Credit Supply versus Housing Demand in the U.S. Boom-Bust Cycle*

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Abstract

We present two sets of evidence demonstrating that credit supply played a quantitatively significant role in the US housing market circa 2008. First, we develop a general equilibrium model featuring heterogeneous households who make housing tenure decisions and take out long-term mortgages, firms that acquire working capital through short-term bank loans, and banks whose ability to intermediate funds depends on their capital. Second, we provide bank- and county-level empirical evidence supporting the credit supply mechanism. Our quantitative findings show that changes in credit supply, stemming from exogenous shocks to bank leverage and/or endogenous shifts in bank balance sheets, played a significant role in the housing market boom-bust and the overall economy. While a housing demand shock substantially contributed to the house price boom, it had little to no impact on output and wages and played a smaller role in driving consumption. Furthermore, our analysis shows that credit supply expansion causes a decline in the bank lending rate and an increase in both mortgage debt and firm loans, generating positive comovement between them. Conversely, an increase in housing demand raises mortgage demand, causing the bank lending rate to increase and firms to reduce borrowing, thereby generating negative comovement between mortgage debt and firm loans. Our empirical evidence supports the credit supply mechanism.

JEL Codes: E21, E32, E44, G21, G51.
Keywords: Credit Supply; House Prices; Financial Crises; Household, Firm, and Bank Balance Sheets; Leverage; Foreclosures, Mortgages; Consumption; and Output.

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1 Introduction

Understanding the drivers of the housing boom and the subsequent 2008 financial crisis remains crucial for both economic policy and theory. Two competing theories have been proposed to explain the boom and the bust. Early research emphasized the role of credit supply in driving both the boom and the severe economic bust. Prominent examples include Mian and Sufi (2009), Shin (2012), Jermann and Quadrini (2012), Chodorow-Reich (2013), Favara and Imbs (2015), Landvoigt et al. (2015), Jensen and Johannesen (2017), Justiniano et al. (2019), and Favilukis et al. (2017). More recent work, however, argues that shifts in housing demand, which in turn affects credit demand rather than credit supply, were the primary driver of the boom-bust cycle (Adelino et al. (2016) and Kaplan et al. (2020)).[1]

In this paper, we present two sets of evidence demonstrating that credit supply played a quantitatively significant role. Our first set of evidence comes from a quantitative general equilibrium model that is built deliberately on Kaplan et al. (2020) who argue that the shifts in credit supply does not generate significant changes in house prices in the presence of rental market for housing and long-term mortgages. In particular, we also model the household sector as overlapping generations facing idiosyncratic income risk under incomplete markets, making housing tenure decisions, and borrowing through long-term defaultable mortgages. However, we extend their framework in two crucial ways that prove essential for understanding the role of credit supply. First, we explicitly model bank balance sheet constraints: banks issue short-term loans to firms and long-term mortgages to households, but their ability to intermediate funds depends on their capital. The balance sheet constraint makes the credit supply dependent on bank equity and hence bank leverage. Second, we incorporate firms' financial dependence by modeling their need for working capital loans from banks. Our second set of evidence provides empirical support for the credit supply mechanism studied in our quantitative model.

The tight link between bank leverage and credit supply allows us to study the effect of credit supply changes resulting from changes in bank leverage, which is observed in the data. To study the boom-bust episode, we first calibrate the model to match several US data moments regarding household and bank balance sheets before 1998. We then introduce an unexpected credit supply shock by increasing bank leverage, calibrated so that the bank

[1]See Gertler and Gilchrist (2018) for a review of the crisis and the literature.

leverage matches the observed rise in the data. This shock alone accounts for 35 percent of the house price increase from 1998 to 2006. To account for the remaining portion of the house price boom, we also introduce a housing demand shock, following Kaplan et al. (2020), concurrently with the leverage shock. We incorporate the housing demand shock for three reasons. First, we aim to understand the relative contributions of these shocks not only to house prices but also to the broader economy. Second, even if our focus were solely on the effects of the leverage shock, potential interactions between the two shocks could amplify or dampen each other's impact.[2] Finally and most importantly, we show that these shocks generate different co-movements across aggregates we can test in the data, which, as we illustrate, provide further support for the credit supply channel. In 2008, both shocks are reverted to their initial steady-state values, triggering the financial crisis. Despite not being a calibrated target, the bank leverage declines during the bust similar to data.

The benchmark economy features a boom-bust cycle similar to the one observed in the US: house prices, GDP, consumption, bank loans, mortgage debt, firm lending, and bank leverage rise significantly during the boom and contract sharply during the bust, and the credit spread spikes at the time of the bust, consistent with the data.

We start by comparing the implications of credit supply versus housing demand shocks. First, exogenous shocks to bank leverage translate into changes in bank credit supply, which in turn affect the equilibrium bank lending rate. Changes in the bank lending rate affect model dynamics both *directly* via household borrowing costs and *indirectly* through their effect on labor income (since firms partly depend on bank borrowing). The housing demand shock, on the other hand, affects household wealth and the collateral constraint via its effect on house prices. Furthermore, during the bust, both shocks cause a deterioration of bank balance sheets due to lower mortgage valuations and increased foreclosures. Consequently, banks are forced to reduce credit supply in response to declines in their equity, further amplifying the effects of each shock.

Our results show that the bank leverage shock accounts for almost all of the decline in the bank lending rate, the rise in output, firm lending in the model during the boom. It also accounts for more than one-third of the increase in house prices, more than half of the increases in mortgage debt and consumption. The housing demand shock, on the other

[2] Indeed, as we show in Section 5.1, the two shocks together generate booms in aggregates that are larger than the sum of the booms generated by each shock individually.

hand, accounts for a larger increase in house prices, but significantly smaller increases in consumption and mortgage debt. However, it counterfactually generates a bust in the real sector during the boom by *reducing* output, wages, and firm lending.

Through a series of experiments, we quantify the role of credit supply in the boom-bust. First, we analyze the effects of the changes in the equilibrium bank lending rate of our benchmark economy. We find that the decline in the bank lending rate during the boom accounts for one-third of the increase in house prices and three-quarters of the increase in consumption, closely mirroring the effects of the leverage shock, which is the main driver of the changes in the lending rate during this period. We then explore how the changes in the bank lending rate affect consumption and house prices *directly* through household borrowing costs and *indirectly* through firm borrowing costs and hence wages. Our analysis reveals that, during the boom, the direct and indirect effects are comparable for house prices; however, the indirect effect is far more important for consumption since the change in consumption is driven by changes in both house prices and wages.

During the bust, both shocks have markedly larger effects on all aggregates than during the boom because the deterioration of bank balance sheets, previously described, leads to a spike in the bank lending rate, which amplifies the downturn. Consequently, the bank lending rate has larger effects during the bust, accounting for half of the decline in house prices and 80 percent of the drop in consumption. Unlike during the boom, where the lending rate was influenced purely by the bank leverage shock, the spike during the bust is driven by both shocks. As in the boom, the lending rate's direct and indirect effects on house prices are comparable, while for consumption, the indirect effect remains more important.

Second, we quantify the amplification arising from the bank balance sheet deterioration and find that it accounts for about 90 percent of the benchmark economy's decline in labor income, one-third of the decline in house prices, and more than half of the decline in consumption. These results imply that the bank balance sheet deterioration amplifies the bust in variables that depend on short-term debt, such as labor income, but it has a relatively smaller effect on house prices, which depend on long-term debt, and a somewhat intermediate effect on consumption, which is driven by both house prices and labor income.[3] When we decompose the effect of the spike into its direct and indirect effects, we find similar effects on

[3] Gertler and Gilchrist (2018) provide evidence that the disruption in banking, as in our model, was central to the overall employment contraction in the data.

house prices; however, the indirect effect is more important for the decline in consumption, as in the previous experiment.

Third, we show that the endogenous changes credit supply amplify even the effect of the housing demand shock during the bust. The large drop in house prices significantly raises foreclosure rates, which erodes bank net worth and, in turn, constrains credit supply. As a result, the bank lending rate rises, increasing borrowing costs for both households and firms. Firms respond by reducing labor demand, leading to a decline in equilibrium wages. Consequently, different from the boom, the housing demand shock does not only reduce house prices, but also reduces output and wages significantly. We find that the endogenous decline in credit supply accounts for one-third of the overall effect of the housing demand shock on house prices and more than half of its effect on consumption during the bust.[4] As in the previous exercises, we further quantify the direct and indirect effects of this credit supply channel. While its direct and indirect effects are both important for house prices, its indirect effect turns out to be more important for consumption, a recurring theme that is present in all three experiments. Overall, we find that the credit supply channel matters during the bust even if the bust is a result of the housing demand shock. The same endogenous credit supply channel also amplifies the impact of the exogenous bank leverage shock during the bust.

The model's credit supply mechanism aligns with several empirical patterns, including some previously interpreted as evidence against it. Notably, the model's cross-sectional predictions match recent micro-level evidence showing that credit expanded uniformly across income quantiles during the boom Adelino et al. (2016), Foote et al. (2016), and Albanesi et al. (2017)). While earlier literature suggested credit supply expansions primarily affected lower-income households, leading some to view this uniform pattern as contradicting the credit supply channel, our model demonstrates that credit supply alone can generate such uniform expansion.

Furthermore, our analysis reveals distinct and testable implications of credit supply and housing demand shocks. In a credit supply-driven boom, declining bank lending rates increase both mortgage and firm borrowing through lower borrowing costs, creating positive comovement between mortgages and firm loans. Conversely, a housing demand shock raises equilibrium bank lending rates, which increases household mortgage debt but reduces firm

[4]During the boom, the credit supply response to the housing demand shock is negligible.

loans due to higher borrowing costs.

We provide empirical evidence that supports our model's credit supply mechanism through three key findings. First, using bank and county-level data, we document a strong positive correlation between mortgage and firm loan growth. This parallel movement is consistent with the credit supply channel, rather than housing demand shocks. Second, we test the model's key transmission mechanism: that credit supply-induced reduction in interest rates stimulates economic activity through both mortgage and firm lending channels. Consistent with this prediction, we find that counties experiencing declining mortgage interest rates showed simultaneous increases in housing market activity, firm lending, household incomes, and employment during the boom. Third, examining bank-level data during both the boom (1998-2006) and bust (2006-2011) periods, we find that changes in bank leverage coincided with changes in mortgage lending, commercial lending, and interest rates in ways that align with the credit supply channel in our model.

Related literature

Our paper contributes to the literature that studies the dynamics of the housing market and the macroeconomy around the 2008 financial crisis. Using a model of representative borrower and saver, Justiniano et al. (2019) demonstrate that credit supply, driven by looser lending constraints in the mortgage market, accounts for the unprecedented rise in home prices, the surge in household debt, the stability of debt relative to home values, and the fall in mortgage rates.[5] However, Kaplan et al. (2020) argue that the absence of the rental market and/or long-term defaultable mortgages are critical for obtaining large effects of credit conditions on house prices since, with rental markets, households can rent a house of their desired size if they are constrained in purchasing one. With these extensions, Kaplan et al. (2020) argue that shifts in household demand due to shocks to house price expectations, rather than changes in credit conditions, were the main driving force behind the boom-bust cycle in the housing market. They also find that temporary shocks to interest rate, essentially

[5] In a similar vein, Kiyotaki et al. (2011) and Adam et al. (2012) find that the decline in interest rates contributed substantially to the house price boom in the U.S. On the other hand, Greenwald (2016), using representative borrower and savers, and Huo and Rios-Rull (2013), Sommer et al. (2013), and Favilukis et al. (2017), using heterogeneous agent frameworks, show that changes in maximum LTV or payment-to-income (PTI) ratios can generate significant changes in house prices and consumption. At the macroeconomic level, focusing on the business cycles including the 2008 crisis, Jermann and Quadrini (2012) find that shocks to firms' financing conditions significantly influence the dynamics of real and financial variables.

a credit supply shock, does not move house prices.

Despite modeling a detailed household structure, similar to Kaplan et al. (2020), we find a more significant role for credit supply due to two key differences.[6] First, we consider permanent changes in bank leverage, calibrated to match the observed changes in the data, which generates permanent changes in the bank lending rate, rather than the LTV, PTI, or temporary interest rate shocks. Second, the credit supply shock in our framework is not an isolated shock to households since firms also need to borrow from banks to produce output. Thus, the changes in credit supply—due to exogenous shocks to bank leverage and/or endogenous changes in bank balance sheets—generate changes in the bank lending rate, which then affect households both directly through their borrowing cost and indirectly through firm borrowing costs. This, in turn, creates a boom-bust cycle in the housing market and the rest of the macroeconomy. We further provide empirical evidence for the correlated responses of household and firm borrowing in response to changes in bank lending rate. Moreover, our analysis highlights the importance of endogenous contractions in credit supply due to deteriorating bank balance sheets in amplifying the crisis.

Landvoigt (2016), Diamond and Landvoigt (2022), and Nord et al. (2024) also combine banking and household sectors, as in our model.[7] Our paper has many points of contact with Diamond and Landvoigt (2022), who also show the importance of credit supply for the boom-bust in house prices and mortgage debt. Different from Landvoigt (2016) and Diamond and Landvoigt (2022), we model the feedback from banks' credit supply to firm borrowing, which significantly contributes to the boom-bust. Furthermore, the richer heterogeneity in our household sector allows us to compare our model's implications with cross-sectional facts, which were argued to be against the credit supply channel. Nord et al. (2024) study distributional effects of banking sector losses.

Mechanisms in our model are supported by empirical findings as well. First, with detailed data from periods after 1996, Fraisse et al. (2020), Gropp et al. (2019), Aiyar et al. (2014), De Marco et al. (2021), Jiménez et al. (2017), and Gete and Reher (2018), causally link regulatory tightenings to declines in credit, and contractions in economic activity. Second,

[6]Nevertheless, we confirm their findings that LTV, PTI, or temporary interest rate shocks barely move house prices.

[7]Elenev (2017), Elenev et al. (2016), and Elenev et al. (2018) also use an approach similar to these papers to address different questions from ours.

Gilchrist and Zakrajšek (2012) and Gertler and Gilchrist (2018) show that credit spreads spike during downturns, predicting declines in subsequent economic activity. The credit spread dynamics in our model are similar to the excess bond premium dynamics reported in these papers. Third, Glaeser et al. (2012) and Justiniano et al. (2019) find that interest rates on firm loans and mortgages declined during the boom. Jayaratne and Strahan (1997) and Favara and Imbs (2015) find significant declines in lending interest rates after the branching deregulation in the US. For the crisis period, Ivashina and Scharfstein (2010) document a more than 50 percent decline in capital expenditure and working capital loans to corporations. Similarly, Adrian et al. (2013) find that capital expenditure and working capital loans to firms have declined substantially, while interest rates on loans more than quadrupled during the crisis. We provide additional support for the credit supply mechanism.

Finally, our framework combines key elements from two strands of literature. On the one hand, an active literature studies the pricing of default risk in the context of household debt, but abstracting from the bank balance sheet effects.[8] On the other hand, the literature on bank balance sheets has studied how depletion of banks' capital reduces their ability to intermediate funds.[9] However, in this literature, banks' asset structure typically takes a simple form, such as one-period bonds, or lacks the rich heterogeneity observed in banks' portfolios. By combining these two strands of the literature, our model allows us to study the rich interactions among households, firms, and banks.

2 Quantitative Model

The model economy is composed of five sectors: (i) households, (ii) financial intermediaries (banks), (iii) rental companies, (iv) firms, and (v) the government.

Total housing stock is fixed at $\bar{\mathrm{H}}$, but the homeownership rate is not. This becomes possible as part of the housing stock is owned by homeowners and the rest is owned by rental companies who rent it to the households. There is perfect competition in all markets.

[8] Among others see Chatterjee et al. (2007), Livshits et al. (2010, 2007), Jeske et al. (2013), Corbae and Quintin (2015), Chatterjee and Eyigungor (2015), Arslan et al. (2015), Guler (2015), Hatchondo et al. (2015), Mitman (2016), Gete and Zecchetto (2024), Kaplan et al. (2020), and Garriga and Hedlund (2020).

[9] See Mendoza and Quadrini (2010), Gertler and Kiyotaki (2010, 2015), Gertler and Karadi (2011), Bianchi and Bigio (2014), and Corbae and D'Erasmo (2013, 2019). See also Bernanke and Gertler (1989), Bernanke et al. (1999), Kiyotaki and Moore (1997), and Buera and Moll (2015) which have studied the financial accelerator mechanism in the context of non-financial firms.

There is no aggregate uncertainty. Boom-bust transitions are generated by two unexpected shocks, both perceived as permanent. Other than the shock periods, there is perfect foresight. Since households are ex post heterogeneous, all the endogenous prices, value functions, and policy functions depend on the aggregate state of the economy and the distribution of households. For notational convenience, we suppress these dependencies.

2.1 Households

We assume that households supply labor inelastically until the mandatory retirement age J_r and live until age J (with $J > J_r$). A household's income process $y(j, z_j)$ is given by $y(j, z_j) = (1 - \tau)\, w \exp(f(j) + z_j)$ for $j \leqslant J_r$ and $y(j, z_j) = w y_R(z_{J_r})$ for $j > J_r$, where $f(j)$ captures the deterministic life-cycle component of income and z_j captures the stochastic component of income modelled as an AR(1) process: $z_j = \rho_\varepsilon z_{j-1} + \varepsilon_j$ with $\varepsilon_j \sim \text{i.i.d. } N(0, \sigma_\varepsilon^2)$. The variable w is the wage per efficiency units of labor, and τ is the labor income tax rate. Function $y_R(z_{J_r})$ approximates the US retirement system.

Households receive utility from consumption and housing services and can choose between renting and owning a house of their desired size. Household preferences take the Epstein-Zin recursive utility formulation:

$$V_{j,i} = \left(u\left(c_j^i, s_j^i\right) + \beta E_j \left(V_{j+1,i}^{1-\sigma}\right)^{\frac{1-\rho}{1-\sigma}} \right)^{\frac{1}{1-\rho}},$$

where E_0 is the expectations operator, β is the discount factor, c_j^i is consumption, and s_j^i is housing services at age j for individual i.[10]

Housing Choices: Households enter the economy as *active* renters and can stay as renters by renting a house at the desired size at the price p_r per unit. They can also purchase a house and become homeowners at any time. There is no unsecured borrowing in the model. However, households have access to the mortgage market to finance their housing purchases subject to a minimum down payment requirement. The terms of mortgage contracts, down payment, and mortgage pricing are endogenous and depend on household characteristics.

[10]In the benchmark model, we assume $\rho = \sigma$ which reduces the preferences to the standard power utility over the composite good. Epstein-Zin formulation of the preferences help us with a more accurate computation of the quantitative model. We also conduct robustness analysis with respect to the risk aversion parameter, σ, and the parameter governing elasticity of intertemporal substitution, ρ, separately in the Internet Appendix.

Homeowners can choose to stay as homeowners or become renters again, by either selling their houses or defaulting on mortgages. Homeowners can pay the existing mortgage or obtain a new one through refinancing. Households also can upgrade or downgrade their houses by selling the current house and buying a new one.[11]

Several transaction costs are associated with housing market transactions. A seller has to pay φ_s fraction of the selling price. Obtaining a mortgage from banks involves a fixed cost (φ_f) and a variable cost (φ_m) as a fraction of the mortgage debt at the origination.

Defaulting on a mortgage is possible but costly. After default, households become *inactive* renters; that is, they temporarily lose access to the mortgage market. Inactive renters become active renters with probability π. Therefore, agents have three statuses regarding their housing decision: homeowner, active renter, or inactive renter.

Mortgage Payments: For tractability, we assume that mortgages are due by the end of life, so that the household's age captures the maturity of the mortgage contract. We also allow for only fixed rate mortgages. Therefore, the mortgage contract can be characterized by its maturity and the periodic mortgage payment m. We assume that the mortgage payments follow the standard amortization formula computed at the bank lending rate r_ℓ.[12]

Optimization Problem of Households: We present the optimization problem of a purchaser here (the rest of the optimization problems are in Appendix B.1). If an active renter chooses to purchase a house, she chooses the mortgage debt level d that determines $q^m(d; a', h, z, j)$, the price of the mortgage at the origination, which is a function of the current state of the household (income realization z and age j), house size h, and asset choice a'. Then, the optimization problem of an active renter who chooses to buy a house is given by

$$V_j^{rh}(a, z) = \max_{c,d,h,a' \geqslant 0} \left\{ \left(u(c, h) + \beta E \left(V_{j+1}^h (a', h, d, z')^{1-\sigma} \right)^{\frac{1-\rho}{1-\sigma}} \right)^{\frac{1}{1-\rho}} \right\} \tag{1}$$

[11]The household sector builds on the ones in Arslan et al. (2015) and Guler (2015) but is extended in important ways, such as refinancing, flexible housing and rental sizes.

[12]The mortgage interest rate differs across households since ex post households are heterogeneous. Ideally, the amortization schedule should be computed at the individual mortgage interest rate instead of risk-free lending rate r_ℓ. However, to avoid using an additional state variable, we assume that mortgage amortization is computed at r_ℓ, as in Hatchondo et al. (2015) and Kaplan et al. (2020). Then, individual default risk will show up in the pricing of the mortgages at the origination rather than in the mortgage interest rate. Thus, essentially all households pay a premium (buy points) at the origination to reduce the mortgage interest rate to risk-free lending rate r_ℓ.

subject to

$$\begin{aligned} c + (1+\delta_h)\, p_h h + \varphi_f + a' &= y(j,z) + a\,(1+r_k) + d\,(q^m(d;a',h,z,j) - \varphi_m)\,, \\ d &\leqslant (1-\iota)\, p_h h, \end{aligned}$$

where V^h is the continuation value for a homeowner, p_h is the house price, δ_h is the proportional maintenance cost of housing, r_k is the rate of return on financial assets, and ι is the minimum down payment requirement.

2.2 Firms

A continuum of perfectly competitive firms produce output by combining capital K and labor N. The firm also chooses hours per worker (or labor utilization rate), u. The wage per efficiency units of a worker $w(\overline{w}, u)$ (same as w in $y(j, z_j)$) is assumed to depend on the hours worked, that is, $w(\overline{w}, u) = \bar{w} + \vartheta \frac{u^{1+\psi}}{1+\psi}$, where ϑ and ψ are constants. In this formulation, hours are chosen by the firm, and workers are assumed to supply hours at no cost, but u, $\overline{w}$, and hence $w(\overline{w}, u)$ are determined in equilibrium. This formulation generates a positive relation between aggregate hours and wages that mimics an aggregate labor supply response to aggregate wages.[13]

Following Cooley and Quadrini (1999, 2004), Mendoza (2010), and Jermann and Quadrini (2012), we assume that the firm finances a fraction μ of the wage payment in advance from banks and pays interest on that portion. Then, the firm's problem is given by

$$\max_{K,N,u} \mathbb{Z}K^{\alpha}(Nu)^{1-\alpha} - (r_k + \delta_k)K - (1 + \mu r_{\ell})\, w(\overline{w}, u)\, N, \tag{2}$$

where $\mathbb{Z}$ is TFP, and δ_k is the depreciation rate of capital. Since a worker's labor income depends on hours worked, labor income and output decline when the firm reduces work hours in response to an increase in bank lending rate r_{ℓ}.[14]

[13]In the Internet Appendix, we show that this formulation is equivalent to assuming no labor utilization on firms but flexible labor supply for households together with GHH preferences for labor.

[14]We could have achieved the same effect with endogenous labor supply. In that case, the firm would reduce labor demand, which would reduce wages. Households would reduce labor supply and output would decline. We choose this formulation because it is easier to handle computationally.

