

House Prices, Heterogeneous Banks and Unconventional Monetary Policy Options

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Abstract

This paper develops a financial mechanism which integrates housing and financial markets through housing-secured debt instruments. In this environment, movements in home prices are amplified through both borrowers and banks' balance sheets, leading to a self-reinforcing credit/liquidity crunch. Macroeconomic downturns are propagated over time through a novel foreclosure channel which is particularly relevant for understanding the *Great Recession*. This financial structure quantitatively captures empirical relationships the Bernanke, Gertler, and Gilchrist (1999) model fails to explain and the qualitative predictions of the model are consistent with dynamic responses from a VAR. The model provides a framework to examine the ability of QE policies and equity injections into big banks to mitigate a housing generated recession. Although both are effective, the nuances of the policies are important. A prolonged asset purchase program is preferable to a short-term equity injection; however, the model suggests the equity injections may have been necessary to prevent an economic collapse at the acute stage of the 2008 Financial Crisis.

Keywords: Financial Crises, Financial Frictions, Housing, Unconventional Monetary Policy

JEL Codes: E32, E44, G01, G21

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1 Introduction

The first drop in U.S. home prices since the Great Depression resulted in the 2008 Financial Crisis, forcing policy makers to ‘Fly Blind,’ and take the exceptional actions of injecting equity into the largest U.S. financial firms and making a myriad of asset purchases without a playbook from economists. Little was known regarding the exact financial mechanisms linking home prices to the rest of the economy, and to date, many questions remain. Why did a drop in home prices set off a financial panic that forced the largest commercial banks to shed relatively more assets than their smaller counter-parts? What is the transmission mechanism of equity injections into these big banks and large-scale asset purchases amidst a housing-centered credit crunch?

In this paper, I propose an empirically motivated financial mechanism which provides an answer to both of these questions. I embed this financial structure into an otherwise standard Real Business Cycle model to illustrate its ability to generate salient features of the U.S. economy. Quantitatively, the model matches empirical correlations that the traditional financial accelerator mechanism (Bernanke, Gertler, and Gilchrist, 1999) (BGG) fails to capture, including the correlation of finance premiums with home prices, investment and output. I then test the model’s qualitative predictions against an estimated VAR. The results of these empirical comparisons support the model’s financial structure.

I am not alone in my efforts to adapt existing financial accelerator frameworks to simulate the effects of unconventional monetary policy in light of the financial crisis. However, these models typically rely on ‘Financial’ shocks to generate a crisis scenario and quadratic investment adjustment costs to propagate the downturn (Gertler and Karadi, 2011). In such models, no distinction is made between housing secured debt and other assets.

I take the alternative viewpoint that housing, and housing secured debt instruments, played a particularly important role in the crisis. In particular, the housing and financial sector in the model I develop are highly integrated – a feature that allows for a financial crunch to originate from a change in primitives such as preferences over housing. Moreover, the use of housing as an ultimate source of collateral for financial assets provides a natural source to propagate downturns as opposed to quadratic investment adjustment costs. Upon default, the liquidation of housing – a durable – increases the stock of homes and therefore decreases prices into the future. Furthermore, the time lag between default and liquidation leads to hump-shaped impulse response functions of output, an empirical feature used to justify quadratic adjustment costs (cf Christiano, Eichenbaum, and Evans (2005)).

Besides treating the housing and the financial sector as independent, other models that have been used to analyze unconventional monetary policy fail to provide an answer regarding the effects, and desirability, of equity injections into “Too Big to Fail” banks. These papers assume either: *(i)* All banks are the same in terms of size and efficiency (Gertler and Kiyotaki, 2010) or *(ii)* Banks differ in terms of size and efficiency, but banks face no agency problems (Hafstead and Smith, 2012).

However, both of these assumptions are at odds with the empirical evidence. Recent estimates of scale efficiency in the financial sector, including off-balance sheet activities, have found that “Bigger is Better” (Wheelock and Wilson, 2012; Bos and Kolari, 2013). As for the later assumption, Demirguc-Kunt, Detragiache, and Merrouche (2013) find that bank capital is an important determinant for the performance of banks, most markedly for big banks – empirical support for over-turning the Modigliani-Miller theorem.¹

With this empirical evidence in mind, I incorporate bank heterogeneity into the financial sector. Big banks naturally arise in equilibrium due to their superior efficiency intermediating housing-secured assets, relative to small banks. The only question is: Why do small banks operate at all in this market if they are technologically dis-advantaged? This is where eschewing the assumption that banks face no agency problems is key. The big/productive banks in the model face a moral-hazard problem. Therefore, the amount of housing-secured assets the productive bank can hold is determined by its capital. In this sense, bank-capital is key for the operation of big/productive banks, consistent with the empirical evidence.

