Flight to Housing in China*

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This version: June, 2021

Abstract

We empirically detect the flight to safety vis-a-vis housing in China: Great economic uncertainty causes the prices of housing assets to soar. To stabilize housing prices, China has imposed purchase restrictions on the housing market. We study the aggregate and distributional effects of this housing policy by developing a two-sector model with heterogeneous households. An uncertainty shock generates a countercyclical housing boom by shifting outward households' demand for housing as a store of value. A vibrant housing sector then leads to an economic recession by crowding out resources that could have been allocated to the real sector. Our quantitative analysis suggests that the policy limiting housing purchases effectively curb surging housing prices. However, the policy restricts households' access to housing that can be used to buffer idiosyncratic uncertainties, creating a larger consumption dispersion. Consequently, the housing policy creates a trade-off between macro-level stability and micro-level consumption risk sharing.

Keywords: Heterogeneous Households, Store of Value, Housing Policy, Aggregate and Distributional Effects, Consumption Risk Sharing

JEL Classification: E21, G11, G18, H31, R21.

*We thank the editor B. Ravikumar, the associate editor, two anonymous referees, Jinhui Bai, Kaiji Chen, Zhao Chen, Jonathan Heathcote, Zhen Huo, Laura Xiaolei Liu, Ming Lu, Wenlan Luo, Michael Zheng Song, Pengfei Wang, Yi Wen, Daniel Xu, Yu Zhang, in particular Vincenzo Quadrini, Tao Zha, and discussants Qi Sun and Fudong Zhang, along with seminar participants at the Macro-Finance Workshop of Shanghai Jiao Tong University, Conference on Uncertainty and Economic Activity, the Macro Workshop at Chinese University of Hong Kong, the Macro-Finance Workshop of Peking University HSBC Business School, Workshop on Macro and Development at DUFE, GRIPS, Peking University, Fudan University, Tsinghua University, Wuhan University, East China Normal University, Nanjing University, Sichuan University and Renmin University of China for useful discussions and comments. The research is supported by Tsinghua University Spring Breeze Fund (2020Z99CFW046), the National Natural Science Foundation of China Project Numbers 71603011 and 72022011, Shanghai Social Science Foundation (No. 2019BJL005). Dong: School of Economics and Management, Tsinghua University, Email: dongfeng@sem.tsinghua.edu.cn; Liu: School of Finance, Shanghai University of International Business and Economics, Email: liujianfeng@suibe.edu.cn; Xu: Peking University HSBC Business School and Shanghai Jiao Tong University, Email: xuzhiwei09@gmail.com; Zhao (corresponding author): China Center for Economic Research, National School of Development, Peking University; Email: zhaobo@nsd.pku.edu.cn.

1 Introduction

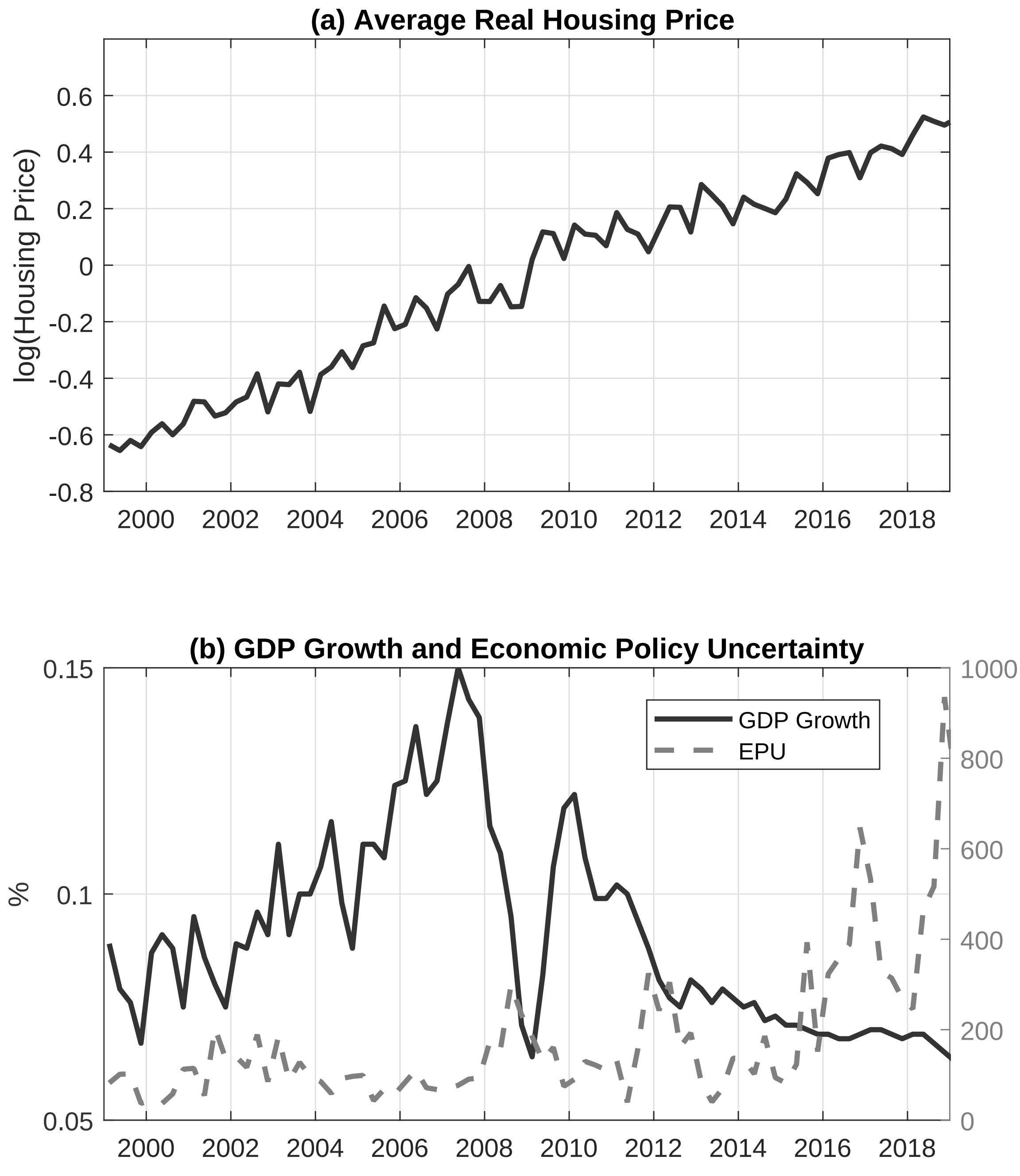
As the second-largest economy and the largest developing economy in the world, China has been the major engine of global economic growth in the past decade. Meanwhile, as in other developing economies, China generally suffers from a safe-asset shortage. On the one hand, China has considerable demand for safe assets as stores of value and contributes to the largest global saving glut. On the other hand, the underdeveloped financial system constrains the capacity of the country to produce safe assets. Furthermore, tight regulation on financial accounts intensifies the scarcity of safe assets in the domestic market as it is costly for Chinese households to hold prime assets issued by advanced economies like the US. In this paper, we provide some evidence that the shortage of safe assets makes Chinese households choose real estate assets as the store of value. The recent Chinese real estate boom along with the economic slowdown provides us with an ideal opportunity to evaluate housing assets as a store of value, or the flight to safety vis-à-vis housing.

Real estate constitutes the largest part of Chinese households' net worth. Between 2004 and 2019, the housing wealth accounted for approximately 50% of Chinese household's net worth, while housing loans accounted for only 10% of the housing wealth.[1] Panel (a) in Figure 1 plots the logarithmic national average real housing price in China. From 1999 to 2019, the average real housing price in China increases by approximately 1.2 logarithmic points, with an average annual growth rate of 6.2%.[2] In contrast to the steady growth of housing prices, China's economic growth has entered a stage of continuous decline since 2010. Panel (b) in Figure 1 plots the year-on-year GDP growth rate

[1]Between 2004 and 2019, the housing wealth accounted for approximately 30% of US households' net worth. During the same period, housing loans accounted for 44% of US households' housing wealth. Data are from People's Bank of China, China's National Balance Sheet by the Chinese Academy of Social Sciences (CASS), and Financial Accounts of the United States.

[2]The National Bureau of Statistics of China (NBSC) publishes the total floor area and revenue of houses sold in different provinces/cities, from which average prices can be calculated by simply dividing the total price paid by the total floor area of the houses sold. The nominal average housing price is deflated by the CPI index. Appendix A.2 describes the construction of these series in detail. The national average housing price published by the NBSC may be affected by the composition of houses in the sample. Unfortunately, China does not have a housing price index based on the repeated sale of houses. Fang et al. (2016) constructed a housing price index using loan's data. Their national housing price index has an average annual growth rate of 14.5% between 2003 and 2013, which exceeds the growth rate of the average housing price level over the same period. This may be related to the fact that newly sold properties are more away from the city center. The correlation between the two series in 2003-2013 was 0.93. Because the data of Fang et al. (2016) cannot be further updated, we still use the average housing price series of the NBSC in the following analysis.

Figure 1: Housing Prices and Economic Policy Uncertainty



Notes: Panel (a) plots the logarithm real housing price per square meters. Panel (b) plots the year-on-year real GDP growth rate and the Economic Policy Uncertainty. All the time series are from 1999Q1 to 2019Q4. The GDP growth series is from the WIND database. The Economic Policy Uncertainty (EPU) is Baker-Bloom-Davis economic policy uncertainty index for China (Baker et al., 2016). Appendix A.2 describes more details about these series.

and the Economic Policy Uncertainty (EPU).[3] We observed that the EPU series rises as the economy slows down. However, we have not noticeably observed a slowdown in the growth rate of housing prices.

We argue that the continued rapid increase in housing prices under adverse economic conditions is consistent with the role of housing assets as a store of value (or safe assets, which are expected to retain their value in adverse systemic events). Uncertainty shocks increase the demand for housing as a store of value, leading to soaring housing prices. To understand why real estate is a safe asset in China, we follow Fang et al. (2016) to compare the annual growth rate of stock prices and housing prices over a longer period (1999-2019). The two price growth rates we compared are precisely what investors (who only pay attention to capital gains and ignores dividends) would value.[4] The results are summarized in Table 1. We have similar findings to Fang et al. (2016): the housing price growth rate is not as volatile as the stock price growth rate. At the same time, the Sharpe ratio (defined as the mean divided by the standard deviation) of the housing price growth rate is much higher than Sharpe ratio of stock price growth rate.[5] Given that the stock return is more volatile than the real return on capital (Gomme et al., 2011), we further compare the real return of non-residential capital and residential capital in China. We find that for both China and the United States, the volatility of the return on real estate capital is less than that of non-real estate capital.[6]

In the empirical analysis, we show that great economic uncertainty leads to high housing prices. Using the households' data from China Family Panel Studies (CFPS) 2010-2018, we find that the county-level uncertainty (measured by the standard deviation of households' permanent labor income risks) increases homeowners' average housing price and housing-wealth-to-income ratio. When labor income uncertainty increases by 25%, real housing prices will rise by 22% to 26%.

[3]We do not have measures about labor income uncertainty at yearly frequency. We argue that labor income uncertainty also rises in China during recessions given the evidence from many developed countries (Storesletten et al., 2004; Zhao, 2013).

[4]Fang et al. (2016) find that during their full sample in 2003-2013, first-tier cities offered the highest average annual return at a staggering level of 15.7% and return volatility of 15.4%, second-tier cities offered an average return of 13.4%, and volatility of 9.9%, while third-tier cities offered the lowest average return of 11.0% among the three tiers and also the lowest volatility of 7.5%.

[5]According to the data of Fang et al. (2016), the Sharpe ratio of housing price growth rate in first-tier cities is 1.01, 1.474 in second-tier cities, and 0.89 in third-tier cities. Our data shows that the Sharpe ratio of the national average housing price growth rate was 0.7 during 1999-2014 and 1.7 during 2015-2019.

[6]See Online Appendix S.1 for details. We thank the editor for making this suggestions.

Table 1: Summary Statistics of Annual Growth of Housing/Stock Prices in China

	1999-2014			2015-2019			1999-2019	
$x =$	Mean	Std	$\frac{\text{Mean}}{\text{std}}$	Mean	Std	$\frac{\text{Mean}}{\text{std}}$	Corr(x,gr_{GDP})	Corr(x, EPU)
gr_{GDP}	0.097	0.021	4.619	0.067	0.004	16.75	1	-0.526***
EPU	120.0	64.3	1.866	480.8	283.0	1.699	-0.526***	1
$gr_{\text{HousePrice}}$	0.056	0.078	0.718	0.071	0.041	1.732	0.152	0.005
$gr_{\text{StockPrice}}$	0.144	0.525	0.274	0.095	0.393	0.242	0.464***	-0.230**

Notes: All data series are quarterly. gr_{GDP} is the year-on-year growth of real GDP. $gr_{\text{HousePrice}}$ is the year-on-year average growth of real housing prices in China. $gr_{\text{StockPrice}}$ is the year-on-year growth of Shenzhen stock price index. EPU is the Baker-Bloom-Davis economic policy uncertainty index for China (Baker et al., 2016). *** p<0.01, ** p<0.05, * p<0.1. Data Source: National Bureau of Statistics of China and the WIND database.

Motivated by the empirical findings, we construct a two-sector dynamic general equilibrium heterogeneous agent model in which housing assets emerge as stores of value. Liquidity constraints confine the households' capacity to insure idiosyncratic uncertainties. As a result, housing assets endogenously serve as stores of value. The Euler equation for asset pricing implies that housing prices in the current period are determined by the expected price and a premium term. As the economy becomes more uncertain, the demand for housing as a store of value increases. Then, an uplifted premium for holding housing leads to a boost in housing prices. The expansion in the housing sector, in turn, diverts resources allocated to the real estate sector, resulting in an aggregate recession.

After calibrating the model to the Chinese economy, we find that a 25% increase in uncertainty (standard deviation of idiosyncratic shocks) raises the equilibrium housing price by 20%, which is consistent with the relatively large impact of income uncertainty on housing prices found in the data. In an extended model where multiple liquid assets (e.g., government bonds) are introduced, we find that the transmission mechanism in our baseline model remains important as long as the supply of other liquid assets is limited.

To stabilize housing prices, the Chinese government implemented a policy that limits the number of homes households can purchase. Correspondingly, we quantitatively evaluate this kind of policy intervention. The tractability of our model allows us to derive, in a transparent way, the process of housing prices as well as the individual optimal decisions following the government's intervention. We show that the policy limiting home purchases can effectively impede the demand for housing and thus the housing boom. The dampened crowding-out effect from the housing sector mitigates the adverse consequences of economic uncertainty on the real sector. However, we also find that the policy intervention prevents households from investing in housing assets as a buffer for consumption risks and reduces the degree of consumption insurance. As a result, social welfare is reduced due to the rising consumption growth dispersion. We conclude that there exists a trade-off between aggregate housing price stability and consumption risk sharing using housing as a safe asset.

Literature Review The current paper is generally related to a large body of the literature, which we do not attempt to go through here. Instead, we highlight only the papers that are most closely related to this study.

First, the flight to quality (safety) and liquidity during the last financial crisis has created considerable demand for the analysis of the shortage of safe assets. Our paper contributes to this strand of the literature. Caballero et al. (2016) and Caballero and Farhi (2017) explore the macroeconomic implications of safe asset shortages. Another relevant paper, Quadrini (2017), shows that, in addition to the standard lending channel, financial intermediation affects the real economy through a novel banking liability channel by issuing liabilities, which are recognized as safe assets by agents facing uninsurable idiosyncratic risk. The underlying mechanism of the global scarcity of safe assets and its aggregate consequences has been well documented in the recent literature (e.g., Gorton and Ordonez, 2013; He et al., 2016; *etc.*). While theoretical works mainly focus on safe assets in the form of debt instruments and their impacts on advanced economies, real assets (especially housing) that are stores of value and their resulting consequences on developing economies are rarely explored. To this end, we fill the gap in the literature by using the Chinese economy as a laboratory to study the conundrum of safe-asset shortage.

Second, our paper contributes to the housing literature through the anatomy of the aggregate and distributional effects of housing policies. Iacoviello (2005) and Liu et al. (2013) show that the collateral channel induced by housing can stimulate private investment. Chen et al. (2016) find that China's housing boom crowds out real investment. Fang et al. (2016) empirically find that housing prices have experienced enormous appreciation from 2000 to 2012, which was accompanied by equally impressive growth in household income, except in a few first-tier cities. Zhao (2015) shows in an OLG model that the housing bubble may emerge as a store of value due to the tight financial friction. Chen and Wen (2017) also argue that China's housing boom is a rational bubble emerging naturally from its economic transition. In contrast, Han et al. (2018) link housing values to fundamental economic variables such as income growth, demographics, migration, and land supply. Dong et al. (2019) integrate housing investment into a New Keynesian DSGE model for the Chinese economy and quantitatively evaluate the implications of stabilization policies.

2 Empirical Facts

In this section, we provide empirical evidence to show that Chinese households demand more housing assets, and housing prices tend to increase when the economy becomes more uncertain. We use the panel data from a nationally representative, biannual longitudinal household-level survey, China Family Panel Studies 2010-2018 (CFPS). According to the CFPS data, the homeownership rate is about 89% for Chinese households aged 15-65 living in urban areas during 2010-2018. Among those homeowners, housing assets account for 74% of their total assets. One important reason behind the high homeownership rate and the large share of housing assets in households' net worth, as argued in this paper, is that households may hold housing assets as stores of value. [7]

Panel (a) in Figure 2 the 2-year changes in the log labor income uncertainty against the 2-year changes in the log real housing price across different counties in urban China between 2014 and 2018, where we measure the labor income uncertainty by the standard deviation of the 2-year changes in the homeowners' residual labor income from the standard Mincer regression with the household fixed effect. Figure 2 indicates a positive correlation: in the counties with a larger increase in the labor income uncertainty, the increase in the housing price is more substantial. Panel (b) in Figure 2 plots the 2-year changes in the average housing-wealth-to-income ratio against the 2-year changes in the log labor income uncertainty across different counties in urban China between 2014 and 2018. Again, it finds a positive correlation: a larger increase in the labor income uncertainty is associated with a

[7] The numbers are comparable to the findings of Cooper and Zhu (2017), which uses the CHFS (China Household Finance Survey) data. They also find that compared to the stock market investment, housing assets are considered to be a relatively safe investment in China.

more considerable increase in the housing-wealth-to-income ratio.

Figure 2: Uncertainty and Housing Prices at the County Level

Notes: Panel a plots the 2-year changes in real housing prices versus the 2-year changes in the county-level labor income uncertainty in urban China between 2014 and 2018. Panel b plots the 2-year changes in the housing-wealth-to-income ratio against the 2-year changes in the county-level labor income uncertainty in China between 2014 and 2018. Each data point in the figure represents one particular county. Data source: CFPS 2010-2018. The county-level labor income uncertainty is defined as the cross-sectional standard deviation of households' 2-year changes of residual household labor income, which is derived from the standard Mincer regression with the household fixed effect. The county-level average real housing price is defined as the sum of households' net value of housing assets divided by the sum of households' housing size in the same county. The county-level housing-wealth-to-income ratio is defined as the sum of households' net value of housing assets divided by the sum of households' labor income in the same county. The solid line denotes the univariate OLS regression line with equal weights. Appendix A.1 provides more details about the sample selection criteria and data constructions.

To provide more rigorous analysis, we run the following county-level fixed-effect regression controlling for the county and the year fixed effects and various county-level characteristics,

$$y_{j,t} = \alpha_j + \beta_t + \gamma \text{UNC}_{j,t} + Z_{j,t} + \varepsilon_{j,t}, \tag{1}$$

where $y_{j,t}$ denotes the county-level log real housing price per square meter or the county-level housing-wealth-to-income ratio at county j and year t; $\text{UNC}_{j,t}$ denotes the log labor income uncertainty at county j and year t; α_j and β_t denote the county and the year fixed effects, respectively. To disentangle the effect of a slowdown from uncertainty, we control for the county-level economic development indicators, $Z_{j,t}$, which includes the share of workers at state-owned enterprises, the share of agricultural employment, the share of self-employed workers, and the average value of log real labor income per capita.

Table 2: Uncertainty and Housing Prices at the County Level

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Log real housing price			Housing-wealth-to-income ratio		
Log labor income uncertainty	0.782**	0.870***	1.042***	10.25***	9.973**	8.635**
	(0.299)	(0.280)	(0.244)	(3.291)	(3.348)	(3.121)
Log average labor income		0.760**	0.792***		-2.415	-1.512
		(0.261)	(0.209)		(3.229)	(3.544)
SOE employment share			-1.185			-1.023
			(1.165)			(16.88)
Self-employment share			-1.185			-1.023
			(0.890)			(10.46)
Agric. employment share			1.761			19.21
			(1.703)			(15.50)
Observations	32	32	32	32	32	32
R-squared	0.447	0.617	0.773	0.568	0.587	0.660
Number of counties	13	13	13	13	13	13

Notes: Data source: CFPS 2010-2018. The county-level labor income uncertainty is defined as the cross-sectional standard deviation of households' 2-year changes of residual household labor income, which is derived from the standard Mincer regression with households fixed effect. The county-level average real housing price is defined as the sum of households' net value of housing assets divided by the sum of households' housing size in the same county. The county-level housing-wealth-to-income ratio is defined as the sum of households' net value of housing assets divided by the sum of households' labor income in the same county. In all specifications, county fixed effect and year fixed effect are controlled. Robust standard errors are clustered at the county level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix A.1 provides more details about the sample selection criteria and data constructions.

Columns 1 to 3 in Table 2 summarize the impact of the county-level labor income uncertainty on the county-level real housing price. The coefficient before log income uncertainty in Column 1 is 0.782, which implies that a 25% percent increase in the county-level labor income uncertainty tends to increase the county-level real housing price by 19.6 percent. The size of the impact increases as we add more controls. In Column 3, although each coefficient of the additional control variables is not significant, we can reject that all the coefficients before the SOE employment share, self-employment share, and agricultural employment share are zero (the F-statistic is 6.36 and the p-value is 0.007).

Columns 4 to 6 in Table 2 summarize the impact of the county-level labor income uncertainty on the county-level housing-wealth-to-income ratio. Column 4 shows that a 25% percent increase in the labor income uncertainty would increase the level of housing-wealth-to-income by 2.56. The size of the impact increases as we add more controls. We cannot reject that all the three coefficients in Column 6 are zero (the F-statistic is 1.42 and the p-value is 0.29).