2.3 Rental Companies

A rental company enters the period with $(1-\delta_h) H_r$ units of rental housing stock where δ_h is the depreciation rate of housing. Then, it chooses H_r'. In that period, the company receives net rent $(p_r - \kappa) H_r'$ and pays dividend $x_r = p_h (1-\delta_h) H_r - p_h H_r' - \frac{\eta}{2} p_h (H_r' - H_r)^2 + (p_r - \kappa) H_r'$ to shareholders where p_r is the rental price per unit of housing and κ is the maintenance cost. The expression $\frac{\eta}{2} p_h (H_r' - H_r)^2$ is the quadratic adjustment cost of changing rental supply. A higher η implies a more segmented housing market. The objective of the real estate companies is to maximize its total market value:

$$(1+r_k) V^{rc}(H_r) = \max_{H_r'} p_h (1-\delta_h) H_t - p_h H_r' - \frac{\eta p_h (H_r' - H_r)^2}{2} + (p_r - \kappa) H_r' + V^{rc}(H_r'), \tag{3}$$

Since both capital and rental company shares are riskless in the steady state and along the transition path, both assets pay the same return except for the two unanticipated shock periods.[15] Given this, the first-order condition of the rental company gives the rental price as a function of house price and rental housing stock:

$$p_r = \kappa + p_h + \eta p_h (H_r' - H_r) - \frac{(1-\delta_h) p_h' + \eta p_h' (H_r'' - H_r')}{1 + r_k'}. \tag{4}$$

This formulates the supply for the rental housing. The demand for rental housing comes from households' housing choices.

2.4 Banks

We assume a competitive banking industry with a continuum of identical banks that are risk-averse and maximize the presented discounted value of utility from consumption: $u(c^B)$, where c^B is the banker's consumption. There is no entry or exit from the banking sector. Banks fund their operations from their net worth ω and by borrowing B' in the international market at a risk-free interest rate r'. They lend L_k' to the firm at r_ℓ', and issue mortgages and purchase existing mortgages.

[15] At the time of an unexpected shock, capital and the rental housing return could be different. Then, the realized return will be different from the contracted return, and these profits/losses are borne by the households proportional to their asset holdings.

Let $\theta = (d; a, h, z, j)$ define the type of a mortgage, ω be the bank's net worth, and $\ell'(\theta)$ be the amount of investment in mortgage type θ (which includes any newly issued as well as existing mortgages). Then, the bank's problem is given by

$$\Psi(L, B) = \max_{\{c^B, L'_k, \ell, B'\}} \left\{ \log\left(c^B\right) + \beta_L \Psi(L', B') \right\} \tag{5}$$

$$c^B + L'_k + \int_\theta p_\ell(\theta)\, \ell'(\theta) = \omega + B',$$

where β_L is the banker's discount factor, $p_\ell(\theta)$ is the price of a type-θ mortgage. The bank's net worth evolves according to

$$\omega' = \int_\theta \int_{\theta'} \nu^l(\theta')\, \Pi(\theta'|\theta)\, \ell'(\theta) + L'_k\left(1 + r'_\ell\right) - B'\left(1 + r'\right),$$

where $\nu^l(\theta) = m_\ell(\theta) + p_\ell(\theta)$, $\Pi(\theta'|\theta)$ is the endogenous transition probability governed by exogenous household characteristics and choices, and $m_\ell(\theta)$ is the mortgage payment banks receive from a household with current state vector θ These payments depend on the actions of the homeowners. If the homeowner sells the house or refinances the mortgage, it is equal to the remaining mortgage principle, d. If the homeowner defaults on the mortgage, it is equal to the resale value of the house, $p_h h(1 - \varphi_e)$. Lastly, if the homeowner chooses to stay in the current house, it is equal to the periodic mortgage payment, which depends on the maturity tied to the age of the individual, mortgage interest rate, r_ℓ, and mortgage principle, d:

$$m_\ell(\theta) = \begin{cases} d & \text{if sell/refinance} \\ p_h h(1 - \varphi_e) & \text{if default} \\ \frac{r_\ell(1+r_\ell)^{J-j}}{(1+r_\ell)^{J-j+1}-1} d & \text{if stay} \end{cases} \tag{6}$$

Banks can default at the beginning of a period by stealing a fraction ξ of their assets and not paying back their creditors. When it does so, it is excluded from banking operations in the future but can save at rate r. We denote the bank's value of default by $\tilde{\Psi}^D\left(\xi \tilde{L}'\right)$, where $\tilde{L}' = \left(\int_\theta \int_{\theta'} \nu^l(\theta')\, \Pi(\theta'|\theta)\, \ell'(\theta) + L'_k\left(1 + r'_\ell\right)\right)$. The expression $L' = L'_k + \int_\theta p_\ell(\theta)\, \ell'(\theta)$ is the investment, and $\tilde{L}'$ is the value of that investment after returns are realized. Investors lend to the bank up to a point where the bank does not default in equilibrium. Then, the enforcement constraint is given as $\Psi(L', B') \geqslant \tilde{\Psi}^D\left(\xi\tilde{L'}\right)$.

The bank does not face any uncertainty in its net worth even though each mortgage is risky because we assume a continuum within each household type, which translates into a continuum within each mortgage type θ.[16] Thus, an important property of the bank's problem is that all assets have to generate the same rate of return r'_ℓ. Therefore, $p_\ell(\theta) = \frac{1}{1+r'_\ell}\int_{\theta'} \nu^l(\theta') \Pi(\theta'|\theta)$ for all θ; that is, the price of each mortgage is the expected present discounted value of its mortgage payments.

Since the bank is indifferent between investing in any asset, we do not have to keep track of its asset distribution in the bank's problem. Then, using $p_\ell(\theta) = \frac{1}{1+r'_\ell}\int_{\theta'} \nu^l(\theta') \Pi(\theta'|\theta)$, we can show that $\tilde{L'} = (1+r'_\ell) L'$ and that the bank's enforcement constraint becomes $(1-\phi')(1+r'_\ell) L' \geqslant (1+r') B'$, which puts an endogenous upper bound on bank leverage.[17] This leverage constraint states that the bank can borrow up to a fraction of its assets and ϕ' reflects the *haircut* on its collateral.[18]

The solution to the bank's problem is given as $L' = \beta_L \widehat{\lambda}\omega$ and $B' = \beta_L(\widehat{\lambda} - 1)\omega$, where $\widehat{\lambda} = \frac{(1+r')}{1+r'-(1-\phi')(1+r'_\ell)}$. Perfect competition among banks together with absence of aggregate risk and continuum of individuals implies that we can separate the individual mortgage pricing problem from the bank portfolio problem. The price of each mortgage is pinned down through the following equation, which implies that, at the time of the mortgage initiation, the present value of mortgage payments discounted at the risk-free lending rate should be equal to the loan amount:

$$dq^m(d; a', h, z, j) = \int_{\theta'} \nu^l_{t+1}(\theta') \Pi(\theta'|\theta) \tag{7}$$

Given d and all other individual state variables, this equation solves gives us $q^m(d; a', h, z, j)$.

[16]Even if a bank invests in a θ-type households' mortgage by a tiny amount, its return is deterministic since a known fraction of θ-type households default. The continuum assumption grants us tractability while keeping the rich heterogeneity in the household sector.

[17]In the Internet Appendix I, we provide the characterization of the bank's problem in detail.

[18]The term ϕ is defined recursively as follows: $\phi = \xi^{1-\beta_L}\left(\left(1+r'\right)/\left(1+r'_\ell\right) - (1-\phi')\right)^{\beta_L}$. If the bank was not able to steal (i.e., $\xi = 0$), then $\phi = 0$ and the *collateral premium* (or, equivalently, the credit spread) $r'_\ell - r'$ would be zero.

2.5 Symmetric Equilibrium

We focus on a symmetric equilibrium in which each bank holds the market portfolio of mortgages. Since each bank's optimal consumption and investment choices are linear in its net worth, we obtain aggregation and can focus on the representative bank. In equilibrium, all economic agents maximize their objectives given bank funding cost r and endogenous prices $\{r_\ell, r_k, \bar{w}, p_h, p_r\}$. Appendix B.4 presents all the equilibrium conditions.

Finally, note that a bank is a leveraged investor. Banks borrow the amount $\widehat{\lambda} - 1$ per unit of their net worth and earn an excess return $r_\ell - r$ on this amount in addition to r_ℓ they earn from their own net worth. Thus, a banker's gross return on net worth is equal to $1 + r'_\ell + (\widehat{\lambda} - 1)(r'_\ell - r')$. In the steady state, we have $1 + r_\ell + (\widehat{\lambda} - 1)(r_\ell - r) = 1/\beta_L$, which we use with the excess return $r_\ell - r$ and the leverage rate $\widehat{\lambda} - 1$ from the data to pin down the banker's discount rate in the calibration section.

3 Calibration

3.1 Calibration of Stationary Model

A model period is two years. Households start the economy at age 25, work until they retire at age 65, and live until age 85. Table I presents externally set and internally calibrated parameters under the columns labeled "External" and "Internal" respectively.

Preferences: We assume that households receive utility from consumption and housing services captured by the following CES utility specification: $u(c, s) = \left((1-\gamma)\, c^{1-\epsilon} + \gamma s^{1-\epsilon}\right)^{\frac{1-\rho}{1-\epsilon}}$. We choose $\epsilon = 1$, which implies a unit elasticity of substitution between housing and consumption, consistent with the estimates in Piazzesi et al. (2007). Following the literature, we set $\sigma = \rho = 2$, which implies an elasticity of intertemporal substitution of 0.5.[19] We calibrate γ to match the share of housing services in GDP as 15 percent and the discount factor β to match the capital-output ratio of 1 in our biennial model.

[19] Through a series of robustness exercises, we have found that the choice of ϵ, ρ and σ does not affect results significantly (Internet Appendix 5.3).

Table I – Parameters (externally set and internally calibrated)

		Value	
Parameter	Explanation	External	Internal
σ	risk aversion	2	
$1/\rho$	elasticity of intertemporal substitution	0.5	
ϵ	elasticity of substitution	1	
α	capital share	0.3	
ψ	curvature on hours	0.5	
ρ_ε	persistence of income	0.92	
σ_ε	std of innovation to AR(1)	0.31	
φ_h	selling cost for a household	7%	
φ_e	selling cost for foreclosures	25%	
ζ	fixed cost of mortgage origination	2	
δ_h	housing depreciation rate	5%	
τ	variable cost of mortgage origination	0.75	
η	rental adjustment cost	1	
π	prob. of being an active renter	0.265	
$\bar{H}$	aggregate house supply	1	
ι	down payment requirement	0	
β	discount factor		0.885
$\underline{h}$	minimum house size		0.773
r	deposit rate		6.33%
γ	weight of housing services in utility		0.176
μ	share of wage bill financed from banks		0.591
β_L	bank discount factor		0.734
ξ	bank seizure rate		0.247
κ	rental maintenance cost		0.044
δ_k	capital depreciation rate		0.20

Table II – Moments

Statistic	Data	Model
Capital-output ratio	1	1
Homeownership rate–aggregate	64%	64%
Mortgage debt-GDP ratio	26.5%	26.5%
Share of housing services in GDP	15%	15%
Ratio of mortgage loans to total loans in bank assets	0.42	0.42
Mortgage premium	0.03	0.03
Bank leverage ratio	10	10
House price-rental price ratio	5.5	5.5
Non-residential investment-output ratio	20%	20%

Income Process: For the income process before retirement, we set the persistence parameter $\rho_\varepsilon = 0.92$ and $\sigma_\varepsilon = 0.31$, which correspond to an annual persistence of 0.96 and a standard deviation of 0.17 following Storesletten et al. (2004). Retirement income approximates the US retirement system, as in Guvenen and Smith (2014).

Production Sector: We set the capital share in output to $\alpha = 0.3$. Denoting Y as the final good or output, we target a capital-output ratio of $\frac{K}{Y} = 1$, which corresponds to a capital-output ratio of 2 annually.[20] We normalize $N = 1$, and $\mathbb{Z} = 1$ and target $u = 1$ at the steady state. Then, since $Y = \mathbb{Z}K^\alpha (Nu)^{1-\alpha}$, we get $Y = K = 1$.

The share of housing services in GDP is 0.15. Since in our model, GDP, which includes the imputed income from housing, corresponds to $Y_A = Y + p_r\bar{H}$, this results in $Y_A = \frac{1}{0.85}$ and $p_r\bar{H} = \frac{0.15}{0.85}$. In the data, the ratio of non-residential investment to GDP is 0.2. Since, at the steady state, this ratio is $\frac{\delta_k K}{Y}$, this gives us a capital depreciation rate of $\delta_k = 0.2$ biennially. Given these targets, the model-implied biennial return to capital becomes $r_k = \alpha\frac{Y}{K} - \delta_k = 10$ percent.

We calibrate the labor utilization function curvature ψ to match the response of hours in the model to the data. We choose $\psi = 0.5$ with which the model generates an employment decline of 1.8 percent in response to a 1 percentage point increase in the bank lending rate, which falls in the middle of the employment effect found in Gertler and Gilchrist (2018). We target $u = 1$ in the steady state. From the firm's problem, $\vartheta = \left(\frac{1-\alpha}{1+\mu r_\ell}\right)\left(\frac{\alpha}{r_k+\delta}\right)^{\frac{\alpha}{1-\alpha}}$ gives us the calibrated value of ϑ.

Housing Market: The probability of an inactive renter becoming an active renter is set to 0.265 to capture the fact that the bad credit flag remains for about seven years in the credit history of households. We set the selling cost (φ_s) to 7 percent for regular sales and to 25 percent for foreclosed properties, consistent with the estimates of Campbell et al. (2011). We set the fixed mortgage origination cost $\zeta = 2$ percent of biennial GDP and the variable cost of mortgage origination $\tau = 0.75$ percent of the mortgage loan (Board of Governors of the Federal Reserve System (2008)). We set the down payment requirement to zero since there is no explicit regulation for down payment. However, in the model many households choose to make some down payment in order to get favorable mortgage terms.

[20]This implies a capital-to-GDP ratio of 1.7.

The ratio of house prices to biennial rental payments is calibrated to 5.5 (Sommer et al. (2013)). We set the biennial depreciation rate for housing units as $\delta_h = 5$ percent (Harding et al. (2007)). The steady-state relation between the rental price and house price is given by $p_r = \kappa + \frac{r_k + \delta_h}{1+r_k} p_h$. This gives us an estimate of κ given our target $\frac{p_h}{p_r} = 5.5$. We restrict the minimum house size for owner-occupied units to be $\underline{h}$ to match a homeownership rate of 64 percent. We set aggregate house supply $\bar{H} = 1$ as normalization. Lastly, we choose $\eta = 1$, which implies partial segmentation between owner-occupied and rental properties and generates a low elasticity of homeownership rate to price-rent ratio as reported in Greenwald and Guren (2024). However, our results turn out to be not sensitive to the particular value of η (see Section 5.3 and Appendix G).[21]

Financial Sector: Since not only banks but also other institutions hold large amounts of mortgage-related products, we follow Shin (2009) and include deposit-taking institutions (US chartered depository institutions and credit unions), issuers of asset backed securities, GSEs, and GSE-backed pools from FED Z1 data in our bank definition. Then, we match bank balance sheets to the 1985-1994 average in the data. We use Tables L.218 and L.219 to obtain the total amount of home residential mortgages held by banks. Banks on average hold \$2.114 trillion of these mortgages, which correspond to 93 percent of all mortgages (stable from 1985 to 1994). To compute the amount of lending to non-financial firms, we use the balance sheets of non-financial firms (Table L.102). We use total loans (loans from depository institutions, mortgages, and other loans), which average to \$2.245 trillion, and miscellaneous liabilities, which average to \$1.23 trillion. Residential mortgages constitute 49 percent of banks' balance sheets if we include the loans only and 34 percent if we also include miscellaneous liabilities as firms financing from banks. Thus, we choose $\frac{\int_\theta p_t(\theta)\Gamma_t(\theta)}{\mu w(\bar{w}_t, u_t) N_t + \int_\theta p_t(\theta)\Gamma_t(\theta)}$ (the ratio of mortgages to banks' total financial assets) as 42 (the average of 49 and 34) percent, which gives μ, the fraction of wage bill financed through banks.

In the steady state, we have $r_\ell - r = \frac{1-\beta_L(1+r)}{\hat{\lambda}\beta_L}$, where $\widehat{\lambda} = \frac{(1+r)}{1+r-(1-\phi)(1+r_\ell)}$ is the endogenous leverage ratio and $\phi = \xi^{1-\beta_L}\left({(1+r)}/{(1+r_\ell)} - (1-\phi)\right)^{\beta_L}$ is the haircut. We calibrate r to match a mortgage debt-GDP ratio of 26.5 percent (corresponding to an 53 percent ratio annually), and we target $r_\ell - r = 3$ percent, representing the average biennial gap between the 30-year mortgage interest rate and the 10-year Treasury rate in the data.

[21] Choosing a lower η results a very high elasticity of homeownership rate to the changes in price-rent ratio (larger than 0.5), which is shown to be implausible in Greenwald and Guren (2024).

We also target the bank leverage ratio $\widehat{\lambda}$ as 10 following Gertler and Kiyotaki (2015). These two targets give us the bank's discount factor β_L and the bank's seizure rate ξ.

Overall, we have 9 parameters that we calibrate internally: discount factor (β), minimum house size ($\underline{h}$), deposit rate (r), weight of housing services in utility (γ), share of wage bill financed by banks (μ), bank's discount factor (β_L), bank's asset seizure rate (ξ), maintenance cost for rental units (κ), and capital depreciation rate (δ_k). The last four of these parameters are identified directly through analytical moments obtained through the model as discussed above. This leaves us with five parameters that we calibrate using the model simulated data to jointly match the following five data moments (Table II): 64 percent average homeownership rate, 26.5 percent mortgage-debt-to-GDP ratio, capital-output ratio of 1, share of mortgages in bank balance sheet as 42 percent, and share of housing services in GDP as 15 percent.

3.2 Calibration of Boom-Bust Shocks

To study the role of bank credit supply, we generate a boom-bust cycle through two separate sets of unexpected shocks. We assume that, before 1998, the economy is at the steady state. In 1998, we shock the economy with unexpected leverage and house demand shocks to generate the boom episode. Both shocks are given as linearly increasing shocks over 20 years, and the full path of all shocks are common knowledge after their realization by all agents in the economy. To generate the bust episode, in 2008, we revert both of these shocks to their initial steady-state levels abruptly and unexpectedly. Below, we discuss how we calibrate these two shocks.

Leverage Shock: The boom and bust periods coincided with important changes in financial markets that shifted credit supply.[22] The Glass-Steagall Act, the bill that separated banking activities from investment banking ones, after being loosened for about a decade, was repealed in 1999. As a result, deposit-taking banks had the opportunity to extend their balance sheets. On the securitization side, from 1995 to 2005, the volume of private-label mortgage-backed securities increased dramatically from negligible levels to $1.2 trillion but disappeared with the crisis. We view both the regulatory changes and changes in investor sentiment toward mortgage-backed securities as the driving force behind the expansion and then contraction of

[22]See Chernenko et al. (2014) for developments in the securitization market and Sherman (2009) for important changes in financial market regulation in the US.

funding to the banking system. Nevertheless, the distinction between the two is not critical for our analysis since the model is calibrated to match the increase in bank leverage until 2008 without taking a stand on the underlying reason.

In the model, the bank leverage is determined by ξ: a lower (higher) value for ξ reflects higher level of (lower) trust for banks by creditors and allows banks to have a higher (lower) leverage. To calibrate the changes in this parameter, we refer to two sources. First, Federal Reserve Bank of New York (2024) documents that the leverage ratio of the consolidated US banking organizations has increased by 25 percent from the first quarter of 1996 to the last quarter of 2007. We use the leverage ratio of all institutions (see page 34 of the report). Second, the Financial Stability Report by Federal Reserve Board (2019) documents that the leverage ratio of security brokers and dealers has increased by 50 percent from the first quarter of 1995 to the first quarter of 2008 (see Figure 3-5 in the report).

Both studies report marked-to-book leverage. However, in our model bank assets, L_{t+1}, and net worth, ω_t, are in market values and the ratio L_{t+1}/ω_t gives the marked-to-market leverage, which is the same as the book leverage when the economy is in steady state. However, after unexpected shocks, market and book values will no longer be equal. To be able to compare the model to the data, we compute the book values of bank loans and net worth and calculate the corresponding book leverage in our model. We calibrate the changes in parameter ξ to have an increase in the financial system book leverage for 37.5 percent (from 1996 to 2006), which falls in the mid-range of 25 percent and 50 percent. The calibration results in a 40 percent decline in ξ. The top left panel in Figure 3 compares the book leverage from our model and these sources.[23]

Housing Demand Shock: The boom leverage shock generates part of the housing boom. We generate the remainder of the housing boom with a housing demand shock in the spirit of Kaplan et al. (2020). We assume that homeowners receive a premium χ_t in $u\left((1+\chi_t)\,c,(1+\chi_t)\,s\right)$ with $\chi_t = 0$ in the initial steady state. We calibrate the increase in χ_t to match the remainder of the house price boom in the data so that both shocks together generate a 28 percent increase in house prices during the boom. Then, χ_t unexpectedly reverts to its initial steady-state value of zero in 2008. The calibration results in an increase

[23]In our framework, the leverage constraint and haircuts on collateralized loans are tightly linked. Available data suggest that haircuts more than doubled for most mortgage-related securities after the crisis (Committee on the Global Financial System (2010)), consistent with the leverage dynamics in our model.

of 0.12 in χ_t over time.

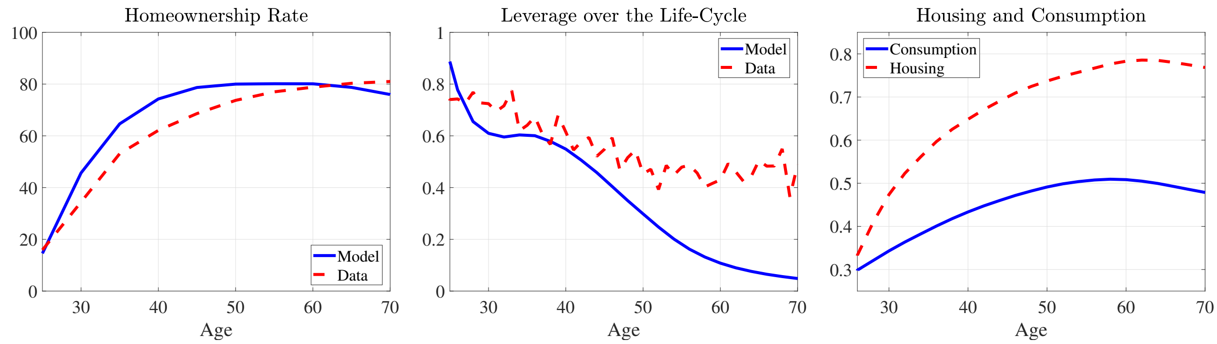
Government interventions at the bust: Even though both shocks return back to their initial steady state levels in 2008, the model economy experiences a large bust, in which bank net worth becomes negative in the absence of any government intervention. This result suggests that the government interventions were necessary to keep the banking sector afloat in the crises. In order to incorporate interventions into our framework that are consistent with the actual experience, we assume that the government borrows from international investors at the rate r in 2008 to finance bailouts to households and banks and rolls over its debt until 2038, after which it increases the labor income tax to balance the government budget in the long run.[24] For the household bailout, we assume that the government pays banks for the portion of a household's debt that is above a threshold leverage ratio. We choose the threshold to match the 3.6 percent increase in the foreclosure rate during the bust. The calibrated threshold is 11 percent, which turns out to be close to the one used by the Home Affordable Modification Program (HAMP).[25] For the bank bailout, we assume that the government injects equity into banks so that the bank net worth ω_t declines by 67 percent in 2008, consistent with the decline in market equity of bank holding companies reported in Begenau et al. (2019, Figure 3, left panel). With this intervention, the bank collateral premium or equivalently the credit spread $(r_\ell - r)$, the measure of the distress in the banking system, increases by 4.7 percentage points (top row, middle panel, Figure 3). For comparison, the excess bond premium from Gilchrist and Zakrajšek (2012) and Gertler and Gilchrist (2018) increases by about 3 percentage points during the 2008 financial crises. Finally, the total bailout amount in the model is 5.3 percent of GDP.[26]

[24]The particular choice of the year after which the labor income tax is increased does not affect the boom-bust dynamics we report in the paper as long as it is in the distant future. We have also experimented with no tax increase as if the bailout amount is a windfall to check the sensitivity of our results. Again, we did not discern any noticeable effect on the boom-bust.