By capturing the rich interaction between the housing market and the heterogeneous financial sector, the model is able to offer an explanation as to why the concentration of assets in the biggest commercial banks decreased with home prices, as illustrated below.

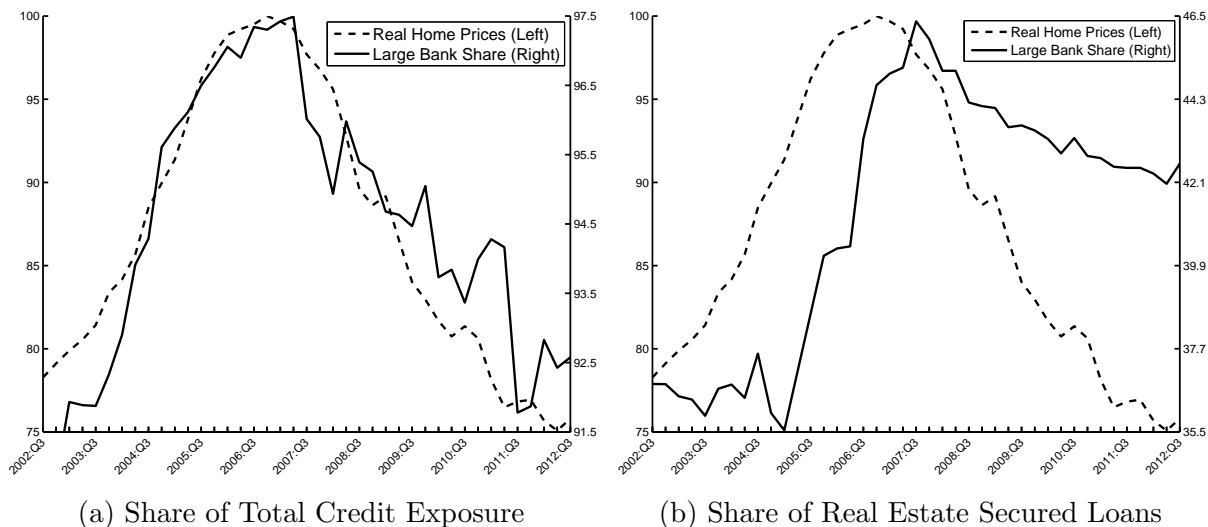


Figure 1: Real home prices (normalized to pre-recession peak) and the share of various assets held by the largest commercial banks.

The financial mechanism I propose is capable of endogenously generating the above co-movement. Beyond simply capturing a correlation, the model provides the insight that the above redistribution increased the severity and length of the Great Recession. However, the same feedback mechanism provides traction for equity injections into big banks and large-scale asset purchase programs.

¹The Modigliani-Miller theorem states that how a firm chooses to fund itself (debt vs. equity) is irrelevant.

2 A DSGE Model with Integrated Housing and Financial Markets

In this section I develop a general equilibrium model capable of capturing the asset redistribution between big and small banks that occurs when home prices change. The model implies that bank heterogeneity amplifies typical business cycles when large banks are leverage constrained. To the extent these large financial firms can more efficiently intermediate secured-debt, the asset concentration that occurs during an upswing moves the economy closer to a Pareto outcome. The other side of this coin however implies that slumps can be made more severe due to this redistribution.

2.1 Related Models and How this Model Differs

The notion that heterogeneity between agents can lead to amplification effects is not new. Kiyotaki and Moore (1997) (hereafter KM) show that an asset price spiral may occur if productive agents are borrowing constrained and the tightness of this constraint depends on asset prices. If an adverse shock results in decreased output for the productive agent, they have fewer assets to borrow against which results in unproductive agents absorbing these assets, which they are willing to do so only at reduced prices. However, since the productive agents binding constraint depends on the price of the asset, the decrease in price only further tightens the collateral constraint - starting the process over.