The regression at the county level (Eq. 1) may fail to control some important households' characteristics and heterogeneity, and these characteristics and heterogeneity could bias the estimation after aggregation. We further specify the following households-level regression (Eq. 2).

$$y^i_{j,t} = \mu^i + \alpha_j + \beta_t + \delta H^i_t + \gamma \text{UNC}_{j,t} + Z_{j,t} + \varepsilon^i_{j,t}, \tag{2}$$

where $y^i_{j,t}$ denotes the log real housing price per square meter or the housing-wealth-to-income ratio for household i at county j and year t; $\text{UNC}_{j,t}$ denotes the log labor income uncertainty at county j and year t. We run a fixed-effect panel regression controlling for household fixed effect μ^i, county fixed effect α_j, year fixed effect β_t, a set of characteristics of the households head H^i_t, including age, age squared, years of education and its squared term, Hukou status, employment status, whether being an SOE worker, whether being self-employed, whether being an agricultural worker, family size and its squared term. $Z_{j,t}$ denote the same set of county-level characteristics controlled in the previous county-level regressions.

The household-level regression results are summarized in Table 3. Columns 1 to 3 report the main results for the fixed-effect panel regression on the individual housing price. Column 1 shows that a 25% increase in the county-level labor income uncertainty leads to a 20.5% increase in housing prices. Compared with the results of county-level regression presented in Table 2, the estimates of household-level regression are very close and more stable as we include more controls at the county level. In fact, in Column 3 of Table 3, we cannot reject the assumption that the three coefficients before the SOE share, self-employment share, and agriculture employment share are zero (the F-statistic is 0.33 and the p-value is 0.81), which also suggests that after fully controlling the heterogeneity of households, the impact of uncertainty on housing prices is relatively robust to additional controls such as county-level economic conditions.

Columns 4 to 6 in Table 3 report the main results for the fixed-effect panel regression on individual

Table 3: Uncertainty and Housing Prices at Household Level

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Log Real Housing Price			Housing-wealth-to-income Ratio		
Log labor income uncertainty	0.820***	0.862***	0.822***	11.44**	11.59**	9.133*
	(0.225)	(0.222)	(0.264)	(5.187)	(5.158)	(5.188)
Log average labor income		0.991***	1.012***		2.069	2.262
		(0.209)	(0.221)		(3.534)	(3.741)
SOE employment share			-0.0547			-41.02
			(1.077)			(25.56)
Self-employment share			0.165			-15.11
			(0.625)			(12.95)
Agric. employment share			0.663			-26.60
			(0.810)			(24.76)
Observations	2,000	2,000	2,000	2,144	2,144	2,144
R-squared	0.125	0.161	0.161	0.365	0.365	0.369
Number of households	1,337	1,337	1,337	1,427	1,427	1,427

Notes: Data source: CFPS 2010-2018. The county-level labor income uncertainty is defined as the cross-sectional standard deviation of households' 2-year changes of residual household labor income, which is derived from the standard Mincer regression with households fixed effect. The real housing price denotes the household-level average real price. The housing-wealth-to-income ratio is defined as households' net value of housing assets divided by households' labor income. In all specifications, county, year, and household fixed effects are controlled. Household characteristics include years of education, age, age squared, hukou status, self-employment status, working status, family size, family-size squared, the State-owned enterprises (SOE) occupation, etc. Robust standard errors are clustered at the household level. *** p<0.01, ** p<0.05, * p<0.1. Appendix A.1 provides more details about the sample selection criteria and data constructions.

housing-wealth-to-income ratio. Column 4 shows that a 25% increase in the county-level labor income uncertainty is associated with 2.86 increase in the level of housing-wealth-to-income ratio. The estimates are slightly larger than those in the county-level regression in Table 2.

In sum, using the households' data from China Family Panel Studies (CFPS) 2010-2018, we find that the county-level uncertainty (measured by the standard deviation of households' permanent labor income risks) increases homeowners' average housing price and housing-wealth-to-income ratio.

3 Baseline Model

Motivated by the aforementioned empirical facts, we now construct a dynamic general equilibrium model to quantitatively evaluate the impact of economic uncertainty on the housing market. In particular, we introduce housing assets into an otherwise standard neoclassical model with incomplete market. We assume that in the model, housing plays only the role of a store of value. Therefore, when households face greater uncertainty, they demand more housing assets. Then, we calibrate the model to the Chinese economy and quantitatively evaluate the aggregate impact of the housing boom. We also introduce the policy limiting home purchases into the baseline model and conduct counterfactual policy analysis.

The economy consists of households who are facing idiosyncratic uncertainty; a housing sector that employs capital, labor and land to produce housing assets; a real sector that uses capital and labor to produce consumption and investment goods; and a government that controls the land supply. We assume households are owners of the firms in the production sectors. We start with the problem of heterogeneous households.

3.1 Households

The economy is populated by a continuum of households with a unit measure. Each household is indexed by $i \in [0, 1]$. Following Benhabib et al. (2011), we assume that, in each period, household i with disposable wealth X_{it} (this will be elaborated later) is hit by an idiosyncratic shock, θ_{it}. This shock can be treated as an idiosyncratic return to wealth, which includes both labor and capital income.[8] We assume that θ_{it} is independently and identically distributed among households and over time. The cumulative probability density $\mathbf{F}(\theta_{it})$ is on the support $[\theta_{\min}, \theta_{\max}]$ with a mean of 1 and a time-varying standard deviation σ_t. Therefore, σ_t captures household-level economic uncertainty. Following Wen (2015), we divide each period into two subperiods. In the first subperiod, before the realization of the idiosyncratic shock θ_{it}, the household makes decisions regarding the labor supply N_{it} and production asset holdings K_{it+1}. In the second subperiod, the idiosyncratic shock θ_{it} is realized. With the knowledge of θ_{it}, the household purchases consumption goods C_{it} and housing assets H_{it+1}. The above setup of timing implies that housing assets can be used as a buffer to smooth consumption and to insure against the idiosyncratic uncertainties caused by θ_{it}.

We now discuss the household's optimization problem. Following Lagos and Wright (2005) and Wen (2015), we specify the household's utility as a quasilinear form of consumption and leisure, i.e., $\log C_{it} - \psi N_{it}$. To make the analysis more transparent, we abstract the residential role of housing. In Section 4.3.2, we allow the housing assets to earn a positive rental rate. The main results in the baseline model remain valid. The household aims to maximize its life-time expected utility:

$$\max_{\{C_{it}, H_{it+1}\}} \mathbf{E}_0 \left[\max_{\{N_{it}, K_{it+1}\}} \tilde{\mathbf{E}}_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_{it} - \psi N_{it} \right) \right], \tag{3}$$

where β is the discount rate and ψ is the coefficient of the disutility of labor. $\mathbf{E}$ and $\tilde{\mathbf{E}}$ denote, respectively, the expectation operators with and without the knowledge of θ_{it}. The budget constraint is given by

$$C_{it} + q_{ht} H_{it+1} = \theta_{it} X_{it}, \tag{4}$$

where q_{ht} is the real housing price, and X_{it} is real disposable wealth, excluding the purchase of investment in physical capital,

$$X_{it} = (1 - \delta_h) q_{ht} H_{it} + w_t N_{it} + r_t K_{it} + D_t - \left[K_{it+1} - (1 - \delta_k) K_{it} \right], \tag{5}$$

[8] Benhabib et al. (2011) have more discussions on the justification of introducing idiosyncratic shocks to both capital and labor income processes. Another reason for introducing idiosyncratic shocks to wealth θ_{it} is merely a technical issue. This specification guarantees an analytical solution for a household's optimal decision and a tractable aggregation of heterogeneous households, despite the large space of state variables.

where δ_k and $\delta_h \in (0,1)$ are the depreciation rates of capital and housing, respectively. w_t and r_t are respectively the real wage rate and the real rate of return on physical capital. D_t is the profit distributed from the production side. As discussed in Wen (2015), the disposable wealth defined in Eq. (5) guarantees that there is an analytical solution for a household's optimal decision, which further allows a tractable aggregation of heterogeneous households.[9]

In addition, we impose a no-short-selling constraint on housing assets; i.e., the amount of housing is required to be nonnegative:[10]

$$H_{it+1} \geq 0. \tag{6}$$

The last inequality indeed imposes a liquidity constraint on holding housing assets. As a result, when the household is facing greater economic uncertainty (σ_t increases), the household tends to hold more housing assets to reduce the risk of the binding of the liquidity constraint (6). Note that our model implicitly assumes that households rely on housing as a saving instrument to provide liquidity. This assumption is broadly consistent with the stylized fact that in China, housing assets are a major saving instrument used by households (housing assets account for almost 80% of household total wealth). Alternatively, we can introduce other types of liquid assets, for instance, government bonds. However, as long as the supply of these assets is limited (which is indeed the reality in China), the main mechanism in our paper remains valid. Section 4.3.2 provides further discussions of this issue.

Let λ_{it} and η_{it} denote the Lagrangian multipliers for the budget constraint (4) and the liquidity constraint (6), respectively. The first order conditions with respect to $\{N_{it}, K_{it+1}, C_{it}, H_{it+1}\}$ are

[9] The definition of X_{it} in (5) implicitly assumes that the housing assets face the same uncertainty as that in the physical capital. In Online Appendix S.4, we further introduce a stochastic housing return such that the housing assets face an extra aggregate uncertainty. The quantitative results indicate that the main results in our baseline remain robust.

[10] In principle, we can allow the minimum requirement of the amount of housing to be a positive number. However, doing so may introduce additional friction on the housing market and would unnecessarily complicate the model as well as the household's optimal decision regarding its demand for housing. Zhang (2016) provides a more detailed analysis of this issue.

given by the following equations

$$\psi = w_t \tilde{\mathbf{E}}_t(\theta_{it}\lambda_{it}), \tag{7}$$

$$\tilde{\mathbf{E}}_t(\theta_{it}\lambda_{it}) = \beta \mathbf{E}_t \left[(r_{t+1} + 1 - \delta_k) \tilde{\mathbf{E}}_{t+1}(\theta_{it+1}\lambda_{it+1}) \right], \tag{8}$$

$$\frac{1}{C_{it}} = \lambda_{it}, \tag{9}$$

$$\lambda_{it} = \beta(1-\delta_h)\mathbf{E}_t \left[\tilde{\mathbf{E}}_{t+1} \left(\theta_{it+1}\lambda_{it+1}\right) \frac{q_{ht+1}}{q_{ht}} \right] + \frac{\eta_{it}}{q_{ht}}. \tag{10}$$

Condition (7) describes the labor supply. (8) is the Euler equation for the intertemporal decision regarding physical capital. Since labor and capital decisions are made prior to the realization of the idiosyncratic shock θ_{it}, the expectation operator $\tilde{\mathbf{E}}$ appears in both equations. (9) is the optimal decision for consumption. (10) is the Euler equation for the intertemporal decision for housing purchases. The right-hand side of this equation describes the expected benefit of holding housing. Note that in the absence of the liquidity constraint (e.g., $\eta_{it} = 0$) and idiosyncratic uncertainty (e.g., $\theta_{it} = 1$ for any i), (8) and (10) imply that the household has no incentive to purchase housing assets. In addition, (7) and (8) indicate that we can define the discount factor, Λ_t, which is similar to that in the representative agent model, as $\Lambda_t \equiv \tilde{\mathbf{E}}_t(\theta_{it}\lambda_{it})$.

3.2 Housing Sector

There is a representative housing producer that rents capital K_{ht} at the rental rate r_t, hires labor N_{ht} at the wage rate w_t, and purchases land L_t at price q_{lt}, which are all inputs used to produce housing h_t. Following Davis and Heathcote (2005) and Han et al. (2018), we specify the production technology as

$$h_t = \left(K_{ht}^{\alpha_h} N_{ht}^{1-\alpha_h} \right)^{1-\gamma} L_t^{\gamma}, \tag{11}$$

where $\gamma \in (0,1)$ is the land share and $\alpha_h \in (0,1)$ describes the capital share. Each period, the housing producer chooses capital, labor, and land to maximize its profit $q_{ht}h_t - r_t K_{ht} - w_t N_{ht} - q_{lt} L_t$.

The optimal demands for the three inputs are given by

$$
\begin{aligned}
r_t &= \alpha_h(1-\gamma)q_{ht}\frac{h_t}{K_{ht}}, && (12)\\
w_t &= (1-\alpha_h)(1-\gamma)q_{ht}\frac{h_t}{N_{ht}}, && (13)\\
q_{lt} &= \gamma q_{ht}\frac{h_t}{L_t}. && (14)
\end{aligned}
$$

The land supply is controlled by the central government. In the benchmark setup, we consider a simple fixed land supply rule, i.e.,

$$L_t = \bar{L}. \tag{15}$$

3.3 Real Sector

The setup of the real sector follows the standard real business cycle literature. There is one representative final good producer. The good market is competitive. The producer hires labor N_{pt} at the wage rate w_t and rents capital K_{pt} with the rental rate r_t to produce the final good Y_{pt}. The production function takes the form of a Cobb-Douglas function, $Y_{pt} = K_{pt}^{\alpha_p} N_{pt}^{1-\alpha_p}$, where $\alpha_p \in (0,1)$ is the capital share. The optimal demand for both capital and labor is given by

$$
\begin{aligned}
r_t &= \alpha_p \frac{Y_{pt}}{K_{pt}}, && (16)\\
w_t &= (1-\alpha_p)\,\frac{Y_{pt}}{N_{pt}}. && (17)
\end{aligned}
$$

3.4 Aggregation and General Equilibrium

We define the aggregate variables in the $\kappa \in \{p,h\}$ sector as $\chi_{\kappa t}$, where $\chi = \{K,N,Y\}$. We define the aggregation of the household-level variables χ_{it}, where $\chi = \{C,H,N,K\}$ as $\chi_t = \int_0^1 \chi_{it} di$. The market clearing conditions for capital and labor imply

$$K_t = \sum_{\kappa\in\{p,h\}} K_{\kappa t} \text{ and } N_t = \sum_{\kappa\in\{p,h\}} N_{\kappa t}. \tag{18}$$

The housing market equilibrium condition implies

$$h_t = H_{t+1} - (1 - \delta_h)H_t. \tag{19}$$

We define the aggregate output $Y_t = Y_{pt} + q_{ht}h_t$. The aggregate resource constraint is given by

$$C_t + q_{ht}h_t + I_t = Y_t, \tag{20}$$

where $I_t = K_{t+1} - (1 - \delta_k)K_t$. We also define the sectoral investment as $I_{\kappa t} = K_{\kappa t+1} - (1 - \delta_k)K_{\kappa t}$, where $\kappa = \{p, h\}$.

The general equilibrium consists of a set of aggregate variables and prices such that individuals solve their optimization problems and all markets clear.

3.5 Households' Decision Rules

In this section, we discuss the heterogeneous households' optimal decisions. In line with Wen (2015), taking as given the aggregate environment, the individual household's consumption and housing decisions follow a trigger strategy. Let θ_{it}^* denote the cutoff of the idiosyncratic shock θ_{it}. We consider following two cases for different values of θ_{it}.

Case 1: $\theta_{it} \geq \theta_{it}^*$. In this case, the households have a relatively high level of wealth, so they tend to hold more housing as a buffer to smooth consumption. As a result, the no-short-selling constraint for housing (6) does not bind; i.e., $H_{it+1} > 0$ and $\eta_{it} = 0$. In Appendix B.1, we show that the cutoff θ_{it}^* satisfies

$$\theta_{it}^* = \frac{1}{X_{it}\beta(1 - \delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)}. \tag{21}$$

Since $\eta_{it} = 0$, the first order conditions (7) and (10) imply that the optimal consumption in this case satisfies $C_{it} = \theta_{it}^* X_{it}$. Because of the budget constraint (4), the optimal housing decision is given by $H_{it+1} = (\theta_{it} - \theta_{it}^*)X_{it}$. This condition indicates that only wealthy households (θ_{it} is larger than the cutoff) hold a positive level of housing assets.

Case 2: $\theta_{it} < \theta^*_{it}$. In this case, the household has a relatively low level of wealth. To smooth consumption, the household will sell all of the housing at hand, $(1-\delta_h)H_{it}$, to obtain extra liquidity, leading to a binding constraint (6). Therefore, the housing decision is simply $H_{it+1} = 0$, and the optimal consumption is $C_{it} = \theta_{it}X_{it}$.

Proposition 1 below characterizes the household's optimal decisions.

Proposition 1 *Conditional on the aggregate states, the cutoff θ^*_{it} and the wealth X_{it} of household i are independent with the individual states; that is, $\theta^*_{it} \equiv \theta^*_t$ and $X_{it} \equiv X_t$. The household's optimal consumption and housing decisions are given by the following trigger strategy:*

$$C_{it} = \min\{\theta^*_t, \theta_{it}\}X_t, \tag{22}$$

$$H_{it+1} = \max\{\theta_{it} - \theta^*_t, 0\}\frac{X_t}{q_{ht}}; \tag{23}$$

where wealth X_t satisfies

$$X_t = \frac{1}{\theta^*_t \Lambda_t} \int \max\{\theta^*_t, \theta_{it}\} d\mathbf{F}(\theta_{it}; \sigma_t). \tag{24}$$

Proof. See Appendix B.1. ■

The independence of individual wealth X_{it} from individual states is mainly due to the specification of quasi-linear utility and the timing of the labor decision. Since the disutility of labor takes a linear form and the labor choice is made before the idiosyncratic shock θ_{it}, the household can adjust its labor supply to reduce variations in the wealth on hand. As a result, individual wealth depends only on the aggregate states, and the wealth distribution in our model is degenerated.

3.6 Impact of Uncertainty on Housing Demand

To study how economic uncertainty (the standard deviation of θ_{it}), σ_t, can affect housing demand, we conduct a partial equilibrium analysis. In particular, we define

$$\Phi(\theta^*_t; \sigma_t) \equiv \int \max\{\theta^*_t, \theta_{it}\} d\mathbf{F}(\theta_{it}; \sigma_t). \tag{25}$$

Appendix B.1 shows that the Euler equation for the optimal decision of housing (10) implies that the housing price can be expressed as

$$q_{ht} = \Phi(\theta_t^*; \sigma_t)(1 - \delta_h)\frac{\mathbf{E}_t q_{ht+1}}{1 + r_t^i}, \tag{26}$$

where $r_t^i \equiv 1/\left(\beta \mathbf{E}_t \Lambda_{t+1}/\Lambda_t\right) - 1$ is the real interest rate. The last equation indicates that the current housing price q_{ht} contains a normal component, the discounted expected price in the next period, and a premium term, $\Phi(\theta_t^*; \sigma_t)$. In fact, this extra term reflects the liquidity premium of holding housing, since the housing asset acts as a buffer to insure against idiosyncratic uncertainty. When the household has a low level of wealth ($\theta_{it} < \theta_{it}^*$), selling the housing on hand could provide the household extra liquidity to smooth consumption. More importantly, conditional on the aggregate states, the premium term $\Phi(\theta_t^*; \sigma_t)$ is increasing in economic uncertainty.[11] Therefore, an upswing in uncertainty may lead to a boom in current housing prices. Intuitively, when the economy becomes more uncertain, the household would prefer the asset that can be used as a buffer to smooth consumption: the *flight-to-liquidity* effect. As a result, the option value of holding housing assets becomes higher when economic uncertainty increases, which means that even though housing prices are relatively high, households are still willing to hold housing assets.

Aggregating the individual household's optimal housing decision (23) yields the aggregate housing demand, which is

$$H_{t+1} = \frac{X_t}{q_{ht}} \int \max\{\theta_{it} - \theta_t^*, 0\} d\mathbf{F}(\theta_{it}; \sigma_t). \tag{27}$$

Since the function in the integral is convex in θ_{it}, again, Jensen's inequality implies that an increase in uncertainty (σ_t) leads to larger housing demand, taking as given the wealth X_t and the cutoff θ_t^*.

4 Quantitative Analysis

The previous analysis qualitatively shows that housing is a store of value that can smooth consumption. The demand for housing becomes higher when economic uncertainty increases. To provide further quantitative analysis, we calibrate the baseline model to the Chinese economy.

[11] This occurs because the term $\max\{\theta_t^*, \theta_{it}\}$ in $\Phi(\theta_t^*; \sigma_t)$ is convex in θ_{it}; Jensen's inequality implies that the premium increases when uncertainty σ_t increases.

4.1 Calibration

One period in the model corresponds to one quarter. We partition the parameters into three subsets. The first subset of parameters includes $\{\beta, \psi, \alpha_p, \delta_k\}$, which are standard in the business cycle literature. We set the discount factor β to be 0.995, implying that the annual real deposit rate is 1.8%.[12] The coefficient of the disutility of labor ψ does not affect the model's dynamics; therefore, we simply normalize it to be 1. Following Song et al. (2011), we set the capital share in the real sector α_p to be 0.5 and the depreciation rate of physical capital δ_k to be 0.025.

The second set of parameters related to the housing sector includes $\left\{\delta_h, \gamma, \alpha_h, \bar{L}\right\}$. We follow Iacoviello and Neri (2010) to set the depreciation of housing assets δ_h to be 0.01, implying an annual depreciation rate of 4%. We now calibrate the land share γ and the capital share $\alpha_h (1-\gamma)$ for the housing sector in the production function. The housing assets in the model are assumed to be those with better quality in reality, such as housing in Tier-one cities. According to the National Bureau of Statistics in China, for Tier-one cities, the ratio of total spending on land purchases in the housing sector to the total revenue in the housing sector is approximately 24.5%, so we specify $\gamma = 0.245$. Regarding the parameter α_h, since data on the shares of labor and the capital income in the housing sector are not available, we use the average ratio of total spending on land purchases in the housing sector to total investment (including land purchases) in the housing sector $(q_l L / (I_h + q_L L))$ in Tier-one cities to pin down the value of α_h, which is 0.7. This value implies that the shares of capital and labor in the housing production function are 52.8% and 22.7%, respectively. Since the land supply in the steady state does not affect the model's dynamics, we simply normalize it to be 1.