[25]HAMP provided debt forgiveness and payment modification to households with leverage ratios above 115 percent. See Ganong and Noel (2020) for the details of these programs.

[26]The US Congress approved \$700 billion as part of the Troubled Asset Relief Program (TARP) in 2009. However, only \$475 billion of this amount was actually used. Private sector GDP in 2009 was \$11.8 trillion (\$14.7 trillion total value added minus \$2.9 trillion value added by the government). The amount of \$700 (\$475) billion is 6 (4) percent of GDP. Even though the bailout amount is larger in the model than in the data, remember that we have only two fiscal interventions and abstract from the monetary policy response since the effectiveness of monetary interventions depends crucially on people's expectations about the future policy path, which makes our decomposition exercises blurry and significantly more complicated.

Figure 1 – Life-Cycle Properties: Model versus Data



Notes: The graph shows the life-cycle properties of housing and mortgage debt. The left panel plots the homeownership rate. The middle panel plots mortgage debt relative to housing value. The data come from the 1995 Survey of Consumer Finances. The right panel plots consumption and housing expenditure over the life cycle from the model.

4 Performance of the benchmark model

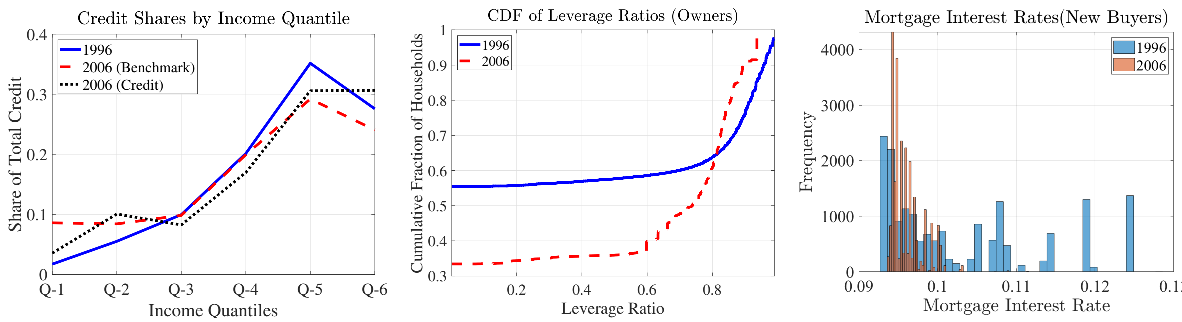
In this section, we compare our model's distributional and aggregate implications during the boom-bust cycle with the data.

4.1 Distributional Implications

The life-cycle implications of the model closely match the data (Figure 1). The homeownership rate increases over the life cycle. Leverage declines with age, but more than the data after age 60. Average consumption and housing increase over the life cycle, consistent with the findings of Aguiar and Hurst (2013).

The left panel of Figure 2 shows that the credit shares of each income quantile remained stable from 1996 to 2006 in the benchmark model with two shocks, consistent with the evidence in Adelino et al. (2016), Albanesi et al. (2017), and Foote et al. (2016). This pattern has been interpreted as evidence against the credit supply channel, given that earlier literature considered credit supply expansions to be more relevant for lower-income households. However, as illustrated in the figure, we find that the leverage shock alone can generate this pattern. The reason for the similar credit growth across different income quantiles is that all types of households benefit from lower borrowing cost and higher labor income when the bank lending rate declines during the boom in response to the credit supply expansion.

FIGURE 2 – Cross-sectional Developments in Credit and Housing during the Boom



Notes: The graph plots several model-implied cross-sectional implications. The left panel plots the mortgage credit distribution across income quantiles in 1996 and 2006 for both the benchmark and the result from the model with only the credit supply shock. The middle and right panels plot the distributions of the leverage ratio and interest on mortgages in 1996 and at the peak of the boom in 2006.

The middle panel shows that household leverage is higher in 2006 than 1996 in the model, in part because the model generates endogenous increases in LTV ratios consistent with the data without appealing to exogenous changes in LTV limits. In fact, Keys et al. (2012) report that the average combined LTV of households increased by 15 percentage points during the crises. Our model generates a 14 percentage points increase, almost matching the data. Finally, the right panel shows that interest rates on mortgages declined from 1996 to 2006, as in the data (Favilukis et al. (2017)).

4.2 Boom-Bust Cycle in Aggregates

Before we present the performance of the model in terms of matching the boom-bust dynamics of important aggregates around 2008, it will be instructive to illustrate how leverage and housing demand shocks transmit to the economy. Figure 1 in the Internet Appendix D illustrates linkages across sectors and the transmission mechanisms of shocks, and Figure 2 shows the dynamics with only leverage and housing demand shocks.

Transmission of the leverage shock: The changes in the bank lending rate r_ℓ is the key mechanism through which the leverage shock transmits to the economy. A lower r_ℓ, for example, implies lower borrowing costs for both households and firms. Then, households' demand for consumption and housing increases, which is the *direct* effect of lower r_ℓ. Furthermore, firms demand more labor and the equilibrium wage increases, and hence households demand more consumption and housing, which is the *indirect* effect of lower r_ℓ.

Exogenous shocks to bank leverage translate into one-for-one changes in the bank lending rate r_ℓ in the absence of any feedback from bank balance sheets. Focusing first on the steady state, an increase in bank leverage decreases the credit spread according to $r_\ell - r = \frac{1-\beta_L(1+r)}{\widehat{\lambda}\beta_L}$. Thus, a permanent increase in $\widehat{\lambda}$ will lead the economy to a steady state with a lower r_ℓ. Moreover, when the bank net worth effects are absent, changes in $\widehat{\lambda}$ will translate into changes in r_ℓ during the transition, as given by this equation. As a result, r_ℓ gradually falls during the boom and is expected to stay low permanently.

The leverage parameter reverts back unexpectedly and permanently to its steady state level at the time of the bust, which translates into a permanent increase in r_ℓ. However, the deterioration of bank balance sheets amplifies the increase in r_ℓ during the bust. We explain this amplification mechanism next.

Although all variables affect each other simultaneously, we will proceed with an iterative approach in demonstrating the amplification mechanism during the bust. For this purpose, remember that the bank net worth in period t is given as

$$\omega_t = \int_\theta \int_{\theta'} \left(m_t\left(\theta'\right) + p_t\left(\theta'\right)\right) \Pi\left(\theta'|\theta\right) \Gamma_{t-1}\left(\theta\right) + L_t^k\left(1 + r_{\ell,t}\right) - B_t\left(1 + r_t\right).$$

The shock that generates the bust is a decrease in $\widehat{\lambda}_t$ back to its steady-state level that reduces loan supply through $L_{t+1} = \beta_L \hat{\lambda}_t \omega_t$.[27] As a result, the equilibrium bank lending rate $r_{\ell,t+1}$ increases. However, a higher $r_{\ell,t+1}$ reduces the bank's net worth at time t by lowering mortgage valuations since $p_t\left(\theta\right) = \frac{1}{1+r_{\ell,t+1}} \int_{\theta'} \left(m_{t+1}\left(\theta'\right) + p_{t+1}\left(\theta'\right)\right) \Pi\left(\theta'|\theta\right)$ for all θ. In response, loan supply L_{t+1} declines further and $r_{\ell,t+1}$ increases more. With higher $r_{\ell,t+1}$, mortgage valuations and bank net worth decline further, which generates further increases in $r_{\ell,t+1}$ and future bank lending rates. This is the key mechanism through which the deterioration of bank balance sheets amplifies the transmission of a shock to bank leverage. Another contributing factor to the decline in bank net worth is the increase in foreclosures. However, we find that they have relatively smaller effect on bank net worth.

The spike in r_ℓ and the sharp drop in bank net worth are short-lived because the amplification mechanism described above works the opposite way in the recovery. When r_ℓ

[27] The term $\widehat{\lambda}_t$ is an endogenous object determined by equation I.1 in Appendix I. The parameter that goes back to its steady-state level is ξ, which eventually decreases $\widehat{\lambda}_t$ to its initial steady-state level.

starts to decline, the market value of the bank's mortgage portfolio starts recovering. This increases the bank's net worth, hence credit supply, reducing r_ℓ's even more. As a result, bank net worth recovers quickly.

Transmission of the housing demand shock. The housing demand shock directly affects house prices, and its effect on the rest of the economy is mostly through house prices. During the boom, for example, an increase in house prices raises consumption because of wealth and collateral effects. During the bust, however, an important indirect effect of the housing demand shock arises as a result of its effect on bank balance sheets since the sharp decline in house prices increases foreclosures. The losses in bank balance sheets cause a decline in bank credit, which initiates a mechanism similar to the one above. This mechanism via banks is an important component in this paper.

Overall, the model generates a significant boom-bust cycle in the banking, housing, and real sectors, closely mimicking the data. Interestingly, although both shocks revert to their initial steady-state levels at the time of the bust, all aggregate variables fall below their steady state, resulting in a severe recession. We now analyze each sector in turn.

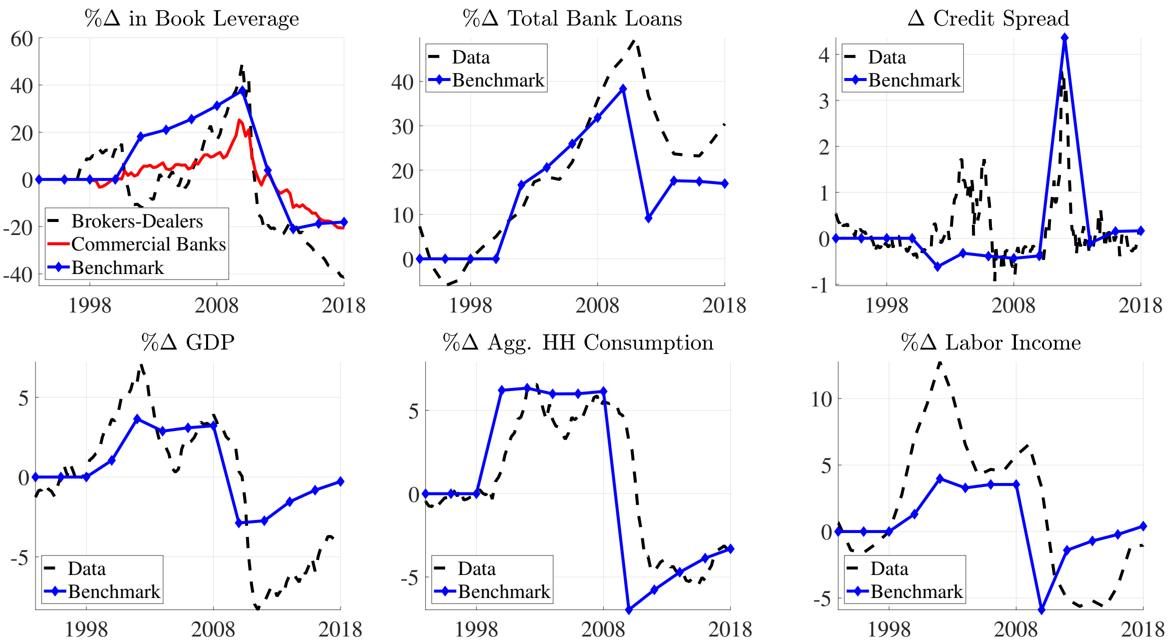
4.2.1 Banking Sector Dynamics

The banking sector experiences a boom-bust cycle in the model, as in the data (Figure 3). The bank book leverage increases by 37.5 percent in the model (as it is calibrated). The decline in leverage during the bust, however, is not targeted. But the model still matches it. The leverage declines by 42.8 percent in the two periods following the bust shocks and recovers slowly. The leverages of commercial banks and security brokers and dealers in the data decline by 27 and 71 percent from 2008 to 2010, respectively.[28]

With higher leverage, the loan supply (both mortgages and firm loans) increases, and the bank lending rate r_ℓ declines. The bank net worth declines during the boom since the bank funding cost r has not changed and r_ℓ is lower. Thus, the banking sector supports more credit with lower bank net worth but with higher debt. The model generates a 38.3 percent rise in bank loans in the boom, slightly below the data. The share of mortgages in banks'

[28] Consistent with what we report here, there is broad agreement that marked-to-book leverage is procyclical (Adrian and Shin (2010), Nuno and Thomas (2017), and Coimbra and Rey (2017)). The marked-to-market bank leverage (L_{t+1}/ω_t) also increases during the boom but spikes at the time of the bust as bank net worth sinks, which is also consistent with the findings in Begenau et al. (2018).

Figure 3 – Boom-Bust Dynamics: The Banking and the Real Sectors



Notes: The graph plots the dynamics of key variables during the boom-bust episode. Data counterparts of bank loans, output, consumption and labor income are percentage deviations from their linear trends obtained from the 1985-2006 period. See Appendix A for data sources. In the text, we compute the bust changes relative to the peak of the boom. There is a recession in 2001 during the period we study, which the model does not attempt to capture. As a result, the model deviates from the data around that year.

portfolios also increases, as does the value of the mortgage pool.

The crisis occurs as the leverage constraint and housing demand parameters revert to their initial steady-state levels. Consequently, the credit spread $r_\ell - r$ jumps by 4.7 percentage points—in line with the spike in the excess bond premium documented in Gilchrist and Zakrajšek (2012) and Gertler and Gilchrist (2018)—and mortgage valuations and bank net worth sink.[29] Since mortgages are long-term assets, banks cannot flexibly adjust their balance sheets by issuing fewer mortgages. Therefore, they reduce their lending to firms.

[29]The dynamics of the bank lending rate are consistent with other empirical findings as well. During the boom, interest rates on firm loans and mortgages declined (Glaeser et al. (2012) and Justiniano et al. (2019)). Jayaratne and Strahan (1997) and Favara and Imbs (2015) find significant declines in lending interest rates after the branching deregulation in the US. For the crisis period, the lending interest rate on loans more than quadrupled (Adrian et al. (2013)).

4.2.2 Real Sector Dynamics

At the peak of the boom, the US per capita GDP was almost 6 percent above its trend. GDP ($Y_A = Y + P_r\overline{H}$) in the model increases by 3.1 percent (bottom row, left panel in Figure 3) during the boom. With the crisis, GDP falls by 4.2 percent from its peak. The aggregate labor income follows a boom-bust pattern similar to the output, which is critical for the boom-bust dynamics in the housing market and consumption, as we analyze in Section 5.2.1 (bottom row, right panel in Figure 3).

The response of aggregate consumption ($C_A = C + P_r\overline{H}$) to the shocks is more abrupt (jumps and stays high) and slightly larger than the data (bottom row, middle panel, in Figure 3).[30] In the model, this is driven by the immediate response of wages and house prices to new information from two unexpected shocks. Since wages and house prices are key determinants of consumption), their jump and fall with the boom and bust create a non-smooth consumption pattern. This undesirable feature is not unique to our model and is common in asset-pricing models that feature unexpected shocks.

The response of the firms' labor demand to the changes in the bank lending rate is the key driver of the boom-bust in the production sector (Section 5.2.1). Our model generates changes in total per capita hours worked, labor income, and firm loans that are similar to the data. Moreover, there is substantial evidence that the labor decisions of firms are indeed influenced by financial conditions, which corroborates the predictions of our model.[31]

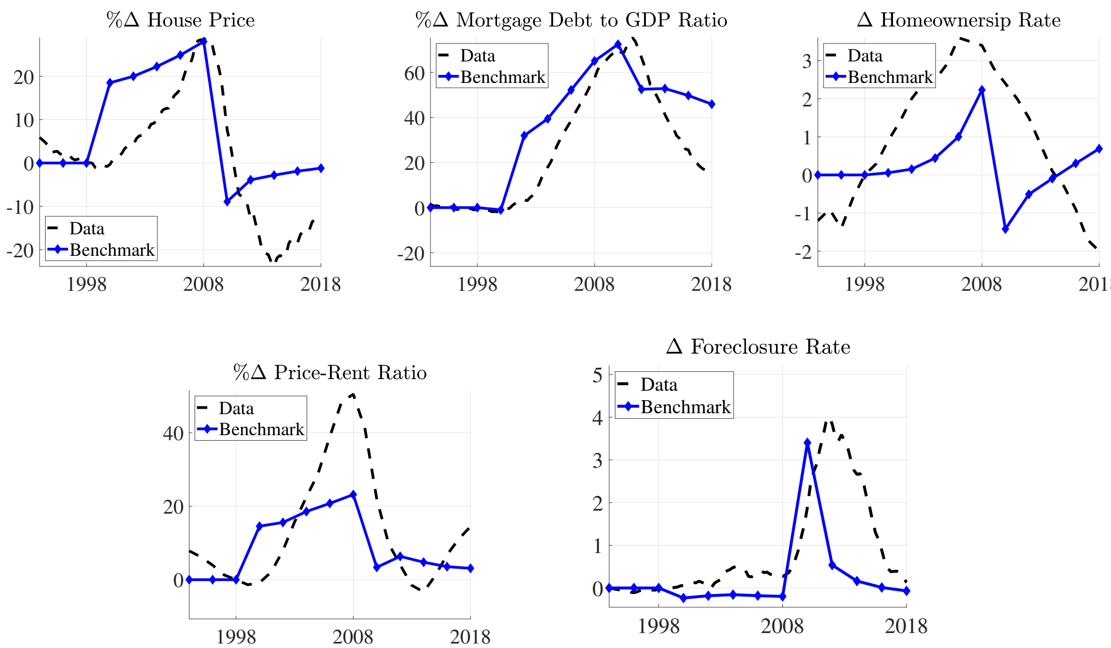
4.2.3 Housing Market Dynamics

House prices increase 28.0 percent during the boom (Figure 4), as the size of the housing demand shock is chosen to match it. Despite not being specific target, the model generates a significant bust in house prices during the bust: a decline of 28.8 percent from their peak

[30] Since the bank borrowing rate r is exogenous, this model is essentially an open economy where output is given as $Y_A = C + I + NX$. In 1998, NX declines and stays negative. Thus, the model implies that there is a net capital inflow to the US during the boom period, which is broadly consistent with the data.

[31] For example, Chodorow-Reich (2013) finds that firms that worked with weaker banks prior to the crisis reduced employment more. Benmelech et al. (2019) find similar evidence from the Depression era, and Popov and Rocholl (2015) bring evidence from Germany during the 2008 crisis. Finally, Ivashina and Scharfstein (2010) document a more than 50 percent decline in bank capital expenditure and working capital loans to corporations, and Adrian et al. (2013) find that capital expenditure and working capital loans to firms have declined substantially, while interest rates on loans more than quadrupled during the crisis. Jermann and Quadrini (2012) use a quantitative model and show that the worsening of firms' ability to borrow during the 2008 crisis played an important role on the deterioration in the labor market.

FIGURE 4 – Boom-Bust Dynamics: The Housing Sector



Notes: The graph plots the dynamics of key variables during the boom-bust episode. The data counterpart of house price is percentage deviation from its linear trend obtained from the 1985-2006 period. See Appendix for data sources.

to 8.9 percent below their initial steady-state level and slowly recover, similar to the data. Furthermore, it generates a significant boom-bust in the price-rent ratio. During the boom, the mortgage-debt-to-GDP ratio increases 73 percent in the model, matching the data. After the bust, household debt gradually declines. The foreclosure rate in the model stays low during the boom and jumps by 3.6 in the bust period (as in the data), as a large decline in house prices during the bust pushes many households to negative equity, which makes default an attractive option. The homeownership rate rises by 2.2 percent during the boom, and declines during the bust because of the decline in housing demand and defaulting households.

5 Quantitative Analyses of the Boom-Bust Cycle

Equipped with a model that can generate economic dynamics that are close to the data, we now study the drivers of the boom-bust cycle. We want to highlight two points about the decomposition exercises. First, if we add different mechanisms sequentially on top of each other to measure their relative contributions, the order of decomposition matters. Since there are many possible orderings, we evaluate the contribution of each mechanism by closing all others and adding that mechanism only.

Second, we need to make sure that our decomposition exercises are not affected by the existence of bailouts. To do that, we keep all parameters and other factors at their boom levels, including the bailout amount which is zero, and compute the size of the bust generated by only one factor without any bailouts. Since there are no bailouts in the boom and in this counterfactual experiment, the change in a variable from the boom to the bust gives the contribution of that factor only.

5.1 The importance of leverage and housing demand shocks

Changes in credit supply and housing demand have been proposed as two competing explanations for the boom-bust cycle in the US housing market. In this section, we quantify the importance of the bank leverage shock (one source of credit supply change) and the housing demand shock to the boom-bust. For this, we solve the equilibrium transition of the model with only one "boom" shock (bank leverage or housing demand) and compute the size of the boom generated by that shock only. We report the results of these exercises under "Boom/Only/Δx_{LS}" and "Boom/Only/Δx_{HDS}" in Table III. We also report the changes in variables from our benchmark under "Boom/Benchmark/$\Delta x_{(\text{LS+ HDS})}$ " for comparison.[32]

Before reporting the boom generated by each shock, note that $\left|\Delta x_{(\text{LS + HDS})}\right| > |\Delta x_{\text{LS}}| + |\Delta x_{\text{HDS}}|$; that is, the boom generated by the two shocks together is larger than the sum of the booms generated by each shock individually. This suggests that the two shocks interact in a way that amplifies each other's effects.

Focusing on the contribution of each shock to the boom, we find that the leverage shock alone generates a 9.5 percent increase in house prices, accounting for a third of the observed increase. Moreover, it accounts virtually all of the decline in the bank lending rate and the increase in wages, output, and lending to firms. It also leads to a 3.9 percent increase in consumption, almost 60 percent of the 6.7 percent benchmark increase, and half of the growth in mortgage debt.

The housing demand shock generates a larger increase in house prices (16.1 percent), as it is deliberately calibrated to match the unexplained portion of the increase in house prices.

[32] In the Internet Appendix we provide Figure 2 and show the dynamics of extended set of variables with housing demand and leverage shocks separately.

TABLE III – Contributions of shocks to leverage (LS) and housing demand (HDS) to boom-bust

	Boom			Bust		
	Benchmark	Only		Benchmark	Only	
	$\Delta x_{(\text{LS + HDS})}$	Δx_{LS}	Δx_{HDS}	$\Delta x_{(\text{LS + HDS +Bailout})}$	Δx_{LS}	Δx_{HDS}
Bank lending rate (Δr_ℓ)	-0.4	-0.4	0.1	4.7	4.4	3.2
Output ($\%\Delta Y$)	3.1	3.1	-0.3	-4.2	-3.9	-2.8
Wages ($\%\Delta w$)	3.5	3.6	-0.4	-9.1	-8.4	-6.2
Firm Loans	3.5	3.6	-0.4	-9.1	-8.4	-6.2
Consumption ($\%\Delta C$)	6.7	3.9	2.4	-11.6	-6.9	-10.8
Mortgage Debt	85.6	44.8	31.5	-11.4	-3.9	-31.6
House price ($\%\Delta p_h$)	28.0	9.5	16.1	-28.8	-12.1	-30.0
Foreclosure rate(Δ)	-0.2	-0.1	-0.2	3.6	0.5	17.6
Price/Rent	23.1	6.7	14.4	-16.1	0.3	-19.1

Note: The table reports the results where we decompose the role of leverage and housing demand shocks. "LS" refers to leverage shock, "HDS" refers to housing demand shock. "Only" columns report the results with only one of the shocks. The percent decline in the bust is calculated with respect to the value at the peak of the boom.

However, it also raises the bank lending rate, which, contrary to the data, reduces firm loans and output and has a smaller effect on consumption (2.4 percent) compared to the leverage shock. Thus, while both shocks contribute to the housing boom, the leverage shock better accounts for the broader macroeconomic patterns observed during the period. Furthermore, while the leverage shock generates a positive co-movement between mortgage debt and firm borrowing, the housing demand shock generates negative co-movement between these two variables, that we test in Section C.

