortgage markets. We use China's recent change of LTV policy for secondary houses as an experiment for this study. By utilizing the unique administrative data of more than 3 million mortgage originations, our empirical design identifies the causal effect of such a policy change by exploiting cross-city variations in exposure to this policy change. Our evidence shows that a loosening of LTV policy for secondary houses caused a mortgage boom for the entire economy, much of which were fueled by increases in mortgage originations to primary homes. Moreover, this loosening policy had a disproportionally positive effect on mortgage demand for primary homes by middle-aged households with high education.

We develop a life-cycle equilibrium model to quantify the mechanism through which a change in LTV policy for secondary houses fuels the entire housing boom. We find that the capital gain channel is the key for a loosening of secondary house LTV policy to have a quantitatively large impact on both house prices and the entire mortgage market. Capital gains from large increases in house prices due to speculative investments in secondary houses allow the homeowners of primary residence to trade up to larger primary homes, which raises the house price further. This positive feedback loop between house prices and housing demand leads to substantial increases in house prices and mortgage borrowings in equilibrium. Such a policy change causes unintended welfare losses, especially for young households who are not homeowners prior to the policy change. Rising house prices make it less affordable for these households to own homes. Our finding suggests that LTV policy restricting access to mortgages for investment purposes is welfare improving and effective in taming housing speculation.

TABLE 1. The effect of a loosening of LTV policy on secondary houses on city-level mortgage

(A) The effect of a loosening of LTV policy on secondary houses on city-level total mortgage origination

	Mortgage amount		Mortgage number	
	(1)	(2)	(3)	(4)
Exposure × Policy	0.245***	0.220***	0.215***	0.206***
	(0.051)	(0.076)	(0.051)	(0.069)
Adjusted R^2	0.885	0.886	0.876	0.876
Observations	1820	1820	1820	1820
City characteristics × Policy	N	Y	N	Y
City controls	Y	Y	Y	Y
City fixed effect	Y	Y	Y	Y
Year-quarter fixed effect	Y	Y	Y	Y

(B) The effect of a loosening of LTV policy on secondary houses on city-level primary home mortgage origination

	Mortgage amount		Mortgage number	
	(1)	(2)	(3)	(4)
Exposure × Policy	0.243***	0.225***	0.226***	0.214***
	(0.051)	(0.076)	(0.050)	(0.069)
Adjusted R^2	0.882	0.882	0.875	0.875
Observations	1820	1820	1820	1820
City characteristics × Policy	N	Y	N	Y
City controls	Y	Y	Y	Y
City fixed effect	Y	Y	Y	Y
Year-quarter fixed effect	Y	Y	Y	Y

(C) The effect of a loosening of LTV policy for secondary houses on the mortgage share of middle-aged households with high education in total mortgages on primary homes

	Mortgage amount		Mortgage number	
	(1)	(2)	(3)	(4)
Exposure × Policy	0.044***	0.029***	0.036***	0.026***
	(0.009)	(0.010)	(0.008)	(0.010)
Adjusted R^2	0.797	0.806	0.807	0.812
Observations	1820	1820	1820	1820
City characteristics × Policy	N	Y	N	Y
City controls	Y	Y	Y	Y
City fixed effect	Y	Y	Y	Y
Year-quarter fixed effect	Y	Y	Y	Y

Notes: All regressions control for time-varying mortgage interest rates. All city characteristics are normalized by their cross-sectional standard deviations. Standard errors, reported in parentheses, are clustered at the city level. The asterisk * denotes statistical significance at the 0.1 level, ** at the 0.05 level, and *** at the 0.01 level.

TABLE 2. Calibrated values of model parameters

Parameter	Interpretation	Value
Demographics		
J^{ret}	Retirement age	19
J	Length of life	29
ν	Share of high ability households	0.4
Preference		
$1/\gamma$	Elasticity of substitution	1.25
σ	Risk aversion	2.00
β	Discount factor	0.96
ϕ_L	Housing preference in low state	0.20
ϕ_H	Housing preference in high state	0.30
Π_{lh}	Probability from ϕ_L to ϕ_H	0.4
ω	Utility discount from renting	0.9
φ	Strength of bequest motive	90
Endowments		
ε_j	Life-cycle profile	He, Ning and Zhu (2017)
ρ_ϵ	Income correlation	İmrohoroğlu and Zhao (2018)
σ_ϵ	Std of income shocks	İmrohoroğlu and Zhao (2018)
η_H	High labor ability	Wang (2012)
ξ	Replacement rate	0.4
Housing		
$\mathcal{H}$	Owner housing grid	$\{0.7, 1.6, 2.5, 3.4, 5.2\}$
$\widetilde{\mathcal{H}}$	Renter housing grid	$\{0.7, 1.6, 2.5\}$
$\hat{h}$	2nd house cutoff	3.4
κ_h	Housing sale transaction cost	0.03
δ_h	Housing depreciation rate	0.02
ψ	Rent company operation cost	0.015
$\alpha/(1-\alpha)$	Housing supply elasticity	4.0
$\bar{L}$	Land endowment	0.298
Financial instruments		
r_b	Interest rate	0.03
r_m	Mortgage rate	0.049
κ_m	Mortgage origination cost	0.02
LTV policy		
λ_1	MDPR for first houses	0.7
λ_2	MDPR for secondary houses	0.4

Notes: One period in the model corresponds to two years in the data. All values to which the time period is relevant are annualized.

TABLE 3. Targeted aggregate moments for the calibration

Moments	Data	Model
Overall homeownership rate	0.86	0.87
Homeownership rate under age 30	0.66	0.69
Share of mortgage origination amount for secondary houses	0.05	0.03
Share of mortgage origination number for secondary houses	0.05	0.04
Homeownership rate for secondary houses	0.15	0.08
Aggregate wealth-to-income ratio	10.21	8.78
Ratio of outstanding mortgage amount to income	3.08	3.36
Ratio of purchased house value to income	7.30	8.56
Ratio of net worth of households with age 75 to that of those with age 55	0.82	0.78
Share of mortgage origination number for middle-aged households	0.58	0.57
Share of mortgage origination number for old households	0.06	0.07
Ratio of net housing wealth to net worth: 10^{th} percentile	0.61	0.67
Ratio of net housing wealth to net worth: median	0.93	0.96
Ratio of net housing wealth to net worth: 90^{th} percentile	1.00	1.00

Notes: We construct housing wealth as the sum of the values of both primary homes and secondary houses. We construct net worth (total net wealth) as the sum of housing wealth and net financial wealth. Net financial wealth is defined as financial assets (bank accounts, cash, bonds, stocks, mutual funds, other financial assets, private business wealth, and private cars), minus financial liabilities (mortgages on primary homes and secondary houses, other debts for houses, debts for cars, education, and private business, and other financial debts). Net housing wealth is measured as housing wealth, minus outstanding mortgage debts and other debts for houses. The data moments for the share of mortgage amount for secondary houses in the total amount of mortgages at origination, the share of origination number for secondary houses in the total number of mortgage originations, and the share of origination number for middle-aged and old households in the total number of mortgage originations are calculated from the Bank Loan Data; the ratio of the house value to income is calculated from E-House China; and other data moments are calculated from the CHFS.

TABLE 4. Targeted cross-sectional moments for the calibration

Moments	Data	Model
Gini coefficient: net worth	0.61	0.47
Gini coefficient: housing wealth	0.56	0.50
Share of net worth for the bottom quintile	0.01	0.03
Share of net worth for the middle quintile	0.10	0.15
Share of net worth for the top quintile	0.64	0.52
Ratio of homeowners' housing wealth to their incomes: the 10th percentile	1.78	4.44
Ratio of homeowners' housing wealth to their incomes: the median	8.18	9.75
Ratio of homeowners' housing wealth to their incomes: the 90th percentile	40.19	13.76

Notes: See the notes in Table 3 for the definitions of housing wealth and net worth. The data moments are calculated from the CHFS.

TABLE 5. Impacts of a loosening of the LTV limit on secondary houses from 0.4 to 0.65

(A) Aggregate impacts on the house price and key mortgage variables (Annualized growth rate %)

	Model	Data
House price	4.91	5.94
Mortgage origination amount	67.87	91.78
Mortgage origination number	28.41	46.51
Mortgage origination amount (primary homes)	48.00	78.98
Mortgage origination number (primary homes)	21.81	42.21
Mortgage origination amount (secondary houses)	335.75	323.92
Mortgage origination number (secondary houses)	155.45	124.36

(B) Changes in the mortgage share of an age-income group in total mortgages on primary homes

	Mortgage share change (%)			
	Origination amount		Origination number	
	Low income	High income	Low income	High income
Young	-1.08 (-3.79)	-0.70 (-1.17)	-2.45 (-2.46)	0.60 (0.52)
Middle-aged	-7.60 (-6.26)	11.80 (11.78)	-5.83 (-5.22)	6.89 (7.26)
Old	-0.79 (-1.19)	-1.64 (0.64)	0.06 (-0.57)	0.73 (0.46)

Notes: Values in parentheses in Table 5b are actual data across age-education groups.

TABLE 6. Contributions (%) to the increase in total mortgages from an increase of households who trade up their primary homes

(A) Contributions to an increase in total mortgages and in housing demand

	Origination amount	Origination number	Housing demand
Primary homes	57.86	78.04	61.56

(B) Contributions by age-income groups

	Origination amount		Origination number		Housing demand	
	Low income	High income	Low income	High income	Low income	High income
Young	8.01	10.61	7.51	19.21	8.04	10.61
Middle-aged	18.14	63.23	17.14	56.14	18.13	63.22
Old	0.00	0.00	0.00	0.00	0.00	0.00

Notes: For each variable, contributions across age-income groups in Table 6b sum up to 100.

TABLE 7. Welfare effects (%) of a relaxation of LTV policy for secondary houses

(A) By age and homeownership

	All households (1)	Renters (2)	Homeowners (3)
All	-0.49	-5.24	0.38
Young	-1.42	-3.04	0.09
Middle-aged	0.46	-2.13	0.59
Old	-0.94	-9.58	0.26

(B) By age-income groups and homeownership

	All households		Renters		Homeowners	
	(1)	(2)	(3)	(4)	(5)	(6)
	Low income	High income	Low income	High income	Low income	High income
Young	-1.02	-2.03	-1.66	-6.88	-0.07	0.23
Middle-aged	0.73	0.07	-1.49	-6.09	0.88	0.17
Old	-1.57	-0.00	-9.00	-14.15	0.07	0.50

TABLE 8. Impacts of a relaxation of the LTV limit on secondary houses under two alternative scenarios

	Alternative 1 (1)	Alternative 2 (2)	Benchmark (3)	Data (4)
House price	0.67	0.53	4.91	5.94
Mortgage origination amount	17.85	5.37	67.87	91.78
Mortgage origination number	0.98	-4.16	28.41	46.51
Mortgage origination amount (primary homes)	-9.89	-18.47	48.00	78.98
Mortgage origination number (primary homes)	-8.60	-12.10	21.81	42.21
Mortgage origination amount (secondary houses)	354.48	298.12	335.75	323.92
Mortgage origination number (secondary houses)	185.21	148.77	155.45	124.36

Notes: Values reported in the table are annualized growth rates (%). The alternative scenario for column 1 is to set the price elasticity of housing supply to $\frac{\alpha}{1-\alpha} = 15$. The alternative scenario for column 2 is to assume a 100% tax rate for capital gains. For comparison, columns 3 and 4 repeat the values reported in Table 5a.