The last set of parameters is related to the distribution of the households' idiosyncratic shock, $\mathbf{F}(\theta_{it}; \sigma_t)$. We assume that θ_{it} follows a log-normal distribution with a mean of 1 and a standard deviation of σ in the steady state. The CHFS survey data show that the Gini coefficient of housing assets in 2012 is approximately 0.6, so we set the value of σ such that the model-implied Gini coefficient of housing assets matches the value in data, which yields a value of 0.9775. Under this value, our model implies that the steady-state national savings rate is 0.43, which closely matches

[12] To calibrate β, we use the real deposit rate, which is the annual rate with a one-year maturity. This series is the annual nominal deposit rates adjusted by the CPI from 2000 to 2016. The average value is approximately 1.8%.

Table 4: Parameter Values

Parameter		Value	Target
β	Discount rate	0.995	Annual interest rate (1999Q1-2016Q4)
ψ	Labor disutility	1	
α_p	Share of capital in the real sector	0.5	Song et al. (2011)
δ_k	Depreciation of physical capital	0.025	Standard
δ_h	Depreciation of housing	0.01	Iacoviello and Neri (2010)
γ	Share of land in the H sector	0.245	$\frac{q_l L}{q_h h}$ in Tier 1 cities
α_h	Parameter of the share of capital in the H sector	0.7	$\frac{q_l L}{I_h + q_L L}$ in Tier-one cities
$\bar{L}$	Steady-state land supply	1	
σ	Std idiosyncratic shock θ_i	0.9775	Gini coefficient of housing holdings, CHFS survey

the real data.[13] Table 4 summarizes the calibrated parameter values.

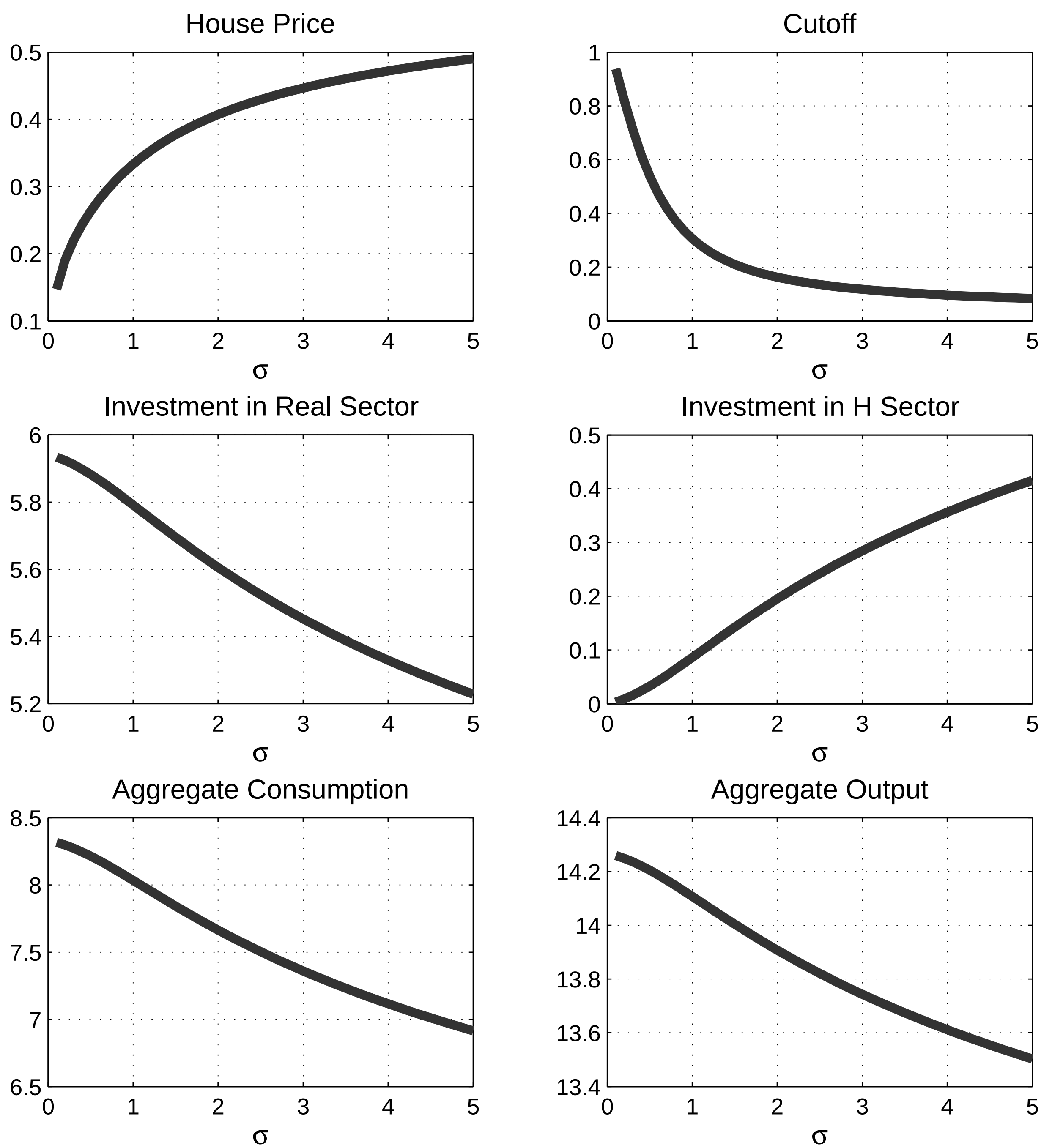
4.2 Aggregate Effect of Uncertainty

4.2.1 Long-run Equilibrium

To analyze the aggregate effect of uncertainty, we first conduct a steady-state analysis. Figure 3 describes the relationship between uncertainty and the key aggregate variables at stationary equilibrium. The figure shows that an increase in uncertainty drives up housing prices in the long run because households demand more housing (or safe) assets as a buffer to smooth their consumption, which confirms our prediction based on the previous partial equilibrium analysis. Furthermore, Figure 3 shows that the housing sector expands but the real sector shrinks due to the crowding-out effect. This pattern is consistent with the empirical finding that in the Chinese economy, the real investment in the housing sector negatively comoves with that in the real sector (Chen et al., 2016). Furthermore, greater uncertainty reduces consumption due to the stronger motive for precautionary saving. Hence, our model can explain the phenomenon of a housing boom associated with an economic recession in the long-run equilibrium.

[13] According to Xie and Jin (2015), housing assets account for almost 80% of total household wealth and the Gini coefficient of urban households' wealth in 2012 is approximately 0.7. Therefore, our model-implied Gini coefficient of housing holdings also fits their dataset reasonably well.

Figure 3: Uncertainty and the Aggregate Economy in the Steady State



Notes: The steady state is computed using different values of σ; the other parameters are calibrated according to Table 4.

4.2.2 Transition Dynamics

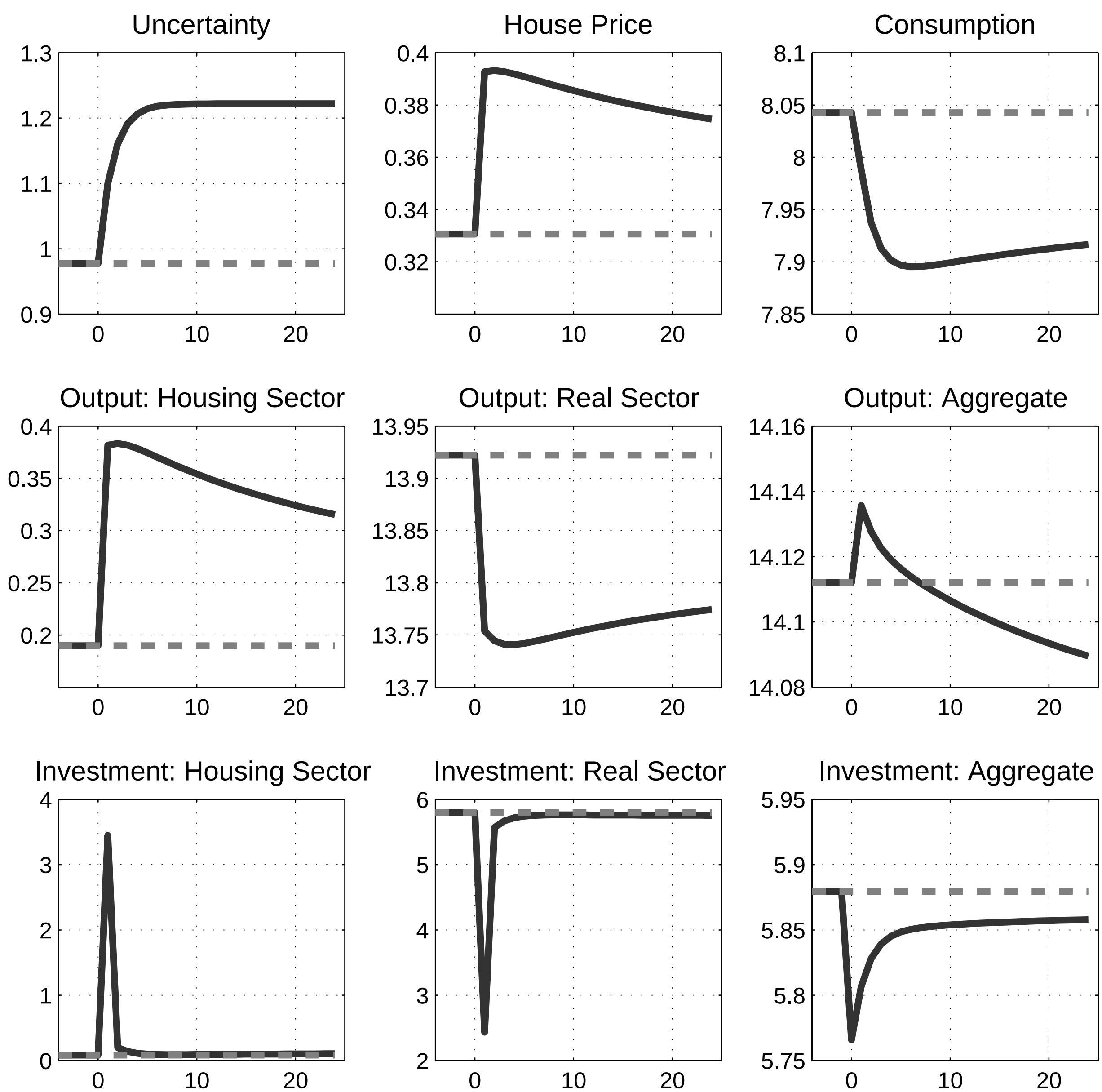
To evaluate the dynamic impact of uncertainty on housing prices and the aggregate economy, we now discuss the transition dynamics when economic uncertainty increases. In particular, we assume that the standard deviation of θ_{it} permanently increases by 25%, and the increment follows the AR(1) process; i.e., $\sigma_t - \sigma^{new} = \rho(\sigma_{t-1} - \sigma^{new})$, where $\sigma_0 = 0.9775, \sigma_{new} = 0.9775 \times 1.25$, and $\rho = 0.5$. Figure 4 presents the transition dynamics.

Figure 4 shows that after a 25% increase in uncertainty, the housing prices rise sharply by 18% from 0.330 to 0.396. Notice that the empirical results (Column 3 in Table 2 and 3) shows that a 25% increase in the labor income uncertainty leads to an increase in housing price of 22% (= $0.82 \times 0.25 = 20\%$) to 26% (= $1.04 \times 0.25 = 26\%$). Therefore, our model's predictions can account for approximately 69%-80% of the impact of income uncertainty on housing prices found in the data. Besides the uncertainty shock, if we simultaneously consider restrictive land supply, the model would generate a more dramatic housing price appreciation and thus fits the data better. Online Appendix S.3 provides more details about the analysis.

Increased demand for housing assets as stores of value leads to a boom in the housing market, which further stimulates more physical capital investment in the housing sector but crowds out those in the real sector. As a result, the output in the real sector declines. The overall output (GDP) in the long run declines associated with an increase in the short run. The overshoot of aggregate output in the short term is mainly due to the expansion of the housing sector. The above transition dynamics are broadly consistent with two stylized facts regarding the Chinese economy: (i) the housing market experiences an expansion while the economy slows down, and (ii) there is a crowding-out effect between the housing sector and the real sector (Chen et al., 2016).[14]

[14]Note that the total investment in housing assets $q_{ht}h_t$ is equal to the output in the housing sector, which is shown in the first panel of the second line in Figure 4. The total capital investment is shown in the last panel of the third line in Figure 4. As the figure shows, a rise in economic uncertainty increases the investment in housing assets while reduces the investment in real capital. The ratio between the investment in housing and that in real capital increases after a positive uncertainty shock, implying that individuals allocate more savings to the housing assets relative to the real capital.

Figure 4: Transition Path after an Increase in Uncertainty



Notes: The transition paths are shown in levels. We specify the persistence of the AR(1) process of σ_t to be 0.5. The dashed lines represent the steady-state level prior to the transition.

4.3 Further Discussions

4.3.1 Various Sources of Shocks

Adverse Technology Shocks Our baseline analysis only discusses the impact of uncertainty shocks. The economic slowdown may be driven by the supply side, for instance, adverse technology shocks. To further disentangle the effects caused by different sources of shocks, in Online Appendix S.2, we simultaneously consider a TFP growth shock which directly leads to an economic slowdown and an uncertainty shock that raises the level of uncertainty. Our quantitative exercise shows that a rise in uncertainty boosts the housing price, while a negative TFP growth shock (the solid line) causes an economic slowdown that depresses the housing price. The above results suggest that the increase in uncertainty, instead of adverse shocks to economic fundamentals, is the driving force for the surge in the Chinese housing price.

A Tightened Land Supply The declining trend of land supply in China may contribute to the rising of housing prices. To quantify the impact of land supply on the housing market, in Online Appendix S.3, we introduce land supply shocks to the baseline model. The quantitative exercise shows that a decline in land supply boosts the housing price, and thus supports the fact that the more restrictive land supply in big cities leads to a larger appreciation of housing prices. Also, Figure S.3.1 in the online appendix shows that a negative land supply shock depresses the real investment and output in the housing sector because of the reduction of land input. Meanwhile, the production sector expands comparing to the initial steady state in response to the land supply shock because the restrictive land supply mitigates the crowding-out effect caused by the housing sector. Therefore, our model implies that the cyclicality of the housing prices and the real economy under the uncertainty shock or the land supply shock differs from each other.

4.3.2 Model with Multiple Stores of Value

In the baseline model, housing is considered as the only safe store of value, and transactions related to housing do not incur any cost. To make the model more realistic, we introduce an alternative asset, namely, government bonds, which can be used as a store of value. In addition, to further differentiate between housing and bonds, we assume that holding housing involves a convex transaction (or adjustment) cost, and housing assets earn a positive rate of return (e.g., rental rate). In the extended model, the budget constraint faced by the households can be written as

$$C_{it} + q_{ht}H_{it+1} + B_{it+1} = \theta_{it}X_{it}, \tag{28}$$

where q_{ht} is the real housing price; B_{it+1} represents bonds holdings. The real disposable wealth X_{it} is written as

$$X_{it} = \left[(1-\delta_h)q_{ht} + r_{ht}\right] H_{it} - \gamma_b \frac{\left(q_{ht-1}H_{it}\right)^{1+\chi}}{1+\chi} + R_{bt-1}B_{it} + w_t N_{it} + r_t K_{it} + D_t - \left[K_{it+1} - (1-\delta_k)K_{it}\right], \tag{29}$$

where r_{ht} is the rental rate of housing and R_{bt} is the interest rate for the bonds. The term $\gamma_b \left(q_{ht-1}H_{it}\right)^{1+\chi} / (1+\chi)$ ($\gamma_b > 0$ and $\chi > 0$) captures the transaction cost for the housings. For simplicity, we assume that r_{ht} is exogenously given.[15] The above setup implies that in the model economy, the government bonds are more liquid than housing. To model market incompleteness, in addition to the non-short-selling constraint for housing (6), we impose a liquidity constraint for the entire holding of housing and bonds. In particular, we assume that total holdings of housing and bonds are required to higher than a lower bound, which is proportional to household wealth $\theta_{it}X_{it}$

$$q_{ht}H_{it+1} + B_{it+1} \geq \zeta\theta_{it}X_{it}, \tag{30}$$

where the parameter $\zeta \in (-1, 1)$ reflects the tightness of the liquidity constraint of the household.[16] A larger value of ζ indicates that the household faces a tighter liquidity constraint. The remaining parts of the model are identical to those in the baseline model. Appendix B.5 provides more details about the households' optimal decisions.

Based on the extended model, we conduct the same quantitative exercises as used in the baseline

[15] Alternatively, we can consider an additional type of households, who are hand-to-mouth and only rent houses. This setup provides a way to endogenize the rental rate r_{ht}.

[16] A negative value of ζ indicates that the household is allowed to hold a negative portion of liquid assets. In this case, the household is a net borrower. Moreover, one important prediction in the ex- tended model is that if the households' liquidity constraint tightens, i.e., ζ becomes larger, their demand for bonds and housing as stores of value will increase, which translates into higher housing prices. Online Appendix S.4 provides more discussion on this issue.

model. Figure 5 reports the transition dynamics and shows that the dynamic impacts of uncertainty on the housing market and the real economy present very similar patterns to those in the baseline model. An increase in economic uncertainty boosts the housing sector but dampens the real economy, though the magnitude is relatively small. This occurs because, in the extended model, the households choose to hold both liquid bonds and housing as stores of value, resulting in a relatively weak response of the housing market to the uncertainty shock.[17]

5 Housing Policy

5.1 Setup

To curb the soaring housing prices in Tier-one cities, the Chinese government has intervened in housing markets from time to time. The policy that limits housing purchases is the most relevant one. In this section, we aim to model this type of housing policy. We then use the extended model to evaluate both the aggregate and distributional consequences of this kind of housing policy.

To model the policy that limits housing purchases, we introduce an additional constraint on housing purchases into the benchmark model. In particular, we assume the amount of housing purchased by a household cannot exceed a limit, which is proportional to its consumption:

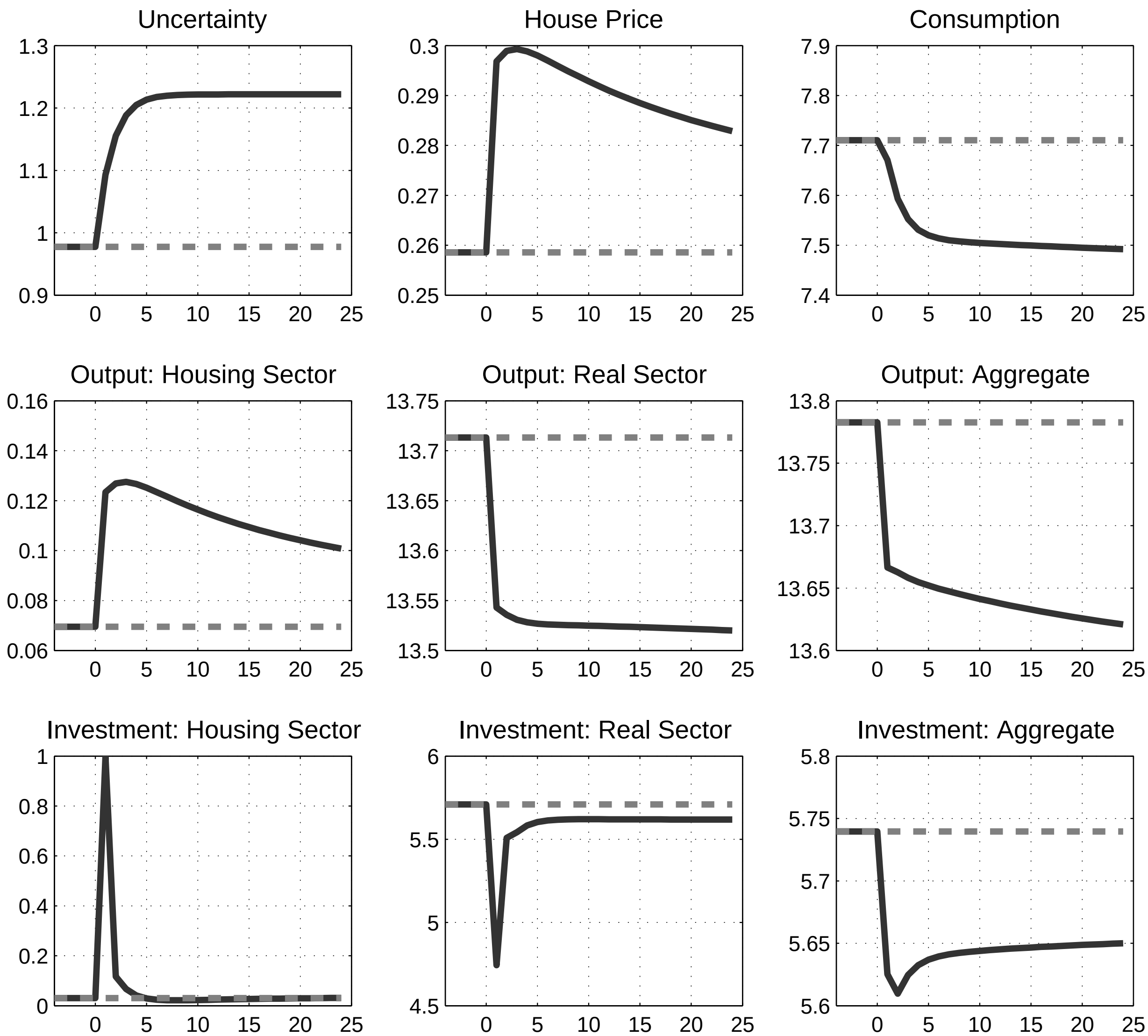
$$q_{ht}H_{it+1} \leq \phi C_{it}. \tag{31}$$

Assuming that the limit of housing purchase is proportional to the household's consumption provides an analytical way to aggregate the economy. The constraint (S.6.1) is equivalent to the setup where the purchase limit is a function of wealth $\theta_{it}X_{it}$, i.e., $q_{ht}H_{it+1} \leq \bar{\phi}\theta_{it}X_{it}$ and $\bar{\phi} = \frac{\phi}{1+\phi}$. [18]

[17] Our model also implies that a positive uncertainty shock reduces the interest rate of the bonds. This prediction is consistent with Chinese data. The correlation between economic uncertainty (measured by economic policy uncertainty, EPU) and the Shibor rate is -0.6 over the periods of 2013M1-2018M9.