To assess the contributions of each of these shocks to the bust, we hit the economy with one bust shock (bank leverage or housing demand) while the economy is at the peak of the benchmark boom generated by both shocks (the "Bust" column in Table III). Each shock alone generates a large bust in the economy. In fact, the sum of the busts generated by each shock is larger than the benchmark bust. However, note that the government bailouts significantly mitigate the bust. Thus, our analysis suggests that the crisis would be much more severe in the absence of these bailouts.[33]

[33] We do not report the amount of bust mitigated by the bailouts. In principle, we could compute the amount of bust generated by both shocks without bailouts, call it $\Delta x_{\text{LS+HDS}}$. Then the difference between the benchmark and the bust generated by this exercise would be the effect of bailouts: $\Delta x_{\text{bailout}} = \Delta x_{(\text{LS + HDS +Bailout})} - \Delta x_{(\text{LS+HDS})}$. However, as we noted earlier, the bank net worth becomes negative in the bust in the absence of bailouts. Figuring out how the economy evolves from that point generates further

We find large effects for both leverage and housing demand shocks during the bust, as each shock weakens bank balance sheets and leads to a contraction in credit supply. Consequently, the bank lending rate rises by 4.4 and 3.2 percentage points, output declines by 3.9 and 2.8 percent, and wages decline 8.4 and 6.2 percent on impact, with leverage and housing demand shocks, respectively. Even if the decline in output is smaller on impact under the housing demand shock, the worsening of household balance sheets generates a subsequent 5.2 percent decline as a result of lower capital accumulation by households. The housing demand shock generates a bigger decline in house prices (30.0 versus 12.1) and a larger increase in the foreclosure rate (17.6 versus 0.5 percentage points) relative to the leverage shock. The disproportionately larger impact of the housing demand shock on foreclosures is mainly because it reduces the ownership benefit and makes foreclosure a more attractive option for a given house price decline. Finally, the decline in consumption is driven by the declines in house prices and income, and the leverage shock generates a 6.9 percent decline while the housing demand shock generates a 10.8 percent decline.

Even though the bank balance sheet channel amplifies the bust generated by each shock, manifesting itself in a spike in the bank lending rate and concurrent declines in output and wages, it is particularly interesting that the effect of the housing demand shock is also amplified due to the endogenous contraction in credit supply. This occurs because the decline in house prices increases foreclosures and weakens bank balance sheets. The resulting decline in credit supply causes the equilibrium bank lending rate to increase. Thus, credit supply affects the economy not only through changes in bank leverage but also by amplifying the role of the housing demand shock. This suggests that even if the bust were created by a housing demand shock alone, credit supply would play an important role. We further investigate this channel in Section 5.2.3.

We would like to conclude this section with three remarks.

First, we find large effects of credit supply on house prices, despite employing a housing and mortgage structure similar to that of Kaplan et al. (2020). Our analysis differs from theirs in three key aspects. Firstly, the credit supply shock in our framework is not an

complications to our analyses. Thus, we cannot obtain $\Delta \mathrm{x}_{\mathrm{LS+HDS}}$. An alternative is to compute the effect of the bailouts as $\Delta \mathrm{x}_{\mathrm{bailout}} = \Delta \mathrm{x}_{(\mathrm{LS\ +\ HDS\ +Bailout})} - (\Delta \mathrm{x}_{\mathrm{LS}} + \Delta \mathrm{x}_{\mathrm{HDS}})$, which can be read as the residual from Table III. To the extent that $\Delta \mathrm{x}_{\mathrm{LS}} + \Delta \mathrm{x}_{\mathrm{HDS}} = \Delta \mathrm{x}_{\mathrm{LS+HDS}}$, these two exercises would give similar results. However, this equality does not necessarily hold since the ordering of decomposition matters.

isolated shock to the household, as firms' production also partly depends on bank credit. Consequently, changes in credit supply–hence the bank lending rate–affect households not only *directly* through household borrowing costs, but also *indirectly* by influencing firms' borrowing costs and labor demand, and thus household income. We analyze the relative importance of these direct and indirect effects in Section 5.2.1. Secondly, credit supply is also endogenous in our model. Exogenous shocks to the model generate changes in bank net worth, which translate into changes in credit supply. This mechanism is particularly important during the bust. We highlight the importance of this channel in Section 5.2.2. Thirdly, we consider permanent changes in bank leverage that translate into permanent changes in the bank lending rate rather than the LTV, PTI, or temporary interest rate shocks considered in Kaplan et al. (2020). In our model, changes in LTV and PTI requirements also shift the housing demand between renting and owning and do not significantly affect aggregate housing demand. Moreover, because of endogenous borrowing limits on households, LTV and PTI limits become almost irrelevant.[34] These conclusions are similar to those in Kaplan et al. (2020). On the other hand, a permanently lower bank lending rate increases total housing demand because it creates a positive income effect—since mortgage payments decline for a given debt amount—and a positive wealth effect—since labor income permanently increases.

Second, Adelino et al. (2016), Albanesi et al. (2017), and Foote et al. (2016) find that credit grew uniformly across income groups during the boom period, a result that has been interpreted as evidence against the credit supply channel since the previous literature considered the credit supply channel to be more relevant for lower-income households. We show that in fact the bank leverage shock alone can generate uniform credit growth across income groups (see left panel of Figure 2).

Third, our findings imply that housing demand and leverage shocks have different effects on the comovement of mortgage and firm lending, and interest rates. While an increase in bank leverage lowers the bank lending rate and increases lending to both firms and mortgages, a housing demand shock increases mortgages, with opposing effects on interest rates and firm lending, compared to leverage shocks. This distinction is more evident during the boom

[34] Relaxing these constraints does not generate any boom in our model. To check whether tightening them generates a bust, we have conducted an experiment in which the LTV limit is reduced from 100 percent to 80 percent, and a PTI ratio of 25 percent is imposed (the benchmark does not have a PTI limit) with 0.6 persistence. Despite their large sizes, the LTV shock generates a small effect on aggregates, while the PTI shock has almost no effect (see Figure 4 in Internet Appendix F).

period since housing demand does not influence credit supply during this time. The empirical analysis in Section C shows that the data support the implications of the leverage shock.

5.2 Credit Supply Mechanism Disentangled

In this section, we conduct a series of experiments to illustrate how changes in credit supply generate a significant boom-bust cycle in the economy. Since shifts in credit supply translate into changes in the bank lending rate, we focus on the effects of these changes and decompose them into their direct effects (affecting household borrowing costs) and indirect effects (affecting firm borrowing costs and, consequently, labor income) across all experiments.

In the first experiment, we quantify the amount of boom-bust accounted for by the changes in the bank lending rate r_ℓ in the benchmark economy. The changes in r_ℓ have permanent components due to exogenous and permanent changes in bank leverage during the boom-bust, as well as a temporary spike at the time of the bust due to the deterioration of the bank balance sheet, which leads to an endogenous contraction in credit supply. In the second experiment, we quantify the contribution of the bank balance sheet deterioration to the bust, which manifests its effect as the temporary spike in the bank lending rate. In the third experiment, we explore how much the effect of the housing demand shock during the bust is amplified through the bank balance sheet deterioration, and hence, the endogenous decline in credit supply.

We do not present the bank balance sheet amplification arising from the leverage shock as a separate experiment since the spikes in the bank lending rate under the benchmark and leverage shock scenarios are quantitatively similar–4.7 percent versus 4.4 percent, respectively. Thus, the bank balance sheet effects from the leverage shock will be comparable to those examined in Section 5.2.2.

Furthermore, the result that the effect of the housing demand shock is amplified by the endogenous contraction in credit supply suggests that, even if the bust were caused by a housing demand shock alone, credit supply still played an important role.

5.2.1 The Direct and Indirect Effects of the Bank Lending Rate on the Boom-Bust

To analyze the role of the changes in bank lending rate r_ℓ in the boom-bust cycle, we compute the amount of boom-bust generated if all shocks are shut down and the benchmark

Table IV – Roles of Bank Lending Rate and Labor Income

	Benchmark	Total	Total r_ℓ effect decomposed	
	Boom	r_ℓ effect	r_ℓ direct	wage effect
Bank lending rate (Δr_ℓ)	-0.4	-0.4	-0.4	–
Wages ($\%\Delta w$)	3.5	3.4	–	3.4
House price ($\%\Delta p_h$)	28.0	8.8	6.5	3.7
Consumption ($\%\Delta C$)	6.7	3.6	0.9	3.0
	Bust			
Bank lending rate (Δr_ℓ)	4.7	4.7	4.7	–
Wages ($\%\Delta w$)	-9.1	-9.1	–	-9.1
House price ($\%\Delta p_h$)	-28.8	-11.4	-5.2	-11.4
Consumption ($\%\Delta C$)	-11.6	-6.8	-0.8	-6.8

Notes: This table reports results on the role of bank lending rate r_ℓ on house prices and consumption for the boom and bust separately. The "Total r_ℓ effect" column reports the results where the benchmark r_ℓ sequence in Figure 3 is fed into the economy (all prices are allowed to react but parameters are fixed). The "r_ℓ direct" column reports the results where all prices (except the house prices) and parameters are fixed. The "wage effect" column reports the results where the wage sequence from the "Total r_ℓ effect" exercise is fed into the economy while keeping the interest rate, the return on capital, and the parameters unchanged. The p_h and p_r are linked by the formula driven from the first order condition of the rental company. Only focusing on changes in p_h keeping p_r constant does not significantly alter the results.

r_ℓ sequence in Figure 3 is fed into the economy (as two unexpected shocks) and all other prices are solved endogenously. Results are shown under the "total r_ℓ effect" column in Table IV.

During the boom, the decline in r_ℓ (which is expected to be permanent) reflects the exogenous increase in bank leverage since the endogenous changes in bank balance sheets have a minimal effect. Thus, the total contribution of r_ℓ to the boom is very similar to the contribution of the leverage shock. Overall, the decline in r_ℓ generates increases of 3.4, 8.8, and 3.6 percent in wages, house prices, and consumption, respectively (the leverage shock generates increases of 3.6, 9.5 and 3.9 percent, respectively).[35]

[35]The small difference is because of the housing demand shock, which affects the benchmark r_ℓ dynamics

Then we generate an r_ℓ-induced bust by increasing r_ℓ unexpectedly (to the benchmark bust sequence) while the economy is at the peak of the benchmark boom. The total effect of r_ℓ causes a 9.2 percent decline in wages (very close to the benchmark decline), which shows that the spike in r_ℓ is the primary cause of the decline in wages at the time of the bust. However, the persistence of the wage decline is smaller under the r_ℓ shock than the benchmark since the housing demand shock in the benchmark further deteriorates household balance sheets and causes larger subsequent declines in capital. The total effects of r_ℓ on house prices and consumption are declines of 13.2 and 6.6 percent, respectively.[36]

Under the column "r_ℓ direct" we measure the direct effect of r_ℓ on the boom by feeding into the economy the r_ℓ boom sequence (a decline of 0.4 percentage points) keeping all parameters, the wage rate w and the return on capital r_k fixed at their steady-state levels. Under the column "wage effect" we measure the indirect effect of r_ℓ by feeding into the economy the boom wage sequence (obtained from the "Total r_ℓ effect" exercise), keeping parameters, r_ℓ and r_k at their steady-state levels. In both exercises, we solve house prices endogenously. We follow the same methodology and terminology in Tables V and VI in Sections 5.2.2 and 5.2.3 as well.

These exercises show that the decline in r_ℓ can generate a 6.5 percent increase in house prices directly through household borrowing costs and an additional 3.7 percent increase by indirectly affecting firm borrowing rates and hence labor income. The indirect effect of r_ℓ on consumption turns out to be more important than its direct effect (3.0 percent versus 0.9 percent) since the changes in consumption are driven by the changes in house prices and labor income.

We reach a similar conclusion for the bust period. While the dynamics of the bank lending rate can *directly* generate an 8.8 percent decline in house prices, they generate an additional 5.7 percent decline *indirectly* through wages. For consumption, the changes in the bank lending rate directly cause a 1.1 percent decline, while the indirect effect through wages reduces it by an additional 5.7 percent, accounting for most of the overall decline in consumption.

relative to an economy with a pure leverage shock, as analyzed in the previous section.

[36]Notice that the effect of r_ℓ is very similar to the effect of the leverage shock during the bust, but this does not have to be the case since the housing demand shock as well as bailouts play significant roles on r_ℓ . However, the increase in r_ℓ from only the leverage shock is 4.4 percentage points, which turns out to be very similar to the benchmark increase in r_ℓ, which is 4.7 percentage points.

The effect of interest rates on house prices might seem higher than those found in the recent literature, such as Adelino et al. (2012). However, our results in this section (and the next one) show that the effect of interest rates on house prices depends critically on two things: (i) how persistent the interest rate shock is, and (ii) whether interest rates affect wages. The boom decomposition in Table IV illustrates that the direct effect of a permanent 0.4 percent decline in the bank lending rate is a 6.5 percent increase in house prices. This implies an elasticity of house price to changes in bank lending rate of 16.25 (=6.5/0.4). Moreover, if we include the indirect effect through wages, then the elasticity increases to 22 (=8.8/0.4).

In contrast, as we show in the next section, the direct effect of a temporary 4.3 percent increase in the bank lending rate is a 1.6 percent decline in house prices, with an implied elasticity of 0.4 (=1.6/4.3). Therefore, our model's implication is consistent with the estimates, if, for example, empirical analysis estimates the direct effects of temporary interest rate changes.

5.2.2 The Role of Bank Balance Sheet Deterioration in the Bust

The 4.7 percentage point increase in the bank lending rate at the time of the bust reflects both the exogenous tightening of the bank leverage constraint and the temporary endogenous contraction of the credit supply due to the bank balance sheet deterioration during the bust period. Here, we focus on the latter and quantify the amplification generated solely by the bank balance sheet deterioration, which is reflected as the 4.3 percentage point spike on top of the permanent 0.4 percentage point increase in the bank lending rate during the bust. To isolate the effect of the spike, we run an experiment where, at the peak of the boom, the economy is shocked with a 4.3 percentage point increase in the bank lending rate. We solve all other prices endogenously.

Table V reports the results of this exercise and compares them with the benchmark results. Despite being temporary, the spike in r_ℓ causes a sizable downturn, indicating a significant amplification of the bust due to the bank balance sheet deterioration. Quantitatively, the bank balance sheet deterioration generates a 8.0 percent decline in wages, accounting for most of the 9.1 percent benchmark decline and 4.9 percent decline in house prices, accounting for 17 percent of the benchmark decline, and 3.8 percent decline in consumption, accounting for more than 30 percent of the benchmark decline. The spike directly lowers house prices by 1.6

Table V – The Role of the Bank Balance Sheet Deterioration in the Bust

Variables	Benchmark Bust $\Delta\%$	Total effect of the spike in r_ℓ	Direct effect of the spike in r_ℓ
Bank lending rate (Δr_ℓ)	4.7	4.3	4.3
Wages ($\%\Delta w$)	-9.1	-8.0	–
House price ($\%\Delta p_h$)	-28.8	-4.9	-1.6
Consumption ($\%\Delta C$)	-11.6	-3.8	-0.2

Notes: This table reports results on the role of the spike in the bank lending rate r_ℓ during the bust on house prices and consumption. The "Total effect of the spike in r_ℓ" column reports the results where the 4.3 percent spike in r_ℓ is fed into the economy at the peak of the boom (all prices are allowed to react, but parameters are fixed). The "r_ℓ direct" column reports the results where all prices except the house prices are fixed.

percent and consumption by 0.2 percent.[37] These results imply that the bank balance sheet deterioration significantly contributes to the severity of the crisis, affecting variables that depend on short-term debt, such as wages, more substantially than variables that depend on long-term debt, such as house prices.

5.2.3 Credit Supply Amplification of Housing Demand Shock in the Bust

Previous literature typically focused on how declines in house prices *directly* affect household consumption through wealth and collateral effects.[38] This household balance sheet mechanism is also present in our model. However, our model features an additional indirect effect of house price declines: increases in foreclosures lower bank net worth and consequently credit supply, causing a spike in the bank lending rate r_ℓ. In this section, we decompose the effect of the housing demand shock into its direct effects on house prices and

[37]We run an alternative experiment where at the peak of the boom, the bank net worth is hit with the bank balance sheet losses of the benchmark economy, keeping all parameters fixed at their boom level (see Table III in the Internet Appendix F). Since the bank leverage parameter is fixed at the boom level, banks supply more credit in this experiment than the benchmark despite the same decline in bank net worth. As a result, the spike in bank lending rate r_ℓ in this experiment is 2.2, smaller than the benchmark spike of 4.7 percentage points. Quantitatively, the decline in bank net worth generates 4.2, 2.0, and 2.4 percent declines in wages, house prices, and consumption, respectively, smaller than those generated by the benchmark spike but are still sizable. Thus, regardless of the type of exercise, we find that bank balance sheet deterioration has significant effects on the bust.

[38]See Mian et al. (2013), Mian and Sufi (2014), Gertler and Gilchrist (2018), and Berger et al. (2018).

TABLE VI – Effects of Housing Demand Shock (HDS)

	HDS bust (total)	HDS direct effect	HDS indirect effect through r_ℓ
Bank lending rate (Δr_ℓ)	3.2	–	3.2
Wages ($\%\Delta w$)	-6.2	–	-6.2
House price ($\%\Delta p_h$)	-30.0	-21.4	-4.4
Consumption ($\%\Delta C$)	-10.8	-5.6	-3.5

Notes: This table reports the results of the effects of housing demand and housing price shocks during the bust. "HDS" refers to the housing demand shock. See the text for details.

consumption and indirect effects through bank balance sheet deterioration and the resulting contraction in credit supply.[39]

First, we focus on the housing demand shock analyzed in Section 5.1 and study its effects on house prices and consumption during the bust.[40] Remember that the total (direct and indirect effects combined) effect of the housing demand shock is obtained by shocking the economy at the peak of the benchmark boom with only the housing demand shock while keeping the other parameters constant at their peak levels. All prices are determined endogenously in equilibrium. The first column in Table VI (which is the replica of the last column in Table III) reports the results. The second column in Table VI reports the direct effect of the housing demand shock (we close its indirect effect by shutting down the equilibrium response of all prices except for house prices).[41] We find that the housing demand shock directly causes a 21.4 percent decline in house prices and a 5.6 percent decline in consumption. This implies an elasticity of aggregate consumption to house prices as 0.26

[39] We also use the direct and indirect terminology for the effect of the bank lending rate. In that case, the direct effect is via household borrowing costs and the indirect effect is via firm borrowing costs.

[40] The indirect effect of the housing demand shock during the boom is negligible.

[41] Shutting down the response of the bank lending rate r_ℓ only and solving r_k and w endogenously has a minimal effect on results since the changes in r_ℓ are the key driving force behind the indirect effect of house prices.

(=5.6/21.4), which is in line with the estimates provided in Berger et al. (2018).

Next, to quantify the indirect effect of the housing demand shock via bank balance sheets, we shock the economy at the peak of the boom with the r_ℓ sequence obtained from the "HDS bust (total)" experiment and solve for w and r_k endogenously.[42] The rise in r_ℓ reflects the extent of damage the decline in house prices causes on bank balance sheets. The third column reports the results: the rise in r_ℓ causes an additional 4.4 percent decline in house prices, amplifying the direct effect by 21 percent, and an additional 3.5 percent decline in consumption, amplifying the direct effect by 63 percent. Thus, even though the direct effect of the housing demand shock is more important for the decline in house prices and consumption, the indirect effect due to contraction in credit supply is also substantial.

We conclude this section with a remark. The indirect effect of a housing bust is highly non-linear in the size of the bust. Since households hold some equity in their houses, small declines in house prices do not generate enough increase in foreclosures to hurt bank balance sheets. However, as larger declines in house prices push households into negative equity, the foreclosure rate increases at a disproportionately higher rate, strengthening the bank balance sheet mechanism. We confirm this by generating a housing demand bust with a 5.5 percent house price decline as opposed to 30.0 percent in the first experiment above. In this case, the bank balance sheet deterioration has much smaller contributions to the house prices and consumption.

5.3 Robustness

We check the robustness of our results to alternative parameterizations of the rental market segmentation parameter (η), the elasticity of substitution between consumption and housing ($^1/_\epsilon$), the coefficient of risk aversion (σ), the elasticity of intertemporal substituion $(1/\rho)$, the bank leverage level $\widehat{\lambda}$, and the labor utilization function curvature (ψ), which are externally set in our benchmark. As in our benchmark, we recalibrate our model for each alternative exogenously set parameterization and analyze the boom-bust dynamics with leverage shocks. For different values of $^1/_\epsilon$, η, and σ, the model generates boom-bust dynamics that are very similar to the benchmark (Figure 5 in the Internet Appendix G).

[42]Whether we solve w and r_k endogenously in this experiment or feed into the economy the w and r_k sequence of the HDS bust, we obtain very similar results.

While the model generates somewhat different dynamics for different values of ψ and $\widehat{\lambda}$, overall, our substantive conclusions. i.e., credit supply played an important role during the boom-bust episode, do not change.

6 Empirical Evidence

Our model reveals stark differences between the implications of credit supply and housing demand increases, differences that are testable in the data. First, a credit supply expansion lowers the equilibrium bank lending rate, which in turn increases mortgage borrowing by households and firm borrowing. Thus, mortgages and firm loans move in the same direction. In contrast, a housing demand shock implies different patterns: with an increase in housing demand, households borrow more in mortgages, which drives the bank lending rate up. With the higher bank lending rate, firms cut back borrowing. As a result, during the boom, while mortgage debt increases, firm loans decline as the bank lending rate rises.

Furthermore, our model links the credit supply expansion to the increase in bank leverage. Thus, we should see that increases in bank leverage are followed by declines in bank lending rates as well as increases in bank lending to firms and households (in mortgages).

In this section, we provide three sets of results that support the credit supply mechanism. First, we find that mortgages and firm loans move together at the county and bank levels, as implied by the credit supply channel. Second, we examine the relationship between aggregate outcomes and shifts in the bank lending rate. Our findings indicate that declines in mortgage interest rates are associated with increases in mortgage lending, house prices, firm loans, employment, and labor income. Third, we find that increases in bank leverage are associated with declines in bank lending rates as well as increases in firm loans and mortgages.

We analyze changes during two key periods: from the pre-boom (1998) to the peak of the boom (2006), and from the peak of the boom to the end of the crisis (2011). This timeline aligns well with our quantitative analysis. Our results are robust to alternative choices for the beginning and end dates of the boom and bust periods. We specifically avoid using 2007 because the first signs of the financial crisis emerged that year. We choose 2011 as the end of the crisis period because bank failures peaked in 2010.

We use several datasets for our analysis. We use CoreLogic's Loan-Level Market Analytics (LLMA) to construct county-level averages of mortgage variables, including interest rates, FICO scores, house prices, loan origination amounts, mortgage type (FRM share), and loan-to-value ratios. We use Community Reinvestment Act (CRA) data for county-level small business lending and BLS county-level data on per-capita income and unemployment rates. We use Call Reports data for bank-level analysis, focusing on changes in bank capital ratios (which is the inverse of the bank leverage ratio), lending patterns, and various balance sheet measures. We provide information about the data as well as descriptive statistics in Appendix Section C.

6.1 The Comovement of Mortgages and Firms Loans

First, we analyze whether the changes in loans to firms and mortgages were positively correlated during the boom period. As we show in Table III, while the increase in bank leverage, and hence credit supply, increases both mortgage lending and firm lending, an increase in housing demand has the opposite effect on lending to firms. We focus on the boom period, since during the bust, housing demand shocks can also generate a co-movement between mortgages and firm loans because of their effects on credit supply.[43]

We provide evidence of comovement from two data sets. First, we use bank-level Call Reports data and analyze how commercial and industrial (C&I) loans and mortgages in bank balance sheets changed from 1998 to 2006, the boom period. The left panel of Figure 5 plots our results, which suggest that bank mortgage lending and firm lending increased together during the boom period, supporting the credit supply mechanism of the paper.