The model I present here builds on the keen insight of this amplification effect, however the KM model is silent with regards to default rates since agents in the model never default. This aspect was critical during the recent crisis where home prices and MBS fell in value in large part due to rising defaults on risky sub-prime loans. However, Bernanke, Gertler, and Gilchrist (1999) (hereafter BGG) develop a financial friction where risky projects are financed and each period some share of financed projects will fail resulting in default. However, BGG features no illiquid collateral, instead all assets are already monetary. This feature of the model misses the role of market liquidity (or illiquidity) which is elegantly captured by KM.

Moreover, BGG and KM don't explicitly include banks.² To the extent that deposits and bank capital are perfect substitutes, the financial sector can be left in the background as household's can then directly fund projects with deposits. On the other hand, if bank capital serves a special role in mitigating financial frictions faced by the bank (on the supply side), then these agents must be explicitly modeled.

Gertler and Kiyotaki (2010) present a model with financial intermediaries where bank capital facilitates bank's ability to obtain funds. Banks in their model face frictions in raising loanable funds however, there are no demand side frictions, so that all loans face zero default risk. Additionally, there is no clear distinction between big banks and small

²In KM the agents can simply be re-interpreted as banks with investment opportunities and this would capture supply side financial frictions. However, to the extent that there are also demand side financial frictions this single banker/investor model would understate the role of collateral values in mitigating this friction.

banks. Banks in their model differ in terms of their investment opportunities but not their efficiency in intermediating loans. Therefore, building on Hafstead and Smith (2012), I include heterogeneous banks with market power - creating bank capital in the model. Banks in this environment differ in size due to differences with regards to their efficiency. Along this dimension, my work resembles Adrian and Shin (2010) who model supply side financial heterogeneity in terms of financial firms ability to value assets.

Finally, in contrasts to these previous contributions, I follow Iacoviello (2005) and Iacoviello and Neri (2010) who explicitly model a housing market. In particular, I do not interpret asset prices generally, but instead I model assets whose underlying value as collateral is tied to home prices. Although my inclusion of demand side and supply side financial frictions in terms of large productive banks and small unproductive banks is novel, this is one of the clearest contributions of this paper. By focusing exclusively on assets whose values are tied to house prices, I am able to generate financial market deterioration from changes in primitives such as technology and preferences.

2.2 Model Description

The model consists of a household, a housing producer, a continuum of entrepreneurs who produce the final consumption good, a banking sector with 2 types of banks (productive and unproductive), both of whom finance investment for goods producers and lastly a central bank is modeled. In this section I will describe the behavior of each agent in turn. Many of the details including the full set of model equations are in the appendix as to not distract from the basic mechanism at work in the model.

2.2.1 Household

The household earns wages by renting labor to goods producers l_t and home builders l_t^h . Additionally, they earn non-labor income from banks in the form of dividends $p_t div_t$, transfer payments $p_t Trans_t$ and principal plus interest payments $p_{t-1} d_{t-1} r_{t-1}^d$ on last periods deposits. The monetary authority may transfer any revenue back to the household in lump-sum form via $p_t \tau_t$. This income can be saved in the form of bank deposits $p_t d_t$ or spent on consumption $p_t c_t$ and housing $p_t^h h_t$. Also, any non-depreciated housing stock, $(1 - \delta^h) h_{t-1}$, can be resold at the market price p_t^h . The resulting budget constraint in any period $t = 0, 1, 2, \dots$ is given by,

$$p_t c_t + p_t^h [h_t - (1 - \delta^h) h_{t-1}] + p_t d_t \leq w_t l_t + w_t^h l_t^h + p_{t-1} d_{t-1} r_{t-1}^d + p_t div_t + p_t trans_t + p_t \tau_t.$$

Although I follow Iacoviello (2005) and Iacoviello and Neri (2010) by modeling a housing market, I do not include home equity borrowing constraints on the household side. Where they focus on the wealth effects of housing price changes in terms of financing consumption, I focus more so on real-estate as collateral for investment and the interaction of house prices and housing-secured assets. That being said, in general equilibrium changes in home prices can impact consumption via traditional income and substitution effects, but not through the home equity channel highlighted by Iacoviello (2005).