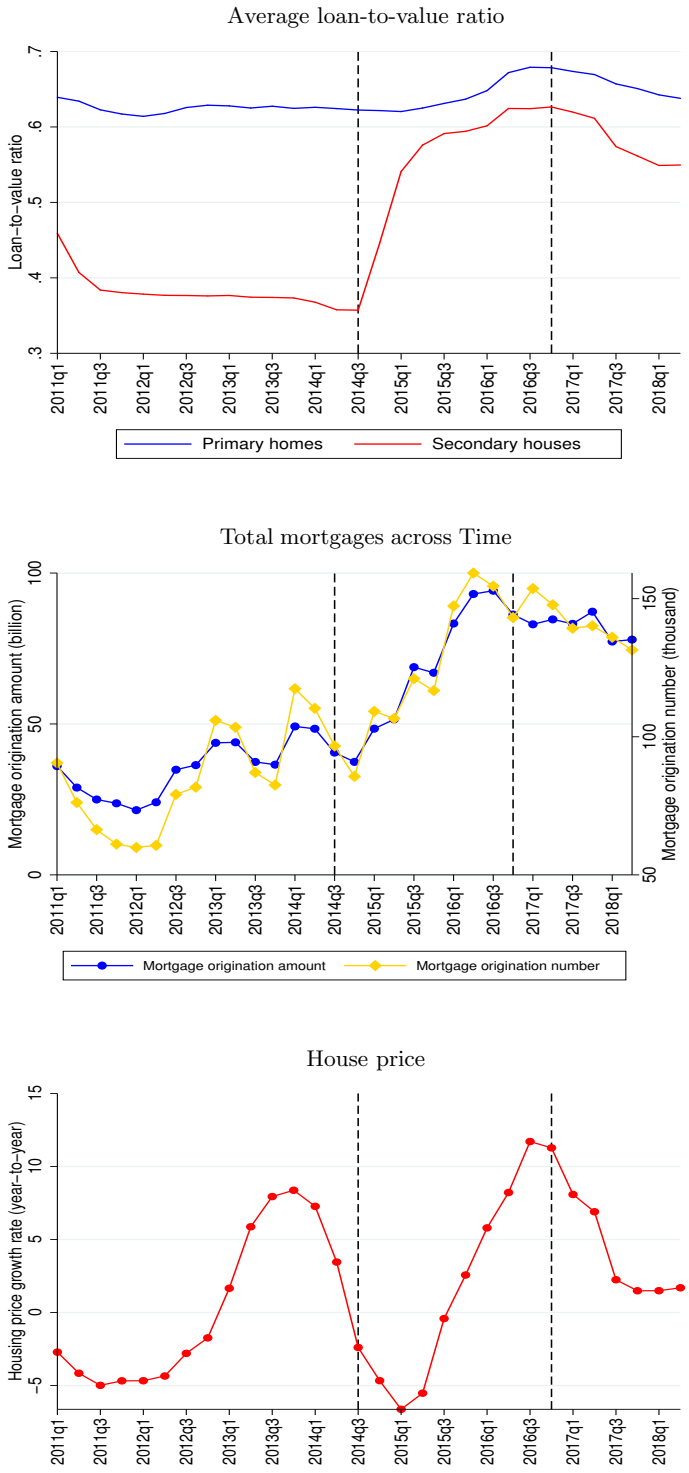


FIGURE 1. Time series of aggregate variables

Notes: The three panels are organized as follows: the LTV ratios for primary homes and secondary houses across time (top panel); the amount and number of mortgage originations (middle panel); the year-to-year growth rate (%) of the real house price (bottom panel). For a given city, the real house price is its nominal house price divided by the GDP deflator. We aggregate city-level real house prices to obtain a national average of real house prices, using each city's population in 2011 as a weight. The first vertical dashed line in each panel marks the time when LTV policy was relaxed. The second vertical dashed line in each panel marks the time when LTV policy was tightened. The most significant change in LTV policy was applied to secondary houses.

Sources: The Bank Loan Data and the NBS.

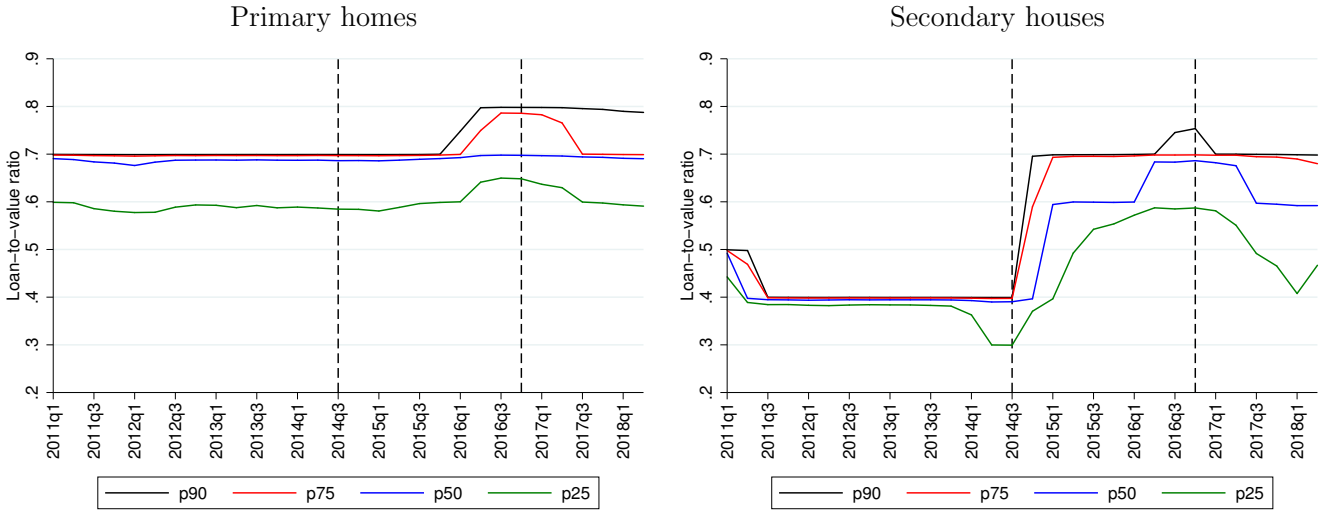


FIGURE 2. Distribution of LTV ratios

Notes: The first vertical dashed line in each panel marks the time when LTV policy was relaxed. The second vertical dashed line in each panel marks the time when LTV policy was tightened. The most significant change in LTV policy was applied to secondary houses. The label "p90" stands for the 90th percentile of the distribution, "p75" the 75th percentile, "p50" the median, and "p25" the 25th percentile.

Source: The Bank Loan Data.

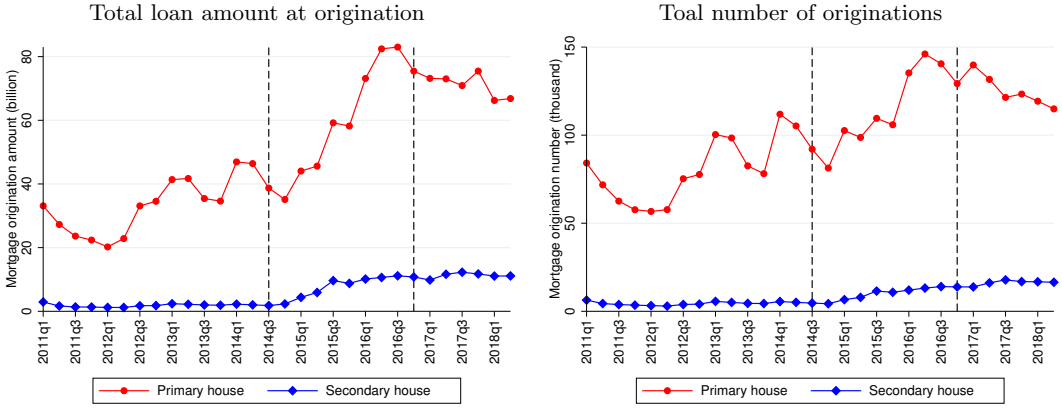


FIGURE 3. Mortgage Originations

Notes: The two panels are organized as follows: the amount of mortgage loans at origination for primary homes and secondary houses across time (left panel); and the number of mortgage originations for primary homes and secondary houses across time (right panel). The first vertical dashed line in each panel marks the time when LTV policy was relaxed. The second vertical dashed line in each panel marks the time when LTV policy was tightened. The most significant change in LTV policy was applied to secondary houses.

Source: The Bank Loan Data.

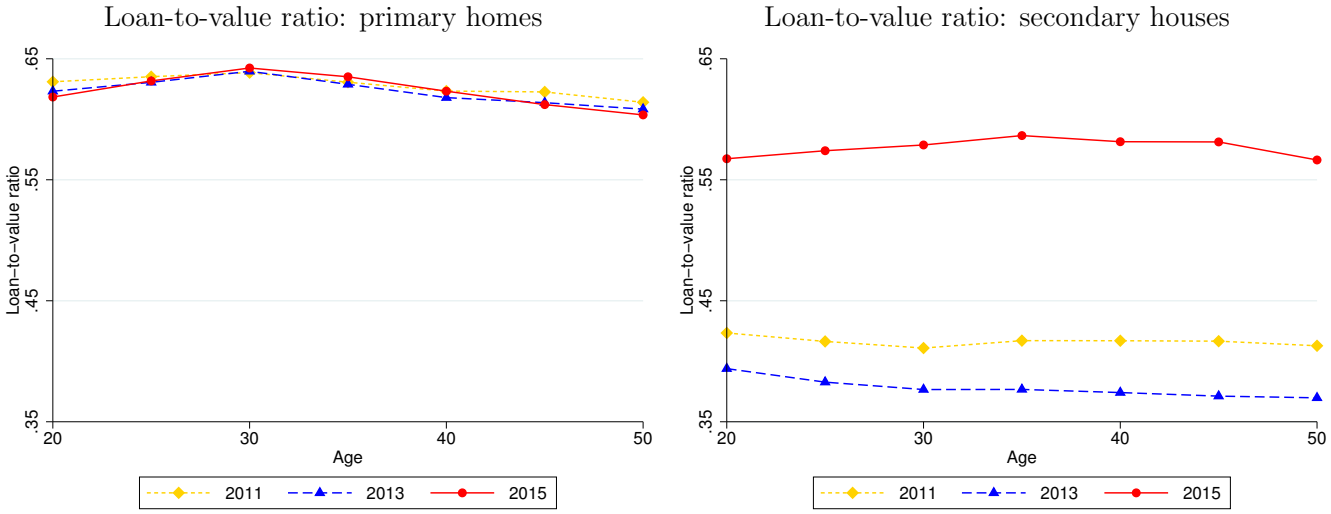


FIGURE 4. Loan-to-value ratio at origination

Notes: The left panel plots the average LTV ratio for primary homes in 2011, 2013 and 2015. The right panel plots the average LTV ratio for secondary houses in 2011, 2013 and 2015. The average LTV ratio is computed for each of five-year age bins (e.g., 23-27 and 28-32).
Source: The Bank Loan Data.