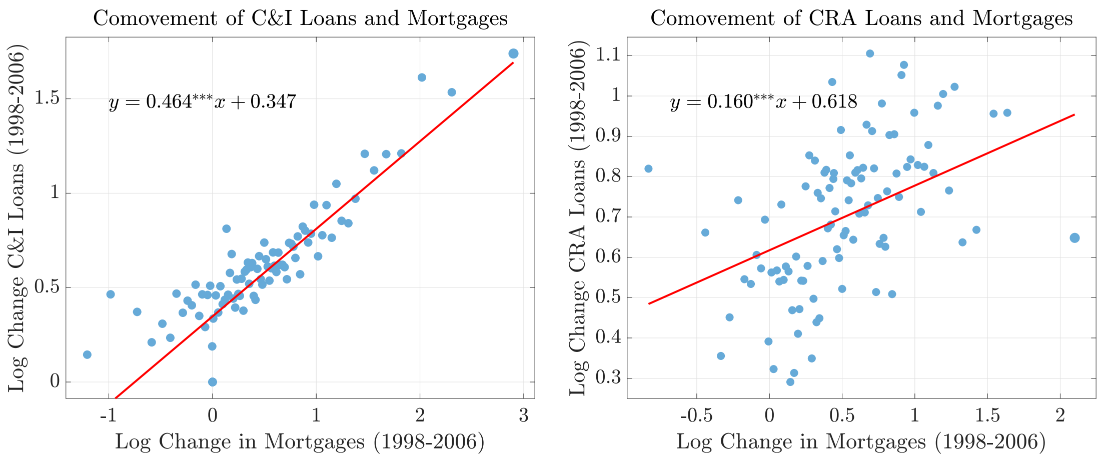
Our second evidence comes from county-level data. For mortgage lending, we use the CoreLogic originations data aggregated to the county level. For firm lending, we use the county-level CRA data, which covers bank lending to small firms by regulated banks. We report the results in Figure 5 (right panel), which shows that growth in firm loans and mortgages was strongly positively correlated at the regional level, as well.

These results are consistent with the credit supply mechanism. As credit supply increases, credit to mortgages and firms increases together. If housing demand were the main driver of the boom, and credit supply played an insignificant role, we would not expect such co-movement.[44]

[43]The co-movement is also strong in the bust in the data.

[44]The positive co-movement between firm loans and mortgages can also be generated by a productivity

FIGURE 5 – The Comovement of Mortgages and Firm Loans During the Boom



Notes: The left panel of the figure plots the binscatter of log change in C&I loans and log change in closed-end first lien mortgages from 1998 to 2006. The data is from Call Reports. The right panel plots the binscatter of log changes in CRA loans and log changes in mortgage lending from 1998 to 2006 at the county level. The mortgage data is from CoreLogic. (*** Significant at 1%, ** Significant at 5%, * Significant at 10%).

6.2 County-level Evidence: Interest Rates and Economic Activity

Next, we use county-level variation in changes in mortgage interest rates to empirically test the model's credit supply mechanism. In our quantitative model, an increase in credit supply lowers interest rates, which increases lending to firms and households. Since firms can finance at a lower rate, labor demand and wages increase. For each county, we calculate the changes in mortgage interest rates from 1998 to 2006 (boom), and from 2006 to 2011 (bust), and use these county-level changes in interest rates as proxies for the changes in credit supply during the boom and bust periods. Then, we examine how several county-level economic variables respond to declines in county-level mortgage interest rates.

To test our hypothesis, we regress the changes in several variables from 1998 to 2006, and from 2006 to 2011 on the changes in mortgage interest rates during the corresponding

shock. However, as Figure 3 in the Internet Appendix illustrates, while a positive productivity shock may lead to increases in both mortgages and firm loans, it also counterfactually results in an increase in bank lending rates.

periods. We estimate the following model separately for the boom and bust periods :

$$\begin{aligned}\Delta Y_{county,\{98-06,06-11\}} &= \beta + \alpha * \Delta r_{county,\{98-06,06-11\}} + \\ &\gamma CONTROLS_{county\{98,06\}} + \theta_{state} + \epsilon_{county,\{98-06,06-11\}}\end{aligned} \tag{8}$$

where the dependent variables $\Delta Y_{county,\ 98-06,\ 06-11}$ are the log changes in per-capita income, house prices, mortgage volume, firm lending, and changes in unemployment rate in a county during the boom (1998 to 2006) or the bust (2006-2011) period. The main explanatory variable is the county-level change in average mortgage interest rate during the the respective period.

We also control for the initial county-level averages at the start of each period (1998 for the boom and 2006 for the bust), including average FICO scores, financial dependence, unemployment rates, housing appraised values (sale values give similar results), combined loan-to-value ratios, and the share of fixed-rate mortgages. We include state fixed effects θ_{state} to account for state-level variation, such as differing policies. We cluster the standard errors at the state level.

Our quantitative model implies a negative correlation between the bank lending rate (i.e., a negative value for α) and per-capita income, house prices, mortgage volume, and firm lending, as well as a positive correlation (i.e., a positive α) with the unemployment rate.

We use weighted OLS regressions (weighted by county labor force) to account for large heterogeneity in county sizes. The measurements from larger counties tend to be more precise, as they are based on larger samples, while small counties often show more variance in economic measures. Additionally, weighting helps address potential heteroskedasticity issues that arise from size-related variance in county-level data.

We report our results in Table VII. In panel A, we report the regression results from the boom period. In Panel B, we report the regression results from the bust period. For both periods, the results support the findings of our model. In counties where mortgage interest rates declined, the unemployment rate declined, and labor income, house prices, mortgages, and firm lending increased significantly.

Our results imply economically large effects. During the boom period, a one percentage point decrease in county-level mortgage interest rates is associated with a 0.264 percentage point reduction in unemployment rates. House prices increase by 0.170 log points, while mortgage volumes and firm lending increase by 0.224 and 0.167 log points, respectively. Income increases by 0.015 log points.[45]

The effects are larger during the bust. A one percentage point increase in county-level mortgage interest rates is associated with a 1.1 percentage point increase in unemployment rates. House prices decrease by 0.449 log points and income by 0.076 log points. Mortgage volumes and firm lending decline by 0.156 (not significant) and 0.136 log points respectively. The results suggest that interest rate changes had larger effects during the bust period, particularly on real economic variables like unemployment and house prices.

We should note that the results are not directly comparable to the model findings since these results do not take fully into account the general equilibrium forces. As people can move to other counties in response to relative changes in income across counties, the effects of the bank lending rate on income and employment in these regressions are likely to be biased downwards.

[45]These numbers correspond to a 18.5 percent increase in house prices, a 25.1 percent increase in mortgage lending, a 18.2 percent increase in firm lending, and a 1.5 percent increase in income.

Table VII – County-level Evidence

Panel A: Boom Period (1998-2006)

Explanatory Variables	(1) Unemployment Rate (change)	(2) Labor Income (log change)	(3) House Prices (log change)	(4) Mortgage Volume (log change)	(5) Firm Lending (log change)
Change in Bank Lending Rate	0.264***	-0.015**	-0.170***	-0.224***	-0.167**
	(0.094)	(0.006)	(0.058)	(0.076)	(0.069)
	0.007	0.024	0.005	0.005	0.019
Controls	Yes	Yes	Yes	Yes	Yes
State Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	2,566	2,572	2,572	2,573	2,570
R-squared	0.916	0.472	0.722	0.349	0.372

Panel B: Bust Period (2006-2011)

Explanatory Variables	(1) Unemployment Rate (change)	(2) Income (log change)	(3) House Prices (log change)	(4) Mortgage Volume (log change)	(5) Firm Lending (log change)
Change in Interest Rate	1.107***	-0.076***	-0.449***	-0.156	-0.136**
	(0.394)	(0.014)	(0.087)	(0.133)	(0.051)
	0.007	0.000	0.000	0.247	0.011
Controls	Yes	Yes	Yes	Yes	Yes
State Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	2,776	2,776	2,769	2,778	2,776
R-squared	0.825	0.459	0.735	0.582	0.273

Notes: The table reports estimates from weighted least squares regressions examining the relationship between changes in interest rates and county-level economic outcomes across different time periods (1998-2006 and 2006-2011), where the dependent variables are changes in unemployment rates, log changes in income, house prices, mortgage origination volumes, and lending to small firms in counties (CRA loans). The main independent variable is the change in average mortgage interest rates between periods in a county, and all regressions include county-level control variables measured at the start of each period: FICO scores, county financial dependence, unemployment rates, appraised values, combined loan-to-value ratios, and the share of fixed-rate mortgages. The dependent and explanatory variables are winsorized at the 1st and 99th percentiles to address potential outliers. The standard errors clustered at the state level to account for within-group correlation. Results are reported with coefficient estimates, standard errors in parentheses, and corresponding significance levels (*** Significant at 1%, ** Significant at 5%, * Significant at 10%).

6.3 Bank-level Evidence

Our model implies that when bank leverage increases, bank lending increases and bank lending rates decline. Moreover, bank lending in firm loans and mortgages both increase. We test these predictions using bank-level Call Reports data. We assess whether banks that lowered (or increased less) their capital ratios more during the boom (from 1998 to 2006) and bust (from 2006 to 2011) increased firm and mortgage lending more, and analyze their average bank lending rate movements. In particular we estimate the following specification separately for the boom and the bust periods:

$$\begin{aligned} \Delta Y_{bank,\{98-06,06-11\}} &= \beta + \alpha * \Delta CapitalRatio_{bank,\{98-06,06-11\}} \\ &\quad + \gamma CONTROLS_{bank\{98,06\}} + \epsilon_{bank,\{98-06,06-11\}} \end{aligned} \tag{9}$$

where the dependent variables $\Delta Y_{bank,\{98-06,06-11\}}$ are changes in bank total loans, C&I loans, household mortgages, and several measures of bank lending rate, during the boom and bust periods.[46] The main control variable is the change in banks' capital ratio (equity/risk weighted assets) during the boom and the bust periods, which is the inverse of the leverage ratio in the model. We also control for major bank variables (log of total assets, liquidity ratio, cash-to-assets ratio, personal loans-to-assets ratio, commercial and industrial loans-to-assets ratio, securities-to-assets ratio, deposits-to-assets ratio, and residential loans-to-assets ratio) using values from the start of the boom and the bust periods. We cluster the standard errors at the bank holding company level.

The results support our model's predictions (Table VIII). Both during the boom and the bust periods, banks that experienced larger declines in bank capital ratio (equivalently, larger increases in leverage), experienced larger increases in total loans, C&I loans and mortgages. They also experienced lower interest rates.

Our analysis implies economically significant effects of bank capital ratio changes on bank lending and interest rates. During the boom, a one standard deviation decline in bank capital ratio (0.061 percentage points) is associated with a 0.228 log point C&I loan growth (42.4 percent of mean growth), a 0.228 log point increase in total loan growth (38.4 percent of mean growth), and a 0.186 log point increase in mortgage loans (42.6 percent of mean growth). In parallel, lower capital ratios are associated with lower interest rate measures. The same one standard deviation decline in capital ratios is associated with a 0.12 standard deviation decline in interest income relative to loans and a 0.43 standard deviation decrease in net interest income relative to loans. These findings suggest that when bank capital declines, banks increase lending growth and lower their interest rates on loans.

[46] Following the banking literature, we use interest income relative to total loans, which is interest income divided by total loans.

Table VIII – Bank-level Evidence

Panel B: Boom Period (1998-2006)

	(1)	(2)	(3)	(4)	(5)
Explanatory Variables	C&I Loans (log change)	Total Loans (log change)	Mortgages (log change)	Average interest rate Interest Income on Loans (relative to loans, change)	Average net interest rate Net Interest Income (relative to loans, change)
Change in Bank Capital Ratio (1/bank leverage)	-3.744***	-3.745***	-3.049***	0.004***	0.042***
	(0.211)	(0.147)	(0.203)	(0.001)	(0.002)
	0.000	0.000	0.000	0.000	0.000
Other Controls	Yes	Yes	Yes	Yes	Yes
Observations	5754	5,915	5854	5,904	5906
R-squared	0.122	0.223	0.133	0.032	0.259

Panel A: Bust Period (2006-2011)

	(1)	(2)	(3)	(4)	(5)
Explanatory Variables	C&I Loans (log change)	Total Loans (log change)	Mortgages (log change)	Average interest rate Interest Income on Loans (relative to loans, change)	Average net interest rate Net Interest Income (relative to loans, change)
Change in Bank Capital Ratio (1/bank leverage)	-3.318***	-3.212***	-3.300***	0.013***	0.127***
	(0.138)	(0.136)	(0.258)	(0.001)	(0.014)
	0.000	0.000	0.000	0.000	0.000
Other Controls	Yes	Yes	Yes	Yes	Yes
Observations	5643	5762	5663	5,753	5754
R-squared	0.194	0.342	0.240	0.377	0.448

Notes: The table reports estimates from least squares regressions examining changes in bank characteristics between 2006 and 2011 (Panel A) and between 1998 and 2006 (Panel B). The dependent variables include changes in commercial and industrial (C&I) loans, total loans, mortgage loans, and interest income measures. The main independent variable of interest is the change in equity ratio, measured as the changes from 1998 to 2006, and 2006 to 2011. All regressions include log of total assets, liquidity ratio, cash-to-assets ratio, personal loans-to-assets ratio, commercial and industrial loans-to-assets ratio, securities-to-assets ratio, deposits-to-assets ratio, and residential loans-to-assets ratio. The dependent and explanatory variables are winsorized at the 1st and 99th percentiles to address potential outliers. The standard errors clustered at the bank holding company level to account for within-group correlation. Results are reported with coefficient estimates, standard errors in parentheses, and corresponding significance levels (*** Significant at 1%, ** Significant at 5%, * Significant at 10%).

7 Conclusion

In this paper, we developed a heterogeneous-agent model that features interactions between household, firm, and bank balance sheets and is consistent with important cross-sectional facts as well as the dynamics of key aggregate variables around the 2008 boom-bust cycle in the US. We used the model to study the contributions of several factors to the boom-bust. In particular, we compared the implications of credit supply versus housing-demand induced boom-busts.

We found that changes in bank leverage, calibrated to observed US changes, account for a significant portion of the boom-bust in US house prices, household mortgage debt, firm borrowing, output, wages, and consumption around 2008. The credit supply expansion during the boom reduces bank lending rates, simultaneously increasing mortgage debt and firm loans. This suggests positive co-movements in these variables, which we test in the data.

While shocks to housing demand can generate a larger boom-bust in house prices, they have counterfactual implications for firm borrowing, output, and wages during the boom. Furthermore, they imply a negative co-movement between mortgage debt and firm loans during the boom. Specifically, while household mortgage debt increases during the boom, firms borrow less due to the increase in the bank lending rate.

On the other hand, the effects of both shocks are amplified in the bust due to endogenous declines in credit supply as banks are forced to cut back credit in response to declines in their equity. Thus, in the bust, both shocks generate declines in household mortgage debt and firm loans, resulting in a positive co-movement driven by endogenous declines in credit supply.

Furthermore, we provided empirical evidence that supports the credit supply mechanism. Overall, our results show that the change in credit supply—whether it is due to the exogenous shocks to bank leverage or an endogenous response to the bank balance sheet deterioration during the bust—is an important contributor to the boom-bust in the housing market and overall economy.

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APPENDIX

A Data Used in the Quantitative Analysis

Bank Book Leverage The data for banks are from Federal Reserve Bank of New York (2024); the data for security brokers and dealers are from Federal Reserve Board (2019).

GDP Real gross domestic product per capita, deflated using PCE chain-type price index (data series code: PCEPI), Quarterly, Seasonally Adjusted Annual Rate from FRED (data series code: GDP). We use quarterly data from 1985 to 2006 and linearly detrend it, and then take the percentage deviation of the data from 1985 to 2019 from this trend.

Aggregate Consumption Real personal consumption expenditures per capita, deflated using PCE chain-type price index (data series code: PCEPI), Quarterly, Seasonally Adjusted Annual Rate from FRED (data series code: PCE). We use quarterly data from 1985 to 2006 and linearly detrend it, and then take the percentage deviation of the data from 1985 to 2019 from this trend.

Labor Income Labor Income come from FRED (data series code: BA06RC1A027NBEA) reported as total wages and salary by BLS. We deflate the data using the PCE chain-type price index (data series code: PCEPI). We linearly detrend it, and then take the percentage deviation of the data from 1985 to 2019 from this trend.

Total Bank Loans Total bank loans data come from FRED (data series code: QBPBSTASTLN). We annualize the data by taking the average of the quarterly observations, deflate them using the PCE chain-type price index (data series code: PCEPI). We linearly detrend it, and then take the percentage deviation of the data from 1985 to 2019 from this trend.

Homeownership Rate Homeownership rate data come from FRED (data series code: RHORUSQ156N). We annualize the data by taking the average of the quarterly observations in a year.

Price-Rent ratio Price rent ratio is computed as the ratio of market value of owner-occuped real estate (data series code: BOGZ1FL155035013Q) and imputed rental of owner-occupied housing (data series code: A2013C1A027NBEA). Both data come from FRED.

House Prices House Price Index for the entire US (Source: Federal Housing Finance Agency) divided by the price index for nondurable consumption (line 6 of NIPA Table 2.3.4. Price Indexes for Personal Consumption Expenditures by Major Type of Product). We use quarterly data from 1985 to 2006 and linearly detrend it, and then take the percent deviation of the data from 1985 to 2018 from this trend. To obtain the changes relative to GDP, we divide the real house price index by the real GDP series.

Mortgage Debt Home Mortgage Liabilities. Source: Flow of Funds D3 Balance Sheet of Households and Nonprofit Organizations.

Foreclosure Rate Foreclosure data come from Mortgage banker's Association and reported as the annual sum of foreclosures started in each quarter.

Credit Spread Credit spread data are the excess bond premium reported in Gilchrist and Zakrajšek (2012) and updated at `https://www.federalreserve.gov/econres/notes/feds-notes/ebp_csv.csv`

B Model Appendix

B.1 Value Functions for Households

B.1.1 Active Renters

An active renter has two choices: continue to rent or purchase a house, that is, $V^r = \max\left\{V^{rr}, V^{rh}\right\}$ where V^{rr} is the value function if she decides to continue renting and V^{rh} is the value function if she decides to purchase a house. If she decides to continue to rent, she chooses rental unit size s at price p_r per unit, makes her consumption and saving choices, and remains as an active renter in the next period. After purchasing a house, she begins the next period as a homeowner. The value function of an active renter who decides to remain as a renter is given by

$$V_j^{rr}(a,z) = \max_{c,s,a' \geqslant 0} \left\{ \left(u(c,s) + \beta E \left(V_{j+1}^r(a',z')^{1-\sigma} \right)^{\frac{1-\rho}{1-\sigma}} \right)^{\frac{1}{1-\rho}} \right\} \tag{B.1}$$

subject to

$$c + a' + p_r s = y(j,z) + a\,(1 + r_k)\,,$$

where a is the beginning-of-period financial wealth, $p_r s$ is the rental payment, r_k is the return to savings, and w is the wage rate per efficiency unit of labor. The expectation operator is over the income shock z'.

B.1.2 Inactive Renters

Inactive renters are not allowed to purchase a house because of their default in previous periods. However, they can become active renters with probability π. Since they cannot buy a house; they only make rental size, consumption, and saving decisions. The value function of an inactive renter is given by

$$V_j^e(a,z) = \max_{c,s,a' \geqslant 0} \left\{ \left(u(c,s) + \beta \left[\pi E V_{j+1}^r(a',z')^{1-\sigma} + (1-\pi) E V_{j+1}^e(a',z')^{1-\sigma} \right]^{\frac{1-\rho}{1-\sigma}} \right)^{\frac{1}{1-\rho}} \right\} \tag{B.2}$$

subject to

$$c + a' + p_r s = y(j,z) + a\,(1 + r_k)\,.$$

B.1.3 Homeowners

The options of a homeowner are: 1) stay as a homeowner, 2) refinance, 3) sell the current house (become a renter or buy a new house), or 4) default. The value function of an owner is given as the maximum of these four options, that is, $V^h = \max\left\{V^{hh}, V^{hf}, V^{hr}, V^{he}\right\}$, where V^{hh} is the value of staying as a homeowner, V^{hf} is the value of refinancing, V^{hr} is the value of selling, and V^{he} is the value of defaulting (being excluded from the ownership option).

A stayer makes a consumption and saving decision given his income shock, housing, mortgage debt, and assets. Therefore, the problem of the stayer can be formulated as follows:

$$V_j^{hh}(a,h,d,z) = \max_{c,a' \geqslant 0} \left\{ \left(u(c,h) + \beta \left(E V_{j+1}^h(a',h,d',z')^{1-\sigma} \right)^{\frac{1-\rho}{1-\sigma}} \right)^{\frac{1}{1-\rho}} \right\} \tag{B.3}$$

subject to

$$
\begin{aligned}
c+\delta_h p_h h+a'+m &= y(j,z)+a(1+r_k)\\
d' &= (d-m)(1+r_\ell),
\end{aligned}
$$

where m is the mortgage payment following the standard amortization schedule computed at the bank lending rate r_ℓ.

The second choice for the homeowner is to refinance, which also includes prepayment. Refinancing requires paying the full balance of any existing debt and getting a new mortgage. We assume that refinancing is subject to the same transaction costs as new mortgage originations. So, we can formulate the problem of a refinancer as

$$
V_j^{hf}(a,h,d,z)=\max_{c,d',a'\geqslant 0}\left\{\left(u(c,h)+\beta\left(EV_{j+1}^{h}(a',h,d',z')^{1-\sigma}\right)^{\frac{1-\rho}{1-\sigma}}\right)^{\frac{1}{1-\rho}}\right\} \tag{B.4}
$$

subject to

$$
c+d+\delta_h p_h h+\varphi_f+a' = y(j,z)+a(1+r_k)+d'\left(q^m(d';a,h,z,j)-\varphi_m\right).
$$

The third choice for the homeowner is to sell the current house and either stay as a renter or buy a new house. Selling a house is subject to a transaction cost that equals fraction φ_s of the selling price. Moreover, a seller has to pay the outstanding mortgage debt, d, in full to the lender. A seller, upon selling the house, can either rent a house or buy a new one. Her problem is identical to a renter's problem. So, we have

$$
V_j^{hr}(a,h,d,z)=V_j^{r}(a+p_h h(1-\varphi_s)-d,z).
$$

The fourth possible choice for a homeowner is to default on the mortgage, if she has one. A defaulter has no obligation to the bank. The bank seizes the house, sells it on the market, and returns any positive amount from the sale of the house, net of the outstanding mortgage debt and transaction costs, back to the defaulter. For the lender, the sale price of the house is assumed to be $(1-\varphi_e)p_h h$. Therefore, the defaulter receives $\max\{(1-\varphi_e)p_h h-d,0\}$ from the lender. The defaulter starts the next period as an active renter with probability π. With probability $(1-\pi)$, she stays as an inactive renter. The problem of a defaulter becomes the following:

$$
V_j^{he}(a,d,z)=\max_{c,s,a'\geqslant 0}\left\{\left(u(c,s)+\beta E\left[\pi V_{j+1}^{r}(a',z')^{1-\sigma}+(1-\pi)V_{j+1}^{e}(a',z')^{1-\sigma}\right]^{\frac{1-\rho}{1-\sigma}}\right)^{\frac{1}{1-\rho}}\right\} \tag{B.5}
$$

subject to

$$
c+a'+p_r s = a(1+r_k)+y(j,z)+\max\{(1-\varphi_e)p_h h-d,0\}.
$$

The problem of a defaulter is different from the problem of a seller in two ways. First, the defaulter receives $\max\{(1-\varphi_e)p_h h-d,0\}$ from the housing transaction, whereas a seller receives $(1-\varphi_s)p_h h-d$. We assume that the default cost is higher than the sale transaction cost, that is, $\varphi_e>\varphi_s$, and the defaulter receives less than the seller as long as $(1-\varphi_s)p_h h-d\geqslant 0$ (i.e., the home equity net of the transaction costs for the homeowner is positive). Second, a defaulter does not have access to the mortgage in the next period with some probability. Such an exclusion lowers the continuation utility for a defaulter. In sum, since defaulting is costly, a homeowner will choose to sell the house instead of defaulting as long as $(1-\varphi_s)p_h h-d\geqslant 0$ (i.e., net home equity is positive). Hence, negative equity is a necessary condition for default in the model. Therefore, in equilibrium, a defaulter gets nothing from the lender.