[18] The above constraint is isomorphic to a borrowing constraint in house purchases. To see this, we assume the individual household i finance her total expenditure of house purchases $q_{ht}H_{it+1}$ through an intra-temporal loan market as that in Miao and Wang (2018). The borrowing capacity takes a Kiyotaki-Moore type of collateral constraint, where the total collateral value is proportional to the household's net worth. The parameter $\bar{\phi}$, in this case, indicates the tightness of the borrowing constraint. Thereby, the main results in this section can be applied to analyze the impact of the tightness of borrowing constraints on the housing market and the aggregate economy.

Figure 5: Transition Path after an Increase in Uncertainty: Extended Model



Notes:The transition paths are shown in levels. The parameter γ_b is set to be 0.01. The supply of the bonds $\bar{B}$ is set to be 1.95, implying a steady-state bond to GDP ratio of 15%, which is consistent with the empirical observation in China. We set the liquidity constraint parameter ζ to 0, and set the quarterly rent to price ratio to 0.01, which is consistent with data for Shanghai and Beijing. The dynamic pattern is pretty robust to the values of the above parameters. The dashed lines represent the steady-state level before the transition.

The parameter ϕ governs the tightness of the housing policy. When $\phi \to \infty$, the model degenerates to the baseline model. When $\phi \to 0$, the housing market is completely shut down. Under the policy that limits housing purchases, the household's optimal decisions differ from those in the baseline case. In particular, the individual household's optimal decisions may include three regimes. When the household's disposable wealth is sufficiently low, to smooth consumption it will sell the housing assets on hand, i.e., the constraint (6) is binding. When disposable wealth is sufficiently high, the household will demand a large amount of housing for precautionary purposes, resulting in a binding constraint for (S.6.1). When disposable wealth is in the middle range, with moderate demand for housing, neither (6) nor (S.6.1) is binding. In the baseline model where the policy that limits housing purchases is absent, only the first and the third scenarios emerge. Therefore, the policy that limits housing purchases primarily affects wealthy households (or those with an abundance of liquidity).

Theoretically, it can be shown that due to the policy intervention, there are two cutoffs of the idiosyncratic shock θ_{it}; i.e., θ_{it}^* and θ_{it}^{**}, where θ_{it}^* has the same definition as that in (21) and $\theta_{it}^{**} = (1+\phi)\,\theta_{it}^*$. These two cutoffs divide the optimal individual decision into three regimes. The following proposition gives the details.

Proposition 2 *Taking as given the aggregate states, the cutoffs θ_{it}^* and θ_{it}^{**}, and the wealth X_{it} of the household i are independent of the individual states; that is, $\theta_{it}^* \equiv \theta_t^*$, $\theta_{it}^{**} \equiv \theta_t^{**}$, and $X_{it} \equiv X_t$. The household's optimal consumption and housing decisions are given by the following trigger strategies:*

$$C_{it} = \left[\theta_{it}\mathbf{1}_{\{\theta_{it}\le\theta_t^*\}} + \theta_t^*\mathbf{1}_{\left\{\theta_{it}^*\le\theta_{it}<\theta_t^{**}\right\}} + \frac{1}{1+\phi}\theta_{it}\mathbf{1}_{\{\theta_{it}>\theta_t^{**}\}}\right]X_t, \tag{32}$$

$$q_{ht}H_{it+1} = \left[0\times\mathbf{1}_{\{\theta_{it}\le\theta_t^*\}} + (\theta_{it}-\theta_t^*)\,\mathbf{1}_{\left\{\theta_{it}^*\le\theta_{it}<\theta_t^{**}\right\}} + \frac{\phi}{1+\phi}\theta_{it}\mathbf{1}_{\{\theta_{it}>\theta_t^{**}\}}\right]X_t; \tag{33}$$

where wealth X_t satisfies

$$X_t = \frac{1}{\theta_t^*\Lambda_t}\Phi(\theta_t^*;\phi,\sigma_t), \tag{34}$$

and the liquidity premium $\Phi(\theta_t^*;\phi,\sigma_t)$ satisfies

$$\Phi(\theta_t^*;\phi,\sigma_t) = \int\left\{\theta_{it}^*\mathbf{1}_{\{\theta_{it}\le\theta_t^*\}} + \theta_{it}\mathbf{1}_{\left\{\theta_{it}^*\le\theta_{it}<\theta_t^{**}\right\}} + \left[\theta_{it}^* + \frac{\phi}{1+\phi}\theta_{it}\right]\mathbf{1}_{\{\theta_{it}>\theta_t^{**}\}}\right\}d\mathbf{F}(\theta_{it};\sigma_t). \tag{35}$$

Proof. See Appendix B.2. ∎

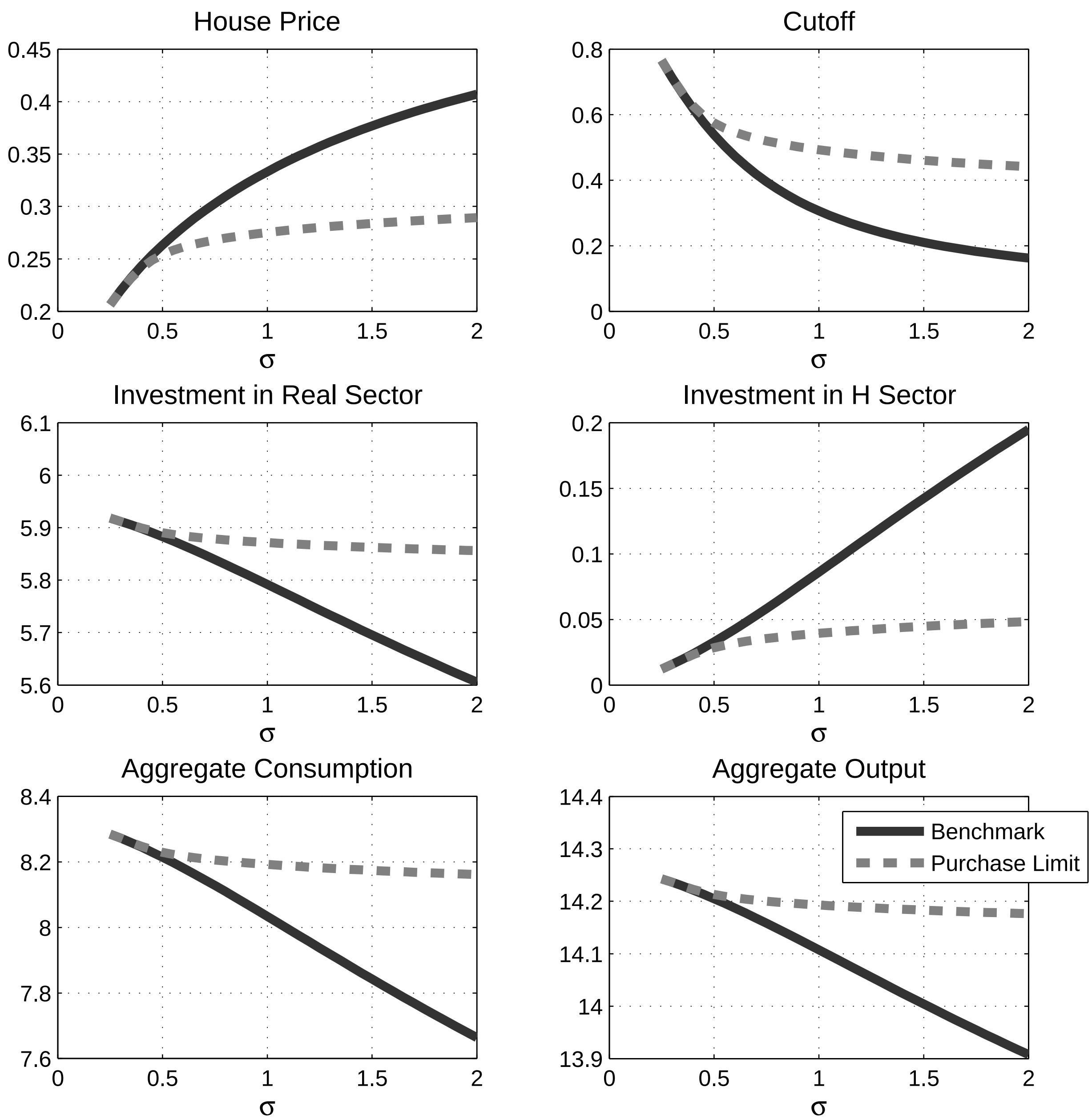
It can be easily verified that when $\phi \to \infty$, the optimal decisions described in Proposition 2 degenerate to those in the benchmark model. As the policy that limits housing purchases restricts the household's access to housing assets, the premium of holding housing assets (the benefit of a store of value) is dampened. The definition of $\Phi(\theta_t^*; \phi, \sigma_t)$ in (35) shows that the limit on housing purchases makes the function in the integral less convex than the one in (25). As a result, given the aggregate states, the premium term $\Phi(\theta_t^*; \phi, \sigma_t)$ is decreasing in ϕ.

5.2 Aggregate Impacts of the Policy Intervention

Long-run Equilibrium and Consumption Risk Sharing We first quantitatively evaluate the aggregate impact of the policy that limits housing purchases in the long-run equilibrium. As we discussed in the previous section, this policy curbs household demand for housing assets and therefore mitigates the crowding-out effect of the housing sector on the real sector in the general equilibrium. Figure 6 compares the steady-state equilibrium in the baseline model and that in the model with the policy that limits housing purchases. It can be seen that in the steady state, greater economic uncertainty may cause a relatively small expansion of the housing market compared to that in the baseline model. Therefore, housing prices and physical investment in the housing sector increase less, and the adverse impact on the real sector is mitigated. As a result, the drop in aggregate consumption and output caused by greater uncertainty is less severe.

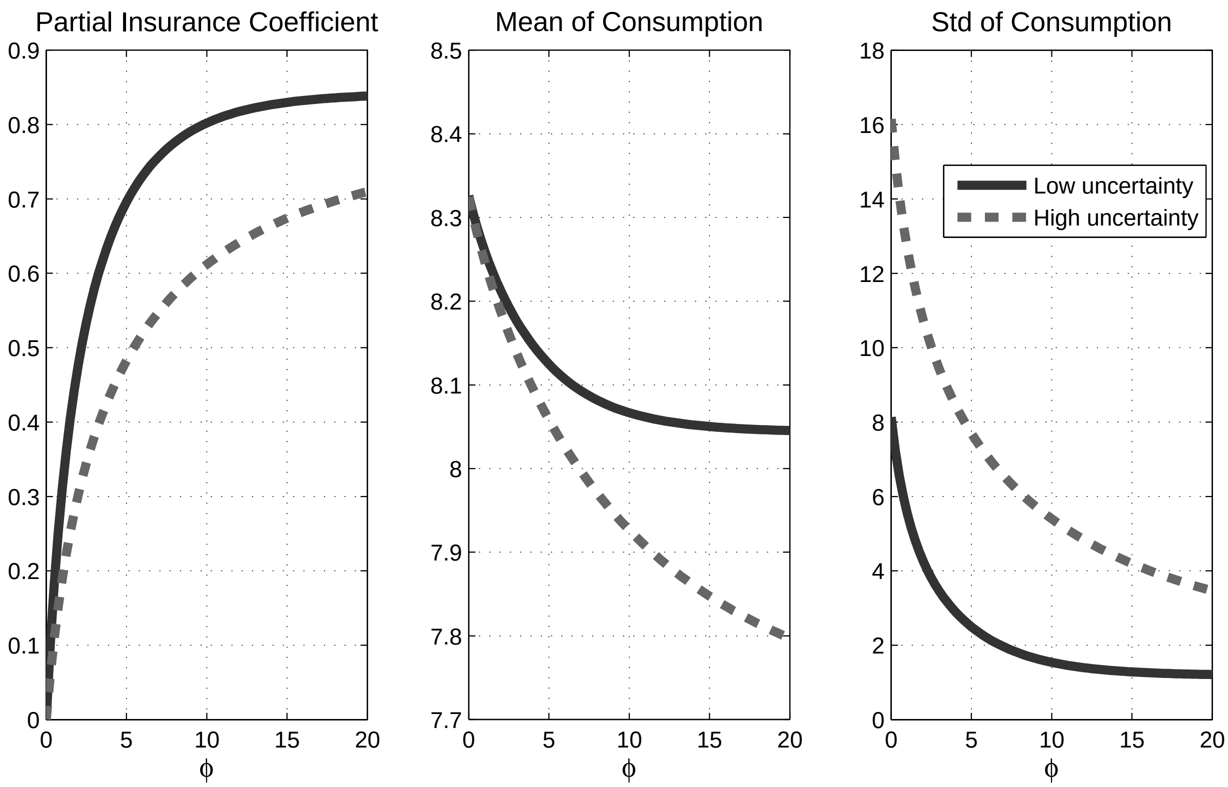
Although the policy that limits housing purchases improves the performance of the aggregate economy when economic uncertainty is high, it also reduces households' access to safe assets that can be used as stores of value. This means that the policy that limits housing purchases inevitably reduces household's ability to insure against idiosyncratic uncertainty, and thus increases the dispersion of household consumption. The first panel in Figure 7 computes the partial insurance coefficient as suggested by Blundell et al. (2008) under the housing policy. A smaller partial insurance coefficient indicates a weaker ability for households to insure against the idiosyncratic uncertainties. There presents a negative relationship between the tightness of regulation and the partial insurance coeffi-

Figure 6: Steady-state Equilibrium under the Policy that Limits Housing Purchases



Notes: The steady state is computed under different values of σ, the ϕ in house-purchase-limit is set to 2.5, and other parameters are calibrated according to Table 4.

Figure 7: Consumption Distortion caused by the Policy that Limits Housing Purchases



Notes: The distribution of consumption is obtained by computing the consumption expenditures of 100,000 households with i.i.d idiosyncratic shocks θ_{it} in the stationary equilibrium. The parameter values except ϕ and σ are set according to the calibration values shown in Table 4. In the low and high uncertainty cases, we set σ to be 0.9775 and 0.9775×2, respectively. The partial insurance coefficient is computed according to Blundell et al. (2008), which is the estimation coefficient obtained through regressing individual consumption growth $\Delta \log(C_{it})$ on the log of idiosyncratic shock θ_{it}.

cient: a tighter regulation (ϕ is smaller) leads to a lower partial insurance coefficient.[19] In an extreme case where the housing market is completely shut down ($\phi = 0$), the partial insurance coefficient becomes zero, therefore the household cannot insure against the uncertainty at all due to the lack of store of value. The figure also shows that an increase in uncertainty reduces the partial insurance coefficient under our calibration. We would like to emphasize that in the stationary equilibrium, the optimal consumption rule in Eq. (33) implies that the risk-sharing ability depends on the marginal propensity of consumption (MPC) since the wealth distribution in our model is degenerated, i.e., $X_{it} = X_t$. See Online Appendix S.5 for more detailed discussion.

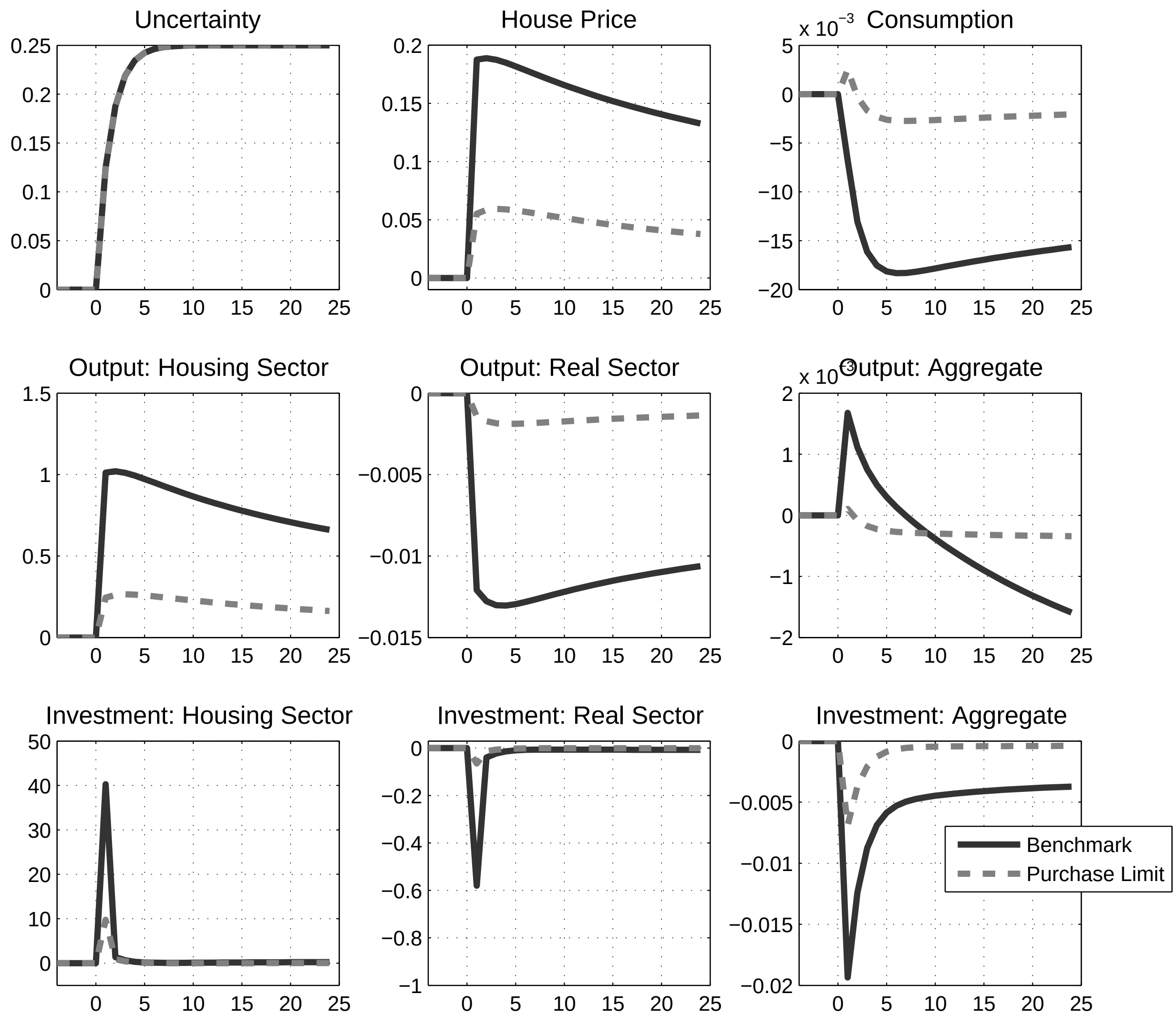
The second and third panels in Figure 7 illustrate the distributional effect of the policy that limits housing purchases on household consumption (see the solid lines). The stationary distribution of consumption has a higher mean and greater dispersion under a tighter policy than that in the looser policy regime. For instance, the mean of consumption is 1.6% higher in the tight regime ($\phi = 2.5$) than that in the looser regime ($\phi = 10$). The standard deviation of consumption in the tighter regime is almost 1.5 times larger than that in the looser regime.

Our quantitative results show that the consumption distortion caused by the policy that limits housing purchases becomes even severe when economic uncertainty is higher. Figure 7 compares the impact of the policy that limits housing purchases on the mean and standard deviation of consumption under different levels of uncertainty. The solid line and the dashed line represent low uncertainty ($\sigma = 0.9775$) and high uncertainty ($\sigma = 0.9775 \times 2$) scenarios, respectively. It can be seen that the policy that limits housing purchases increases the mean and standard deviation of consumption to levels that are much higher in the former case than in the latter one. This result indicates that the reduction in the degree of consumption insurance caused by the housing policy increases with economic uncertainty.[20]

[19] We also compute the partial insurance coefficients for the different tightness of liquidity (ζ) or different supply of government bonds $\bar{B}$. The quantitative results show that a tighter liquidity constraint or a smaller supply of government bonds leads to a lower partial insurance coefficient. The above results support our theory that excessive demand for (or a shortage of) safe assets may hinder the households' ability to insure against their idiosyncratic uncertainties.

[20] Here we focus on the risk-sharing channel through which the house purchase limit policy may affect the consumption dynamics. The dynamics of return on the physical capital may also affect the consumption dynamics. In Online Appendix S.5, we provide more discussion on the risk-sharing channel and study whether the capital return has quantitative impacts on the housing market under the housing policy.

Figure 8: Transition Path under the Policy that Limits Housing Purchases



Notes: The transition is computed by assuming that uncertainty σ_t increases permanently by 25%. For the purchase limit case, the parameter ϕ is set to 2.5, and for the baseline case, $\phi = \infty$. The other parameter values are set according to the calibration values shown in Table 4.

Dynamic Impacts of the Policy Intervention To evaluate the dynamic impact of the policy that limits housing purchases, we compare the transition dynamics after an increase in economic uncertainty under the policy intervention with those in the baseline model. Figure 8 shows that a tighter purchase limit policy largely dampens the housing boom after an increase in uncertainty. As a result, the crowding-out effect between the real sector and the housing sector is mitigated.