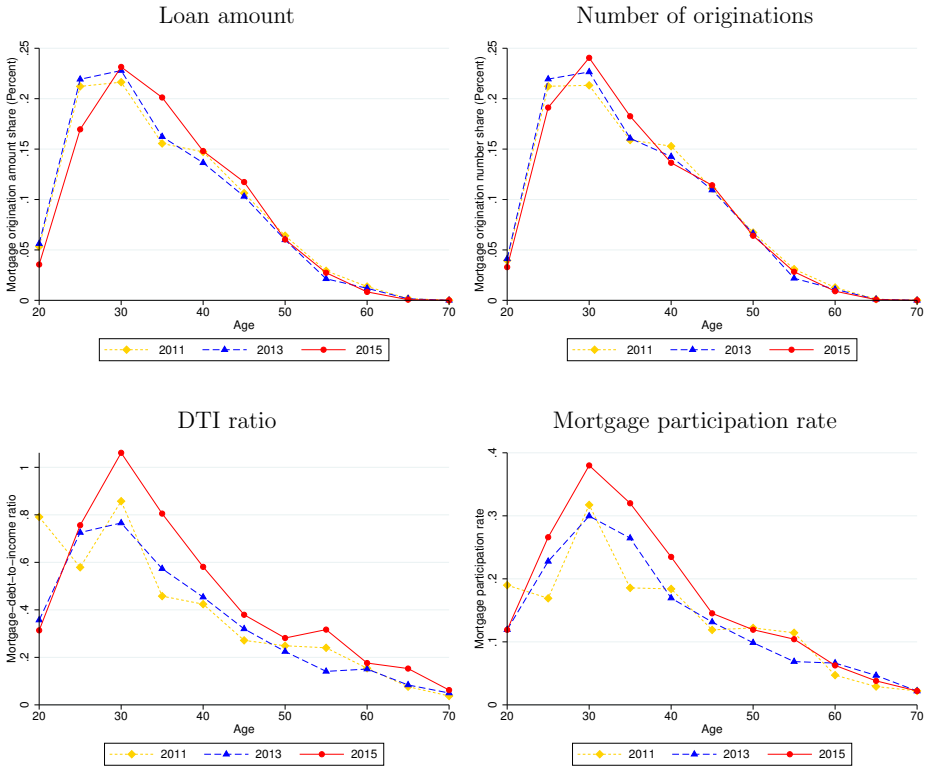


FIGURE 5. Mortgage loans across age groups

Notes: Top left panel: the share of loan amount for each age group in the total loan amount at origination in 2011, 2013 and 2015. Top right panel: the share of origination numbers for each age group in total origination numbers in 2011, 2013 and 2015. The acronym "DTI" stands for debt to income (debt in this paper is mortgage debt). Bottom left panel: the average DTI ratio for each age group in 2011, 2013 and 2015. Bottom right panel: the average fraction of households with positive mortgage debt within each age group in all households in 2011, 2013 and 2015.
Sources: The Bank Loan Data and the CHFS.

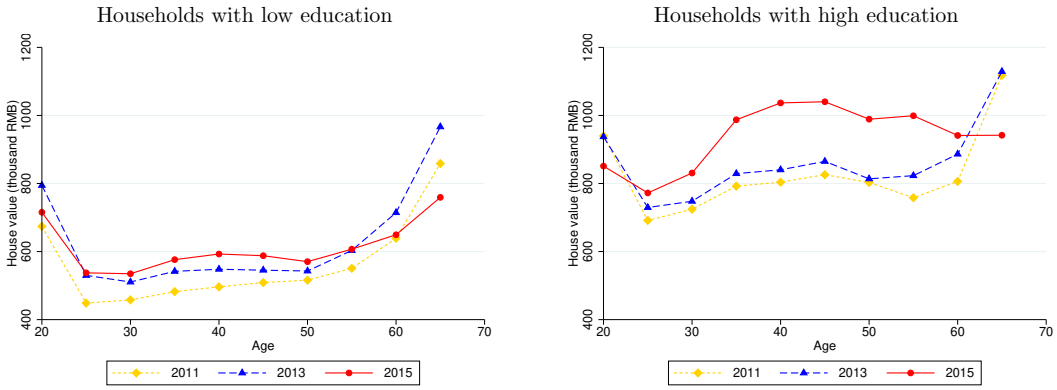


FIGURE 6. Average house value: primary homes

Notes: The house value for each household in a given year is deflated by the monthly NBS index of the house price in the city in which the household resided during the month of that year when the mortgage was originated.
Sources: The Bank Loan Data and the NBS.

FIGURE 7. Quarterly effects of policy exposure on mortgage originations and on the mortgage share for middle-aged high-educated households

Notes: The solid line represents the estimate of β, the dashed lines contain a 90% confidence interval, and the dash-dotted lines contain a 95% confidence interval.

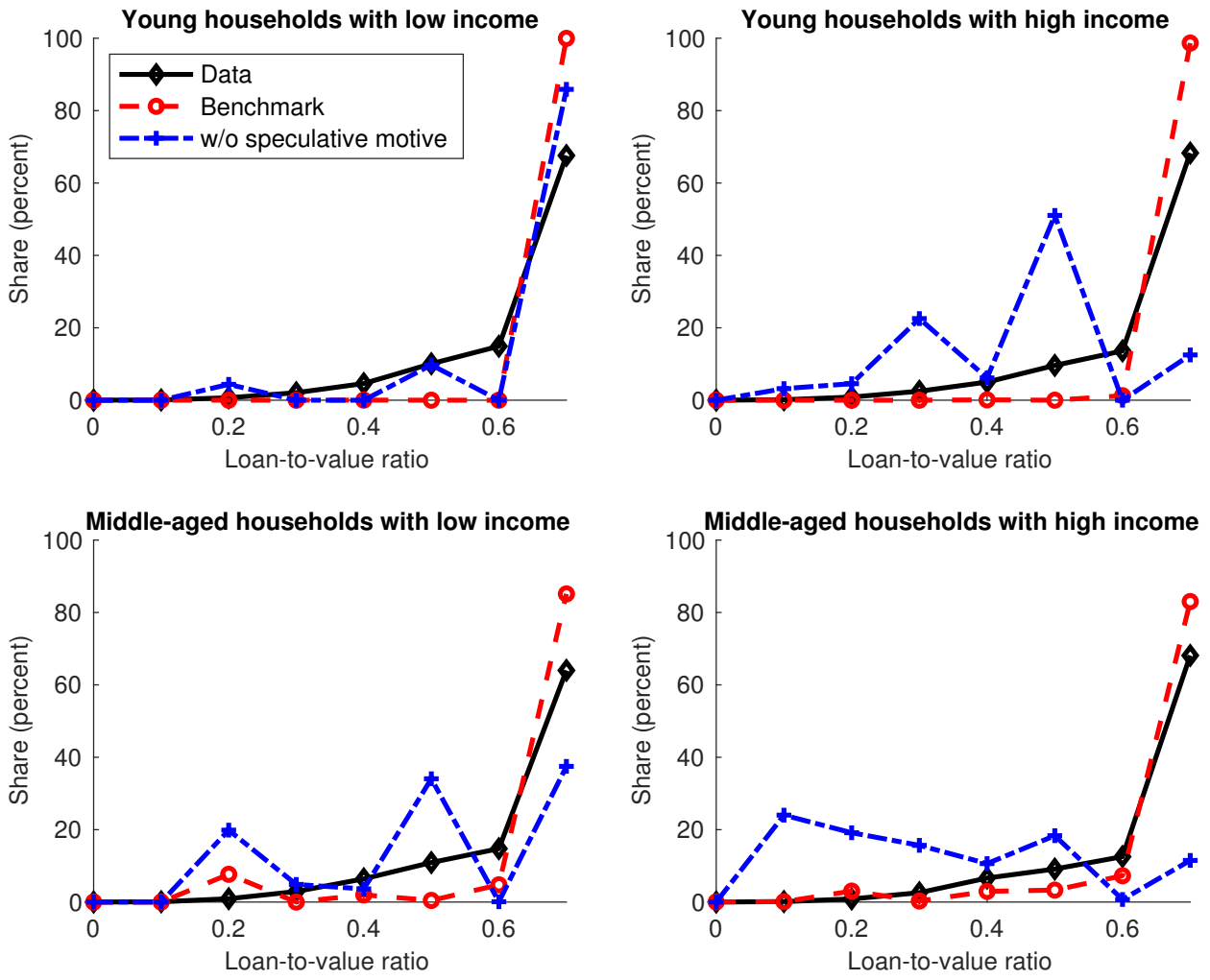


FIGURE 8. The LTV distribution for primary homes financed by mortgages: model versus data

Notes: The top panels display the empirical LTV distribution at origination for young households; the bottom panels display the empirical LTV distribution at origination for middle-aged households. The empirical LTV distributions are based on the data in 2013 from the Bank Loan Data. The benchmark economy is our model with a stochastic regime for the utility of housing services. The economy without speculative motive turns off this stochastic regime while keeping all other parts of the model intact.