The household maximizes their lifetime expected utility subject to the flow budget constraint above. The household's lifetime expected utility is specified by

$$U = \sum_{i=0}^{\infty} \mathbb{E}_t \left\{ \ln(c_{t+i}) + \eta_{t+i}^h \ln(h_{t+i}) + \eta^l \ln(1 - l_{t+i}) + \eta^h \ln(1 - l_{t+i}^h) \right\},$$

where η_t^h represents a shift in the elasticity of demand for housing. I specify this as an exogenous process following a first order auto-regressive process, in line with Iacoviello and Neri (2010).

$$\ln(\eta_t^h) = (1 - \rho_{\eta^h}) \bar{\eta}^h + \rho_{\eta^h} \ln(\eta_{t-1}^h) + \varepsilon_t^{\eta^h} \quad \varepsilon_t^{\eta^h} \sim \mathcal{N}(0, \sigma_{\eta^h}) \quad (1)$$

2.2.2 goods Production

The goods producing sector is comprised of a continuum of entrepreneurs. Entrepreneurs have limited resources to finance capital required to produce the final good so they must borrow from banks. A financial friction arises whereby entrepreneurs borrow funds from banks this period to purchase capital used in production next period. Their output next period is subject to idiosyncratic productivity disturbances only observable by banks after paying a monitoring cost.

Entrepreneur's Debt Contract: The Demand Side Financial Friction

A continuum of entrepreneurs $j \in \mathbb{R}_+$ supply wholesale goods to retailers using capital and labor. Entrepreneurs only live for 2 periods and only care about their second period utility. In the first period they have no endowment and no technology but they have a unit of labor supply. In the second period of their lives they are endowed with 1 unit of an asset which can be narrowly thought of as land, \bar{n} , which can be transformed into housing only by entrepreneurs and banks. However, capital must be purchased this period to be useful tomorrow. Denote the quantity of capital purchased in period t by entrepreneur j by k_t^j and denote the period t price of capital by q_t . To purchase this capital the entrepreneur will receive financing from the banking sector. More specifically, the entrepreneur uses last period's wages $p_t w_t^e$ and pledges tomorrow's endowment \bar{n}^j as collateral for a secured loan in the amount $p_t^n \bar{n}^j$ and the remaining portion of the capital purchase is financed with an unsecured loan in the amount $p_t b_t^j$. More concretely,

$$q_t k_t^j = p_t^n \bar{n}^j + p_t b_t^j + p_t w_t^e \quad (2)$$

is entrepreneur j 's balance sheet constraint.

Without default, distinguishing between secured and unsecured loans is trivial. However, in the second period of their life, entrepreneurs are subjected to an idiosyncratic productivity shock ω_{t+1}^j which is *i.i.d.* across entrepreneurs and time. I assume throughout the analysis in this paper, $\omega_{t+1}^j \sim \ln \mathcal{N}\left(\frac{-(\sigma_t^\omega)^2}{2}, \sigma_t^\omega\right)$ with CDF at time t denoted by $F_t(\omega_{t+1}^j)$. The choice

of parameters implies $\mathbb{E}\{\omega_{t+1}^j\} = 1$ so that in the aggregate this idiosyncratic shock has no direct impact on production, but the existence of uncertainty at the firm level impacts aggregate output through financial imperfections (BGG). To capture exogenous increases in the cross-sectional dispersion of idiosyncratic productivity shocks I allow σ_t^ω to vary over time. I posit the simple auto-regressive process,

$$\ln(\sigma_t^\omega) = (1 - \rho_{\sigma^\omega})\bar{\sigma}^\omega + \rho_{\sigma^\omega}\ln(\sigma_{t-1}^\omega) + \varepsilon_t^{\sigma^\omega} \quad \varepsilon_t^{\sigma^\omega} \sim \mathcal{N}(0, \sigma_{\sigma^\omega}) \quad (3)$$

for this demand-side *risk* shock. Christiano, Motto, and Rostagno (2013) show that such shocks have played a significant role in shaping the U.S. business cycle. Moreover, these shocks prove useful in the empirical analysis of the paper as they provide a structural interpretation for exogenous increase in the external finance premium.

Since projects are financed before the idiosyncratic productivity shock can be observed by either the entrepreneur or the bank, entrepreneurs who receive a low productivity value will default upon their loan. Denote the real gross interest rate on unsecured loans by $r_t^{L,j}$ and denote the gross real return on capital common to all entrepreneurs by r_{t+1}^k . Then for any entrepreneur j , we can define the cut-off value of $\bar{\omega}_{t+1}^j$ by the equation

$$\bar{\omega}_{t+1}^j r_{t+1}^k r_t^{L,j} q_t = p_t b_t^j r_t^{L,j}. \quad (4)$$

This equation defines the minimum level of productivity needed to pay back the unsecured loan. For entrepreneur j , the loan will be repaid if $\omega_{t+1}^j \geq \bar{\omega}_{t+1}^j$ and will otherwise be defaulted upon. However, the bank can not observe the level of productivity without paying an auditing cost in proportion $\mu \in (0, 1)$ to the entrepreneur's revenue.³ Banks who do not pay for auditing never find out if the entrepreneur actually received a low productivity draw or if they simply chose to renege on their loan. Given this arrangement, the optimal debt-contract dictates that banks will audit only defaulting entrepreneurs and only entrepreneurs who receive a bad-draw will default on their loans.