B.2 Firm's Problem

The firm's first-order conditions are given as

$$
\begin{aligned}
\alpha \mathbb{Z}\left(\frac{K}{Nu}\right)^{\alpha-1} &= r_k + \delta \\
(1-\alpha)\,\mathbb{Z}u\left(\frac{K_t}{Nu}\right)^{\alpha} &= \left(1+\mu r_\ell'\right)\left(\bar{w} + \vartheta \frac{u^{1+\psi}}{1+\psi}\right) \\
(1-\alpha)\,\mathbb{Z}\left(\frac{K_t}{Nu}\right)^{\alpha} &= \left(1+\mu r_\ell'\right)\vartheta u^{\psi}.
\end{aligned}
$$

B.3 Government

The government runs a pay-as-you-go pension system. It collects social security taxes from working-age households and distributes to retirees. We assume the pension system runs a balanced budget:

$$
\sum_{j=1}^{J_R}\sum_{z}\tau y\left(j,z\right)\pi_j\left(z\right) = \sum_{j=J_R+1}^{J}\sum_{z} y_R\left(j,z\right)\pi_j\left(z\right), \tag{B.6}
$$

where $\pi_j\left(z\right)$ is the measure of individuals with income shock z at age j.

B.4 Definition of Equilibrium

We provide the definition of equilibrium for the steady state. The equilibrium definition for the transition is similar.

Definition 1. A Stationary Competitive Equilibrium is a collection of value functions for households, V^o $(o \in \{h, r, d\})$, for banks Ψ, for real estate companies, V^{rc}, policy functions for households' consumption (g_c), saving (g_a), housing services (g_s), housing stock (g_h), mortgage debt (g_d), tenure decisions (g_o), firms' labor (N), capital (K), utilization (u), real estate companies' housing stock (H_r), banks' consumption (c_B), loans $\left(\ell, L^k, L\right)$, borrowing (B), prices for labor (w), capital (r_k), houses (p_h), rental properties (p_r), loans (r_ℓ, q^m), taxes (τ), and a stationary distribution (Γ) such that

1. Given prices and taxes, policy functions for households solve households' problems in equations B.1-B.5, and V^o is the associated value functions for households.
2. Given prices, firms' policy functions (K, N, u) solve firms' problem in equation 2.
3. Given prices, real estate companies' policy function (H_r) solves equation 3.
4. Given prices, banks' policy functions(c_B, L, B) solve equation 5.

5. q^m solves equation 7.Given stationary distribution Γ, markets clear:

$$\text{asset market: } \int a d\Gamma(\theta) = A = K + V^{rc}(H_r)$$

$$\text{labor market: } N = 1$$

$$\text{housing market: } \int s d\Gamma(\theta) = \bar{H}$$

$$\text{credit market:} L_k + \int_\theta p_\ell(\theta)\, \ell(\theta) = L$$

$$\text{rental market: } \int s d\Gamma(\theta, o \in \{r, d\}) = H_r$$

   where $L_k = \mu w(\bar{w}, u) N$ is the firm's borrowing, $\ell(\theta) = \Gamma(\theta)$, i.e. banks' mortgage holding is equal to the demand for mortgages by households, p_ℓ is given by $p_\ell(\theta) = \frac{1}{1+r'_\ell} \int_{\theta'} (m_\ell(\theta') + p_\ell(\theta'))\, \Pi(\theta'|\theta)$.

6. Given stationary distribution Γ, the government runs balanced-budget, i.e. τ solves equation B.6

7. The distribution Γ is stationary and consistent with the policy functions of households:

$$\Gamma = G(\Gamma)$$

   where the mapping G is obtained through the policy functions of households and evolution of exogenous states.

C Data for Empirical Analysis

We combine several data sets for our analysis.

CoreLogic: From CoreLogic, we use the Loan-Level Market Analytics (LLMA) originations data set, which contains detailed loan-level data on individual residential mortgage loans in the United States. The data set provides information about loan and borrower characteristics at origination, such as interest rates, loan amounts, loan-to-value ratios, property ZIP code and appraisal value, borrower FICO scores, and loan types (ARM or FRM).

We calculate county-level yearly averages of key mortgage variables from 1998 to 2011. In particular, for each county and year, we calculate the averages of mortgage interest rates, loan amounts, cumulative loan-to-value ratios, appraised values (we use these instead of sales price since the data are more available), and the share of FRMs in a county at origination.

We use county-level variation in mortgage interest rates to empirically test the model's credit supply mechanisms. In our quantitative model, an increase in credit supply lowers interest rates, which increases lending to firms and households. Since firms can finance at a lower rate, labor demand and wages increase. For each county, we calculate the changes in mortgage interest rates from 1998 to 2006 (boom), and from 2006 to 2011 (bust), and use these county-level changes in interest rates as measures of changes in credit supply conditions during the boom and bust periods. We control for the average FICO score on mortgages in each county since this might affect the level of mortgage interest rates.

Table I gives summary statistics of these data. During the boom period (1998-2006), counties experienced significant increases in lending and asset values, with mortgage volume growing by an average of 98.6 percent and small business lending surging by 117.6 percent. House values appreciated, on average, 60.4 percent in nominal terms. This period was characterized by declining mortgage interest rates (average decrease of 1.02 percentage points) and favorable labor market conditions, with a slight decrease in unemployment (-0.25 percentage points) and substantial growth in per-capita income (37 percent). Loan-to-value ratios increased from an average of 77.1 percent in 1998 to 81.3 percent in 2006, suggesting higher leverage during the boom period. The bust period (2006-2011) saw a reversal: unemployment rose sharply (average increase of 3.87 percentage points), mortgage volumes contracted by 33 percent, and small business lending fell by 31.7 percent.

Community Reinvestment Act (CRA): The Community Reinvestment Act (CRA) requires that large banks annually report small business lending data at the county level. This helps us study credit to (relatively small) firms at the county-level.

Other data: To study the effect of credit supply on the labour market, we use county-level per-capita income and unemployment data from the BLS. To control for firm loan demand at the county level, we construct a county external financial dependence measure for each county following Arslan et al. (2024).

US Call Reports: The bank balance sheet data come from the Call Reports, which are submitted by banks subject to regulation by the Federal Reserve System, Federal Deposit Insurance Corporation, and the Comptroller of the Currency. We obtain the data from Drechsler et al. (2021), and complement it with additional data from Wharton Research Data Services (WRDS). We drop the smallest 10 percent of the banks.[47]

For the boom (1998 to 2006) and the bust (from 2006 to 2011) periods, we calculate the changes in risk-weighted capital ratio, which is our main explanatory variable.[48] We also construct a set of additional control variables. Consistent with existing literature on bank lending behavior, we include the bank liquidity ratio (normalized by bank assets) and bank size (the logarithm of bank assets), and the shares (relative to total assets) of C&I loans, mortgages, personal loans, deposits, and cash, in the balance sheets of the banks at the beginning of the boom and bust periods. For each bank, we construct multiple dependent variables: log changes in C&I loans, total loans, and mortgages; and changes in interest income on loans (relative to loans); and net interest income (relative to loans).

[47] As of 2006, this corresponds to bank assets of values larger than about 11 million USD.

[48] The results are robust to using total assets.

Table I – **County Level – Descriptive Statistics**

Panel A: 1998-2006 Period						
	Observations	Mean	Median	Std. Dev.	Min	Max
Dependent Variables						
Change in Unemployment Rate (1998-2006). Source: BLS	2733	-0.25	0.20	2.35	-19.40	7.70
% Change in per-capita income (1998-2006). Source: BLS	2697	37.01	35.67	14.11	-16.67	284.09
% Change in appraised house value (1998-2006). Source: CoreLogic	2709	60.38	51.14	54.40	-64.04	1280.30
% Change in mortgage volume (1998-2006). Source: CoreLogic	2712	98.57	63.90	155.39	-90.34	3622.71
% Change in lending to small firms (1998-2006). Source: CRA	2740	117.60	67.53	349.16	-84.88	9602.53
Control Variables						
Change in average mortgage interest rate in a county (1998-2006). Source: CoreLogic	2712	-1.02	-0.87	0.71	-10.35	2.81
Average FICO score in 1998. Source: CoreLogic	2710	684.10	686.62	28.29	541.20	798.00
Unemployment rate in 1998. Source: BLS	2740	5.49	4.60	3.40	1.00	30.10
Average appraised house value in 1998. Source: CoreLogic	2719	122551.21	108701.62	64162.73	18034.00	1497679.11
Average combined LTV in 1998. Source: CoreLogic	2719	77.14	77.61	5.26	17.00	107.02
Share of FRMs in 1998 (originations). Source: CoreLogic	2707	0.89	0.90	0.08	0.00	1.00

Panel B: 2006-2011 Period						
	Observations	Mean	Median	Std. Dev.	Min	Max
Control Variables						
Change in Unemployment Rate (2006-2011). Source: BLS	3013	3.87	3.60	2.04	-3.70	14.30
% Change in per-capita income (2006-2011). Source: BLS	2973	21.61	18.59	15.92	-47.89	198.91
% Change in appraised house value (2006-2011). Source: CoreLogic	2931	11.99	11.42	25.17	-76.41	176.28
% Change in mortgage volume (2006-2011). Source: CoreLogic	2945	-32.97	-36.68	32.02	-99.32	387.64
% Change lending to small firms (2006-2011). Source: CRA	3025	-31.68	-36.55	35.69	-94.43	327.46
Control Variables						
Change in average mortgage interest rate in a county (2006-2011). Source: CoreLogic	2945	-2.62	-2.64	0.50	-6.75	4.36
Average FICO score in 2006. Source: CoreLogic	2992	680.25	680.38	20.68	515.50	775.67
Unemployment rate in 2006. Source: BLS	3016	5.21	4.80	2.12	1.60	20.70
Average appraised house value in 2006. Source: CoreLogic	2990	191119.12	155903.33	121935.21	36850.00	1964071.54
Average combined LTV in 2006. Source: CoreLogic	2955	81.30	82.00	5.87	37.69	107.37
Share of FRMs in 2006 (originations). Source: CoreLogic	2989	0.78	0.80	0.12	0.00	1.00

We report descriptive statistics in Table II. During the boom (1998-2006), banks experienced strong loan growth across all categories, with total loans increasing by 59.4 percent, C&I loans growing by 53.8 percent, and first-lien residential mortgages expanding by 43.7 percent. Interest income on loans relative to total loans decreased by 0.4 percentage points. The bust period (2006-2011) showed significantly slower loan growth: total loans grew by 23.9 percent, C&I loans by 13 percent, and residential mortgages by 31.7 percent. Banks' risk-weighted capital ratios decreased during the boom (-1.6 percentage points) and increased during the bust (0.3 percentage points).[49]

[49]The increase in bank equity ratios becomes significantly larger in later years.

Table II – **Bank Level – Descriptive Statistics**

Panel A: 1998-2006 Period	Observations	Mean	Median	Std. Dev.	Min	Max
Dependent Variables						
Log Change in Commercial and Industrial Loans.	7084	0.538	0.426	0.820	-1.605	3.304
Log Change in Total Loans.	7313	0.594	0.495	0.632	-0.739	2.934
Log Change in First-Lien Residential Mortgages.	6929	0.437	0.322	0.687	-1.208	3.073
Change in Interest on Loans/Total Loans.	7044	-0.004	-0.004	0.002	-0.012	0.000
Change in Net Interest Income/Average Loans.	7044	-0.003	-0.002	0.006	-0.043	0.010
Control Variables						
Change in Risk-Weighted Capital Ratio (in percentage points).	7215	-0.016	-0.004	0.061	-0.293	0.165
Log of Total Assets in 1998.	6138	11.501	11.282	1.190	9.526	19.511
Liquidity Ratio in 1998 (in percentage points).	6138	0.347	0.333	0.142	0.015	0.794
Cash to Assets Ratio in 1998 (in percentage points).	6138	0.065	0.050	0.064	0.000	1.000
Personal Loans to Assets Ratio in 1998 (in percentage points).	5928	0.088	0.072	0.080	0.000	1.015
Commercial and Industrial Loans to Assets Ratio in 1998 (in percentage points).	6138	0.111	0.089	0.103	0.000	1.007
Securities to Assets Ratio in 1998 (in percentage points).	6138	0.293	0.280	0.145	0.000	0.986
Real Estate Loans to Assets Ratio in 1998 (in percentage points).	5928	0.179	0.154	0.129	0.000	0.613

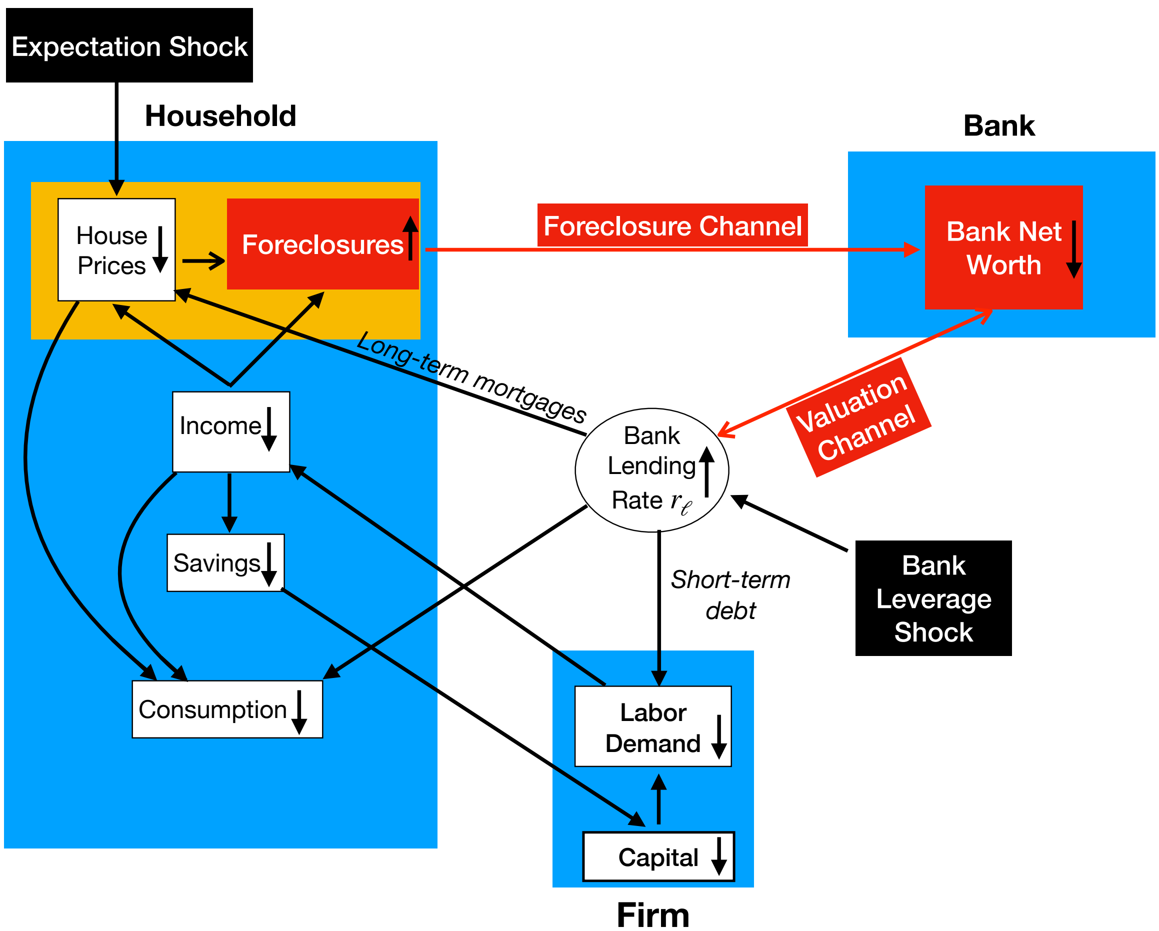
Panel B: 2006-2011 Period	Observations	Mean	Median	Std. Dev.	Min	Max
Dependent Variables						
Log Change in Commercial and Industrial Loans.	6164	0.130	0.051	0.678	-1.617	2.642
Log Change in Total Loans.	6306	0.239	0.153	0.475	-0.661	2.493
Log Change in First-Lien Residential Mortgages.	5997	0.317	0.187	0.626	-0.920	3.093
Change in Interest on Loans/Total Loans.	6062	-0.005	-0.004	0.003	-0.016	0.000
Change in Net Interest Income/Average Loans.	6063	-0.003	0.000	0.017	-0.150	0.011
Control Variables						
Change in Risk-Weighted Capital Ratio (in percentage points).	6148	0.003	0.012	0.080	-0.502	0.179
Log of Total Assets in 2006.	6013	12.046	11.813	1.309	9.950	20.873
Liquidity Ratio in 2006 (in percentage points).	5989	0.285	0.258	0.159	0.010	0.847
Cash to Assets Ratio in 2006 (in percentage points).	6005	0.056	0.040	0.063	0.000	0.991
Personal Loans to Assets Ratio in 2006 (in percentage points).	5791	0.056	0.040	0.075	0.000	1.024
Commercial and Industrial Loans to Assets Ratio in 2006 (in percentage points).	5989	0.114	0.092	0.099	0.000	0.993
Securities to Assets Ratio in 2006 (in percentage points).	5989	0.238	0.211	0.158	0.000	0.998
Real Estate Loans to Assets Ratio in 2006 (in percentage points).	5791	0.156	0.131	0.116	0.000	0.562

Notes: Summary statistics are based on the quarterly US Call Reports restricted to US banks.

INTERNET APPENDIX

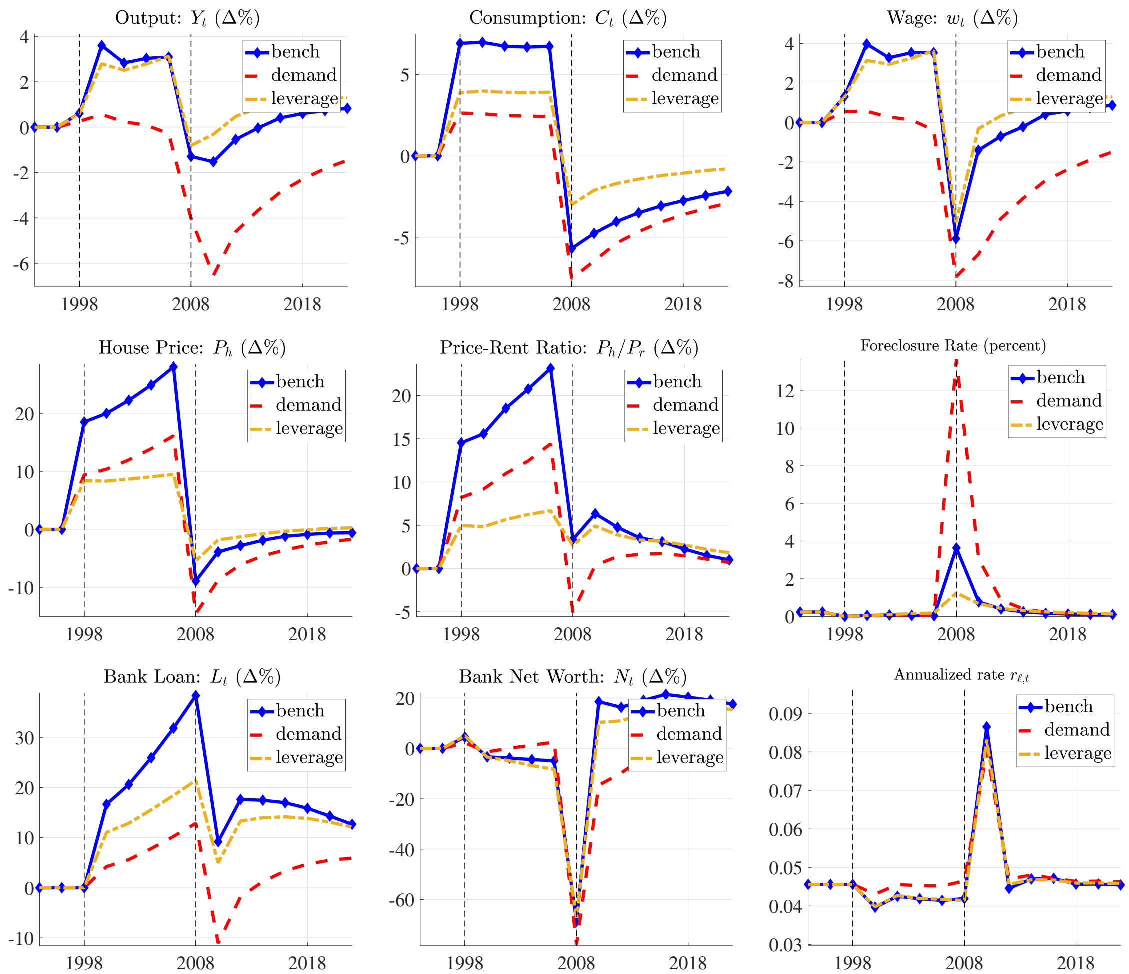
D Linkages across sectors

Figure 1 – Linkages across sectors and amplification channels during the bust



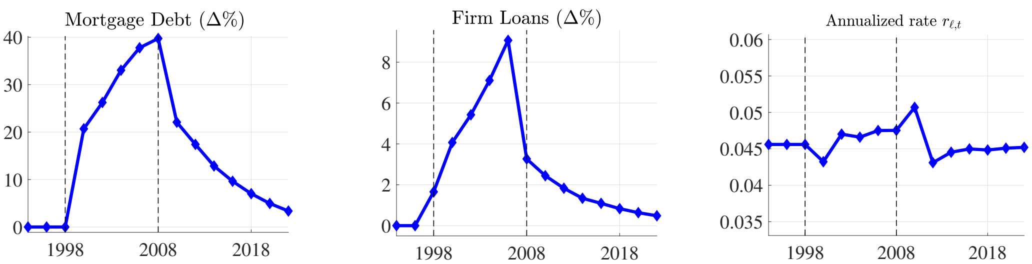
E Model Dynamics with only Credit Supply, Housing Demand and Productivity Shocks

FIGURE 2 – Model Dynamics with Credit Supply and Housing Demand Shocks



Notes: The graph plots the dynamics of key variables during the boom-bust episode in the benchmark economy. The "demand" and "leverage" lines correspond the model dynamics where only that shock is given to the model economy.

Figure 3 – Model Dynamics with Productivity Shocks



Notes: The graph plots the dynamics of mortgages, firm loans, and bank lending rate during the boom-bust episode in the economy where there is only productivity shock. The size of the shock is chosen to generate a similar increase in house prices compared to demand and leverage shocks.

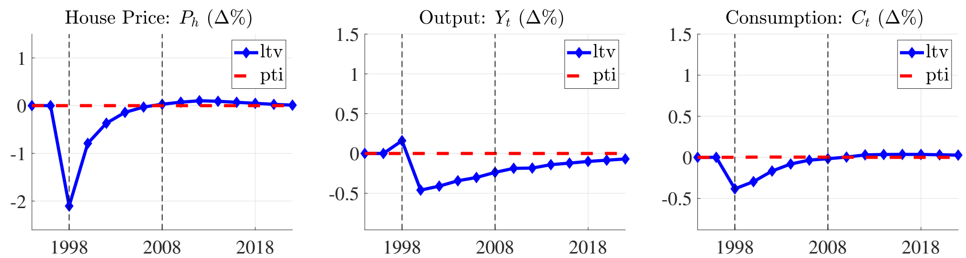
F Extensions

Table III – Effects of Bank Net Worth Shock during the Bust

Variables	Benchmark	Bank net worth shock
Bank lending rate (Δr_ℓ)	4.7	2.2
Wages ($\%\Delta w$)	-9.0	-4.2
House Prices ($\%\Delta p_h$)	-28.8	-2.0
Consumption ($\%\Delta C$)	-11.6	-2.4

Notes: This table reports the results of the exercise where we shock the economy at the peak of the boom with bank net worth losses from the benchmark economy during the bust. We solve for all prices endogenously. The parameters remain at the peak of the boom values.