5.3 Welfare Implications

Despite the mitigation of the crowding-out effect, the policy that limits housing purchases confines households' access to assets that can act as stores of value. A larger reduction in the degree of consumption insurance leads to adverse effects on social welfare. To illustrate this, we let W_t denote social welfare, which satisfies

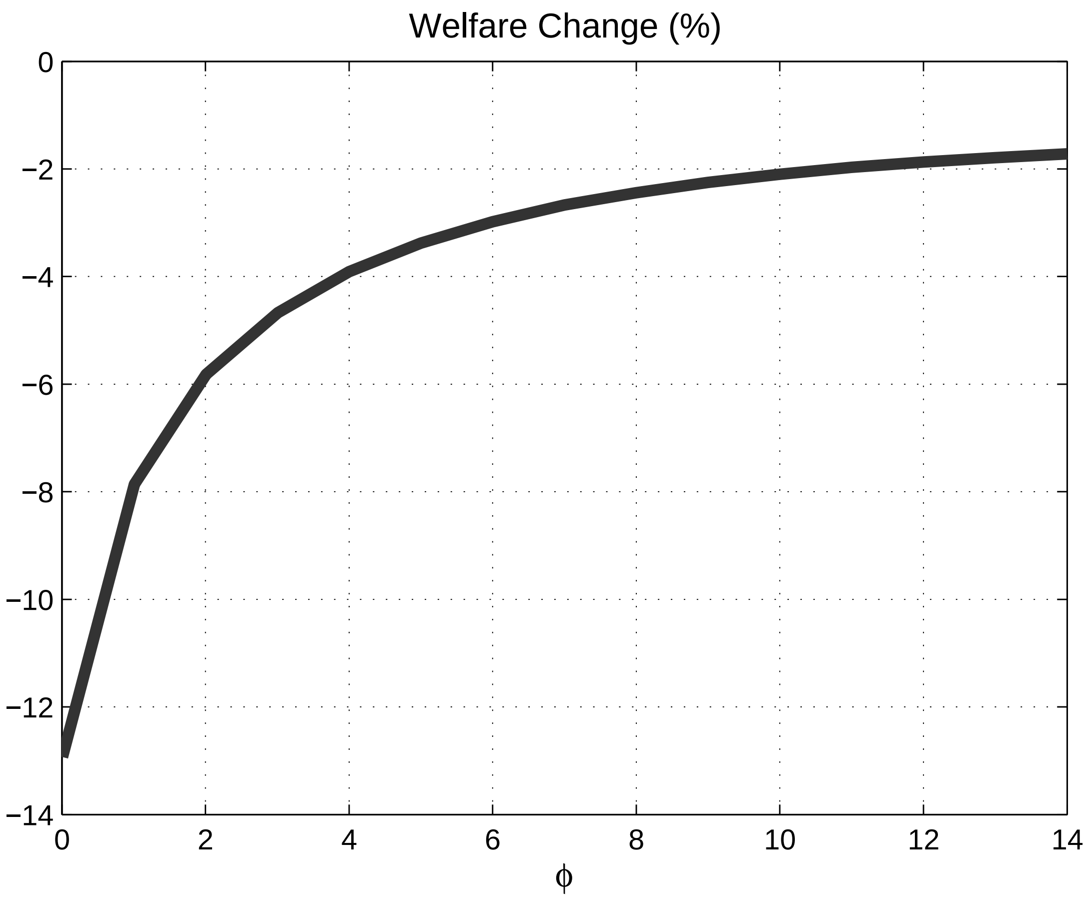
$$W_t = U_t - \psi N_t + \beta W_{t+1}, \tag{36}$$

where $U_t = \int \log C_{it} di$ and $N_t = \int N_{it} di$. According to the optimal consumption rule under the policy intervention, U_t is

$$U_t = \int \left[\log(\theta_{it}) \mathbf{1}_{\{\theta_{it} \le \theta_t^*\}} + \log(\theta_t^*) \mathbf{1}_{\left\{\theta_{it}^* \le \theta_{it} < \theta_t^{**}\right\}} + \log\left(\frac{1}{1+\phi}\theta_{it}\right) \mathbf{1}_{\{\theta_{it} > \theta_t^{**}\}} \right] d\mathbf{F}(\theta_{it}) + \log X_t. \tag{37}$$

Figure 9 compares the welfare effect of economic uncertainty under various levels of tightness of the policy that limits housing purchases (captured by the value of ϕ). As greater uncertainty hurts the real economy, the change in welfare is generally negative when there is a permanent increase in σ. Take the case of $\phi = 4$ as an example. When economic uncertainty increases by 25%, welfare (along the transition path) is reduced by approximately 4%. If the policy becomes tighter, namely $\phi = 2$, a 25% increase in uncertainty would cause a 6% reduction in welfare. This result suggests that the adverse effect of uncertainty on welfare along the transition becomes more severe when the policy that limits housing purchases is tighter.

Figure 9: Welfare Implications of the Policy that Limits Housing Purchases



Notes: The level of welfare is computed for the whole transition path after a 25% permanent increase in σ_t. The change in welfare is the percentage difference between welfare after the transition and that in the original steady state.

6 Conclusion

This paper aims to analyze how housing acts as safe assets by investigating the aggregate and distributional consequences of the housing policy in China. The shortage of safe assets, a global syndrome, is acute in developing economies such as China, whose financial market is underdeveloped and capital accounts are tightly regulated. Based on the household survey and household-level transaction data, we find that economic uncertainty boosts housing prices, especially during the recent economic slowdown when economic uncertainty increases. The results suggest that housing assets especially those with relatively high quality become desirable stores of value when economic uncertainty is high.

To quantify the economic consequences of the housing boom, we introduce housing assets as stores of value into a two-sector macroeconomic model with household heterogeneity and market incompleteness. Due to financial underdevelopment, housing acts as a major safe asset used to buffer idiosyncratic uncertainty. An increase in economic uncertainty leads to a housing boom due to precautionary motives. An expansion in the housing sector crowds out resources that could have been allocated to the real sector, leading to an economic slowdown. Therefore, our model makes sense of the recent great divergence between housing prices and the economic fundamentals of China's macroeconomy.

To curb the exaggerated housing boom, the Chinese government has implemented a policy that limits housing purchases to restrict individual access to the housing market in big cities. Our quantitative exercise reveals that the housing policy largely depresses the aggregate demand for housing when there is great economic uncertainty and thus alleviates the adverse effects of the housing boom on the real economy. However, the housing policy also limits individual's access to housing as a store of value, reducing the degree of consumption insurance. Consequently, the dispersion in consumption is exacerbated and social welfare is reduced. Therefore, the housing policy creates a trade-off between macro-level stability and micro-level consumption risk sharing.

Complementary to the safe-asset literature, we provide both empirical and quantitative evidence to identify housing as safe assets through the lens of economic uncertainty. In addition, our paper offers a novel channel through which the housing boom affects a real economy with an underdeveloped financial market. The model's tractability allows us to conduct a potentially intriguing extension transparently. For instance, by introducing rental market friction and hand-to-mouth households that only rent housing, we can explain the phenomenon that high housing prices are accompanied by high vacancy rates. We could evaluate the dynamic interactions between internal and external policies (e.g., capital control) by extending the model to an open economy. We could also extend the model to decompose the flight to quality (safety) and the flight to liquidity by introducing multiple types of housing assets. We leave these analyses for future research.

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Appendix

A Data and Empirics

A.1 CFPS Household Survey Data

The CFPS data is a nationally representative, biannual longitudinal survey of Chinese communities, families, and individuals launched in 2010 by the Institute of Social Science Survey (ISSS) at Peking University. In the 2010 baseline survey, the CFPS interviewed almost 15,000 families and almost 30,000 individuals within these families, for an approximately response rate of 79%. The CFPS respondents are tracked through annual follow-up surveys.

In Section 2, we present the relationship between household-level labor income uncertainty and the growth rate of real housing prices. Here, we provide more details about the data constructions. The dataset we employ contains all the waves (2010, 2012, 2014, 2016, and 2018) of CFPS.

Household Income Uncertainty We follow Blundell et al. (2008) and Santaeulàlia-Llopis and Zheng (2018) to construct the household-level labor income uncertainty. The procedure includes two steps. First, we apply the following sample selection criteria: (1) drop observations with negative household labor income and negative total assets (net worth); (2) retain only urban homeowners; (3) keep households with a head aged 15-65. This procedure gives us 17,465 households.

We then run the standard Mincer regression on the households' labor income and obtain the residual labor income

$$\log\left(y_{j,t}^{i}\right) = \alpha^{i} + \beta X_{t}^{i} + \delta_{t} + \gamma_{j} + z_{j,t}^{i}, \tag{A.1}$$

where i denotes the household's ID, t denotes time, and j denotes county. α^{i} denotes the household fixed effect. $y_{j,t}^{i}$ is real labor income per capita in 2010 constant price (deflated by urban CPI); X_{t}^{i} denotes the vectors of characteristics of the family head, such as the age and its squared term, years of education and its squared term, Hukou status, employment status, whether being an SOE worker, whether being self-employed, whether being an agricultural worker, family size and its squared term;

δ_t denotes the year fixed effect, γ_j denotes the county fixed effect. We winsorize $y^i_{j,t}$ at 1 and 99 percentiles.

We assume that the household-level residual labor income follows a random walk

$$z^i_{j,t} = z^i_{j,t-1} + \varepsilon^i_{j,t}, \tag{A.2}$$

where the labor income shocks $\varepsilon^i_{j,t}$ are independently distributed across individuals, counties, and time. Since our data is biannual, we define the labor income uncertainty between t and $t-2$ for county j to be

$$\sigma_{j,t} = \left[\mathbf{Var}\left(z^i_{j,t} - z^i_{j,t-2}\right)\right]^{\frac{1}{2}}, \text{ for } t = \{2012, 2014, 2016, 2018\}. \tag{A.3}$$

We drop counties that contain a limited number of observations (less than 30). This procedure together with the calculation procedure of county-level housing prices gives us 47 county-level observations used in the county-level panel regression (25 counties in 2012, 12 counties in 2014, 5 counties in 2016, and 5 counties in 2018). We define the 2-year changes in the household labor income uncertainty as

$$\Delta \ln \sigma_{j,t} = \ln \sigma_{j,t} - \ln \sigma_{j,t-2}, \text{ for } t = \{2014, 2016, 2018\}, \tag{A.4}$$

which eventually gives us 19 county-year observations plotted in the Figure 2.

County-Level Housing Prices We calculate the average housing price in county j at year t, as the sum of the gross value of housing assets that households currently live in divided by the sum of housing area (in square meters) that households currently live in. We drop counties that contain a limited number of observations on housing value or housing size (less than 30). We then deflate the nominal housing prices using urban CPI and converted them into 2010 constant prices, $P_{j,t}$. We define the growth rate of real housing price as

$$\Delta p^j_t = \ln P_{j,t} - \ln P_{j,t-2}, \text{ for } t = \{2012, 2014, 2016, 2018\}. \tag{A.5}$$

Figure 2 presents the scatter plot $(\Delta p^j_t, \Delta\sigma_{j,t})$, for $t = \{2014, 2016, 2018\}$.

A.2 Other Data

1. Data series in Figure 1: (**i**) The national average real housing price is equal to the total house sales divided by the total house sales area (square meters), which is deflated by the CPI index. Both series are monthly and published by the National Bureau of Statistics. We add up the monthly data to the quarter, and finally get the quarterly data from 1999Q1-2019Q4.

(**ii**) The real GDP growth rate is from the WIND database, and the series covers the period from 1999Q1 to 2019Q4.

2. Data used in the Calibration: Data on total land purchases in the housing sector in Tier-one cities for Beijing and Shanghai were collected from the WIND database. The data series in Tier-one cities for Guangzhou and Shenzhen were collected from the Bureau of Statistics of the local governments.

B Proofs and Dynamic System

B.1 Proof of Proposition 1

Taking as given the aggregate environment, the individual household's consumption and housing decisions follow a trigger strategy. Let θ_{it}^* denote the cutoff of idiosyncratic shock θ_{it}. We consider the following two cases for the optimal decisions given the cutoff θ_{it}^*.

Case 1: $\theta_{it} \geq \theta_{it}^*$. In this case, the household has a relatively high level of wealth. They tend to hold more housing as a buffer to smooth consumption. As a result, the liquidity constraint for housing (5) does not bind, i.e., $H_{it+1} > 0$ and $\eta_{it} = 0$.

From the Euler equation for the housing decision (10), we obtain

$$\lambda_{it} = \beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right). \tag{B.1}$$

The optimal condition for consumption (9) implies

$$C_{it} = \left[\beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1}. \tag{B.2}$$

Putting last equation into the budget constraint yields

$$q_{ht}H_{it+1} = \theta_{it}X_{it} - \left[\beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1}. \tag{B.3}$$

Since $H_{it+1} > 0$, we must have the following relation

$$\theta_{it} \geq \left[\beta(1-\delta_h)X_{it}\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1} \equiv \theta_{it}^*, \tag{B.4}$$

which defines the cutoff θ_{it}^*.

Case 2: $\theta_{it} < \theta_{it}^*$. In this case, the household has a relatively low wealth. To smooth the consumption, the household tends to utilize all the liquidity, leading to a binding liquidity constraint, i.e., $H_{it+1} = 0$ and $\eta_{it} > 0$. From the budget constraint, we immediately have

$$C_{it} = \theta_{it} X_{it} = \frac{\theta_{it}}{\theta^*_{it}} \left[\beta(1-\delta_h) \mathbf{E}_t \left(\Lambda_{t+1} \frac{q_{ht+1}}{q_{ht}} \right) \right]^{-1}, \tag{B.5}$$

where the second equality comes from the definition of the cutoff θ^*_{it}.

From the Euler equation for the housing decision (10), we get

$$\lambda_{it} = \frac{\theta^*_{it}}{\theta_{it}} \left[\beta(1-\delta_h) \mathbf{E}_t \left(\Lambda_{t+1} \frac{q_{ht+1}}{q_{ht}} \right) \right]. \tag{B.6}$$

Since $\theta_{it} < \theta^*_{it}$, (10) implies $\eta_{it} > 0$.

Plugging (B.4) and (B.6) into the Euler equation for the capital decision (8) yields

$$1 = \beta(1-\delta_h) \Phi(\theta^*_{it}; \sigma_t) \mathbf{E}_t \left(\frac{\Lambda_{t+1}}{\Lambda_t} \frac{q_{ht+1}}{q_{ht}} \right), \tag{B.7}$$

where $\Phi(\theta^*_{it}; \sigma_t) = \int_{\theta_{\min}}^{\theta_{\max}} \max\{\theta_{it}, \theta^*_{it}\} d\mathbf{F}(\theta_{it}; \sigma_t)$. Note that last equation can be further expressed as the housing pricing equation

$$q_{ht} = \Phi(\theta^*_{it}; \sigma_t)(1-\delta_h) \frac{\mathbf{E}_t q_{ht+1}}{1+r^i_t}, \tag{B.8}$$

where $r^i_t = 1/\left(\beta \mathbf{E}_t \Lambda_{t+1}/\Lambda_t\right) - 1$ is the real interest rate.

Eq. (B.7) further implies the cutoff θ^*_{it} is independent with each household i. So we can simply write θ^*_{it} as θ^*_t. The definition of X_{it} shows that the liquid wealth X_{it} is also identical among households so we can drop the subscript i for X_{it}. The definition of X_{it} implies

$$X_t = \left[\beta(1-\delta_h) \theta^*_t \mathbf{E}_t \left(\Lambda_{t+1} \frac{q_{ht+1}}{q_{ht}} \right) \right]^{-1}. \tag{B.9}$$

The optimal consumption rules in previous analysis implies

$$C_{it} = \min\{\theta_{it}, \theta^*_t\} X_t. \tag{B.10}$$

Combining last equation and the budget constraint yields

$$H_{it+1} = \max\{\theta_{it} - \theta_t^*, 0\}\frac{X_t}{q_{ht}}. \tag{B.11}$$

From (B.7) and (B.9), we immediately have

$$X_t = \frac{1}{\theta_t^* \Lambda_t}\int_{\theta_{\min}}^{\theta_{\max}} \max\{\theta_{it}, \theta_t^*\} d\mathbf{F}(\theta_{it}; \sigma_t). \tag{B.12}$$

We thus obtain Proposition 1.

B.2 Proof of Proposition 2

Let ξ_{it} denote the Lagrangian multiplier for house-purchase-limit (S.6.1). The first order conditions with respective to $\{C_{it}, H_{it+1}\}$ now take the form

$$\lambda_{it} = \frac{1}{C_{it}} + \phi\xi_{it}, \tag{B.13}$$

$$\lambda_{it} + \xi_{it} = \beta(1-\delta_h)\mathbf{E}_t\left[\tilde{\mathbf{E}}_t\left(\theta_{it+1}\lambda_{it+1}\frac{q_{ht+1}}{q_{ht}}\right)\right] + \frac{\eta_{it}}{q_{ht}}. \tag{B.14}$$

Given the aggregate environment, the individual household's consumption and housing decisions follow trigger strategies. Let θ_{it}^* and θ_{it}^{**} denote two cutoffs of idiosyncratic shock θ_{it}.

Similar to the proof of Proposition 1, we consider the following three cases about different housing decision rules given the cutoff value θ_{it}^*.

Case 1: $\theta_{it}^* \leq \theta_{it} \leq \theta_{it}^{**}$. In this case, the household's liquid wealth is in the middle, with moderate demand of liquidity, both of the liquidity constraint (6) and housing purchase limit constraint (S.6.1) are not binding, i.e., $0 \leq H_{it+1} \leq \phi C_{it}/q_{ht}$, $\eta_{it} = 0$ and $\xi_{it} = 0$.

(7) and (B.14) imply

$$\lambda_{it} = \beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right). \tag{B.15}$$

From (B.13), we obtain the consumption decision

$$C_{it} = \left[\beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1}. \tag{B.16}$$

The resource constraint implies the optimal housing decision is

$$q_{ht}H_{it+1} = \theta_{it}X_{it} - \left[\beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1}. \tag{B.17}$$

The relationship $0 \leq H_{it+1} \leq \phi C_{it}/q_{ht}$ implies

$$\theta_{it} \geq \left[\beta(1-\delta_h)X_{it}\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1} \equiv \theta_{it}^*, \tag{B.18}$$

$$\theta_{it} \leq (1+\phi)\left[\beta(1-\delta_h)X_{it}\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1} \equiv \theta_{it}^{**}, \tag{B.19}$$

which define two cutoffs θ_{it}^* and θ_{it}^{**}. The definitions also imply $\theta_{it}^{**} = (1+\phi)\theta_{it}^*$.

Case 2: $\theta_{it} < \theta_{it}^*$. In this case, the household has a relatively low wealth. To smooth the consumption, the household tends to utilize all the liquidity, leading to a binding liquidity constraint (6). Therefore, the housing decision is simply $H_{it+1} = 0$, $\eta_{it} > 0$ and $\xi_{it} = 0$. The budget constraint implies that the consumption satisfies

$$C_{it} = \theta_{it}X_{it} = \frac{\theta_{it}}{\theta_{it}^*}\left[\beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]^{-1}. \tag{B.20}$$

From (B.13), we have

$$\lambda_{it} = \frac{\theta_{it}^*}{\theta_{it}}\left[\beta(1-\delta_h)\mathbf{E}_t\left(\Lambda_{t+1}\frac{q_{ht+1}}{q_{ht}}\right)\right]. \tag{B.21}$$

Since $\theta_{it} < \theta_{it}^*$, (B.14) implies $\eta_{it} > 0$.

Case 3: $\theta_{it} > \theta_{it}^{**}$. In this case, the household has a sufficiently high level of liquid wealth. So they tend to demand more housing as a buffer for the precautionary purpose. As a result, the house-purchase-limit constraint (S.6.1) is binding, i.e., $H_{it+1} = \phi C_{it}/q_{ht}$, $\eta_{it} = 0$ and $\xi_{it} > 0$.

The budget constraint implies that the consumption satisfies

$$C_{it} = \frac{\theta_{it}}{1+\phi} X_{it} = \frac{\theta_{it}}{\theta_{it}^*(1+\phi)} \left[\beta(1-\delta_h)\mathbf{E}_t \left(\Lambda_{t+1} \frac{q_{ht+1}}{q_{ht}} \right) \right]^{-1}. \tag{B.22}$$

From (B.13) and (B.14), we have

$$\lambda_{it} = \left(\frac{\theta_{it}^*}{\theta_{it}} + \frac{\phi}{1+\phi} \right) \left[\beta(1-\delta_h)\mathbf{E}_t \left(\Lambda_{t+1} \frac{q_{ht+1}}{q_{ht}} \right) \right]. \tag{B.23}$$

Plugging (B.18), (B.19) and (B.23) into the Euler equation for the capital decision (8) yields

$$1 = \beta(1-\delta_h)\Phi(\theta_{it}^*; \phi, \sigma_t)\mathbf{E}_t \left(\frac{\Lambda_{t+1}}{\Lambda_t} \frac{q_{ht+1}}{q_{ht}} \right), \tag{B.24}$$

where $\Phi(\theta_{it}^*; \phi, \sigma_t) = \int_{\theta_{\min}}^{\theta_{\max}} [\theta_{it}^* \mathbf{1}_{\{\theta_{it} < \theta_{it}^*\}} + \theta_{it} \mathbf{1}_{\{\theta_{it}^* \le \theta_{it} \le \theta_{it}^{**}\}} + (\theta_{it}^* + \frac{\phi}{1+\phi}\theta_{it}) \mathbf{1}_{\{\theta_{it} > \theta_{it}^{**}\}}] d\mathbf{F}(\theta_{it}; \sigma_t)$. Last equation and the definitions of cutoffs imply θ_{it}^* and θ_{it}^{**} are independent with idiosyncratic states. Thus, we can simply drop the subscript i for these two variables.

Also, it is obvious that X_{it} is independent with the idiosyncratic states. So we have

$$X_t = \left[\beta(1-\delta_h)\theta_t^* \mathbf{E}_t \left(\frac{\Lambda_{t+1}}{\Lambda_t} \frac{q_{ht+1}}{q_{ht}} \right) \right]^{-1}. \tag{B.25}$$

Summarizing the consumption rules yields the optimal consumption decision

$$C_{it} = \left[\theta_{it} \mathbf{1}_{\{\theta_{it} < \theta_t^*\}} + \theta_t^* \mathbf{1}_{\{\theta_t^* \le \theta_{it} \le \theta_t^{**}\}} + \frac{\theta_{it}}{1+\phi} \mathbf{1}_{\{\theta_{it} > \theta_t^{**}\}} \right] X_t. \tag{B.26}$$

Last equation and the budget constraint imply the optimal housing demand

$$H_{it+1} = \left\{ \theta_{it} - \left[\theta_{it} \mathbf{1}_{\{\theta_{it} < \theta_t^*\}} + \theta_t^* \mathbf{1}_{\{\theta_t^* \le \theta_{it} \le \theta_t^{**}\}} + \frac{\theta_{it}}{1+\phi} \mathbf{1}_{\{\theta_{it} > \theta_t^{**}\}} \right] \right\} \frac{X_t}{q_{ht}}. \tag{B.27}$$

Finally, (B.24) and (B.25) immediately give

$$X_t = \frac{1}{\theta_t^* \Lambda_t} \Phi(\theta_t^*; \phi, \sigma_t). \tag{F.19}$$

We thus prove Proposition 2.

B.3 Full Dynamic System of Baseline Model

The full dynamic system for the baseline model can be summarized as follows.

1. Labor supply

$$\psi = w_t \Lambda_t, \tag{B.28}$$

where $\Lambda_t = \tilde{\mathbf{E}}_t(\theta_{it}\lambda_{it})$.