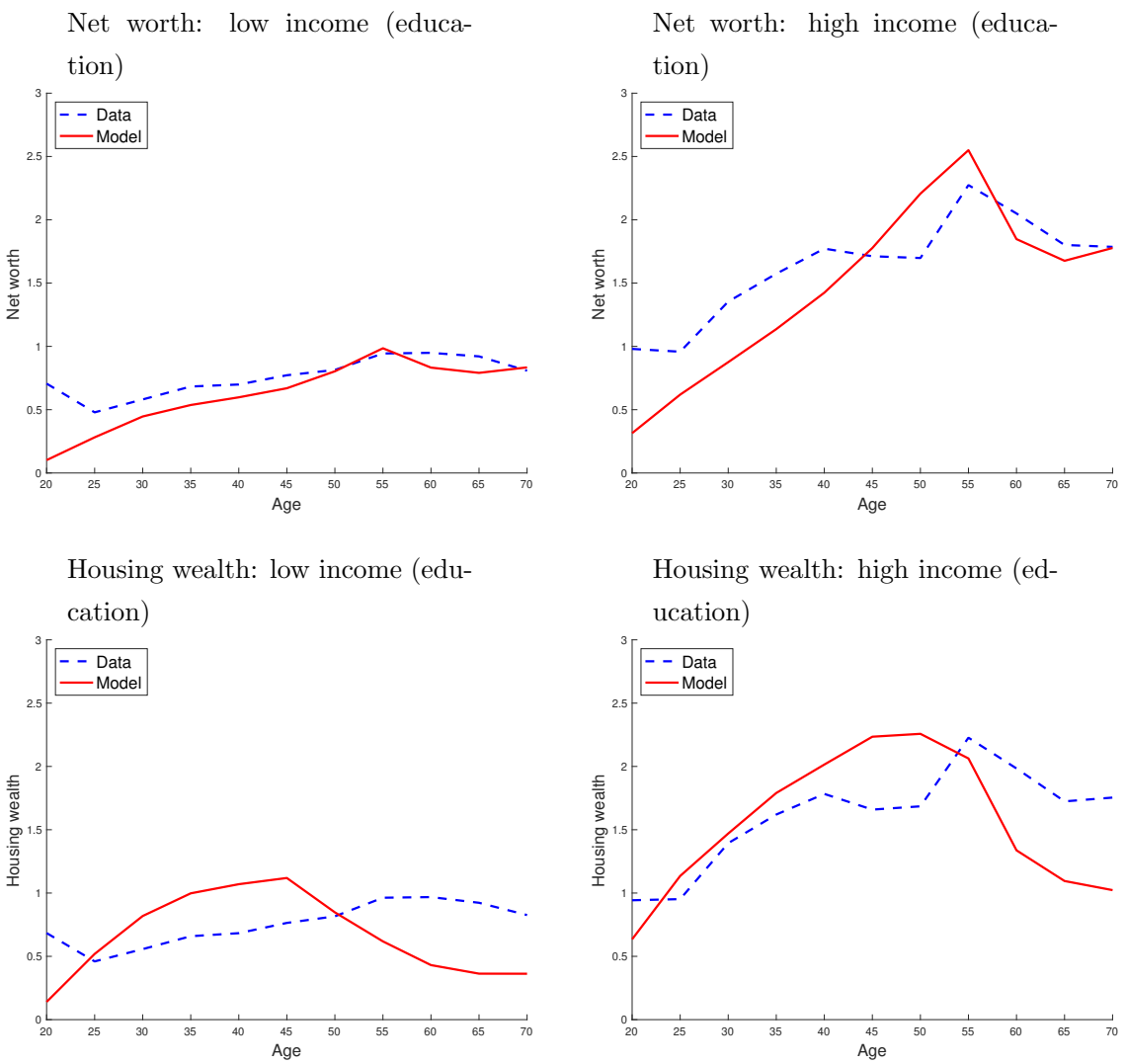


FIGURE 9. Life-cycle profile of wealth

Notes: See the notes in Table 3 for the definitions of housing wealth and net worth. The top panels display net worth (normalized by the average net worth) for low-income and high-income groups. The bottom panels display housing wealth (normalized by the average housing wealth) for low-income and high-income groups. The empirical profiles are based on the survey data in 2013. Education in the survey data is used as a proxy for incomes.

Source: The CHFS.

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Online Appendices
(Not For Publication)

Appendix A. Representativeness of the data

Our loan-level data comes from one of the four largest state banks (Big Four), which may contain a potential sample bias. One concern regarding our Bank Loan Data is its representativeness, in particular, whether its aggregate and cross-sectional patterns are compatible with other representative sample. In this section, we document that our data is compatible with other data sources. We begin by comparing aggregate moments calculated from the Bank Loan Data, from the publicly available annual reports published by this particular bank that provided us with the Bank Loan Data (we refer to this bank as the Sample Bank for the rest of our discussion), and from the aggregate mortgage data published by the CEIC (a major data platform to which one can have access with a subscription fee). We then compare cross-sectional moments implied by the Bank Loan Data with those from Fang, Gu, Xiong and Zhou (2016), who use loan-level data on mortgage originations to newly-built houses from a different Big Four bank.

A.1. **Aggregate time series.** There are two potential caveats in comparing our data with the CEIC aggregate data. First, the total mortgages reported from the CEIC aggregate data include mortgages on both newly built and existing houses; the Bank Loan Data includes only newly built houses. Second, the CEIC aggregate data contains total *outstanding* mortgage loans for the whole economy in China; the Bank Loan Data contains each mortgage loan amount, which is used to obtain our aggregated loan data for comparison. We take two steps to compare our mortgage data with the CEIC aggregate data. We first compare the growth rate of total outstanding mortgage amount from the CEIC with the growth rate of total outstanding mortgage amount for the Sample Bank, which we obtain from the Loan bank's publicly available annual reports. We then compare the aggregated mortgage amount from the Bank Loan Data with the difference of total outstanding mortgage amount from the Sample Bank.[45]

The left panel of Figure A.1 reports the growth rates of total outstanding mortgage amount for the Chinese entire economy from CEIC's aggregate data and from the Sample Bank's annual reports. The growth rate from the Sample Bank tracks closely that from the CEIC. In particular, the (annualized) mortgage growth rates for both series rose rapidly in the second half of 2014 and peaked in the first half of 2016 at around 15%. Afterwards, the growth rates of total outstanding mortgage amount for both series declined steadily and fell below 10% in the first half of 2018—the end of our sample. This result suggests that the

[45]The Bank Loan Data contains mortgages in China's 70 major cities, while the Sample Bank's annual reports contain total *outstanding* mortgage amount for the entire economy.

growth rate of mortgages from the Sample Bank should be representative of the growth rate of mortgages in the whole economy.

The right panel reports the mortgage amount aggregated from the Bank Loan Data in comparison with the difference of total outstanding mortgages from the Sample Bank's annual reports (each series is normalized by its value in the first half year of 2011). We see that these two series track each other closely. Both series have a secular increase over time. Moreover, there was an accelerated rise after the second half 2014 until it peaked in the second half of 2016 for both series. Together with the result displayed in the left panel, this result suggests that the overall trend of newly originated mortgages from the Bank Loan Data should be representative of the trend for the whole economy.

A.2. **Cross-city distribution of mortgage borrowers.** Since our empirical design is based on cross-city heterogeneity in ex-ante exposure to the policy change, we now demonstrate the representativeness of our sample by comparing the cross-city distributions of various statistics for mortgage borrowers between the Bank Loan Data and Fang, Gu, Xiong and Zhou (2016). Apart from the Bank Loan Data, the only other source of mortgage-level data is Fang, Gu, Xiong and Zhou (2016), who obtained from another Big Four bank one million loans over the period of 2003-2012 across 120 cities in China. From this administrative data, Fang, Gu, Xiong and Zhou (2016) present a set of characteristics of mortgage borrowers across three tiers of cities in China.[46] We use the same criteria as Fang, Gu, Xiong and Zhou (2016) to classify cities into three tiers and mortgage borrowers into different income groups, and compare the same statistics between our data and theirs for the three tiers of cities for the year 2012, the last year in which their data overlaps with ours.[47]

Figure A.2 displays various characteristics of mortgage borrowers with mean values from the two data sources and 95% confidence intervals from the Bank Loan Data (our data source). The left column of graphs in the figure correspond to mortgage borrowers with bottom incomes and the right column mortgage borrowers with middle incomes.[48] The top row of graphs shows that across three tiers of cities, the mean down payment ratios for both

[46]It is customary to group Chinese cities into three tiers. The first tier includes four cities with the largest populations—Beijing, Shanghai, Guangzhou, and Shenzhen. There are 31 second-tier cities, including two autonomous municipalities, the capital cities of 24 provinces, and four coastal cities that are economic centers for China. The rest of cities belong to the third tier.

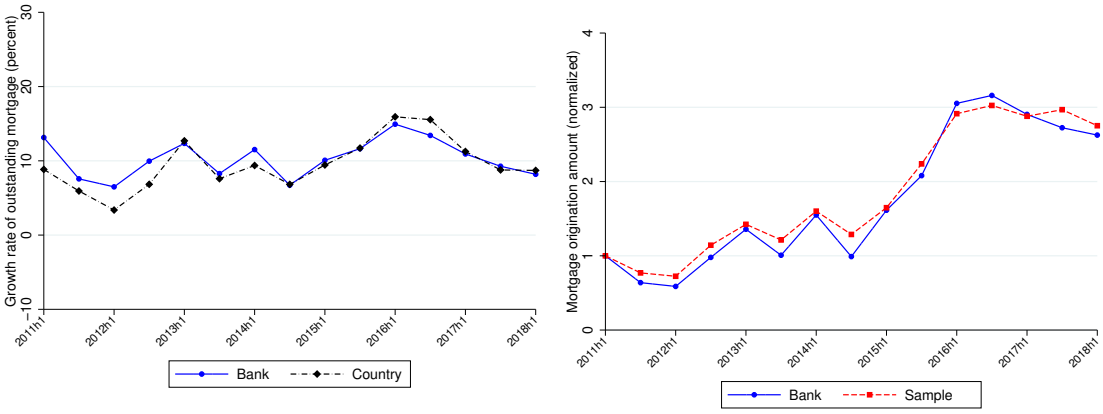
[47]Both the Bank Loan Data and the administrative data used by Fang, Gu, Xiong and Zhou (2016) cover a total of 35 tier-one and tier-two cities. The data used by Fang, Gu, Xiong and Zhou (2016), however, misses 17 tier-three cities that are contained in the Bank Loan Data.

[48]Fang, Gu, Xiong and Zhou (2016) consider only bottom-income and middle-income mortgage borrowers. According to their definition, the bottom-income group is defined as mortgage borrowers with household incomes in the bottom 10% percentile of the income distribution of all mortgage borrowers in a given city

bottom-income and middle-income groups are close between the sample of Fang, Gu, Xiong and Zhou (2016) and our sample. For instance, for both second-tier and third-tier cities, both samples reveal that the down payment ratios for the bottom-income group is 0.45, higher than those for the middle-income group (0.4). The second row of graphs shows that for the ratio of the house price to income, the mean values from the sample of Fang, Gu, Xiong and Zhou (2016) for the three tiers of cities, close to the corresponding mean values from the Bank Loan Data, are well within the 95% confidence intervals calculated from the Bank Loan Data. For example, for the tier-one cities, the ratios of the house price to income in the bottom-income and middle-income groups are 9.2 and 7.5 from the sample of Fang, Gu, Xiong and Zhou (2016), well within the 95% confidence intervals of our sample. The third row of graphs shows the average size of the houses purchased by bottom-income and middle-income mortgage borrowers in the three tiers of cities. For each tier of cities and each income group, the mean value from the sample of Fang, Gu, Xiong and Zhou (2016) falls within the 95% confidence interval from our sample. The average sizes of houses purchased by the bottom-income and middle-income groups in the tier-two cities, for example, are 80 and 90 square meters, close to the corresponding mean values from our sample. The bottom row of graphs displays the average age of mortgage borrowers. In all three tiers of cities, mortgage borrowers in the sample of Fang, Gu, Xiong and Zhou (2016) are on average in their early 30s with the borrowers in the bottom-income group slightly younger than those in the middle-income group. For each income-city-tier group, the average age of mortgage borrowers in the sample of Fang, Gu, Xiong and Zhou (2016), close to the average value from our sample, is well within the 95% confidence interval calculated from our sample.

To summarize, by comparing the Bank Loan Data with aggregate data and another representative loan-level database, we show that our data is representative of the aggregate dynamics of mortgage originations as well as various characteristics of mortgage borrowers across cities.

in 2012; the middle-income group is defined as those with household incomes between the 45th and 55th percentiles of the income distribution of all mortgage borrowers in a given city in 2012.