FIGURE 4 – LTV and PTI Busts



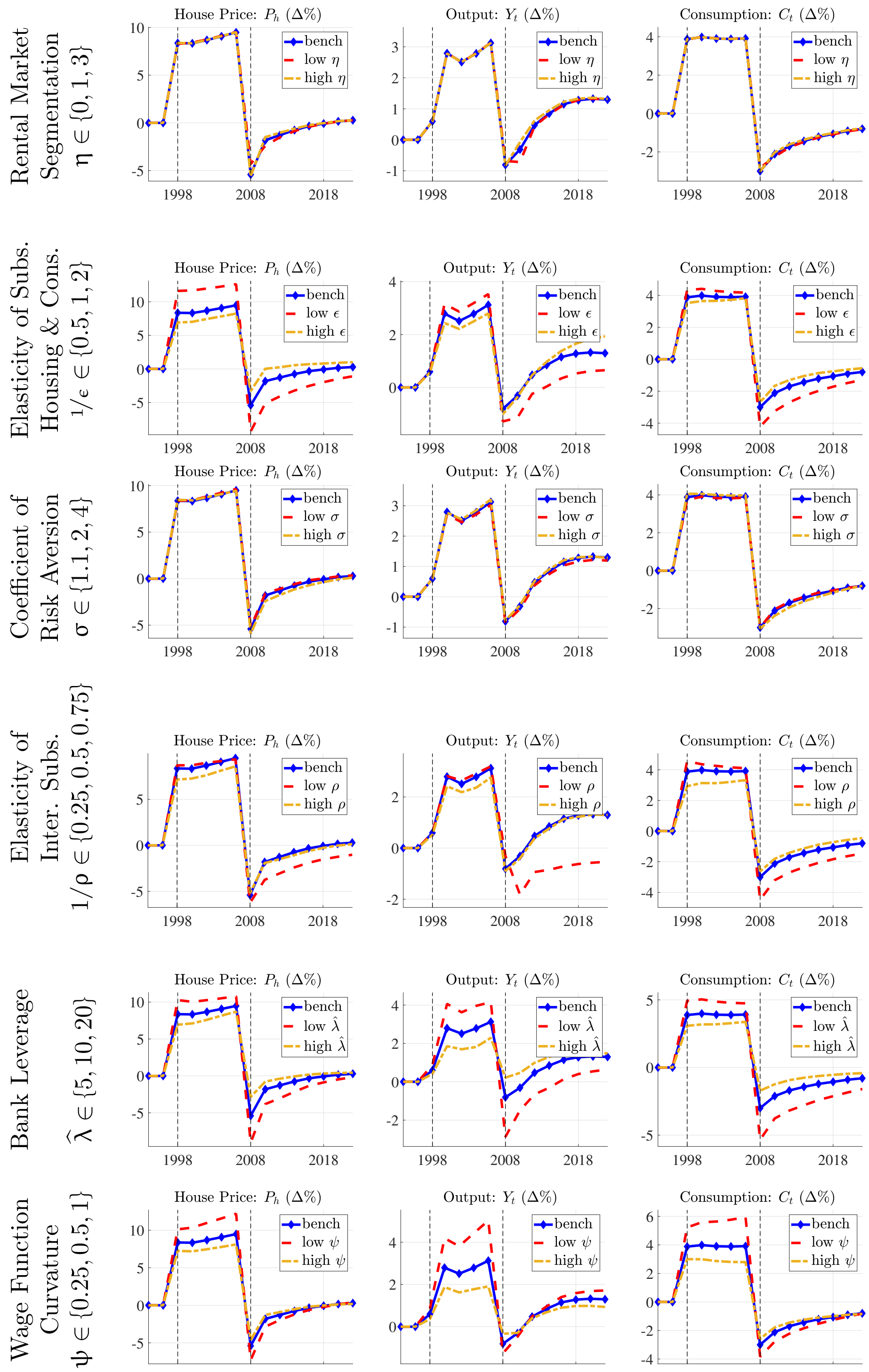
Notes: This figure plots the model dynamics where LTV and PTI constraints tighten unexpectedly. The LTV constraint tightens from 100 to 80 percent, and the PTI constraint tightens to 25 percent (no PTI constraints in the benchmark) with a persistence of 0.6. We focus on the bust since relaxation of the constraints does not generate significant booms.

G Robustness

For all robustness analysis, we recalibrate the initial steady state of the model. Then we feed into the economy the same bank leverage shocks from our benchmark. We report our results in in Figure 5. The boom-bust dynamics look almost identical for different values of η, ϵ, and σ. A parameter that influences model dynamics is labor utilization curvature ψ. The response of hours (hence, of output and wages) to changes in r_ℓ depends on the labor utilization curvature ψ. In our benchmark, we set $\psi = 0.5$ so that the employment response to changes in credit spreads in our benchmark is consistent with the data. For higher values of ψ, the response of employment to changes in r_ℓ becomes smaller; hence, the importance of the changes in credit supply (both exogenous and endogenous) for the boom-bust. To check the sensitivity of our results, we conduct our decomposition exercises with $\psi \in \{0.25, 1\}$. When $\psi = 1$, the leverage shock generates a smaller boom-bust than out benchmark. When $\psi = 0.25$, the effect of the leverage shock becomes larger. In either case, however, we conclude that the leverage shock significantly contributes to the boom-bust in house prices.

The robustness with respect to bank leverage shows that the bank leverage level also influences the model dynamics. To check the sensitivity of our results, we conduct alternative exercises with $\widehat{\lambda} \in \{5, 20\}$. We find that as bank leverage increases, the effect of the leverage shock declines, yet remains important.

Figure 5 – The two-shock boom-bust dynamics with alternative parameterizations



H Equivalence of GHH preferences and Labor Utilization

Consider the following simplified static model. Households supply labor to firms and consume the labor income. Firms hire workers, pay market wages and produce output. Output is only produced by labor. Below we show that the model with labor utilization on firm's problem and inelastic labor supply for households is equivalent to the model without labor utilization on firm's problem and flexible labor supply on households when their preferences are GHH form.

H.1 Static Model with Labor Utilization

Households derive utility only from consumption and labor supply is inelastic. Then, the household's problem becomes:

$$\max_{c} \frac{c^{1-\sigma}}{1-\sigma}$$

subject to

$$c = w(u)$$

$w(u)$ is their labor income.

Firms produce output using only labor, but they can choose the utilization rate of labor, u, subject to convex wage payments as a function of utilization representing overtime payments. Then, the firm's problem becomes:

$$\max_{n,u} \{znu - w(u)n\}$$

where

$$w(u) = \bar{w} + \chi \frac{u^{1+\psi}}{1+\psi}$$

First-order conditions to the firm's problem imply:

$$zn = w'(u)$$
$$zu = w(u)$$

Using the FOC w.r.to u and imposing the market clearing condition of $n = 1$, we get:

$$z = w'(u) = \chi u^{\psi}$$

which results

$$u = \left(\frac{z}{\chi}\right)^{\frac{1}{\psi}}$$

The FOC w.r.to n implies (when $n = 1$):

$$w(u) = zu = \left(\frac{z^{1+\psi}}{\chi}\right)^{\frac{1}{\psi}}$$
$$c = w(u) = \left(\frac{z^{1+\psi}}{\chi}\right)^{\frac{1}{\psi}}$$

H.2 Static Model with GHH preferences

Household's problem can be written as:

$$\max_{c,n} \frac{\left(c-\chi\frac{n^{1+\psi}}{1+\psi}\right)^{1-\sigma}}{1-\sigma}$$

subject to

$$c = wn$$

First-order conditions to the household's problem yield:

$$\chi n^{\psi} = w$$

which results the following labor supply schedule:

$$n^{s} = \left(\frac{w}{\chi}\right)^{\frac{1}{\psi}}$$

Firms' problem can be written as:

$$\max_{n}\{zn - wn\}$$

First-order condition to the firm's problem results:

$$z = w$$

Substituting this to the household's problem we get

$$c = wn = \left(\frac{z^{1+\psi}}{\chi}\right)^{\frac{1}{\psi}}$$

which yields the exact same allocation as in the model with labor utilization.

I Characterization of the Bank's Problem

In this section, we will provide proofs for the characterization of the bank's problem. We will start with the steady-state value functions and decision rules and continue obtaining value functions in the transition by iterating backward from the steady state.

The bank's problem is given as

$$\Psi_t\left(L_t, B_t\right) = \max_{B_{t+1}, L_{t+1}, c_t^B} \left\{\log\left(c_t^B\right) + \beta_L \Psi_{t+1}\left(L_{t+1}, B_{t+1}\right)\right\}$$

subject to

$$\begin{aligned} c_t^B + L_{t+1} &= \left(1+r_{\ell,t}\right)L_t - \left(1+r_t\right)B_t + B_{t+1} \\ \Psi_{t+1}\left(L_{t+1}, B_{t+1}\right) &\geqslant \tilde{\Psi}^D_{t+1}\left(\xi\left(1+r_{\ell,t+1}\right)L_{t+1}\right), \end{aligned}$$

where $\tilde{\Psi}^{D}_{t}(W) = \max_{W'} \log(W - W') + \beta_L \tilde{\Psi}^{D}_{t+1}((1 + r_{t+1})W')$.

I.1 Steady State with $r_\ell > r$

We will characterize the case $r_\ell > r$ and leave the cases for $r_\ell \leqslant r$ for brevity. We will start with the value function of the bank when it defaults.

Since the bank can steal a fraction ξ of assets after the return has been realized and can continue saving at interest rate r, the bank's problem in the period of default is given as

$$\tilde{\Psi}^{D}\left(\xi L'\right) = \max_{s'} \log\left(\xi L' - W'\right) + \beta_L \Psi^{D}\left((1+r)W'\right),$$

and after default, it becomes

$$\tilde{\Psi}^{D}(W) = \max_{s'} \log\left(W - W'\right) + \beta_L \Psi^{D}\left((1+r)W'\right).$$

Lemma 1. $\tilde{\Psi}^{D}(W)$ *is given as*

$$\tilde{\Psi}^{D}(W) = \frac{1}{1-\beta_L}\log(W) + \frac{\beta_L}{(1-\beta_L)^2}\log(\beta_L(1+r)) + \frac{\log(1-\beta_L)}{1-\beta_L}.$$

The bank's problem in the no-default state solves

$$\Psi(L, B) = \max_{L', B'} \log\left((1+r_\ell)L - (1+r)B + B' - L'\right) + \beta_L \Psi\left(L', B'\right)$$

subject to

$$\Psi\left(L', B'\right) \geqslant \tilde{\Psi}^{D}\left(\xi(1+r_\ell)L'\right).$$

Proposition 1. *The solution to the bank's problem is given as follows:*

1. Value function:

$$\begin{aligned}\Psi(L, B) &= \frac{1}{1-\beta_L}\log\left((1+r_\ell)L - (1+r)B\right) \\ &+ \frac{\beta_L}{(1-\beta_L)^2}\log\left(\frac{(1+r)(1+r_\ell)\beta_L\phi}{1+r-(1+r_\ell)(1-\phi)}\right) + \frac{\log(1-\beta_L)}{1-\beta_L}.\end{aligned}$$

2. The no-default constraint can be written as

$$(1+r_\ell)(1-\phi)L' \geqslant (1+r)B'$$

where ϕ is given as

$$\phi = \xi^{1-\beta_L}\left(\frac{1+r}{1+r_\ell} - (1-\phi)\right)^{\beta_L}.$$

3. The bank's solution satisfies the following expression regardless of whether or not the no-default constraint binds:
$$L' - B' = \beta_L \left((1+r_\ell)L - (1+r)B\right).$$

4. The decision rules when the no-default constraint is binding (if $r_\ell > r$):

$$\begin{aligned} L' &= \frac{(1+r)}{1+r-(1-\phi)(1+r_\ell)}\beta_L \left((1+r_\ell)L - (1+r)B\right) \\ B' &= \frac{(1-\phi)(1+r_\ell)}{1+r-(1-\phi)(1+r_\ell)}\beta_L \left((1+r_\ell)L - (1+r)B\right). \end{aligned}$$

Proof. (Proposition 1) We will use the expressions for value functions and verify the claims above. First, drive the capital requirement constraint:

$$\Psi\left(L', B'\right) \geqslant \tilde{\Psi}^D\left(\xi(1+r_\ell)L'\right).$$

$$\frac{1}{1-\beta_L}\log\left((1+r_\ell)L' - (1+r)B'\right) + \frac{\beta_L}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi'}{(1+r)-(1+r_\ell)(1-\phi')}\right) \geqslant$$
$$\frac{1}{1-\beta_L}\log(\xi(1+r_\ell)L') + \frac{\beta_L}{(1-\beta_L)^2}\log(\beta_L(1+r)),$$

where ϕ' is the capital requirement constraint in the next period. The expression above gives

$$\log\left(\frac{(1+r_\ell)L' - (1+r)B'}{\xi(1+r_\ell)L'}\right) \geqslant \frac{\beta_L}{1-\beta_L}\log\left(\frac{\beta\left((1+r)-(1+r_\ell)(1-\phi')\right)}{(1+r_\ell)\beta_L\phi'}\right)$$

$$\frac{(1+r_\ell)L' - (1+r)B'}{(1+r_\ell)L'} \geqslant \xi\left(\frac{((1+r)-(1+r_\ell)(1-\phi'))}{(1+r)\phi'}\right)^{\frac{\beta_L}{1-\beta_L}}.$$

We will show below that the solution of ϕ' is the fixed point of

$$\phi = \xi\left(\frac{((1+r)-(1+r_\ell)(1-\phi'))}{(1+r)\phi'}\right)^{\frac{\beta_L}{1-\beta_L}}.$$

Then this constraint can be written as

$$(1+r_\ell)(1-\phi)L' \geqslant (1+r)B'.$$

Now, we can solve the bank's problem:

$$\begin{aligned}
\Psi(L,B) &= \max_{L',B'} \log\left((1+r_\ell)L-(1+r)B+B'-L'\right)+\beta_L\Psi\left(L',B'\right)\\
&= \max_{L',B'} \log\left((1+r_\ell)L-(1+r)B+B'-L'\right)\\
&+ \frac{\beta_L}{1-\beta_L}\log\left((1+r_\ell)L'-(1+r)B'\right)\\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi'}{(1+r)-(1+r_\ell)(1-\phi')}\right)+\frac{\beta_L\log(1-\beta_L)}{1-\beta_L}
\end{aligned}$$

subject to

$$(1+r_\ell)(1-\phi)L' \geqslant (1+r)B'.$$

Imposing the balance sheet constraint, we obtain

$$\begin{aligned}
\Psi(L,B) &= \max_{L',B'} \log\left((1+r_\ell)L-(1+r)B+\frac{(1+r_\ell)(1-\phi)L'}{1+r}-L'\right)\\
&+ \frac{\beta_L}{1-\beta_L}\log\left((1+r_\ell)L'-(1+r)\frac{(1+r_\ell)(1-\phi)L'}{1+r}\right)\\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi'}{(1+r)-(1+r_\ell)(1-\phi')}\right)+\frac{\beta_L\log(1-\beta_L)}{1-\beta_L}
\end{aligned}$$

$$\begin{aligned}
\Psi(L,B) &= \max_{L'} \log\left((1+r_\ell)L-(1+r)B-\frac{(1+r)-(1+r_\ell)(1-\phi)}{1+r}L'\right)\\
&+ \frac{\beta_L}{1-\beta_L}\log\left((1+r_\ell)\phi L'\right)\\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi'}{(1+r)-(1+r_\ell)(1-\phi')}\right)+\frac{\beta_L\log(1-\beta_L)}{1-\beta_L}.
\end{aligned}$$

The first-order condition is

$$\frac{\frac{(1+r)-(1+r_\ell)(1-\phi)}{1+r}}{(1+r_\ell)L-(1+r)B-\frac{(1+r)-(1+r_\ell)(1-\phi)}{1+r}L'}=\frac{\beta_L}{1-\beta_L}\frac{1}{L'},$$

which gives

$$\begin{aligned}
L' &= \frac{\beta_L(1+r)}{(1+r)-(1-\phi)(1+r_\ell)}\left((1+r_\ell)L-(1+r)B\right)\\
B' &= \frac{\beta_L(1-\phi')(1+r_\ell)}{(1+r)-(1-\phi')(1+r_\ell)}\left((1+r_\ell)L-(1+r)B\right).
\end{aligned}$$

Given these decision rules, the value function is given by

$$
\begin{aligned}
\Psi(L,B) &= \frac{1}{1-\beta_L}\log\left((1+r_\ell)L-(1+r)B\right)\\
&+ \frac{\beta_L}{1-\beta_L}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi}{(1+r)-(1+r_\ell)(1-\phi')}\right)\\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi'}{(1+r)-(1+r_\ell)(1-\phi')}\right)+\frac{\log(1-\beta_L)}{1-\beta_L}.
\end{aligned}
$$

Equating this expression to our initial guess,

$$
\frac{1}{1-\beta_L}\log\left((1+r_\ell)L-(1+r)B\right)+\frac{\beta_L}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi}{(1+r)-(1+r_\ell)(1-\phi)}\right)+\frac{\log(1-\beta_L)}{1-\beta_L},
$$

we obtain

$$
\begin{aligned}
\frac{\beta_L}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi}{(1+r)-(1+r_\ell)(1-\phi)}\right) &= \frac{\beta_L}{1-\beta_L}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi}{(1+r)-(1+r_\ell)(1-\phi)}\right)\\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log\left(\frac{(1+r_\ell)(1+r)\beta_L\phi'}{(1+r)-(1+r_\ell)(1-\phi')}\right),
\end{aligned}
$$

which gives

$$
\frac{\phi}{(1+r)-(1+r_\ell)(1-\phi)}=\frac{\phi'}{(1+r)-(1+r_\ell)(1-\phi')}.
$$

Since these expressions are monotone (and declining) in ϕ, they imply that $\phi=\phi'$. By imposing this into

$$
\phi=\xi\left(\frac{1+r-(1+r_\ell)(1-\phi')}{(1+r)\phi'}\right)^{\frac{\beta_L}{1-\beta_L}}.
$$

we obtain

$$
\phi=\xi^{1-\beta_L}\left(\frac{1+r-(1+r_\ell)(1-\phi)}{(1+r)}\right)^{\beta_L}.
$$

□

I.2 Transition

Assume that the last period of the transition is period T and the economy is in steady state with r_ℓ and r from period $T+1$ and onward. The following proposition characterizes the bank's solution in the transition, where all prices $r_{\ell,t}$ and r_t are potentially changing.

Proposition 2. *The solution to the bank's problem is given as follows:*

1. The value function:

$$
\Psi_t(L_t,B_t)=\frac{1}{1-\beta_L}\log\left((1+r_{\ell,t})L_t-(1+r_t)B_t\right)+\Omega_t+\frac{\log(1-\beta_L)}{1-\beta_L},
$$

where

$$\Omega_t = \frac{\beta_L}{1-\beta_L}\log\left(\frac{\beta_L\phi_{t+1}(1+r_{t+1})1+r_{\ell,t+1}}{1+r_{t+1}-(1-\phi_{t+1})1+r_{\ell,t+1}}\right)+\beta_L\Omega_{t+1};$$

$$\Omega_T = \Omega = \frac{\beta_L}{(1-\beta_L)^2}\log\left(\frac{\beta_L\phi(1+r)\,(1+r_\ell)}{1+r-(1-\phi)\,(1+r_\ell)}\right);$$

$$\phi_t = \xi^{1-\beta_L}\left(\frac{1+r_{t+1}}{1+r_{\ell,t+1}}-(1-\phi_{t+1})\right)^{\beta_L};$$

and

$$\phi_T = \phi.$$

2. The no-default constraint in period t can be written as

$$\left(1+r_{\ell,t+1}\right)(1-\phi_{t+1})\,L_{t+1} \geqslant (1+r_{t+1})\,B_{t+1}.$$

3. The bank's solution satisfies the following expression regardless of whether or not the no-default constraint binds:

$$L_{t+1}-B_{t+1} = \beta_L\left((1+r_{\ell,t})L_t-(1+r_t)B_t\right).$$

4. The decision rules when the no-default constraint is binding (if $r_{\ell,t+1} > r_{t+1}$):

$$\begin{aligned} L_{t+1} &= \frac{\beta_L(1+r_{t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})}\left((1+r_{\ell,t})L_t-(1+r_t)B_t\right) \\ B_{t+1} &= \frac{\beta_L(1-\phi_{t+1})(1+r_{\ell,t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})}\left((1+r_{\ell,t})L_t-(1+r_t)B_t\right). \end{aligned}$$

5. The decision rules when the no-default constraint is not binding (if $r_{\ell,t+1} \leqslant r_{t+1}$):

$$B_{t+1} = \begin{cases} \in \left[0, \frac{\beta_L(1-\phi_{t+1})(1+r_{\ell,t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})}\left((1+r_{\ell,t})L_t-(1+r_t)B_t\right)\right] & \text{if } r_{\ell,t+1} = r_{t+1} \\ 0 & \text{if } r_{\ell,t+1} < r_{t+1} \end{cases}$$

and

$$L_{t+1} = B_{t+1} + \beta_L\left((1+r_{\ell,t})L_t-(1+r_t)B_t\right).$$

Proof. We are going to solve the problem backward starting from period T.