2. Euler equation for physical capital

$$1 = \beta \mathbf{E}_t \left\{ \frac{\mathbf{\Lambda}_{t+1}}{\Lambda_t} \left[r_{t+1} + (1 - \delta_k) \right] \right\}. \tag{B.29}$$

3. Asset pricing for housing price

$$q_{ht} = \Phi_t (1 - \delta_h) \frac{\mathbf{E}_t q_{ht+1}}{1 + r_t^i}. \tag{B.30}$$

where $\Phi_t \left(\theta_t^*; \sigma_t\right) = \displaystyle\int \max \{\theta_t^*, \theta_{it}\} d\mathbf{F}(\theta_{it}; \sigma_t)$, and $r_t^i \equiv 1/\left(\beta \mathbf{E}_t \Lambda_{t+1}/\Lambda_t\right) - 1$.

4. Aggregate consumption:

$$C_t = \int \min \{\theta_t^*, \theta_{it}\} d\mathbf{F}(\theta_{it}; \sigma_t) X_t. \tag{B.31}$$

5. Aggregate housing demand:

$$H_{t+1} = \frac{X_t}{q_{ht}} \int \max\{\theta_{it} - \theta_t^*, 0\} d\mathbf{F}(\theta_{it}; \sigma_t); \tag{B.32}$$

6. Disposable wealth:

$$X_t = \frac{1}{\theta_t^* \Lambda_t} \int \max \{\theta_t^*, \theta_{it}\} d\mathbf{F}(\theta_{it}; \sigma_t). \tag{B.33}$$

7. Supply of housing asset:

$$h_t = \left({K_{ht}}^{\alpha_h} N_{ht}^{1-\alpha_h} \right)^{1-\gamma} L_t^{\gamma}. \tag{B.34}$$

8. Demand for K_{ht} :

$$r_t = \alpha_h(1-\gamma)q_{ht}\frac{h_t}{K_{ht}}. \tag{B.35}$$

9. Demand for N_{ht} :

$$w_t = (1-\alpha_h)(1-\gamma)q_{ht}\frac{h_t}{N_{ht}}. \tag{B.36}$$

10. Demand of land L_t :

$$q_{lt} = \gamma q_{ht}\frac{h_t}{L_t}. \tag{B.37}$$

11. Supply of land

$$L_t = \bar{L}. \tag{B.38}$$

12. Total output in real sector:

$$Y_{pt} = K_{pt}^{\alpha_p} N_{pt}^{1-\alpha_p}. \tag{B.39}$$

13. Demand for K_{pt} :

$$r_t = \alpha_p \frac{Y_{pt}}{K_{pt}}. \tag{B.40}$$

14. Demand for N_{pt} :

$$w_t = (1-\alpha_p)\frac{Y_{pt}}{N_{pt}}. \tag{B.41}$$

15. Law of motion of H_t :

$$H_{t+1} = (1-\delta_h) H_t + h_t. \tag{B.42}$$

16. The aggregate resource constraint is given by

$$C_t + q_{ht}h_t + I_t = Y_t, \tag{B.43}$$

where $I_t = K_{t+1} - (1-\delta_k)K_t$.

17. Aggregate capital:

$$K_t = K_{pt} + K_{ht}. \tag{B.44}$$

18. Aggregate labor:

$$N_t = N_{pt} + N_{ht}. \tag{B.45}$$

B.4 Steady State in Baseline Model

We now solve the steady state. According to the definition of r^i, it is easy to obtain $r^i \equiv \frac{1}{\beta} - 1$. From the asset pricing equation, we have

$$\Phi(\theta^*) = \int \max\{\theta^*, \theta_i\} d\mathbf{F}(\theta_i; \sigma) = \frac{1}{\beta(1-\delta_h)}, \tag{B.46}$$

which can solve the cutoff θ^* directly. From the Euler equation for physical capital, we can obtain the steady-state $r = 1/\beta - 1 + \delta$.

From capital demand function (B.40), we then obtain Y_p/K_p and K_p/N_p through

$$r = \alpha_p \frac{Y_p}{K_p} = \alpha_p \left(\frac{K_p}{N_p}\right)^{\alpha_p - 1}. \tag{B.47}$$

Moreover, the wage rate is given by

$$w = (1-\alpha_p) \frac{Y_p}{N_p} = (1-\alpha_p) \left(\frac{K_p}{N_p}\right)^{\alpha_p}. \tag{B.48}$$

From the labor supply function, we have $\Lambda = \psi/w$. From the definition of X, we have

$$X = \frac{1}{\theta^* \Lambda} \int \max\{\theta^*, \theta_i\} d\mathbf{F}(\theta_i; \sigma). \tag{B.49}$$

In turn, aggregate consumption and housing demand are respectively given by

$$C = \int \min\{\theta^*, \theta_i\} d\mathbf{F}(\theta_i; \sigma) X, \tag{B.50}$$

$$q_h H = X \int \max\{\theta_i - \theta^*, 0\} d\mathbf{F}(\theta_i; \sigma). \tag{B.51}$$

According the law of motion of H, we have $h = \delta_h H$, so we can solve $q_h h$.

From (B.35), we have $K_h = \alpha_h(1-\gamma)q_h h/r$. And from (B.36), we have

$$N_h = \frac{r}{w}\frac{1-\alpha_h}{\alpha_h}K_h. \tag{B.52}$$

Since $L = \bar{L}$, we can solve the h according to $h = \left(K_h^{\alpha_h} N_h^{1-\alpha_h}\right)^{1-\gamma} \bar{L}^{\gamma}$. And the housing price q_h is easy to solve.

Furthermore, we can obtain land price

$$q_l = \gamma q_h \left(K_h^{\alpha_h} N_h^{1-\alpha_h}\right)^{1-\gamma} \bar{L}^{\gamma-1}. \tag{B.53}$$

Since $I = \delta K = \delta\left(K_p + K_h\right)$, through the resource constraint, we have

$$C = Y_{pt} - \delta_k K = \left(\frac{K_p}{N_p}\right)^{\alpha_p} N_p - \delta_k \frac{K_p}{N_p} N_p - \delta_k K_h, \tag{B.54}$$

Using the precious results, we can solve K_p and N_p. Aggregate output Y is defined as $Y = Y_p + q_h h$.

B.5 Extended Model with Multiple Stores of Value

In the extended model, we introduce risk free bond as an alternative store of value. The household's problem is essentially the same as that in the baseline model. The budget constraint now becomes

$$C_{it} + q_{ht}H_{it+1} + B_{it+1} = \theta_{it}X_{it}, \tag{B.55}$$

where q_{ht} is the real housing price; B_{it+1} is the stock of bond; X_{it} is the real disposable wealth excluding the purchase of investment in physical capital,

$$X_{it} = \left[(1-\delta_h)q_{ht} + r_{ht}\right]H_{it} - \gamma_b \frac{\left(q_{ht-1}H_{it}\right)^{1+\chi}}{1+\chi} + R_{bt-1}B_{it} + w_t N_{it} + r_t K_{it} + D_t - \left[K_{it+1} - (1-\delta_k)K_{it}\right], \tag{B.56}$$

where δ_k and $\delta_h \in (0,1)$ are depreciation rates of capitals and housings, respectively; w_t and r_t are respectively the real wage rate and the real rate of return to physical capital; D_t is the profit distributed from the production side; r_{ht} is the rental rate of the housing and R_{bt-1} is the interest rate for the bond. For simplicity, we assume both of r_{ht} is exogenously given.

In addition, similar to the baseline setup the amounts of housing and bond are assumed to be greater than zero:

$$q_{ht}H_{it+1} + B_{it+1} \geq \zeta\theta_{it}X_{it}, \tag{B.57}$$

$$q_{ht}H_{it+1} \geq 0. \tag{B.58}$$

Denote λ_{it}, μ_{it} and η_{it} respectively as the Lagrangian multipliers for the budget constraint (B.55), the liquidity constraints (B.57) and (B.58). The first order conditions with respective to $\{N_{it}, K_{it+1}, C_{it}, H_{it+1}, B_{it+1}\}$ are given by following equations

$$\psi = w_t\Lambda_t, \tag{B.59}$$

$$\Lambda_t = \beta\mathbf{E}_t\left[(r_{t+1} + 1 - \delta_k)\Lambda_{t+1}\right], \tag{B.60}$$

$$\frac{1}{C_{it}} = \lambda_{it}, \tag{B.61}$$

$$\lambda_{it} = \beta\mathbf{E}_t\left[\Lambda_{t+1}\frac{(1-\delta_h)\,q_{ht+1} + r_{ht+1}}{q_{ht}}\right] - \beta\gamma_b\mathbf{E}_t\Lambda_{t+1}\left(q_{ht}H_{it+1}\right)^{\chi} + \mu_{it} + \eta_{it}, \tag{B.62}$$

$$\lambda_{it} = \beta\mathbf{E}_t\Lambda_{t+1}R_{bt} + \mu_{it}. \tag{B.63}$$

(B.59) and (B.60) indicate that we can define the discount factor, Λ_t, analogous to representative agent model, as $\Lambda_t \equiv \tilde{\mathbf{E}}_t(\theta_{it}\lambda_{it} - \zeta\theta_{it}X_{it}) = \frac{\psi}{w_t}$. Define $\theta^*_{it} = 1/\left(\beta\mathbf{E}_t\Lambda_{t+1}R_{bt}X_{it}\right)$.

The household's optimal decisions follow trigger strategy as those in the baseline model.

Case 1. $\theta_{it} > \theta^*_{it}$. In this case, household would like to hold positive amount of safe assets, i.e., $q_{ht}H_{it+1} + B_{it+1} > \zeta\theta_{it}X_{it}$. So we have $\mu_{it} = 0$ and $\eta_{it} \geq 0$. From the FOCs, we have

$$q_{ht}H_{it+1} = \max\left\{\left\{\frac{\mathbf{E}_t\Lambda_{t+1}\left[\frac{(1-\delta_h)q_{ht+1}+r_{ht+1}}{q_{ht}} - R_{bt}\right]}{\mathbf{E}_t\Lambda_{t+1}\gamma_b}\right\}^{\frac{1}{\chi}}, 0\right\}. \tag{B.64}$$

For the moment, we assume the following condition is always satisfied,

$$\frac{(1-\delta_h)\, q_{ht+1} + r_{ht+1}}{q_{ht}} > R_{bt}, \tag{B.65}$$

so that $\eta_{it} = 0$ and the housing demand is given by

$$q_{ht} H_{it+1} = \left\{ \frac{\mathbf{E}_t \Lambda_{t+1} \left[\frac{(1-\delta_h) q_{ht+1} + r_{ht+1}}{q_{ht}} - R_{bt} \right]}{\mathbf{E}_t \Lambda_{t+1} \gamma_b} \right\}^{\frac{1}{\chi}}. \tag{B.66}$$

Since $\mu_{it} = \theta_{it} = 0$, from (B.63) we further have $C_{it} = \theta^*_{it} X_{it}$ and

$$q_{ht} H_{it+1} + B_{it+1} = (\theta_{it} - \theta^*_{it})\, X_{it}. \tag{B.67}$$

Case 2. $\theta_{it} \leq \theta^*_{it}$. The household has no incentive to hold assets, i.e., $q_{ht} H_{it+1} + B_{it+1} = \zeta \theta_{it} X_{it}$ and $C_{it} = (1-\zeta)\, \theta_{it} X_{it}$. In this case, for $\theta_{it} = \theta^*_{it}$ we have the relationship $1/\left(\theta^*_{it} X_{it}\right) = \beta \mathbf{E}_t \Lambda_{t+1} R_{bt}$, which defines the cutoff θ^*_{it}. So we can solve μ_{it} as

$$\mu_{it} = \left[\frac{1}{(1-\zeta)\, \theta_{it}} - \frac{1}{\theta^*_{it}} \right] \frac{1}{X_{it}}. \tag{B.68}$$

The FOCs for housing and bonds imply

$$q_{ht} H_{it+1} = \left\{ \frac{\mathbf{E}_t \Lambda_{t+1} \left[\frac{(1-\delta_h) q_{ht+1} + r_{ht+1}}{q_{ht}} - R_{bt} \right]}{\mathbf{E}_t \Lambda_{t+1} \gamma_b} \right\}^{\frac{1}{\chi}} + \eta_{it}, \tag{B.69}$$

therefore $q_{ht} H_{it+1} \geq 0$ under the assumption $\frac{(1-\delta_h) q_{ht+1} + r_{ht+1}}{q_{ht}} \geq R_{bt}$. It further implies $\eta_{it} = 0$. So the housing holding for any household is obtained as

$$q_{ht} H_{it+1} = \left\{ \frac{\mathbf{E}_t \Lambda_{t+1} \left[\frac{(1-\delta_h) q_{ht+1} + r_{ht+1}}{q_{ht}} - R_{bt} \right]}{\mathbf{E}_t \Lambda_{t+1} \gamma_b} \right\}^{\frac{1}{\chi}}. \tag{B.70}$$

From (B.63), we can further have

$$1 = \beta \mathbf{E}_t \frac{\Lambda_{t+1}}{\Lambda_t} R_{bt} \Phi_t \left(\theta_{it}^*; \sigma_t\right), \tag{B.71}$$

where the premium of holding housings $\Phi_t \left(\theta_{it}^*\right)$ satisfies

$$\Phi_t \left(\theta_{it}^*\right) = \int_{\theta_{it} < \theta_{it}^*} \left(\theta_{it}^* + \zeta \theta_{it}\right) d\mathbf{F}\left(\theta_{it}; \sigma_t\right) + \int_{\theta_{it} \geq \theta_{it}^*} \theta_{it} d\mathbf{F}\left(\theta_{it}; \sigma_t\right). \tag{B.72}$$

The last equation implies the cutoff is irrelevant to the individual state. So for simplicity, we can write $\theta_{it}^* \equiv \theta_t^*$. It is straightforward to show that the premium $\Phi_t \left(\theta_{it}^*\right)$ increases with ζ. This is because a larger ζ implies a more severe liquidity constraint, thereby holding housing produces a large premium. The asset pricing equation of housings (B.71) further implies that a larger ζ induces a lower interest rate. Since the housing demand is decreasing in the interest rate R_{bt}, a tighter liquidity constraint (ζ is larger) may lead to a higher housing price.

The individual household's optimal decision is summarized as follows.

Proposition B.1 *Taking as given the aggregate states, the cutoff θ_{it}^* and the wealth X_{it} of the household i are independent with the individual states, that is, $\theta_{it}^* \equiv \theta_t^*$ and $X_{it} \equiv X_t$; the household's optimal consumption, housing and bond decisions are given by following trigger strategy:*

$$C_{it} = \left[(1-\zeta)\theta_{it}\mathbf{1}_{\{\theta_{it} \leq \theta_t^*\}} + \theta_t^* \mathbf{1}_{\{\theta_{it} > \theta_t^*\}}\right] X_t, \tag{B.73}$$

$$q_{ht} H_{it+1} = \left\{ \frac{\mathbf{E}_t \Lambda_{t+1} \left[\frac{(1-\delta_h) q_{ht+1} + r_{ht+1}}{q_{ht}} - R_{bt}\right]}{\mathbf{E}_t \Lambda_{t+1} \gamma_b} \right\}^{\frac{1}{\chi}}, \tag{B.74}$$

$$B_{it+1} = \theta_{it} X_{it} - C_{it} - q_{ht} H_{it+1}, \tag{B.75}$$

where the wealth X_t satisfies

$$X_t = \frac{1}{\theta_t^* \Lambda_t} \int \left\{ (\theta_t^* + \zeta \theta_{it}) \mathbf{1}_{\{\theta_{it} \leq \theta_t^*\}} + \theta_{it} \mathbf{1}_{\{\theta_{it} > \theta_t^*\}} \right\} d\mathbf{F}(\theta_{it}; \sigma_t). \tag{B.76}$$

In the deterministic equilibrium, the aggregate housing demand is given by

$$H_{t+1} = \frac{1}{q_{ht}} \left\{ \frac{1}{\gamma_b} \left[\frac{(1-\delta_h)\, q_{ht+1} + r_{ht+1}}{q_{ht}} - R_{bt} \right] \right\}^{\frac{1}{\chi}}. \tag{B.77}$$

(B.72) implies that when the uncertainty σ_t increases, R_{bt} decreases. This will shift the housing demand curve upwardly. Therefore, it would be expected that uncertainty raises housing prices even though the liquid bond is introduced. Moreover, as long as the total bond supply is limited (i.e., the financial market is incomplete) and the adjustment cost γ_b is small, the main results in our baseline model still hold.

Online Appendix

This online appendix provides more detailed discussions about the empirical issues, various model extensions, and other sensitivity analyses.

S.1 Real Returns on Capital

Gomme et al. (2011) calculated the return to capital using National Income and Product Accounts and show that the S&P 500 return is approximately six times more volatile than the return to business capital. To argue that housing is a safer asset than capital, we also calculate the real return of non-residential capital and residential capital in China separately according to the method in Gomme et al. (2011). Figure S.1.1 plots the main results. Panel (a) in this figure plots the real returns on capital in the US for housing and non-housing capital. Panel (b) plots the real returns on housing and non-housing capital in China. It is obvious from the figure that, for both China and the United States, the volatility of the return on real estate capital is less than that of non-real estate capital.

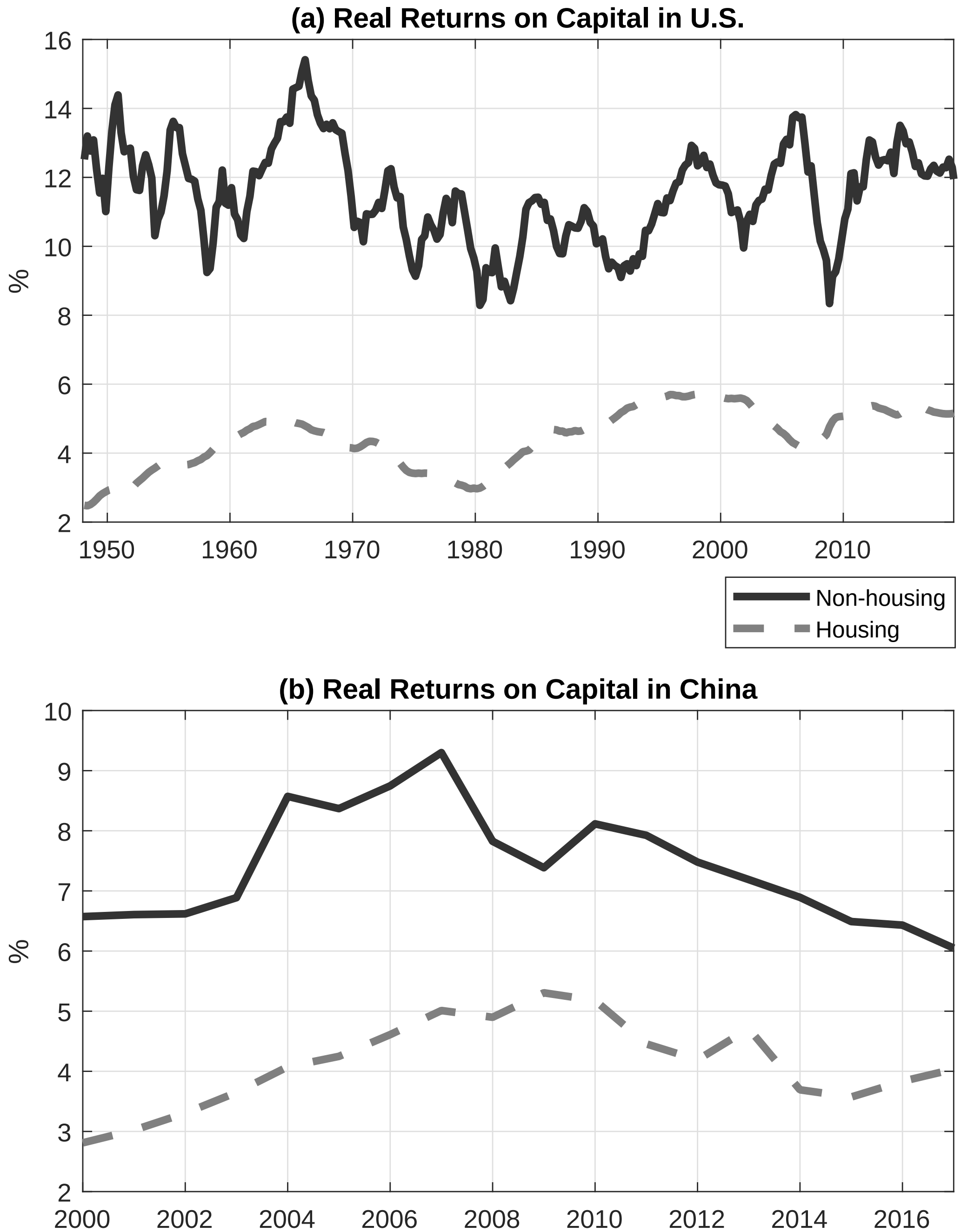
We further calculate the standard deviations for the returns on capital and find that the returns on housing capital have lower volatility than non-housing capital in both the US and China. See Table S.1.1 for the details. There are some caveats about China's data. First, although the housing net operating surplus is available, the data on housing rental income is missing. We impute housing rental income based on the ratio of rent to housing prices in major Chinese cities. Second, the tax data in the housing sector is missing. Therefore, we only calculate the pre-tax return. Third, the housing proprietor's income is missing.

S.2 Model with Technology Shocks

Our baseline analysis only focuses on the impact of uncertainty shocks. The economic slowdown may be driven by the supply side, for instance, negative technology shocks. To further disentangle the effects caused by different sources of shocks, we conduct the following counterfactual exercise.

In particular, we introduce a TFP growth shock which directly leads to an economic slowdown

Figure S.1.1: Real Returns on Capital in the US and China



Notes: Panel (a) and (b) plot the real returns on capital for housing and non-housing capitals in the U.S. and China, respectively. The US data series are quarterly from 1949Q1-2019Q4. The China data series are yearly from 2000 to 2017. The pre-tax returns to the business capital and the housing capital are from the updates to Gomme et al. (2011), downloaded from https://paulgomme.github.io. Data on the net operating surplus and capital stock in the real estate sector in China are from the WIND database. We impute the housing rental income based on the ratio of rent to housing prices in major Chinese cities.