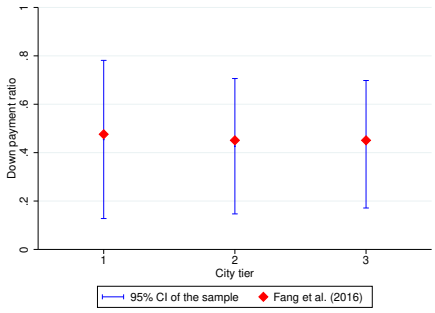


Growth rate of outstanding mortgage amount

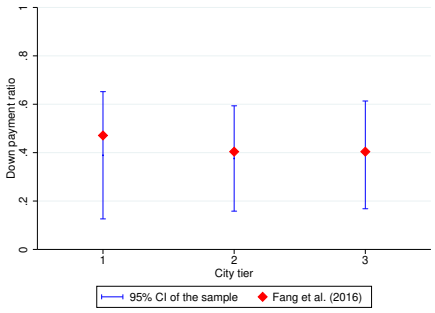
Mortgage amount

FIGURE A.1. Aggregate amount of mortgage loans: sample vs bank vs country

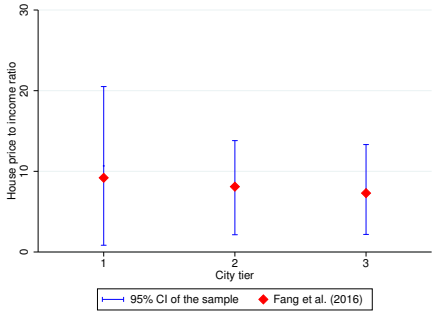
Notes: The left panel reports the growth rates of total outstanding mortgage amount for China's whole economy from the CEIC aggregate data (labeled as "Country" in the legend) and from the Sample Bank's annual reports (labeled as "Bank" in the legend). The right panel reports the amount of newly originated mortgages from the Bank Loan Data (labeled as "Sample" in the legend) and the difference in total outstanding mortgage amount from the Sample Bank's annual reports (labeled as "Bank" in the legend).



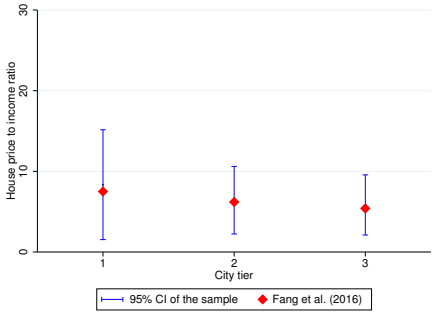
Down payment ratio: bottom-income



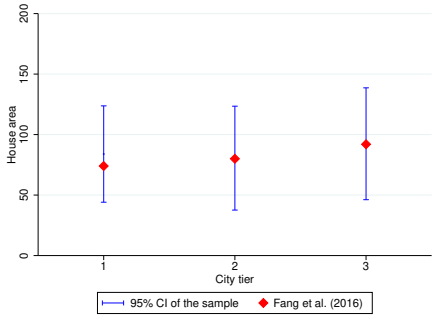
Down payment ratio: middle income



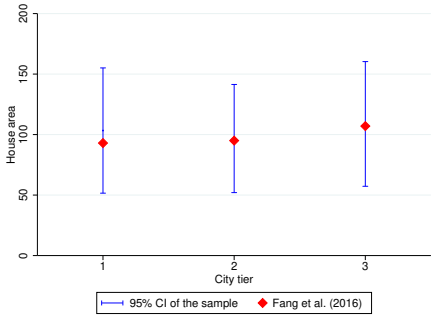
Ratio of the house price to income: bottom income



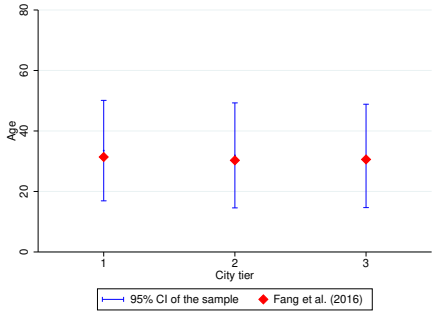
Raito of the house price to income: middle income



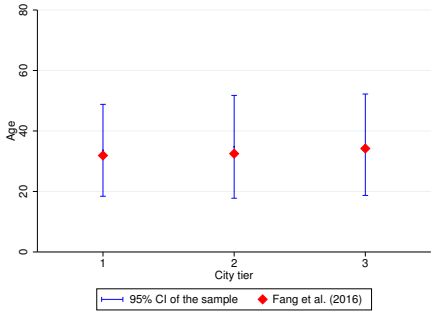
House area: bottom income



House area: middle income



Age: bottom income



Age: middle income

FIGURE A.2. A comparison of mortgage borrowers' characteristics between the Bank Loan Data and Fang et al. (2016)

Notes: The results reported here are for the year 2012, the last year in which the administrative data used by Fang, Gu, Xiong and Zhou (2016) overlaps with the Bank Loan Data. The values from Fang, Gu, Xiong and Zhou (2016) are mean values. The 95% confidence intervals are calculated from the Bank Loan Data as the mean values plus/minus 1.96 times the corresponding standard deviations.

Appendix B. Summary statistics

Table B.1 presents descriptive statistics for the main variables in our mortgage data sample. For each variable, we report its average and standard deviation for two subperiods (2011Q1-2014Q3 and 2014Q4-2016Q3) as well as the full sample period, which covers the period 2011Q1-2018Q2. The full sample has $3,011,765$ borrowers to finance primary homes and $259,024$ borrowers to finance secondary houses.

We first compare individual borrower characteristics for the primary and secondary houses during 2011Q1-2014Q3—the period before LTV policy was relaxed (comparing panels A and B in the table). The share of primary home mortgages in total mortgage origination numbers during this period is 94.8%. Borrowers for primary houses were, on average, four years younger than those for secondary houses. The fraction of borrowers with a college degree and above was smaller for primary houses than for secondary houses (47% versus 62%). This observation implies that borrowers for secondary houses were, on average, wealthier than those for primary homes. The average house size and value were larger for secondary houses than for primary houses. On the other hand, the average mortgage balance when mortgages for primary homes were originated was similar in size to that for secondary houses (438,250 RMB versus 436,900 RMB). Since the average monthly mortgage payment for a secondary house was 20% higher than for a primary home (4,046 RMB versus 3,347 RMB), the mortgage maturity for secondary houses was shorter than that for primary houses.

The average LTV ratio when mortgages for primary houses were originated was higher than that for secondary houses (63% versus 38%), reflecting the different LTV policies for these two types of houses. The average mortgage rate for primary houses was about 1% lower than that for secondary houses (6.55% versus 7.40%), also reflecting the different mortgage rate policies on primary versus secondary houses. The ratio of debt to income (DTI) is 4.0 when mortgages were originated for primary houses, but only 2.52 for secondary houses, implying that borrowers for secondary houses had on average higher incomes than those for primary houses.

We now compare borrower characteristics for primary and secondary houses between the two subperiods 2011Q1-2014Q3 and 2014Q4-2016Q3. For primary houses, the fraction of borrowers with college degree and above increased from 47% in the first subperiod to 59% in the second subperiod, while the average age of borrowers increased from 34.50 to 34.68 (panel A of the table). The average size for primary homes also increased because many homeowners traded up their homes (i.e., sold their existing homes and bought larger houses) during the boom. The average initial mortgage loan increased by about 30% (from 438,250 RMB to 566,590 RMB), whereas the average LTV ratio changed little. An increase in mortgage loans

for primary homes led to a higher mortgage debt burden with a 13% increase in monthly mortgage payment (from 3,347 RMB to 3,800 RMB) and an increase of the average DTI from 4.0 to 4.19, even when the average mortgage rate fell from 6.55% in the first subperiod to 5.14% in the second subperiod.

For secondary houses, we observe a similar increase in the fraction of borrowers with college degree and above (from 62% to 72%) as well as an increase in the average age of mortgage borrowers (from 38.6 to 39.37). The initial mortgage loan per borrower was 94% higher in 2014Q4-2016Q3 than in 2011Q1-2014Q3 (849,030 RMB versus 436,900 RMB), partly because the LTV ratio increased from 0.38 to 0.59 and partly because the average house value increased by 23%. As a result, the mortgage debt burden for secondary houses increased substantially with a 44% increase in the monthly mortgage payment and an increase in the ratio of mortgage debt to income from 2.52 to 3.39. The average mortgage rate for secondary houses fell by more than 2% from 7.40% to 5.20% and the share of mortgage loan amount (number) for secondary houses increased from 5.2% to about 11% (8%).

Table B.2 reports summary statistics for the CHFS data. We include all three surveys from 2013 onward, as the sample in the 2011 survey (the first survey) has relatively few observations. While our mortgage loan database includes only households with new mortgages, the CHFS database includes households with and without mortgages as well as those who paid their mortgages in full. For example, the two variables, outstanding mortgage debt and the ratio of mortgage debt to income, include households without mortgages. As one can see, the outstanding mortgage debt increased significantly from 2013 to 2015 and from 2015 to 2017. The share of housing assets in total household assets declined slightly from 80.38% in 2013 to 79.24% in 2015 and then to 76.22% in 2017. The average home ownership rate increased from 86% in 2013 to 89.26% in 2015 and then fell slightly to 88.09% in 2017.

TABLE B.1. Summary statistics for mortgage origination data

	2011Q1-2014Q3		2014Q4-2016Q3		2011Q1-2018Q2	
	Mean	SD	Mean	SD	Mean	SD
Panel A: Summary statistics for borrowers purchasing the primary house						
Age	34.50	9.02	34.68	8.81	34.50	8.98
Fraction of borrowers with college degree and above	0.47	0.50	0.59	0.49	0.56	0.50
House size (square meters)	103.22	35.75	105.38	35.42	105.46	35.59
House value (thousands of RMB)	698.79	863.61	879.75	1129.47	845.14	1063.90
Mortgage Loan (thousands of RMB)	438.25	565.76	566.59	741.31	538.72	684.17
Monthly mortgage payment (RMB)	3347.46	4795.01	3800.44	4600.51	3685.97	4596.21
Loan-to-value (LTV) ratio	0.63	0.11	0.65	0.12	0.64	0.12
Mortgage rate (percent)	6.55	0.63	5.14	0.83	5.62	1.03
Mortgage debt to (annual) income ratio	4.00	1.71	4.19	1.89	4.19	1.86
Number of borrowers	1,212,014		919,998		3,011,765	
Panel B: Summary statistics for borrowers purchasing a secondary house						
Age	38.60	7.69	39.37	7.73	38.81	7.80
Fraction of borrowers with college degree and above	0.62	0.49	0.72	0.45	0.71	0.45
House size (square meters)	116.99	52.32	119.09	53.28	117.04	51.53
House value (thousands of RMB)	1158.61	1511.99	1426.21	1873.07	1372.35	1672.66
Mortgage loan (thousands of RMB)	436.90	615.26	849.03	1179.92	721.13	931.30
Monthly mortgage payment (RMB)	4046.10	5311.81	5826.17	7817.19	5174.01	6263.09
Loan-to-value (LTV) ratio	0.38	0.07	0.59	0.13	0.53	0.15
Mortgage rate (percent)	7.40	0.37	5.20	0.77	5.77	1.13
Mortgage debt to (annual) income Ratio	2.52	1.49	3.39	1.82	3.12	1.83
Number of borrowers	66,962		80,339		259,024	

Notes: Descriptive statistics for the variables used in this paper. The sample contains all new mortgage loans advanced by the bank for purchasing new residential properties, covering 70 cities that correspond to the city sample used by NBS for constructing its 70-city house price index.
Source: The Bank Loan Data.