Period T:

$$\begin{aligned} \Psi_T(L_T, B_T) &= \max_{L_{T+1},B_{T+1}} \log\left((1+r_{\ell,T})L_T-(1+r_T)B_T-(L_{T+1}-B_{T+1})\right) \\ &+ \frac{\beta_L}{1-\beta_L}\log\left((1+r_\ell)L_{T+1}-(1+r)B_{T+1}\right) \\ &+ \left(\frac{\beta_L}{1-\beta_L}\right)^2\log\left(\frac{\beta_L\phi(1+r_\ell)(1+r)}{1+r-(1-\phi)(1+r_\ell)}\right)+\frac{\beta_L}{1-\beta_L}\log(1-\beta_L) \\ &\text{s.t.} \\ (1-\phi)(1+r_\ell)L_{T+1} &\geqslant (1+r)B_{T+1}. \end{aligned}$$

The decision rules of this problem are given as

$$
\begin{aligned}
L_{T+1} &= \frac{\beta_L(1+r)}{1+r-(1-\phi)(1+r_\ell)}\left((1+r_{\ell,T})L_T-(1+r_T)B_T\right)\\
B_{T+1} &= \frac{\beta_L(1-\phi)(1+r_\ell)}{1+r-(1-\phi)(1+r_\ell)}\left((1+r_{\ell,T})L_T-(1+r_T)B_T\right)\\
L_{T+1}-B_{T+1} &= \beta_L\left((1+r_{\ell,T})L_T-(1+r_T)B_T\right)\\
(1+r_\ell)L_{T+1}-(1+r)B_{T+1} &= \frac{\beta_L\phi(1+r_\ell)(1+r)}{1+r-(1-\phi)(1+r_\ell)}\left((1+r_{\ell,T})L_T-(1+r_T)B_T\right)
\end{aligned}
$$

which give

$$
\begin{aligned}
\Psi_T\left(L_T,B_T\right) &= \frac{1}{1-\beta_L}\log\left((1+r_{\ell,T})L_T-(1+r_T)B_T\right)\\
&+ \frac{\beta_L}{(1-\beta_L)^2}\log\left(\frac{\beta_L\phi(1+r_\ell)(1+r)}{1+r-(1-\phi)(1+r_\ell)}\right)+\frac{1}{1-\beta_L}\log(1-\beta_L).
\end{aligned}
$$

The value function when the bank defaults is

$$
\tilde{\Psi}_T^D\left(\xi(1+r_{\ell,T})L_T\right) = \frac{1}{1-\beta_L}\log\left(\xi(1+r_{\ell,T})L_T\right)+\frac{\beta_L}{(1-\beta_L)^2}\log(\beta_L(1+r))+\frac{\log(1-\beta_L)}{1-\beta_L}.
$$

The no-default condition in period T can be written as

$$
(1-\phi_T)(1+r_{\ell,T})L_T \geqslant (1+r_T)B_T,
$$

where

$$
\phi_T = \xi^{1-\beta_L}\left(\frac{1+r}{1+r_\ell}-(1-\phi)\right)^{\beta_L}.
$$

Period $T-1$:

$$
\begin{aligned}
\Psi_{T-1}\left(L_{T-1},B_{T-1}\right) &= \max_{L_T,B_T}\log\left((1+r_{\ell,T-1})L_{T-1}-(1+r_{T-1})B_{T-1}-(L_T-B_T)\right)\\
&+ \frac{\beta_L}{1-\beta_L}\log\left((1+r_{\ell,T})L_T-(1+r_T)B_T\right)\\
&+ \left(\frac{\beta_L}{1-\beta_L}\right)^2\log\left(\frac{\beta_L\phi(1+r_\ell)(1+r)}{1+r-(1-\phi)(1+r_\ell)}\right)+\frac{\beta_L}{1-\beta_L}\log(1-\beta_L)\\
\text{s.t.}&\\
(1-\phi_T)(1+r_{\ell,T})L_T &\geqslant (1+r_T)B_T.
\end{aligned}
$$

The decision rules for this problem are given as

$$\begin{aligned}
L_T &= \frac{\beta_L(1+r_T)}{1+r_T-(1-\phi_T)(1+r_{\ell,t})}\left((1+r_{\ell,T-1})L_{T-1}-(1+r_{T-1})B_{T-1}\right)\\
B_T &= \frac{\beta_L(1-\phi_T)(1+r_{\ell,t})}{1+r_T-(1-\phi_T)(1+r_{\ell,t})}\left((1+r_{\ell,T-1})L_{T-1}-(1+r_{T-1})B_{T-1}\right)\\
L_T-B_T &= \beta_L\left((1+r_{\ell,T-1})L_{T-1}-(1+r_{T-1})B_{T-1}\right)\\
(1+r_{\ell,t})L_T-(1+r_T)B_T &= \frac{\beta_L\phi_T(1+r_{\ell,t})(1+r_T)}{1+r_T-(1-\phi_T)(1+r_{\ell,t})}\left((1+r_{\ell,T-1})L_{T-1}-(1+r_{T-1})B_{T-1}\right),
\end{aligned}$$

which give

$$\begin{aligned}
\Psi_{T-1}\left(L_{T-1},B_{T-1}\right) &= \frac{1}{1-\beta_L}\log\left((1+r_{\ell,T-1})L_{T-1}-(1+r_{T-1})B_{T-1}\right)\\
&+ \frac{\beta_L}{1-\beta_L}\log\left(\frac{\beta_L\phi_T(1+r_{\ell,t})(1+r_T)}{1+r_T-(1-\phi_T)(1+r_{\ell,t})}\right)\\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log\left(\frac{\beta_L\phi(1+r_\ell)(1+r)}{1+r-(1-\phi)(1+r_\ell)}\right)+\frac{1}{1-\beta_L}\log(1-\beta_L).
\end{aligned}$$

The value function when the bank defaults is

$$\begin{aligned}
\tilde{\Psi}^D_{T-1}\left(\xi(1+r_{\ell,T-1})L_{T-1}\right) &= \frac{1}{1-\beta_L}\log\left(\xi(1+r_{\ell,T-1})L_{T-1}\right)+\frac{\beta_L}{1-\beta_L}\log(\beta_L(1+r^D_T))\\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log(\beta_L(1+r^D))+\frac{\log(1-\beta_L)}{1-\beta_L}.
\end{aligned}$$

The no-default condition in period $T-1$ can be written as

$$(1-\phi_{T-1})(1+r_{\ell,T-1})L_{T-1}\geqslant(1+r_{T-1})B_{T-1},$$

where

$$\phi_{T-1}=\xi^{1-\beta_L}\left(\frac{1+r_T}{1+r_{\ell,t}}-(1-\phi_T)\right)^{\beta_L}.$$

Period $T-2$**:**

$$\begin{aligned}
\Psi_{T-2}\left(L_{T-2}, B_{T-2}\right) &= \max_{L_{T-1}, B_{T-1}} \log\left((1+r_{\ell,T-2})L_{T-2} - (1+r_{T-2})B_{T-2} - (L_{T-1} - B_{T-1})\right) \\
&+ \frac{\beta_L}{1-\beta_L}\log\left((1+r_{\ell,T-1})L_{T-1} - (1+r_{T-1})B_{T-1}\right) \\
&+ \frac{\beta_L^2}{(1-\beta_L)^2}\log\left(\frac{\beta_L\phi_T(1+r_{\ell,t})(1+r_T)}{1+r_T-(1-\phi_T)(1+r_{\ell,t})}\right) \\
&+ \frac{\beta_L^3}{(1-\beta_L)^2}\log\left(\frac{\beta_L\phi(1+r_\ell)(1+r)}{1+r-(1-\phi)(1+r_\ell)}\right) + \frac{\beta_L}{1-\beta_L}\log(1-\beta_L) \\
&\text{s.t.} \\
(1-\phi_{T-1})(1+r_{\ell,T-1})L_{T-1} &\geqslant (1+r_{T-1})B_{T-1}.
\end{aligned}$$

The decision rules of this problem are given as

$$\begin{aligned}
L_{T-1} &= \frac{\beta_L(1+r_{T-1})}{1+r_{T-1}-(1-\phi)(1+r_{\ell,T-1})}\omega_{t-2} \\
B_{T-1} &= \frac{\beta_L(1-\phi_{T-1})(1+r_{\ell,T-1})}{1+r_{T-1}-(1-\phi_{T-1})(1+r_{\ell,T-1})}\omega_{t-2} \\
L_{T-1} - B_{T-1} &= \beta_L\omega_{t-2} \\
(1+r_{\ell,T-1})L_{T-1} - (1+r_{T-1})B_{T-1} &= \frac{\beta_L\phi_{T-1}(1+r_{\ell,T-1})(1+r_{T-1})}{1+r_{T-1}-(1-\phi_{T-1})(1+r_{\ell,T-1})}\omega_{t-2}, \\
\omega_{t-2} &= \left((1+r_{\ell,T-2})L_{T-2} - (1+r_{T-2})B_{T-2}\right),
\end{aligned}$$

which give

$$\begin{aligned}
\Psi_{T-2}\left(L_{T-2}, B_{T-2}\right) &= \frac{1}{1-\beta_L}\log\left((1+r_{\ell,T-2})L_{T-2} - (1+r_{T-2})B_{T-2}\right) \\
&+ \frac{\beta_L}{1-\beta_L}\log\left(\frac{\beta_L\phi_{T-1}(1+r_{\ell,T-1})(1+r_{T-1})}{1+r_{T-1}-(1-\phi_{T-1})(1+r_{\ell,T-1})}\right) \\
&+ \frac{\beta_L^2}{1-\beta_L}\log\left(\frac{\beta_L\phi_T(1+r_{\ell,t})(1+r_T)}{1+r_T-(1-\phi_T)(1+r_{\ell,t})}\right) \\
&+ \frac{\beta_L^3}{(1-\beta_L)^2}\log\left(\frac{\beta_L\phi(1+r_\ell)(1+r)}{1+r-(1-\phi)(1+r_\ell)}\right) + \frac{1}{1-\beta_L}\log(1-\beta_L).
\end{aligned}$$

The value function when the bank defaults is

$$\begin{aligned}
\tilde{\Psi}^D_{T-2}\left(\xi(1+r_{\ell,T-2})L_{T-2}\right) &= \frac{1}{1-\beta_L}\log\left(\xi(1+r_{\ell,T-2})L_{T-2}\right) + \frac{\log(1-\beta_L)}{1-\beta_L} \\
&+ \frac{\beta_L}{1-\beta_L}\log(\beta_L(1+r_{T-1})) + \frac{\beta_L^2}{1-\beta_L}\log(\beta_L(1+r_T)) \\
&+ \frac{\beta_L^3}{(1-\beta_L)^2}\log(\beta_L(1+r)).
\end{aligned}$$

The no-default condition in period $T-2$ can be written as

$$(1-\phi_{T-2})(1+r_{\ell,T-2})L_{T-2} \geqslant (1+r_{T-2})B_{T-2},$$

where

$$\phi_{T-2} = \xi^{1-\beta_L}\left(\frac{1+r_{T-1}}{1+r_{\ell,T-1}} - (1-\phi_{T-1})\right)^{\beta_L}.$$

The derivations suggest that the value functions and decision rules have the same pattern. Thus, they will take the same form of the previous period. □

I.3 Bank's solution

Given the collateral constraint the bank is facing, we can explicitly solve for the bank's problem, which is summarized in the following proposition.

Proposition 3. *The decision rules when the no-default constraint binds (if $r_{\ell,t+1} > r_{t+1}$) are*

$$\begin{aligned} L_{t+1} &= \frac{(1+r_{t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})}\beta_L\omega_t \\ B_{t+1} &= \frac{(1-\phi_{t+1})(1+r_{\ell,t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})}\beta_L\omega_t, \end{aligned}$$

where $\omega_t = (1+r_{\ell,t})L_t - (1+r_t)B_t$.

The decision rules when the no-default constraint does not bind (if $r_{\ell,t+1} \leqslant r_{t+1}$) are:

$$B_{t+1} = \begin{cases} \in \left[0, \frac{\beta_L(1-\phi_{t+1})(1+r_{\ell,t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})}\omega_t\right] & \text{if } r_{\ell,t+1} = r_{t+1} \\ 0 & \text{if } r_{\ell,t+1} < r_{t+1} \end{cases}$$

and

$$L_{t+1} = B_{t+1} + \beta_L\left((1+r_t^*)L_t - (1+r_t)B_t\right).$$

I.4 Characterization of the Bank's Problem in Stationary Equilibrium

We can further characterize the bank's problem under stationarity. Throughout the paper, we will focus on stationary equilibria where the capital requirement constraint is binding. If it did not bind, then bank balance sheets would not have any impact on the economy. However, we do not rule out the case that there might be some periods in the transition where this constraint becomes slack. Using the general formula capturing both the exogenous and endogenous capital requirement constraint, we have the following decision rules when the constraint binds:

$$L_{t+1} = \beta_L\widehat{\lambda}_t\omega_t \quad \text{and} \quad B_{t+1} = \beta_L\left(\widehat{\lambda}_t - 1\right)\omega_t,$$

where

$$\widehat{\lambda}_t = \frac{(1+r_{t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})}. \tag{I.1}$$

Then the law of motion for net worth is given as

$$\omega_{t+1} = L_{t+1}\left(1+r_{\ell,t+1}\right) - B_{t+1}\left(1+r_{t+1}\right).$$

Then, we can obtain the next period's net worth as

$$\omega_{t+1} = \beta_L\left(\widehat{\lambda_t}\left(1+r_{\ell,t+1}\right) - \left(\widehat{\lambda_t}-1\right)\left(1+r_{t+1}\right)\right)\omega_t.$$

Imposing steady state $\omega_{t+1} = \omega_t$ and $\widehat{\lambda_t} = \widehat{\lambda}$ gives

$$r_\ell - r = \frac{1-\beta_L(1+r)}{\widehat{\lambda}\beta_L},$$

where $r_\ell - r$ is the premium due to the bank capital constraint. If $\beta_L(1+r) < 1$ and $\widehat{\lambda} < \infty$, then $r_\ell - r > 0$. Thus, the capital constraint will be binding in the stationary equilibrium. To understand this point, assume that $\beta_L(1+r) < 1$ but the bank starts with a high net worth so that the capital requirement constraint is not binding. In that case, $r_{\ell,t+1} = r$ and the bank's decision rule is $L_{t+1} - B_{t+1} = \beta_L\omega_t$. Using that, we can show that $\omega_{t+1} = (1+r)\,\beta_L\omega_t < \omega_t$. Thus, the bank econsumes from its net worth until the capital constraint starts to bind. Thus, the economy will converge to a stationary equilibrium where it actually binds.

J Computational Appendix

Denote the state variable of the household as $\theta = (a, h, d, z, j, s)$ where s is the housing tenure, j is the age of the household, z is the income efficiency shock, d is the ratio of mortgage debt to initial house price level, h is the size of the owner-occupied unit, and a is the financial wealth after the return is realized. For active/inactive renters ($s \in \{r, i\}$) $h = d = 0$. We discretize a into 120 and d into 30 exponentially spaced points. The age j runs from 1 to 30, and h is linearly discretized into 5 points. Income shock z is discretized into 15 points, and grid points and transition probabilities are computed using the Tauchen method. Since this is a life-cycle model, the grid points for income shocks are age dependent to better approximate the AR(1) process with a Markov process. We approximate the US retirement system following Guvenen and Smith (2014). We adjust the retirement income level such that working age-households pay 12 percent tax.

J.1 Steady-State Computation

The steady state of the model is computed as follows:

1. From the bank's problem, the lending rate at the steady state is $r_\ell = r + \frac{1-\beta_L(1+r)}{\widehat{\lambda}\beta_L}$.

2. Make a guess on K and p_h.

3. Given these guesses, using the firm's problem, compute w and u:

$$
\begin{aligned}
u &= \left(\frac{(1-\alpha)K}{(1+\phi r_\ell)\vartheta}\right)^{\frac{1}{\alpha+\psi}} \\
w &= \vartheta^{\frac{\alpha-1}{\alpha+\psi}}\left(\frac{(1-\alpha)K^\alpha}{(1+\phi r_\ell)}\right)^{\frac{1+\psi}{\alpha+\psi}} \\
r_k &= \alpha\left(\frac{K}{u}\right)^{\alpha-1}-\delta
\end{aligned}
$$

4. Using the rental companies' problem, compute the rent price:

$$
p_r = \kappa + \frac{1-\delta_h}{1+r_k}p_h
$$

5. Given all these prices, solve the household's problem recursively:
   (a) Solve the terminal period problem where all dynamic choices are set to 0: $a' = d' = 0$. This gives the value for the household, $V_J(\theta)$, and the continuation value of the mortgage contract, $v_J^l(\theta)$.
   (b) Given $V_j(\theta)$ and $v_j^l(\theta)$, solve $V_{j-1}(\theta)$ and $v_{j-1}^l(\theta)$:
      i. Given $V_j(\theta)$ and $v_j^l(\theta)$, first solve the expected continuation values $EV_j(\theta)$ and $Ev_j^l(\theta)$.
      ii. Solve for mortgage prices at the origination, $q^m(\theta)$.
      iii. The solutions to the problems for the inactive renter and the active renter who decides to become a renter are straightforward. Their choices are housing services, consumption, and saving. We interpolate the expected value of the continuation value using linear interpolation, and to choose the optimal saving level, we first search globally over a finer discrete space for a' to bracket the maximum.[50] Once the maximum is bracketed, we solve for the optimum using Brent's method. Given the saving choice, we compute the optimal housing services using the analytical expression for it.[51] Then, we use the budget constraint to compute the consumption.
      iv. The most complex and time-consuming problem is the problem of the renter who decides to purchase a house. This household chooses consumption, saving, house size, and mortgage debt. We restrict the choice of down payment and house size to finite sets. For down payment, the grid points for d are the choices, and for house size the grid points for h are the choices.[52] For each down payment and house size choices, we solve the household's objective function, $V_{j-1}^{d,h}$, by finding the optimal saving level, as we discussed in point 5(b)iii. Given all household choices, we can

[50] For saving choice, we use 120 grid points.

[51] Since the utility function is CES in consumption and housing services, we can obtain an analytical expression for optimal housing services.

[52] Increasing the number of grid points for d and h beyond the levels we set does not noticeably change the results.

obtain $q^m(\theta)$. We use linear interpolation for the points off the grid. Also given the choice of d and h, the mortgage debt becomes $dp_h^* h$ where p_h^* is the equilibrium price level at the initial steady state. Once the objective function is solved for a given down payment and house size choice, we set $V_{j-1}(\theta) = max_{d,h}\left\{V_{j-1}^{d,h}\right\}$.

v. The solution of the homeowner's problem:

A. Stayer: The stayer's problem is simple since the household only chooses consumption and saving. We solve it similar to the inactive renter's problem. The only exception is that in the continuation value, the variable keeping track of the principal amount d will be adjusted. Given current d, $d' = (d - m)(1 + r_\ell)$ where $m = \frac{r_\ell(1+r_\ell)^{J-j}}{(1+r_\ell)^{J-j+1}-1}$. We use linear interpolation over d' to compute the expected continuation value for the household.

B. Seller: The seller's problem is the same as the problem of an active renter except that in the budget constraint, the household will have the term due to the proceedings from the sale of the house: $p_h h(1 - \varphi_s) - dhp_h^*$

C. Refinancer: The refinancer's problem is the same as the problem of a renter who purchases a house except that she is restricted to purchasing the same house.

D. Defaulter: The defaulter's problem is the same as the active renter's problem.

vi. Solving the homeowner's problem also gives us the mortgage payment for each type of mortgage contract and allows us to compute the continuation of the mortgage contract, $v_j^l(\theta)$:

$$v_{j-1}^l(\theta) = m(\theta) + \frac{1}{1+r_\ell}\int_{\theta'} v_j^l(\theta')\,\Pi(\theta'|\theta),$$

where

$$m(\theta) = \begin{cases} dhp_h^* & \text{if } s \in \{hr, hf\} \\ p_h h(1-\varphi_e) & \text{if } s = he \\ \frac{r_\ell(1+r_\ell)^{J-j}}{(1+r_\ell)^{J-j+1}-1} dhp_h^* & \text{if } s = hh \end{cases}$$

(c) Repeat step (b) for each $j = \{J-1, ..., 1\}$.

6. Given the policy functions for the household, simulate the economy $N = 20,000$ individuals for $J = 30$ periods. This gives us aggregate saving, A, aggregate housing demand, H^d, and aggregate rental demand, H^r. Given aggregate saving, we update the aggregate capital guess as $K = (1-\lambda_k)K + \lambda_k(A - V^{rc}(H^r))$ where $V^{rc} = \frac{p_r - \kappa - \delta_h p_h^0}{r_k} H^r$ is the value of rental companies. Given aggregate housing demand, we update the house price guess as $p_h = p_h\left(1 + \lambda_h \frac{H-\bar{H}}{\bar{H}}\right)$. We set $\lambda_k = \lambda_h = 0.1$. We continue this process until $max\left(|A - W(H^r) - K|, \left|H - \bar{H}\right|\right) < \epsilon$ where $\epsilon = 10^{-4}$.

7. Once equilibrium prices and allocations are solved, we solve for bank-related variables: bank net worth, bank assets, and bank liabilities using the steady-state analytical equations for these variables.

J.2 Transition Algorithm

The transitional problem has two main differences. First, we need to solve for a path of equilibrium prices and allocations along the transition. Second, we need to adjust the algorithm to capture the fact that the risk-free mortgage interest rate can change along the transition. This second point is important because in order to save from an additional state variable, we assume individuals pay points at the origination time to reduce the risk-adjusted mortgage interest rate to the risk-free mortgage interest rate. This allows us to eliminate the mortgage interest rate as an additional state variable. However, since shocks are permanent, this assumption can artificially distort the equilibrium. Consider a decline in the risk-free mortgage interest rate from 5 percent to 4 percent. If we still assume all new mortgages are priced at 5 percent, this would imply that banks would be paid more than the principal amount if they still use the same amortization schedule we use in the steady-state algorithm. That will result in q^m being significantly larger than 1, implying a substantial subsidy from banks to individuals. More importantly, if we also apply this new risk-free mortgage interest rate to existing mortgages, that would imply a reduction of all the existing mortgage payments: a positive wealth shock to all existing mortgage owners and a negative shock to banks.[53]

To tackle this issue without further complicating the solution algorithm, we assume that after the shock is realized, all new mortgages will be priced at the new risk-free mortgage rate, whereas all existing mortgages will still be paid using the old risk-free mortgage rate. We also include an additional state variable in the household's problem to keep track of whether the household purchased a house before or after the shock is realized. This allows us to compute the mortgage payments more accurately without substantially distorting the solution algorithm.

Given these modifications, the rest of the algorithm is as follows:

1. Fix the time it takes for the transition to happen: T periods. We set $T = 60$ corresponding to 120 years.

2. Solve the initial steady state of the problem as outlined above. Store the initial steady-state distribution denoted as $\Gamma_0(\theta)$.

3. Given the boom shock, solve the final steady state of the problem as outlined above. Store $V_T(\theta)$ and $v_T^l(\theta)$.

4. Guess the path of aggregate capital stock, rental demand, house price, and lending rate: $\left\{K_{t+1}, H_t^{r,0}, p_t^h, r_{\ell,t+1}^0\right\}_{t=1}^{T-1}$.

5. Given these guesses, compute $\{w_t, r_{k,t+1}, p_t^r\}$ using the good-producing firm's and rental companies' problem. Compute V_t^{rc} using the rental companies' problem.

[53] Since we keep track of the principal balance as a state variable, we need to know the risk-free mortgage rate to compute the implied mortgage payments. Another formulation could be to keep track of the mortgage payments. However, in this case, we still need to know the risk-free mortgage rate in order to compute the implied principal amount since it affects the resources of homeowners in the event of selling/refinancing/defaulting.

6. Solve each cohort's problem for each period they are alive, starting from the cohort born in period $-J+2$ until the cohort born in period $T-1$[54]:

   (a) For each generation, given prices, solve the household's problem and the continuation value of the contract as in the steady-state problem above. The only difference is that for new mortgage buyers, the risk-free mortgage interest rate is the final steady-state risk-free mortgage interest rate, whereas for existing mortgage owners, it is the initial steady-state risk-free mortgage interest rate. This also affects the continuation value for households and mortgage contracts since we need to keep track of whether a mortgage originated before or after the shock.

   (b) Given the policy functions for each generation, simulate the economy starting from the initial steady-state distribution $\Gamma_0(\theta)$ for T periods. We fix the same random numbers for the idiosyncratic shocks to household.

   (c) Using the simulated path, compute the aggregates: $A_{t+1}, H_t^{r,1}, H_t^d$, $M_t = \int \nu_t^l(\theta)$.

   (d) Update guesses:

$$\begin{aligned}
K_{t+1} &= (1-\lambda_k)\, K_{t+1} + \lambda_k \left(A_{t+1} - V_{t+1}^{rc}\left(H_{t+1}^r\right)\right) \\
H_t^r &= (1-\lambda_{rc})\, H_t^{r,0} + \lambda_{rc} H_t^{r,1} \\
p_t^h &= p_t^h \left(1 + \lambda_h \frac{H_t^d - \bar{H}}{\bar{H}}\right) \\
r_{\ell,t+1}^0 &= (1-\lambda_r)\, r_{\ell,t+1}^0 + \lambda_{rc} r_{\ell,t+1}^1
\end{aligned}$$

   where $r_{\ell,t+1}$ solves

$$L_{t+1} = \frac{(1+r_{t+1})}{1+r_{t+1}-(1-\phi_{t+1})(1+r_{\ell,t+1})} \beta_L \omega_t$$

   where $L_{t+1} = M_{t+1} + \phi w_{t+1}(\bar{w}, u_{t+1})$ and

$$\omega_t = \begin{cases} L_t\left(1+r_{\ell,t}\right) - B_t\left(1+r_t\right) & \text{if } t = 1 \\ \left(1+r_{\ell,t}^0\right)\phi_t L_t & \text{if } t > 1. \end{cases}$$

   (e) Iterate this process until convergence occurs on guesses. The convergence criteria are defined as $\max\left|K_{t+1} + V_{t+1}^{rc}\left(H_{t+1}^r\right) - A_{t+1}\right| < \epsilon_k$, $\max\left|H_t^{r,1} - H_t^{r,0}\right| < \epsilon_h$, $\max\left|H_t^d - \bar{H}\right| < \epsilon_h$, and $\max\left|r_{\ell,t}^1 - r_{\ell,t}^0\right| < \epsilon_r$ where $\epsilon_k = \epsilon_h = 10^{-3}$ and $\epsilon_r = 10^{-4}$.

[54]A household of age j belonging to a cohort born in period $g \in \{-J+2, ..., T-1\}$ will be subject to prices p_{g+j-1}.