Table S.1.1: Real Returns on Capital in the US and China

	US 1947-2018			China 2000-2019		
	Mean	Std	$\frac{\text{Mean}}{\text{std}}$	Mean	Std	$\frac{\text{Mean}}{\text{std}}$
Non-housing capital	11.52	1.42	8.13	7.41	0.93	7.95
Housing Capital	4.44	0.86	5.17	4.14	0.73	5.69

Notes: The US data series are quarterly from 1949Q1-2019Q4. The China data series are yearly from 2000 to 2017. The pre-tax returns to the business capital and the housing capital are from the updates to Gomme et al. (2011), downloaded from https://paulgomme.github.io. Data on the net operating surplus and capital stock in the real estate sector in China are from the WIND database. We impute the housing rental income based on the ratio of rent to housing prices in major Chinese cities.

and an uncertainty shock that raises the level of uncertainty. We introduce a TFP component A_t into the production function in the real sector, which takes the form of $Y_{pt} = K_{pt}^{\alpha}(A_t N_{pt})^{1-\alpha}$. The growth of TFP is assumed to follow an AR(1) process with a persistence parameter of 0.5.

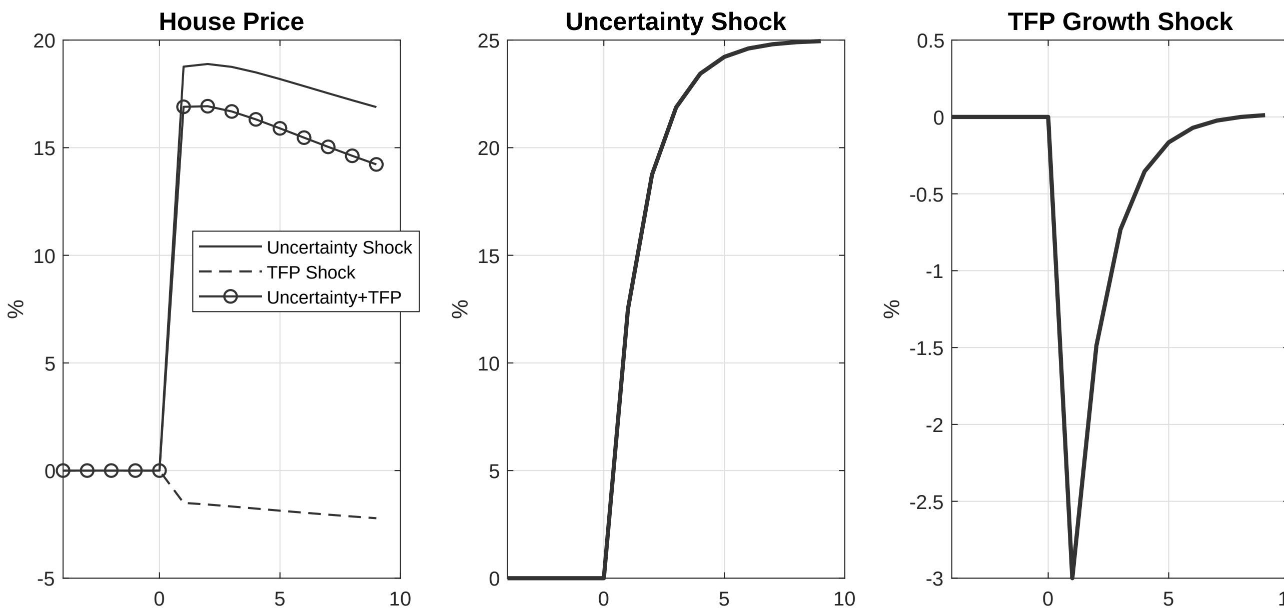
We calibrate the shock to TFP growth to be -0.03 such that the growth of TFP temporarily drops by 3% and gradually rebounds. The simulated real GDP growth in the first four periods (corresponding to one year) drops approximately 4%, which is close to the magnitude of the economic slowdown observed in the Chinese data. For the uncertainty process, we assume it is hit by a persistent positive shock such that the level of uncertainty increases by 25% as that in the baseline analysis. Figure S.2.1 reports the dynamics of housing price in response to the above two shocks. The first panel in Figure S.2.1 shows that a rise in uncertainty boosts the housing price (the dashed line), while a negative TFP growth shock (the solid line) causes an economic slowdown to depresses the housing price. The above results suggest that the increase in uncertainty, instead of negative shocks to economic fundamentals, is the driving force for the surge in the Chinese housing price.

S.3 Model with a Tightening Land Supply Policy

In recent years, large cities in China are facing a declining trend of land supply due to the tightening land policy, which may contribute to the rising of housing prices. To quantify the impact of land supply on the housing prices, we assume that the stock of land L_t follows an accumulation process

$$L_t = (1 - \delta_l)L_{t-1} + l_t, \tag{S.3.1}$$

Figure S.2.1: Housing price Dynamics under Uncertainty and TFP Growth Shocks



Notes: This figure reports the dynamics of housing price under uncertainty and TFP growth shocks. All the paths are the percentage deviation from the initial steady state. The growth of TFP is assumed to follow an AR(1) process with a persistence parameter of 0.5. The uncertainty permanently increases by 25% following an AR(1) process with a persistence parameter of 0.5 as that in the baseline model. Other parameters are calibrated according to the baseline analysis. The solid line is for the case where only the uncertainty shock presents. The dashed line is for the case where only TFP growth shock presents. The line with circles is for the case where both of the shocks are considered.

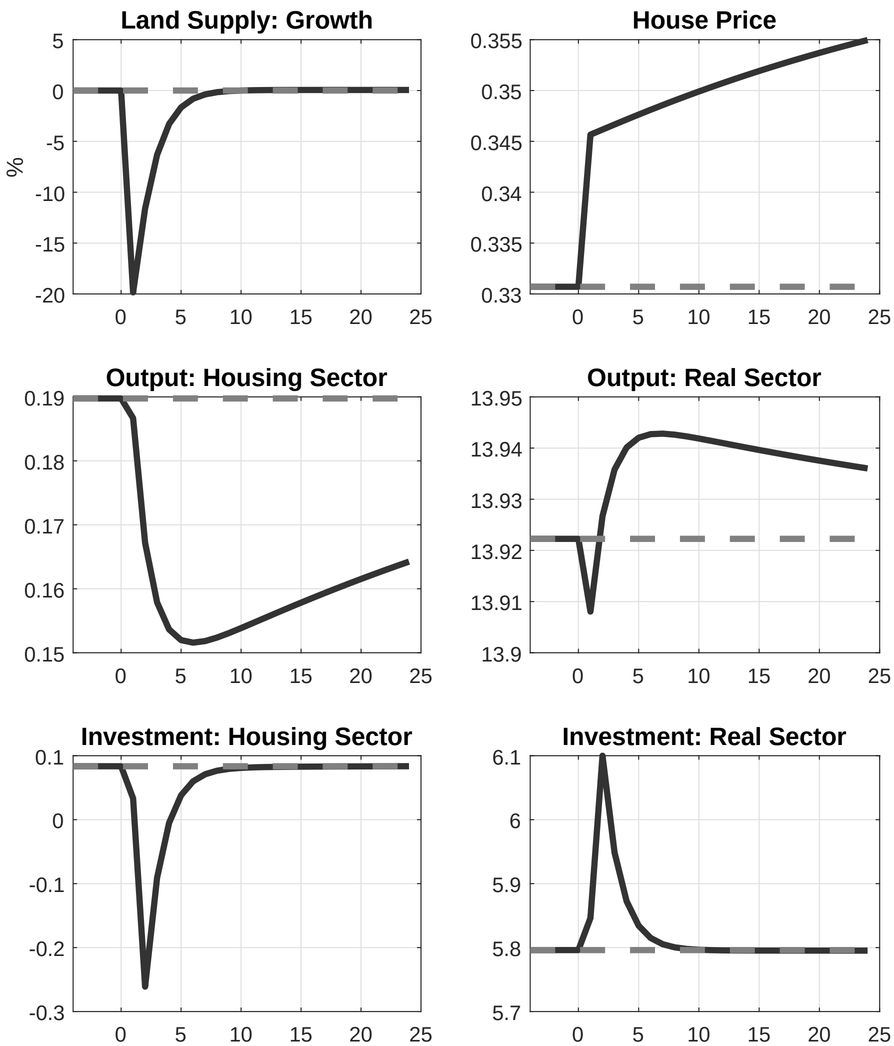
where δ_l is the depreciation rate of land stock and l_t is the newly developed land. We specify δ_l to take a very small value such that l_t plays a role in long-run land supply shock. We further specify l_t to follow an AR(1) process with a persistence parameter of 0.5. We then conduct the following quantitative analysis. We assume the economy initially stays at the steady state where the land stock L_t is normalized to be 1. In the first period, a negative land supply shock hits the economy such that the growth rate of land supply drops 20%. Figure S.3.1 reports the responses of the housing market to the land supply shock. It shows that a decline in land supply boosts the housing price, which increases approximately by 7% from 0.33 to 0.355. Thus, the above exercise supports the fact that the more restrictive land supply in tier 1 cities leads to a larger appreciation of housing prices. Also, Figure S.3.1 shows that a negative land supply shock depresses the real investment and output in the housing sector because of the reduction of land input. Meanwhile, the production sector expands comparing to the initial steady state in response to the land supply shock because the restrictive land supply mitigates the crowding-out effect caused by the housing sector. Therefore, our model implies that the cyclicality of the housing prices and the real economy under the uncertainty shock or the land supply shock differs from each other.

If we simultaneously consider restrictive land supply and a positive uncertainty shock, the model would generate a more dramatic housing price appreciation and thus fits the data better. Figure S.3.2 reports the dynamics of housing prices when both the uncertainty shock and the land supply shock are introduced. It shows that the housing price increases by approximately 25% under the uncertainty and land supply shocks. In this case, the model's prediction fits the empirical observation even better.

S.4 Further Discussion on the Extended Model

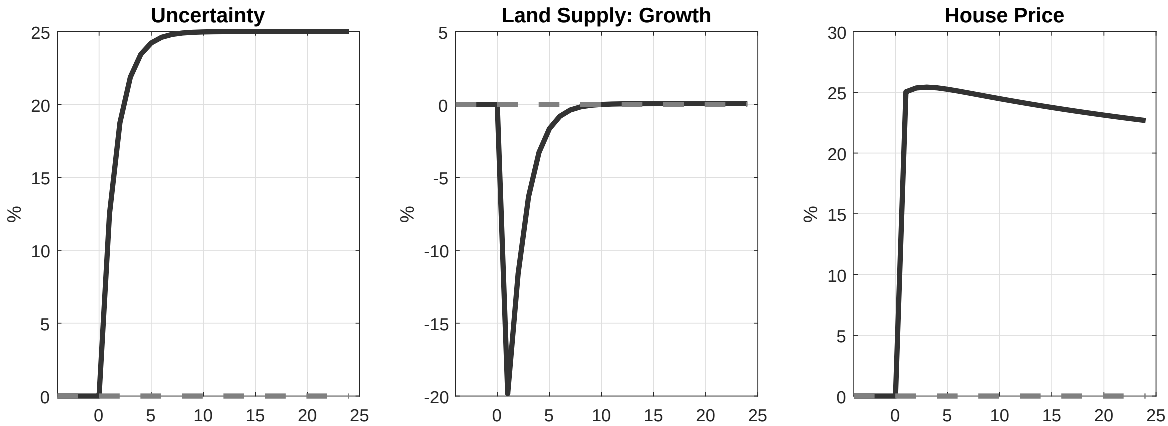
Stochastic Housing Return In the baseline model, we assume that housing assets and physical capital face the same level of uncertainty, we relax this assumption by introducing an aggregate stochastic shock to the housing return. In particular, our quantitative exercise is based on the extended version of the model presented in Section 4.3.2. In this extension, the housing assets derive a positive return in the form of rental rate, r_{ht}. To facilitate the quantitative analysis, we assume

Figure S.3.1: Transition Path after a Decrease in Land Supply



Notes: The transition paths are shown in levels. In the exercise, we assume that the land stock (L_t) initially stays at the steady-state value, which is normalized to be 1, and is then hit by a negative shock such that the growth rate of land stock L_t temporarily decreases by 20%. The level of uncertainty is set to be a constant with the same value as that in the baseline calibration.

Figure S.3.2: Transition Path after Negative Uncertainty and Land Supply Shocks



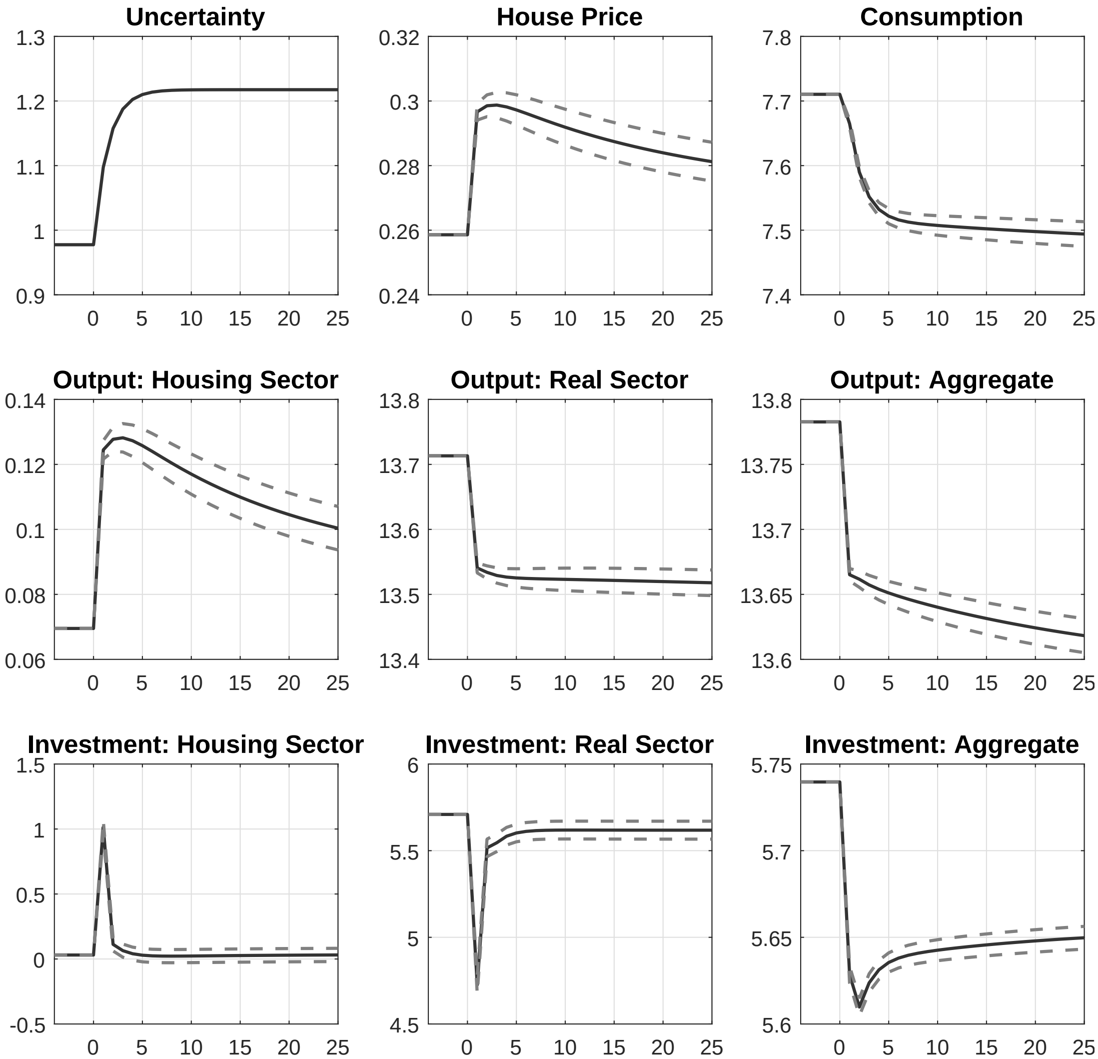
Notes: The transition paths are shown in the percentage deviation from the initial steady state. In the exercise, we assume that the land stock (L_t) initially stays at the steady state value, which is normalized to be 1, and is then hit by a negative shock such that the growth rate of land stock L_t temporarily decreases by 20%. The uncertainty shock σ_t is specified to be the same deterministic AR(1) process as that in the baseline analysis.

that the rental rate satisfies $r_{ht} = \tau_t q_{ht}$, where τ_t follows an exogenous AR(1) process $\log(\tau_t/\tau) = \rho_\tau \log(\tau_{t-1}/\tau) + \varepsilon_{\tau t}$ with a stochastic shock $\varepsilon_{\tau t} \sim \mathbf{N}(0, \sigma_\tau)$. Comparing to the physical capital, housing assets face additional aggregate risks. We then quantitatively evaluate the dynamic impact of the uncertainty shock on the housing market and real economy as those in Figure 4 in the main text.[21] Figure S.4.1 below shows the dynamic responses of the housing market and real economy to a rise in uncertainty when the aggregate risks of housing return are considered. It can be seen that an uncertainty shock leads to a boom in the housing market and crowds out the real economy, as we have shown in the baseline case. Therefore, the main results in the baseline model remain robust when the assumption that housing assets and physical capital face the same level of uncertainty is relaxed.

Households' Liquidity Constraint and Housing Prices One important prediction in the extended model in Section 4.3.2 is that if the households' liquidity constraint tightens, i.e., ζ becomes larger, their demand for bonds and housing as stores of value will increase, which translates into

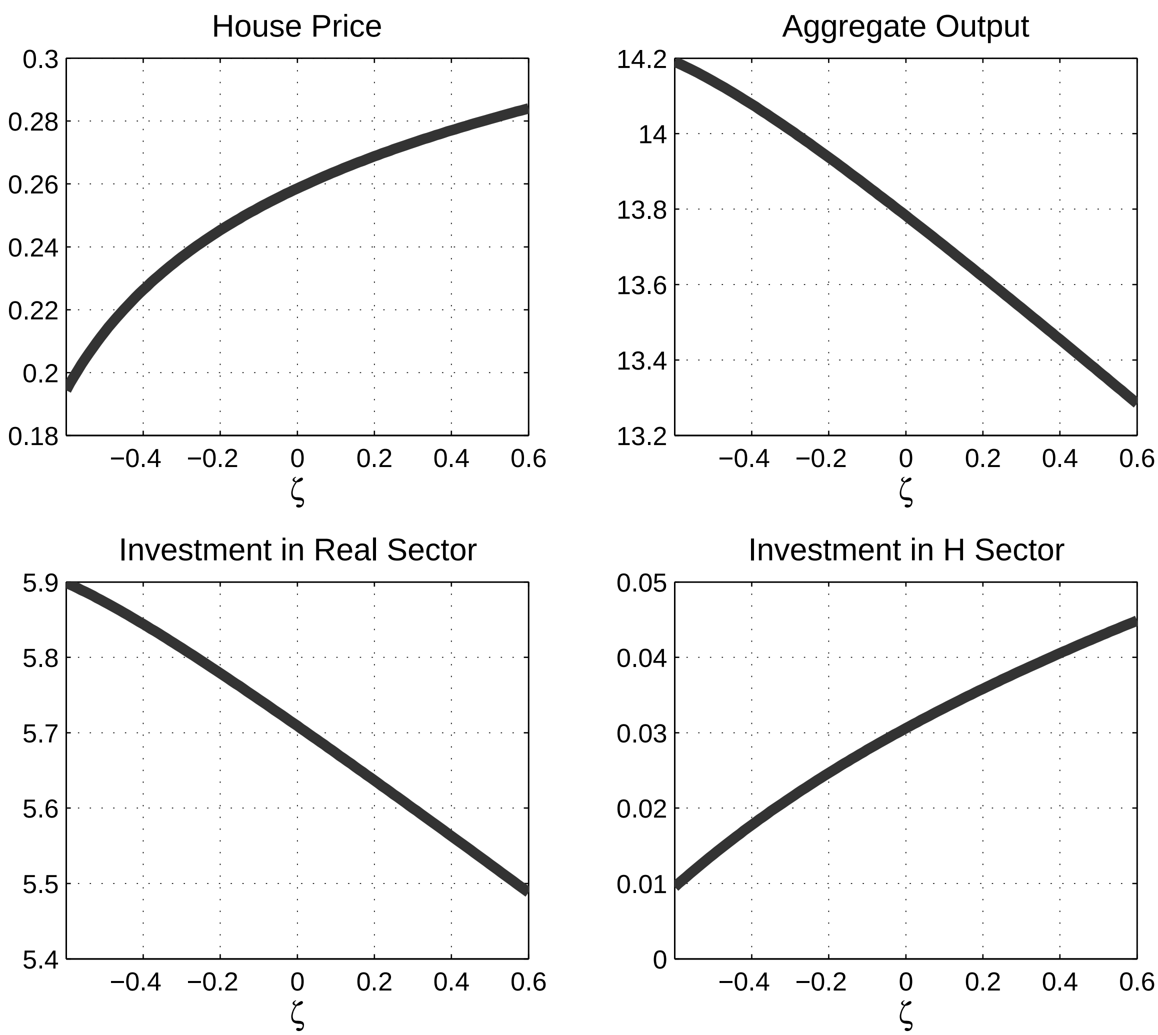
[21] The quantitative approach for computing the dynamic paths in response to an uncertainty shock in this extension is quite different from the baseline model since the extended model contains a deterministic process of a rise in uncertainty and an additional stochastic aggregate shock to the rental rate. We compute the rational expectation solution by adding a deterministic process of uncertainty shock to the state-space model that is obtained by implementing the second-order Taylor expansion of the system around the steady state. We then compute simulated paths conditional on the initial steady state and the deterministic process of uncertainty shock. We use the software `Dynare` to implement the above quantitative procedure.

Figure S.4.1: Transition Path after an Increase in Uncertainty: Stochastic Rental Rate



Notes: The transition paths are shown in levels. The model is based on the extended model analyzed in Section 4.3.2. In the exercise, we assume that the rental rate shock τ_t follows an AR(1) process with a persistence parameter of 0.95. The standard deviation of the innovation σ_τ is set to be 0.1. We also specify the uncertainty shock σ_t to be the same deterministic AR(1) process as that in the baseline analysis. The parameter γ_b is set to be 0.01, and the supply of the bonds B is set to be 1.95, implying a steady-state bond to GDP ratio of 15%. We set the liquidity constraint parameter ζ to 0, set the quarterly rent to price ratio to 0.01, which is consistent with data for Shanghai and Beijing. We simulated dynamic paths under the rental rate shocks, conditional on the initial steady state and the deterministic process of uncertainty shock. The procedure is implemented through the software `Dynare`. The solid lines are the mean of responses to the uncertainty shock when stochastic rental rate shocks are considered. The dashed lines represent the 90% confidence interval of the simulated responses to the uncertainty shock.