TABLE B.2. Summary statistics for the CHFS Data

	2013		2015		2017	
	Mean	SD	Mean	SD	Mean	SD
Age	50.34	14.98	52.15	14.93	54.41	14.94
Income (thousands of RMB)	75.29	94.85	81.27	103.63	98.82	112.84
Outstanding mortgage debt (thousands of RMB)	24.59	212.10	30.86	197.95	41.08	221.65
Net wealth (thousands of RMB)	765.47	1223.51	984.67	1500.15	1226.68	1870.10
Share of housing assets in net wealth (percent)	80.38	47.81	79.24	43.50	76.22	44.17
Homeownership (percent)	86.02	34.68	89.26	30.97	88.09	32.39
Number of observations	19,181		25,607		27,245	

Notes: Descriptive statistics for the variables used in this paper. The two variables, outstanding mortgage debt and the ratio of mortgage debt to income, include households without mortgage. In addition to our mortgage sample, the CHFS database includes households who paid their mortgage debts in full.
Source: The CHFS.

Appendix C. Additional tables and figures

Table C.1. Correlates of exposure to LTV policy on secondary houses

	Dependent variable is exposure		
	β	R^2	N
Log of income level in 2011	0.463***	0.214	70
	(0.107)		
Income growth in 2011	-0.309***	0.095	70
	(0.115)		
Log of population in 2011	-0.053	0.003	70
	(0.121)		
Population growth in 2011	0.001	0.000	70
	(0.121)		
Unemployment rate change in 2011	0.027	0.001	70
	(0.121)		
Log of house price in 2011	0.568***	0.323	70
	(0.100)		
Exposure to national house price variations	0.143	0.020	70
	(0.120)		

Notes: This table reports results from bi-variate regressions of policy exposure on city-level characteristics in 2011. Variables are normalized by their cross-sectional standard deviations. The coefficient, reported as β, is interpreted as a β-standard-deviation change in exposure produced by a one-standard-deviation change in a city-level observable. To construct exposure to national house price variations, we follow Guren et al. (2018) to regress monthly house price growth in a certain city on national average house price growth (leaving the city out) in the period from 2006m1 to 2010m12, i.e. $\Delta p_{i,t} = \phi_i + \gamma_i \Delta P_{-i,t} + \nu_{i,t}$, where $\Delta p_{i,t}$ is monthly house price growth in city i at time t and $\Delta P_{-i,t}$ is national average house price growth (leaving city i out) at time t. The calculation of house price growth in each city is based on Fang, Gu, Xiong and Zhou (2016). The estimated coefficient ($\hat{\gamma}_i$) is our city-level exposure to national house price variations. The asterisk * denotes statistical significance at the 0.1 level, ** at the 0.05 level, and *** at the 0.01 level.

TABLE C.2. Welfare effects (%) of a change in the LTV limit on secondary houses while the house price is held constant

	All households (1)	Renters (2)	Homeowners (3)
All	0.04 (-0.49)	0.01 (-5.24)	0.05 (0.38)
Young	0.05 (-1.42)	0.01 (-3.04)	0.08 (0.09)
Middle-aged	0.08 (0.46)	0.01 (-2.13)	0.09 (0.59)
Old	0.00 (-0.94)	0.00 (-9.58)	0.00 (0.26)

Notes: For comparison, the benchmark results reported in Table 7a are displayed in parentheses.

TABLE C.3. Welfare effects (%) of a tightening of LTV policy for secondary houses

	All households (1)	Renters (2)	Homeowners (3)
All	0.51	9.59	-0.82
Young	1.98	7.39	-0.37
Middle-aged	-1.19	3.39	-1.44
Old	1.39	13.79	-0.38

APPENDIX D. HOUSEHOLD PROBLEM AND DEFINITION OF EQUILIBRIUM

D.1. **Household problem.** We now describe a household's problem in recursive forms. Each period, a household's idiosyncratic state vector $\chi = (b, m, h, y)$. Denote $\mu(\chi)$ as the measure of households across individual states and the aggregate states vector as $\Omega = (\phi, \mu)$. We solve the problem of a household in two steps. First, the household chooses the intermediate housing status as described above. Conditional on its housing status, it then chooses the size of housing to either rent or purchase, together with the choice of consumption and saving in financial assets.

At the beginning of each period, a household without a house solves the following problem by choosing between renting or buying a house.

$$V_j^N(b, y; \Omega) = \max\{V_j^r(b, y; \Omega), V_j^b(b, y; \Omega)\},$$

where V_j^N, V_j^r, and V_j^b denotes the value functions for a household without a house, value function of the renter and value function of the homebuyer, respectively.

In the case of changing their housing position, the household needs to sell the house first.[49] Accordingly, it solves the following problem:

$$V_j^H(b, m, h, y; \Omega) = \max\{V_j^p(b, m, h, y; \Omega), V_j^s(b, m, h, y; \Omega)\},$$

where V_j^H, V_j^p, and V_j^s, denote the value functions for a household with a house, value function of keeping the house and value function of selling the house, respectively. If a household chooses to sell the house, it needs to pay all the outstanding mortgage debt associated with the sold house. Accordingly, the financial wealth after selling the house is

$$b_n = b + (1 - \delta_h - \kappa_h)p_h h - (1 + r_m)m - \kappa_j. \tag{D.1}$$

After the household sells the house, it can then choose whether to rent or buy a new house by solving the following problem:

$$V_j^s(b, m, h, y; \Omega) = \max\{V_j^{sr}(b_n, y; \Omega), V_j^{sb}(b_n, y; \Omega)\},$$

subject to (D.1). V_j^{sr} is the value function for a household who sells its house and chooses to rent and V_j^{sb} is the function for a household who sells its house and chooses to buy a new house.

Now we switch to the choice of housing size. Since a household dies after age J, we first describe the problem of a household with age $j < J$. For a renter, it solves the following problem.

$$V_j^r(b, y; \Omega) = \max_{\{c, b', \tilde{h}'\}} u(c, s; \phi) + \beta E_{y', \phi'}[V_{j+1}^N(b', y'; \Omega')|y, \phi],$$

subject to

$$\begin{aligned} s.t. \quad & c + \rho_h \tilde{h}' + q_b b' \leq b + y \\ & b' \geq 0 \\ & s = \omega \tilde{h}', \tilde{h}' \in \widetilde{\mathcal{H}} \\ & \mu' = \Gamma_\mu(\mu; \phi', \phi). \end{aligned}$$

A homebuyer solves the following utility maximization problem

$$V_j^b(b, y; \Omega) = \max_{\{c, b', m', h'\}} u(c, s; \phi) + \beta E_{y', \phi'}[V_{j+1}^H(b', m', h', y'; \Omega')|y, \phi],$$

[49]For simplicity, we assume that once a household decides to sell the house, it sells all housing stock.

subject to

$$\begin{aligned} s.t. \quad & c + p_h h' + q_b b' + \kappa_m \cdot 1_{\{m'>0\}} + \kappa_j \leq b + y + m' \\ & b' \geq 0,\ m' \geq 0 \\ & s = h', h' \in \mathcal{H}^1 \\ & m' \leq \lambda_m(h') p_h h' \\ & \mu' = \Gamma_\mu(\mu; \phi', \phi). \end{aligned}$$

A homeowner who chooses to keep its house and pay the mortgage solves the following problem:

$$V_j^p(b, m, h, y; \Omega) = \max_{\{c, b', \pi\}} u(c, s; \phi) + \beta E_{y', \phi'}[V_{j+1}^h(b', m', h', y'; \Omega') | y, \phi],$$

subject to

$$\begin{aligned} s.t. \quad & c + \delta_h p_h h + \pi + q_b b' \leq b + y \\ & b' \geq 0 \\ & s = \min\{h', \hat{h}\}, h' = h \\ & \pi \geq \pi_m \equiv \frac{r_m (1 + r_m)^{J+1-j}}{(1 + r_m)^{J+1-j} - 1} m \\ & m' = (1 + r_m) m - \pi \\ & \mu' = \Gamma_\mu(\mu; \phi', \phi). \end{aligned}$$

Similar to a renter's problem, a household who sells its house and chooses to rent solves

$$V_j^{sr}(b_n, y; \Omega) = \max_{\{c, b', \tilde{h}'\}} u(c, s; \phi) + \beta E_{y', \phi'}[V_{j+1}^n(b', y'; \Omega') | y, \phi],$$

subject to

$$\begin{aligned} s.t. \quad & c + \rho_h \tilde{h}' + q_b b' \leq b_n + y \\ & b' \geq 0 \\ & s = \omega \tilde{h}', \tilde{h}' \in \widetilde{\mathcal{H}} \\ & \mu' = \Gamma_\mu(\mu; \phi', \phi). \end{aligned}$$

Finally, similar to the homebuyer's problem, a household who sells its house and chooses to buy a new house solves

$$V_j^{sb}(b_n, y; \Omega) = \max_{\{c, b', m', h'\}} u(c, s; \phi) + \beta E_{y', \phi'}[V_{j+1}^h(b', m', h', y'; \Omega') | y, \phi],$$

subject to

$$\begin{aligned} s.t. \quad & c + p_h h' + q_b b' + \kappa_m \cdot 1_{\{m'>0\}} \leq b_n + y + m' \\ & b' \geq 0,\ m' \geq 0 \\ & s = h', h' \in \mathcal{H} \\ & m' \leq \lambda_m(h') p_h h' \\ & \mu' = \Gamma_\mu(\mu; \phi', \phi). \end{aligned}$$

D.2. **Equilibrium.** Denote $\chi^H = (b, m, h, y)$ and $\chi^N = (b, y)$ as the idiosyncratic state vectors for homeowners and non-homeowners, respectively. Also, let μ_j^H and μ_j^N be the measure of these two types of households at age j. A recursive competitive equilibrium consists of household value functions $\{V_j^N\left(\chi^N;\Omega\right), V_j^H\left(\chi^H;\Omega\right), V_j^r\left(\chi^N;\Omega\right), V_j^b\left(\chi^N;\Omega\right), V_j^p\left(\chi^H;\Omega\right), V_j^s\left(\chi^H;\Omega\right)\}$, household decision rules, aggregate functions for construction labor $N_h(\Omega)$, rental units stock $\tilde{H}'(\tilde{H};\Omega)$, homebuyers' housing stock $H'(H;\Omega)$, housing investment $I_h(\Omega)$, rental price $\rho_h(\Omega)$, house price $p_h(\Omega)$, and a law of motion for the aggregate states:

(1) Households optimize with value functions and associated decision rules;
(2) Construction sector firms maximize profits with associated labor demand and housing investment functions $\{N_h, I_h\}$;
(3) The labor market clears at the wage rate $w = \Theta$;
(4) The rental market clears at price ρ_h;
(5) The housing market clears at price p_h:

$$\tilde{H}' + H' = (1 - \delta_h)(\tilde{H} + H) + I_h.$$

(6) The aggregate law of motion is induced by the exogenous stochastic processes and all the decision rules, and it is consistent with individual behavior.

Appendix E. Numerical Solution Procedure

This section outlines the steps taken to solve the model numerically. First, we provide the computation strategy for the rental company and households' problems. Next, we describe how to calculate the stationary equilibria. Finally, we end with a solution algorithm for transitions.

First, given house price and current state Ω, one can solve the rental company's problem and compute the rental price ρ_h from the optimality condition of the rental company, which is

$$\rho_h(\Omega) = \psi + p_h(\Omega) - \frac{1 - \delta_h}{1 + r_b} E_{\Omega'}[p_h(\Omega')|\Omega].$$

The household value and policy functions are solved via backward induction starting with the final period of life. We discretize the idiosyncratic state χ by fixing grids on liquid assets $\mathcal{B}$ (20 points), mortgages $\mathcal{M}$ (30 points), house sizes $\mathcal{H}$ (5 points), and income $\mathcal{Y}$ (2×3 points). Households choose liquid assets and house sizes on the grids of $\mathcal{B}$ and $\mathcal{H}$ respectively. Household mortgage choice when purchasing a house is restricted to be on $\mathcal{M}$. However, when households repay the mortgage, the next period mortgage balance can be exactly $\mathcal{M}$, or follow the amortization schedule, which is computed via linear interpolation between grid points.

Second, stationary equilibria are calculated for a given policy regime and constant house price. The following algorithm is used to find the market clearing house price[50]:

1. Make an initial guess of the market clearing house price $\tilde{p}_h$.
2. Given $\tilde{p}_h$, solve the rental price ρ_h from the rental company's problem. Then solve backward for the households' value and policy functions. Given households' choices, solve forward for the distribution of households over individual states.
3. Calculate the aggregate housing demand and housing investment in the stationary equilibria. With housing investment, solve the implied house price $\bar{p}_h$ from the first-order condition for the real estate developer.
4. Compare $\tilde{p}_h$ and $\bar{p}_h$. If not the same, replace $\tilde{p}_h$ by a weighted average of $\tilde{p}_h$ and $\bar{p}_h$, and return to step 2.

Third, for a given path of policies, we define the vector of equilibrium house prices as $p_{h,t}$. Recall that μ_t captures the distribution of households over individual states. The algorithm for calculating the transition paths proceeds as follows. First, guess the approximate length of the transition phase, T. If the transition can be achieved in a smaller number of periods, the last transition periods will be similar to the new steady state. After solving for the stationary equilibria before and after the policy change, we know the starting distribution μ_0, the end house price $p_{h,T}$, and households' value functions V_T. The algorithm then iterates over the following steps:

1. Guess a sequence of house price vector $\tilde{p}_{h,t}$ for $t = 1, \ldots, T-1$.
2. Given $\tilde{p}_{h,t}$, solve the rental price $\rho_{h,t}$ from the rental company's problem. Then solve backward for the households' value and policy functions at each time t. Given households' choices, solve forward for the distribution of households over individual states across time.

[50]Since there is potential housing preference state switching and high preference state is an absorbing one, the stationary equilibrium in the high housing preference state is solved first by searching for the market clearing house price following the same algorithm. In this case, there is no state switching in the future, so the house price will always stay the same.

3. Calculate the aggregate housing demand and housing investment for each time t. With housing investment, solve the implied house price $\bar{p}_{h,t}$ from the first-order condition for the real estate developer.
4. Compare $\tilde{p}_{h,t}$ and $\bar{p}_{h,t}$. If not the same, replace $\tilde{p}_{h,t}$ by a weighted average of $\tilde{p}_{h,t}$ and $\bar{p}_{h,t}$, and return to step 2.

Appendix F. Estimate of house supply elasticity

To estimate house supply elasticity, we run the following two-stage regression. The regression in the second stage is

$$\log(P_{i,t}) = \xi_i + \psi_t + \beta \log(\widehat{H_{i,t}}) + \theta X_{i,t} + \varepsilon_{i,t}, \tag{F.1}$$

where $\widehat{H_{i,t}}$ is the prediction from the first-stage regression. The first-stage regression is

$$\log(H_{i,t}) = \phi_i + \chi_t + \sum_k \gamma_k Z_i \mathbf{1}_{t=k} + \omega X_{i,t} + e_{i,t}, \tag{F.2}$$

where $P_{i,t}$ is the house price index for city i in year t, $H_{i,t}$ is the sales area of newly built houses for city i in year t, ξ_i and ϕ_i are city fixed effects in the second and first stages, ψ_t and χ_t are yearly fixed effects, $X_{i,t}$ represents a vector of controls, and Z_i is the exposure measure for city i. The vector of control variables, $X_{i,t}$, includes log of lagged average city income, log of lagged city population, lagged city unemployment rate, and log of lagged house price index. The inverse of the housing supply elasticity, β, is the coefficient of interest. Table F.1 reports the estimated value of β, which is equal to 0.250 and statistically significant at the 5% level.

Table F.1. Estimate of the inverse of the housing supply elasticity

	House price ($\log(P_{i,t})$)
$\log(H_{i,t})$	0.250**
	(0.120)
City controls	Y
City fixed effect	Y
Year fixed effect	Y
N	490
R^2	0.2207
First-stage F stat	28.20

Notes: The standard error, reported in parentheses, is clustered at the city level. The asterisk * denotes statistical significance at the 0.1 level, ** at the 0.05 level, and *** at the 0.01 level.

Appendix G. A Simple Model

We develop a parsimonious two-period economy with households heterogeneous in their housing and mortgage debt positions. Depending on their initial housing and mortgage positions, households make decisions on housing tenure, housing trade-up or invest in a secondary house for pure speculative purposes. We aim to keep the model as simple as possible to highlight the role of house price increases associated with a relaxation of LTV limits on secondary houses on housing trade up decisions.

G.1. **Households.** Each household lives two periods. The household utility is linear in consumption in both periods and housing service flow for housing purchased in period 1:

$$U = \begin{cases} c_1 + Ec_2 + \phi h, & \text{if } c_1, c_2 \geq 0 \text{ and } h > 0 \\ -\infty & \text{otherwise} \end{cases}, \tag{G.1}$$

where c_1 and c_2 are consumption in period 1 and 2, and h is housing service flow.

Households can rent or buy houses. Only two house sizes are available: H_1 and H_2, with $H_1 < H_2$. Households can purchase a secondary house, which does not provide housing service utility. For simplicity, we assume that housing purchase follows a climb of ladders, that is, a household needs to first purchase H_1 before switching to a larger house H_2. If a household buys a second house, he also needs to start with H_1 before switching to a larger house H_2.

At the beginning of period 1, there are three types of households distinguished by initial housing and mortgage positions. Type 0 household (a non-homeowner) has no initial housing stock and no outstanding mortgage debt. Type 1 (a potential buyer of a larger primary house) household, who is an existing homeowner, has house size H_1, and outstanding mortgage χ_1 at the beginning of period 1. Type 2 household (a potential buyer of a larger secondary house) has primary house size H_2 and secondary house size H_1, with outstanding mortgage χ_2 and χ_1 for primary and secondary houses respectively at the beginning of period 1. The measure for each type of household is μ_0, μ_1, and μ_2, respectively. For households' incomes in period 1, we also allow them to be heterogeneous and denote them with $y_1^{(i)}$ for type i. For income in period 2, we assume y_2 is sufficiently large such that the constraint $c_2 \geq 0$ is never binding.

There is no saving technology apart from housing and the only borrowing allowed is mortgage. The mortgage is long-term in that if an existing homeowner keeps his existing home, he can pay the mortgage balance at the end of period 2. However, if a homeowner sell his existing home in period 1, he needs to pay the outstanding mortgage in full.

The maximum loan-to-value ratio for a new mortgage on a primary home is different from that on a secondary house: λ_1 for purchasing primary homes and λ_2 for purchasing secondary houses.

Define the gross return of housing for a house purchased in period 1 as $R^h = p'/p$, where p and p' denote the house price in period 1 and 2, respectively. For simplicity, we assume that the expected return of housing (ER^h) is always larger than one.

To close the model, we assume that real estate developers supply housing in competitive market, and house price function is $p = S(H)$, where H is total stock of housing in a period, $S'(H) > 0$. For rental housing, we assume that the government purchases houses from real estate developers and provides rental housing with rental price per unit $\rho = \psi p$.

G.2. **Households' Problems.** We now describe the housing decisions for each type of household. Since utility is linear for consumption, the marginal rate of substitution between current and future consumption is one. Given $ER^h > 1$, one unit of investment in housing can lead to more than one unit of consumption in future, and the marginal rate of transformation is larger than one. We show below that as long as the household's budget is allowed to make sure non-negative consumption in the first period, households would like to increase their investment in housing, by becoming a first-time home buyer for type 0, or trading up for a larger primary house for type 1, or purchasing a larger second house for type 2.

Type 0: A type 0 household chooses between rent or buy H_1. If he choose to be a renter, the utility is

$$\begin{aligned} EU^{rent} &= I_{\{c_1 \geq 0\}} \cdot (c_1 + c_2 + \phi H_1) + I_{\{c_1 < 0\}} \cdot (-\infty) \\ s.t. \quad & c_1 + \rho H_1 = y_1^0 \\ & c_2 = y_2 \end{aligned} \tag{G.2}$$

If he chooses to buy a house, the utility is

$$\begin{aligned} EU^{buy} &= I_{\{c_1 \geq 0\}} \cdot (c_1 + Ec_2 + \phi H_1) + I_{\{c_1 < 0\}} \cdot (-\infty) \\ s.t. \quad & c_1 + pH_1 = y_1^0 + m \\ & m = \lambda_1 p H_1 \\ & c_2 = y_2 + R^h \cdot pH_1 - m \end{aligned} \tag{G.3}$$

where m is the mortgage originated in period 1.

Type 0 household's housing tenure choice solves the following problem

$$V^0 = \max\{EU^{rent}, EU^{buy}\}. \tag{G.4}$$

In the case of renting, by substituting the budgets constraints into utility, we can get

$$EU^{rent} = y_1^0 + y_2 + (\phi - \rho)H_1, \tag{G.5}$$

where we assume that rental is always affordable, i.e. $y_1^0 \geq \rho H_1$.

For the case of buying, the utility depends on household's income and house price. If $y_1^0 < (1-\lambda_1)pH_1$, the budget constraint in the first period implies that $c_1 < 0$, and $EU^{buy} = -\infty < EU^{rent}$. However, if $y_1^0 \geq (1-\lambda_1)pH_1$, by substituting the budgets constraints into utility, we can get

$$EU^{buy} = y_1^0 + y_2 + (\phi - \rho)\, H_1 + \left[(ER^h - 1)p + \rho\right] H_1, \tag{G.6}$$

It is easy to see that $EU^{buy} > EU^{rent}$ as $ER^h > 1$.

In summary, a type 0 household chooses to rent if $y_1^0 < (1-\lambda_1)pH_1$, and to buy a house otherwise.