Figure S.4.2: Liquidity Constraint and the Aggregate Economy under Multiple Assets



Notes: The steady state is computed under different values of ζ; the other parameters take the same values as those in Figure 5.

higher housing prices. Appendix B.5 provides a more rigorous analysis regarding this issue. To document the impact of the liquidity constraint on the housing and real sectors, we compute the steady state of the aggregate economy under different values of ζ. Figure S.4.2 shows that a tighter liquidity constraint (ζ is larger) induces higher housing prices, which confirms our previous analysis. Furthermore, Figure S.4.2 shows that aggregate output declines when ζ increases. This occurs because higher demand for housing leads to a more severe crowding-out effect of the housing sector on the real sector.

S.5 Further Discussion on the House Purchase Limit Policy

In the analysis of housing policy, we focus on the risk-sharing channel through which the house purchase limit policy may affect the consumption dynamics. The dynamics of return on the physical capital may also affect the consumption dynamics. In this appendix, we aim to study whether the capital return has an impact on the housing market under the housing policy. To start with, we report the dynamics of rate of return on physical capital, r_t, which is defined as the marginal product of capital in real sector, i.e., $r_t = \alpha_p \frac{Y_{pt}}{K_{pt}}$. Figure S.5.1 shows that a rise in the economic uncertainty increases the equilibrium capital return r_t (solid line in the left panel). According to the definition of r_t, its response is mainly determined by the dynamics of capital stock. This is because the housing boom attracts more capital flowing from the real sector to the housing sector, as is shown in the upper-right panel of Figure S.5.1. Lower capital stock in the real sector leads to a high marginal product of capital r_t.[22] The home purchase limit policy depresses the demand for housing and thus mitigates the crowding-out effect of the housing boom. As a result, the reduction of physical capital in the production sector is less than that in the baseline model, implying a milder increase in the equilibrium capital return r_t than that in the baseline analysis (dashed lines in Figure S.5.1).

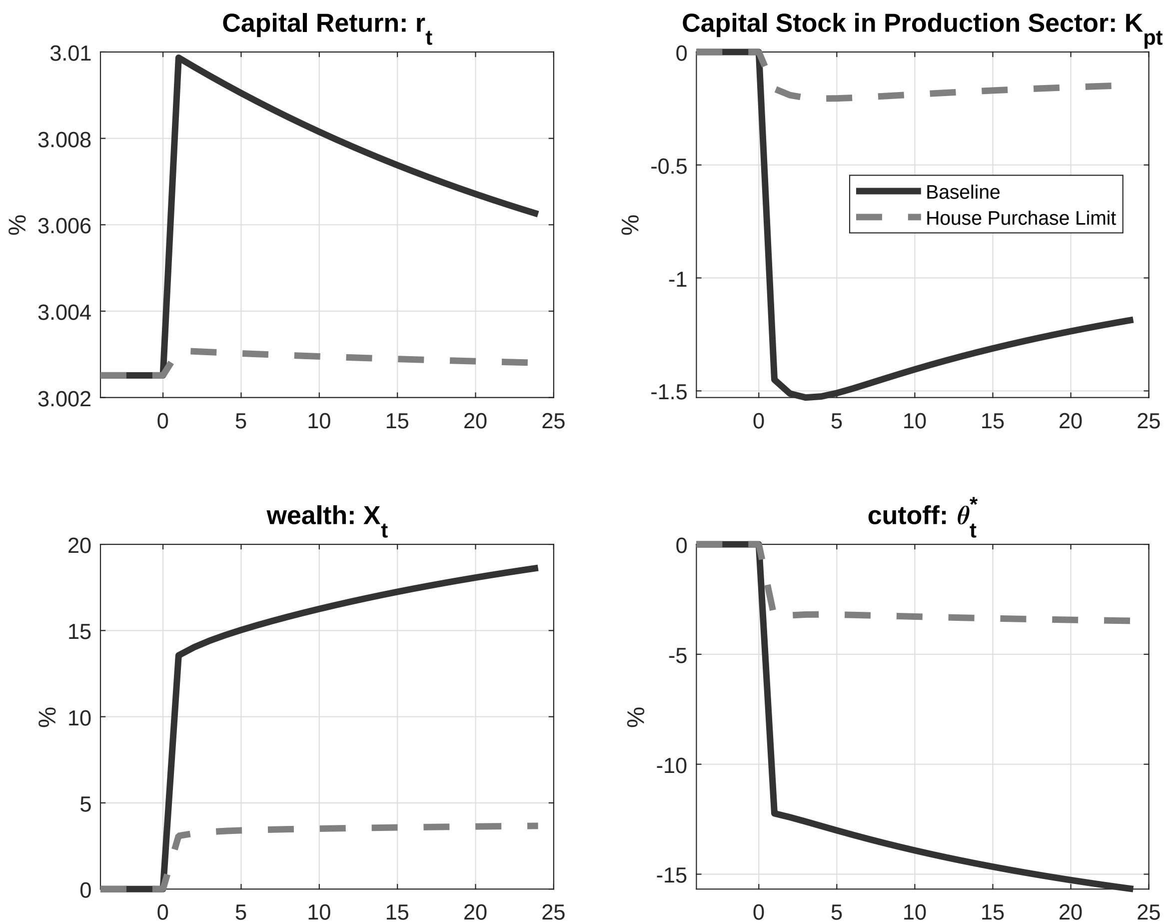
We now discuss the risk-sharing mechanism. In our analysis, we employ the partial insurance coefficient to quantify households' risk-sharing ability. We define the partial insurance coefficient as one minus the regression coefficient of individual consumption growth on the idiosyncratic shock θ_{it}. The optimal consumption rule (Eq. 34 in the main text) in the baseline model implies that

$$\log(C_{it}) = \min\{\log(\theta_{it}), \log(\theta_t^*)\} + \log(X_t). \tag{S.5.1}$$

If the households are not financially constrained ($\theta_{it} < \theta_t^*$), the consumption would achieve an optimal level $\theta_t^* X_t$ which is irrelevant to the individual states. In this case, the idiosyncratic risks can be fully insured. In contrast, for the financially constrained households ($\theta_{it} < \theta_t^*$), their consumption

[22] Notice that as we assume that physical capital can freely move across sectors, the rate of return on capital in the housing sector equates to that in the real sector. From Eq. (13) in the main text, due to the large appreciation of housing prices, the increase in the capital stock after the uncertainty shock does not reduce capital return in the housing sector.

Figure S.5.1: Dynamic Impact on Capital Return under Uncertainty Shock



Notes: This figure shows the transition paths of rate of return on physical capital r_t and capital stock in production sector K_{pt} in response to a positive uncertainty shock, which is specified to be the same deterministic AR(1) process as that in the baseline analysis. For the case of house purchase limit, the parameters are specified as the same as those in the baseline analysis. The dynamics of K_{pt}, X_t and θ_t^* are measured by the percentage deviation from the initial steady states.

is $\theta_{it}X_t$, thus the idiosyncratic risks cannot be fully insured. Figure S.5.2 below provides a graphic illustration. Under the house purchasing limit policy, the household's optimal consumption decision rule is given by

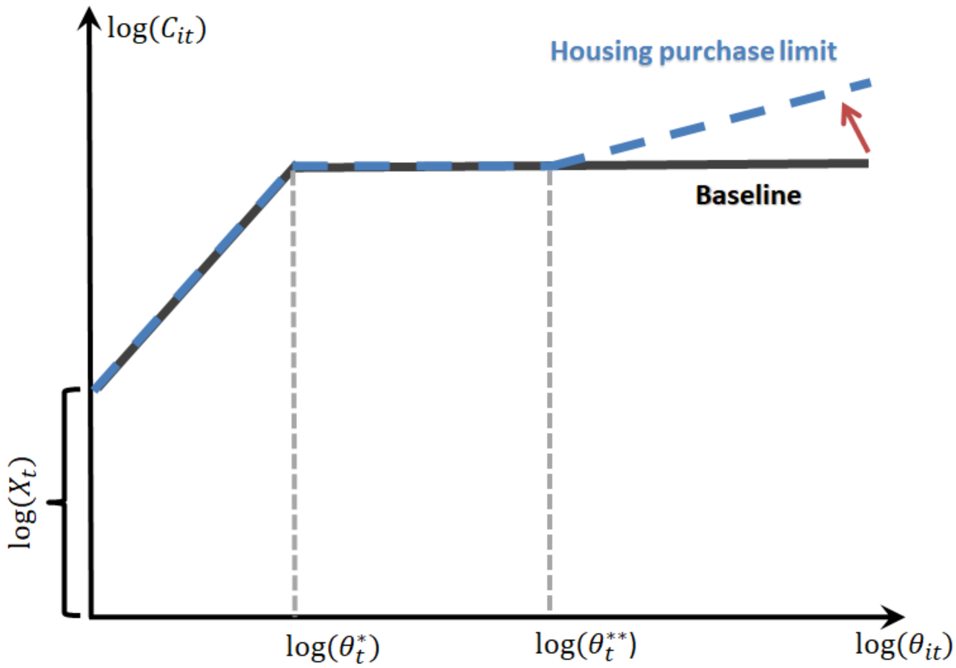
$$\log(C_{it}) = \log\left\{\left[\theta_{it}\mathbf{1}_{\{\theta_{it}\leq\theta_t^*\}} + \theta_t^*\mathbf{1}_{\{\theta_{it}^*\leq\theta_{it}<\theta_t^{**}\}} + \frac{1}{1+\phi}\theta_{it}\mathbf{1}_{\{\theta_{it}>\theta_t^{**}\}}\right]\right\} + \log(X_t). \tag{S.5.2}$$

In this case, due to the regulation, for those wealthy households ($\theta_{it} > \theta_t^{**}$), they cannot hold an optimal level of housing to insure themselves against the idiosyncratic risks, resulting in a more responsive consumption to θ_{it} shock, see the dashed line in Figure S.5.2. The optimal consumption rule implies that the partial insurance coefficient in the baseline model is larger than that in the model with housing policy since the consumption in the latter case is more volatile than that in the baseline case.

Figure 8 in the main text quantitatively illustrates how the purchase limit policy affects the household's ability of risk-sharing in the *stationary equilibrium*. We would like to emphasize that in the stationary equilibrium, the optimal consumption rule discussed above implies that the risk-sharing ability depends on the marginal propensity of consumption (MPC) since the wealth distribution in our model is degenerated, i.e., $X_{it} = X_t$. As shown in Figure S.5.2, the MPC depends on the cutoff values θ_t^*, which is determined by Eq. (B.46) in the appendix. Since the capital return, r_t is an aggregate variable that only affects the degenerated wealth X_t, it is not the primary channel through which the housing policy affects the household's risk-sharing ability.

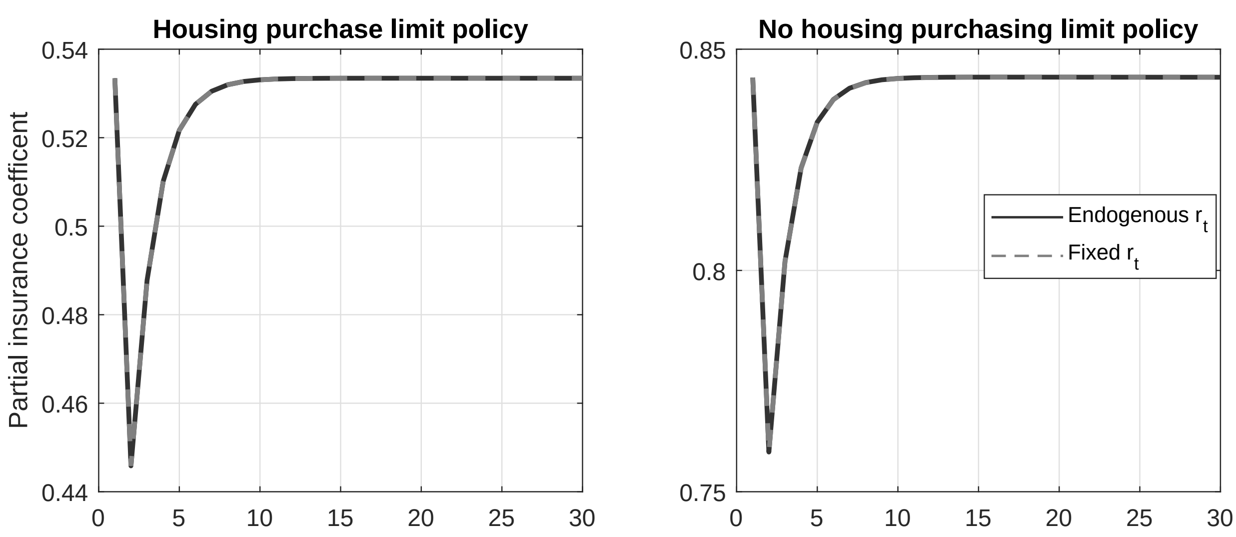
The above argument also applies to the dynamic equilibrium. In particular, we consider a quantitative exercise where the capital return r_t is forced to stay at the initial steady state. Under this setup, the channel of capital return would be completely shut down. Figure S.5.3 reports the dynamics of partial insurance coefficients in response to a positive uncertainty shock in the model with an endogenous r_t and in the one with a constant r_t. The figure shows that both a higher uncertainty and the housing policy weaken the households' risk-sharing ability. More importantly, the dynamic paths of partial insurance coefficients in the two cases are visibly the same, implying that the capital return plays a minor role in changing the household's risk-sharing ability.

Figure S.5.2: Optimal Consumption Rule in the Model with/without Policies



Notes: This figure shows the optimal consumption rules under different models. The solid line is for the baseline model and the dashed line is for the model with house purchase limit policy.

Figure S.5.3: Partial Insurance Coefficients in the Dynamic Equilibrium



Notes: This figure reports the dynamic of partial insurance coefficients in response to a positive uncertainty shock under different models. The solid line is for the model with an endogenous capital return r_t, and the dashed line is for the model with a fixed capital return r_t, which is set to stay at the initial steady state. The left panel is for the case where housing purchase limit policy is introduced. The right panel is for the case without the housing policy. The uncertainty σ_t is set to follow an AR(1) process: $\log(\sigma_t/\sigma) = \rho \log(\sigma_{t-1}/\sigma) + \varepsilon_t$, where σ and ρ are set to be the same as those in the baseline analysis. In the first period, we assume that a 25% of uncertainty shock ε_t hits the economy. In each period, we compute the partial insurance coefficient according to the approach in Figure 8 in the main text.

S.6 Sensitivity Analysis on Parameter Values

Parameter value of σ In our quantitative analysis, we calibrate the standard deviation parameter σ by matching the model-implied Gini coefficient of housing asset with that in the CHFS survey data. The calibration procedure gives a value of 0.9775. The high value of σ is probably because the idiosyncratic shock θ_{it} in our model is i.i.d over time, which guarantees an analytical form of individual decisions and a tractable evolution of distributions. In our calibration exercise, we do not employ the moments of income uncertainty observed in the data because the shock and its process in our model cannot be directly compared with their counterparts in the data. Our main results are robust regarding the value of σ. Figure S.6.1 reports the transition dynamics in response to uncertainty shocks in the benchmark model under a wide range of parameter values of σ.[23] As the figure shows, a positive uncertainty shock leads to a housing boom, which crowds out the real economy. This pattern presents for the different values of σ, implying that the mechanism discussed in our paper is robust for the level of σ.

Besides, the analysis of consumption distortions presented in Figure 7 in the main text is robust for different values of σ. Figure S.6.2 reports the main results under different values of σ.

Parameter value of ϕ In the extended model with purchase limit policy, our model's setup of policy is isomorphic a borrowing constraint on housing purchases. To see this, we start from the purchase limit policy, which is assumed that the amount of housing purchased by a household cannot exceed a limit. In our setup, we assume that the upper limit is proportional to its consumption:

$$q_{ht}H_{it+1} \leq \phi C_{it}. \tag{S.6.1}$$

From the budget constraint $C_{it} + q_{ht}H_{it+1} = \theta_{it}X_{it}$, the constraint (S.6.1) is equivalent to the setup where the purchase limit is proportional to the wealth $\theta_{it}X_{it}$ in hand, i.e.,

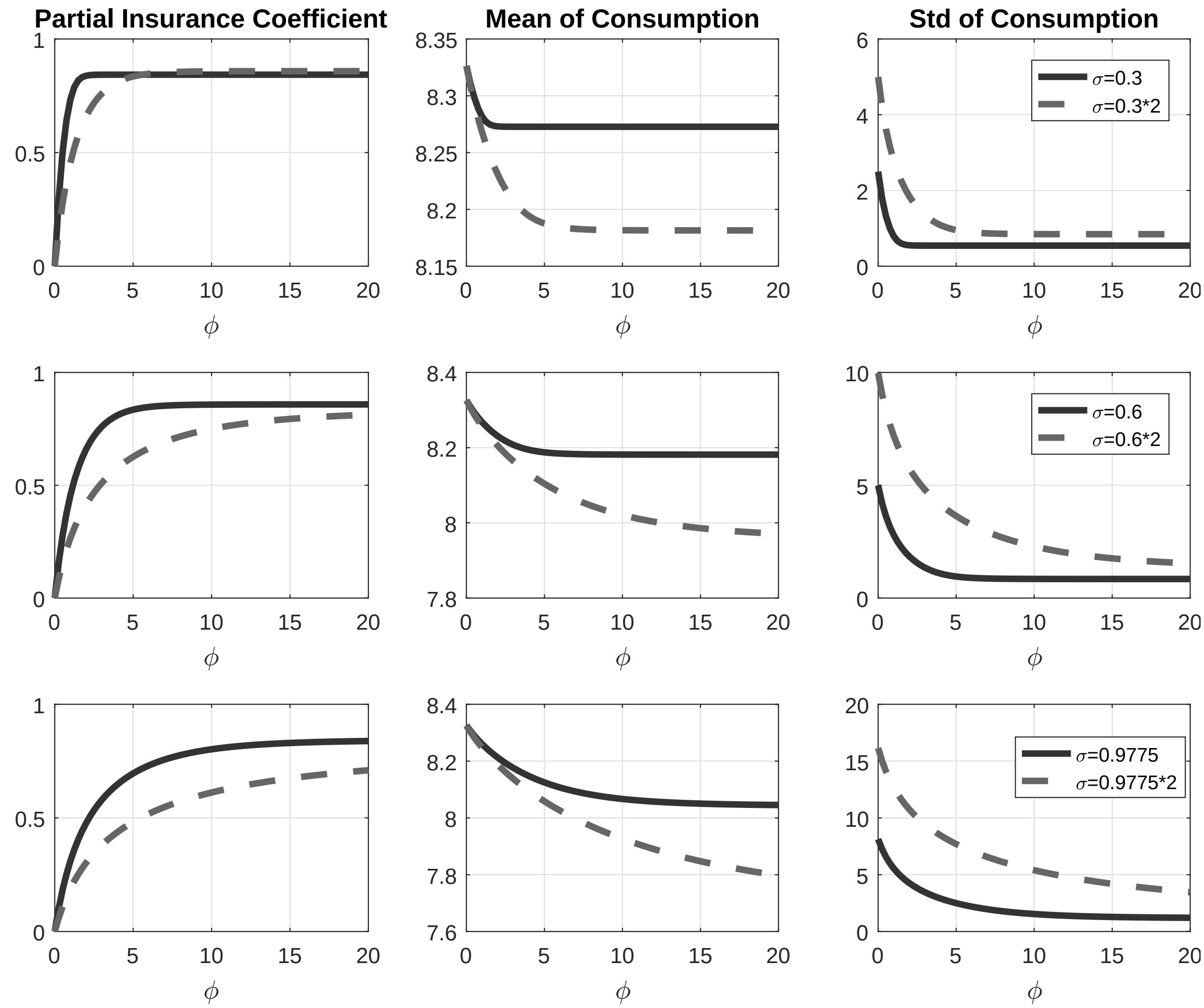
$$q_{ht}H_{it+1} \leq \bar{\phi}\theta_{it}X_{it}, \tag{S.6.2}$$

[23] Similar results can be found in the model with house purchase limit policy.

Figure S.6.1: Transition Path after an Increase in Uncertainty under Different Values of σ

Notes: The transition paths for different values of σ are shown in the percentage deviation from the initial level. We specify the persistence of the AR(1) process of σ_t to be 0.5.

Figure S.6.2: Consumption Distortion caused by the Policy that Limits Housing Purchases under Different Values of σ



Notes: The distribution of consumption is obtained by computing the consumption expenditures of 100,000 households with i.i.d idiosyncratic shocks θ_{it} in the stationary equilibrium. The parameter values except ϕ and σ are set according to the calibration values shown in Table 4. The parameter values for σ are $\{0.3, 0.6, 0.9775\}$. The corresponding results are presented by solid lines. The dashed lines report the results when the uncertainty increases by two times. The partial insurance coefficient is computed according to Blundell et al. (2008), which is the estimation coefficient obtained through regressing individual consumption growth $\Delta \log(C_{it})$ on the log of idiosyncratic shock θ_{it}.

where $\bar{\phi} = \frac{\phi}{1+\phi}$. The above constraint is essentially a borrowing constraint in house purchases. To see this, we assume the individual household i can finance her total expenditure of house purchases $q_{ht}H_{it+1}$ through an intra-temporal loan market as that in Miao and Wang (2018).[24] The borrowing capacity takes a Kiyotaki-Moore type of collateral constraint, where the total collateral value is proportional to the household's net worth. The parameter $\bar{\phi}$, in this case, indicates the tightness of the borrowing constraint. Therefore, the value of 2.5 for the parameter ϕ implies a borrowing constraint parameter of 0.7 ($= \frac{2.5}{1+2.5}$). Because the mean of θ_{it} is 1, the inequality implies that housing asset has to be less than 70% of total households' wealth, which is a reasonable number. Besides, the main results in Section 5.2 remain valid for different values of ϕ. Figure S.6.3 reports the results of sensitivity analysis.

[24] Alternatively, we could extend the model with multiple stores of value in Section 4.3.2 by introducing the above borrowing constraint and an inter-temporal loan market. The analysis changes little.

Figure S.6.3: Transition Path under the Policy that Limits Housing Purchases with Different Values of ϕ

Notes: The transition is computed by assuming that uncertainty σ_t increases permanently by 25%. For the purchase limit case, the parameter ϕ is set to $\{0.5, 2.5, 5\}$, respectively, and for the baseline case, $\phi = \infty$. The other parameter values are set according to the calibration values shown in Table 5.