Type 1: a type 1 household chooses between stay or churn up. If he stays, his utility becomes

$$\begin{aligned} EU^{stay} &= I_{\{c_1 \geq 0\}} \cdot (c_1 + Ec_2 + \phi H_1) + I_{\{c_1 < 0\}} \cdot (-\infty) \\ s.t. \quad & c_1 = y_1^1 \\ & c_2 = y_2 + R^h \cdot pH_1 - \chi_1 \end{aligned} \tag{G.7}$$

If he chooses to trade up for a larger house, his utility is

$$\begin{aligned} EU^{up} &= I_{\{c_1 \geq 0\}} \cdot (c_1 + Ec_2 + \phi H_2) + I_{\{c_1 < 0\}} \cdot (-\infty) \\ s.t. \quad & c_1 + pH_2 + \chi_1 = y_1^1 + m + pH_1 \\ & m = \lambda_1 pH_2 \\ & c_2 = y_2 + R^h \cdot pH_2 - m \end{aligned} \tag{G.8}$$

Type 1 household's optimal choice solves the following problem

$$V^1 = \max\{EU^{stay}, EU^{up}\}. \tag{G.9}$$

In the case of staying, by substituting the budgets constraints into utility, we can get

$$EU^{stay} = y_1^1 + y_2 + ER^h \cdot pH_1 - \chi_1 + \phi H_1. \tag{G.10}$$

In the case of churning up, the utility depends on household's income and house price. If $y_1^1 + pH_1 < (1-\lambda_1)pH_2 + \chi_1$, the budget constraint in the first period implies that $c_1 < 0$,

and $EU^{up} = -\infty < EU^{stay}$. However, if $y_1^1 + pH_1 \geq (1-\lambda_1)pH_2 + \chi_1$, by substituting the budgets constraints into utility, we can get

$$EU^{up} = y_1^1 + y_2 + ER^h \cdot pH_1 - \chi_1 + \phi H_1 + \left[(ER^h - 1) \cdot p + \phi\right](H_2 - H_1). \tag{G.11}$$

Again $ER^h > 1$ is sufficient for $EU^{up} > EU^{stay}$.

In summary, type 1 households choose to stay if $y_1^1 + pH_1 < (1-\lambda_1)pH_2 + \chi_1$, and to churn up otherwise.

Type 2: A type 2 household chooses between stay in his existing houses H_2 and H_1 or buy a larger second house H_2 after selling H_1. If he stay, his utility becomes

$$\begin{aligned} EU^{stay} &= I_{\{c_1 \geq 0\}} \cdot (c_1 + Ec_2 + \phi H_2) + I_{\{c_1 < 0\}} \cdot (-\infty) \\ s.t. \quad & c_1 = y_1^2 \\ & c_2 = y_2 + R^h \cdot p(H_2 + H_1) - \chi_2 - \chi_1 \end{aligned} \tag{G.12}$$

If he choose to buy a larger second house, his utility becomes

$$\begin{aligned} EU^{2ndH} &= I_{\{c_1 \geq 0\}} \cdot (c_1 + Ec_2 + \phi H_2) + I_{\{c_1 < 0\}} \cdot (-\infty) \\ s.t. \quad & c_1 + pH_2 + \chi_1 = y_1^2 + m + pH_1 \\ & m = \lambda_2 pH_2 \\ & c_2 = y_2 + R^h \cdot p(H_2 + H_2) - \chi_2 - m \end{aligned} \tag{G.13}$$

A type 2 household's optimal choice solves the following problem

$$V^2 = \max\{EU^{stay}, EU^{2ndH}\}. \tag{G.14}$$

In the case of staying, by substituting the budgets constraints into utility, we can get

$$EU^{stay} = y_1^2 + y_2 + ER^h \cdot p(H_2 + H_1) - \chi_2 - \chi_1 + \phi H_2. \tag{G.15}$$

In the case of buying a second house, the utility depends on household's income and house price. If $y_1^2 + pH_1 < (1-\lambda_2)pH_2 + \chi_1$, the budget constraint in the first period implies that $c_1 < 0$, and $EU^{2ndH} = -\infty < EU^{stay}$. However, if $y_1^2 + pH_1 \geq (1-\lambda_2)pH_2 + \chi_1$, by substituting the budgets constraints into utility, we can get

$$EU^{2ndH} = y_1^2 + y_2 + ER_h \cdot p(H_2 + H_1) - \chi_2 - \chi_1 + \phi H_2 + (ER_h - 1) \cdot p(H_2 - H_1), \tag{G.16}$$

so $ER^h > 1$ implies that $EU^{2ndH} > EU^{stay}$.

In summary, type 2 households choose to stay if $y_1^2 + pH_1 < (1-\lambda_2)pH_2 + \chi_1$, and to buy a larger second house otherwise.

G.3. **A status quo Equilibrium.** We consider a status quo equilibrium in which households of all types maintain their initial housing and mortgage position. This equilibrium is isomorphic to the steady-state equilibrium if the economy last for infinite periods. Specifically, type 0 households rent houses at size H_1, while type 1 and type 2 households chooses to stay in their home at size H_1 and $H_2 + H_1$, respectively. Total housing demand is

$$H^D = \mu_0 H_1 + \mu_1 H_1 + \mu_2 (H_2 + H_1), \tag{G.17}$$

and house price is

$$p = S(H^D) = S(\mu_0 H_1 + \mu_1 H_1 + \mu_2 (H_2 + H_1)). \tag{G.18}$$

From the analysis in the previous section, we know this can be an equilibrium if the house price is such that no households can increase their housing investment while maintaining non-negative consumption in period 1. This implies that the following conditions have to be satisfied:

(1) For type 0 households to rent a house (cannot afford to buy)

$$y_1^0 < (1-\lambda_1)pH_1, \tag{G.19}$$

where the inequality comes from a type 0 household's budget constraint for purchasing a house. This implies that $p > y_1^0 / ((1-\lambda_1)H_1)$.

(2) For a type 1 household to stay (cannot afford to churn up), we need

$$y_1^1 + pH_1 < (1-\lambda_1)pH_2 + \chi_1, \tag{G.20}$$

where the inequality comes from a type 1 household's budget constraint for churning up.

(3) For a type 2 to stay (cannot afford to buy a larger secondary house), we need

$$y_1^2 + pH_1 < (1-\lambda_2)pH_2 + \chi_1, \tag{G.21}$$

where the inequality comes from a type 2 household's budget constraint for buying a larger secondary house.

We would like to focus on the condition for type 1 household to stay. Note that in a status quo equilibrium, the initial mortgage comes from borrowing in the previous period. This implies $\chi_1 = \lambda_1 p H_1$. Put it into equation G.20, and we get

$$p > \frac{y_1^1}{(1-\lambda_1)(H_2 - H_1)}. \tag{G.22}$$

This means that as house price increases, the condition is *more likely* to hold. In other words, a type 1 household would not afford to churn up under a higher house price. $(G.22)$ is consistent with the prediction in our full-blown model at the steady state, in which a household that receives a high income shock is more likely to trade up their primary homes. Similarly, for a type-2 household to keep his current housing position, we need

$$p > \frac{y_1^2}{(1-\lambda_2)(H_2 - H_1)}. \tag{G.23}$$

G.4. **A Relaxation of LTV limits for Secondary Houses.** We now consider the policy experiment in which the LTV limits for a type 2 households increases unexpectedly to a higher level, denoted as $\widehat{\lambda}_2$, from its counterpart in the status-quo equilibrium, while LTV limits for the other two types of households remained unchanged. In such an equilibrium, the outstanding mortgage balance for all households is exogenous to the equilibrium house prices. Our purpose is to find the sufficient conditions for an equilibrium in which type 1 households trade up their primary houses while type 2 households purchase their larger secondary houses.

Denote $\tilde{p}^1 = S(\mu_0 H_1 + \mu_1 H_1 + \mu_2(H_2 + H_2))$, and $\tilde{p}^2 = S(\mu_0 H_1 + \mu_1 H_2 + \mu_2(H_2 + H_2))$ as the equilibrium house prices in period 1 that correspond, respectively, to the following two cases: (1) only type 2 households buy their larger secondary houses, while both type 0 and type 1 households remain status quo; (2) type 1 households trade up their primary homes and type 2 households buy larger secondary houses. Clearly, $p < \tilde{p}^1 < \tilde{p}^2$. Assume $y_1^2 + \tilde{p}^i H_1 > (1 - \widehat{\lambda}_2)\tilde{p}^i H_2 + \chi_1$ for $i = 1, 2$, so that type 2 households will buy a larger secondary house in both cases under the new LTV limit $\widehat{\lambda}_2$. This implies that

$$\tilde{p}^1 \geq \frac{\chi_1 - y_1^2}{H_1 - \left(1 - \widehat{\lambda}_2\right) H_2}. \tag{G.24}$$

And for type 0 households, since their LTV limits are unchanged, a higher house price of either $\tilde{p}^1$ or $\tilde{p}^2$ in the new equilibrium will keep them renting in both cases.

We now focus on type 1 households. The equilibrium depends whether budget constraint for churning up can hold. We make the following assumption

$$H_1 > (1 - \lambda_1) H_2. \tag{G.25}$$

We have the following lemma:

Lemma 1. Let Assumption $(G.25)$ hold. Under the following condition, a unique equilibrium exists, in which type 1 households trade up their primary homes and type 2 households buy larger secondary houses,

$$\tilde{p}^1 \geq \frac{\chi_1 - y_1^1}{H_1 - (1 - \lambda_1) H_2}. \tag{G.26}$$

Accordingly, the equilibrium house price is $\tilde{p}^2$.

Proof: The inequality $(G.26)$ implies that

$$y_1^1 + \tilde{p}^1 H_1 \geq (1 - \lambda_1)\tilde{p}^1 H_2 + \chi_1.$$

In other words, all type 1 households are able to afford churning up under a house price $p < \tilde{p}^1 < \tilde{p}^2$, under which only type 2 households increase their housing investment. Thus, all type 1 households choose to trade up for a larger primary home H_2, under which the equilibrium house price is $\tilde{p}^2$. Note that $\tilde{p}^1 < \tilde{p}^2$ and $(G.26)$ imply that

$$y_1^1 + \tilde{p}^2 H_1 \geq (1 - \lambda_1)\tilde{p}^2 H_2 + \chi_1.$$

This implies that type 1 households still choose to trade up their primary homes under the equilibrium house price $\tilde{p}^2$.

For the inequality $(G.26)$ to hold, $\chi_1 - y_1^1$ needs to be sufficiently small. Moreover, a larger initial housing wealth H_1, which implies larger capital gains by selling H_1, would also makes this inequality more likely to hold. In our full-flown model, the middle-age high income households tend to have smaller outstanding mortgage balance, but large income and larger housing wealth. This explains why the middle-aged high income households in our full-blown model are more likely to trade up their primary homes when LTV limits for secondary houses increases. And their churning up amplifies the increases in equilibrium house price from $\tilde{p}^1$ to $\tilde{p}^2$.

(G.26) suggests that the likelihood for type 1 households to trade up their primary homes depends not only their own housing net worth and income, but also the price increases driven by the speculative investment in secondary homes. The larger is $\tilde{p}^1$, the more likely that type 1 households would trade up their primary homes. Note that the magnitude of $\tilde{p}^1$ (relative to p) depends on the size of type 2 households (those who have secondary houses) in the economy $\mu_2/(\mu_0 + \mu_1 + \mu_2)$. The higher is the size of type 2 households, the higher is $\tilde{p}^1$,

which implies a larger capital gain for type 1 households to sell their primary homes. As a result, it is more likely for type 1 households to trade up their primary homes.

Alternatively, if

$$\tilde{p}^1 < \frac{\chi_1 - y_1^1}{H_1 - (1-\lambda_1) H_2} \leq \tilde{p}^2,$$

there are two equilibria. In one equilibrium, none of type 1 households churn up and house price is $\tilde{p}^1$. And in the other equilibrium, all of type 1 households churn up and house price is $\tilde{p}^2$. If

$$\tilde{p}^2 < \frac{\chi_1 - y_1^1}{H_1 - (1-\lambda_1) H_2},$$

the only equilibrium is that none of type 1 households churn up and house price is $\tilde{p}^1$.