To make matters more explicit I define the expected revenue to the bank for loaning $p_t b_t^j$ to entrepreneur j in (5). This expected revenue is comprised of 2 terms, the first of which is non-defaulting loan revenue and the second is revenue net of auditing costs on non-performing loans.

$$\underbrace{(1 - F_t(\bar{\omega}_{t+1}^j)) p_t b_t^j r_t^b}_{\text{Non-Defaulting Payoff}} + (1 - \mu) \underbrace{\int_0^{\bar{\omega}_{t+1}^j} \omega_{t+1}^j dF_t(\omega_{t+1}^j) r_{t+1}^k k_t^j q_t}_{\text{Defaulting Payoff}} \quad (5)$$

For the bank to be willing to make this loan, this expected pay-off must be at least equal to bank's cost of making the loan. In BGG the cost of making the loan is simply the cost of obtaining the funds via deposits - $p_t b_t^j r_t^d$. However since the banking sector in this model

³This follows from Townsend (1979), but has been popularized in this context by Carlstrom and Fuerst (1997) and BGG.

has market power this is no longer the case. For the time being simply define the rate the bank charges to entrepreneurs per dollar loaned by r_t^e .⁴ Then the incentive compatibility constraint can be expressed as,

$$p_t b_t^j r_t^e = (1 - F_t(\bar{\omega}_{t+1}^j)) p_t b_t^j r_t^b + (1 - \mu) \int_0^{\bar{\omega}_{t+1}^j} \omega_{t+1}^j dF_t(\omega_{t+1}^j) r_{t+1}^k k_t^j q_t. \quad (6)$$

We can simplify this expression (and the resulting entrepreneur's optimization problem) by defining the following terms. First let $G_t(\bar{\omega}_{t+1}^j)$ be defined as the expected productivity value for defaulting entrepreneurs.

$$G_t(\bar{\omega}_{t+1}^j) = \int_0^{\bar{\omega}_{t+1}^j} \omega_{t+1}^j dF_t(\omega_{t+1}^j) \quad (7)$$

Also let $\Gamma_t(\bar{\omega}_{t+1}^j)$ be defined as the expected share of entrepreneurial profits going to the bank gross of auditing costs.

$$\Gamma_t(\bar{\omega}_{t+1}^j) = (1 - F_t(\bar{\omega}_{t+1}^j)) \bar{\omega}_{t+1}^j + G_t(\bar{\omega}_{t+1}^j) \quad (8)$$

Now I can combine (6) with (4), (7) and (8) to rewrite the bank's incentive compatibility as,

$$p_t b_t^j r_t^e = (\Gamma_t(\bar{\omega}_{t+1}^j) - \mu G_t(\bar{\omega}_{t+1}^j)) r_{t+1}^k k_t^j q_t. \quad (9)$$

We can now formally state the problem faced by entrepreneur j . To keep the debt-contract tractable, I assume the entrepreneur is risk-neutral with regards to aggregate consumption. In particular, I assume they seek to maximize their income and then allocate that income between consumption and housing services. Entrepreneur j therefore seeks to maximize total income⁵ subject to the bank's IC constraint.

$$\begin{aligned} & \max_{k_t^j, \bar{\omega}_{t+1}^j} && (1 - \Gamma_t(\bar{\omega}_{t+1}^j)) r_{t+1}^k k_t^j q_t \\ & \text{subject to} && [q_t k_t^j - p_t^n \bar{n}^j - p_t w_t^e] r_t^e = (\Gamma_t(\bar{\omega}_{t+1}^j) - \mu G_t(\bar{\omega}_{t+1}^j)) r_{t+1}^k k_t^j q_t \end{aligned}$$

The solution to this optimization problem pins down the cut-off value $\bar{\omega}_{t+1}^j$ and the entrepreneur's demand for capital k_t^j .⁶ The problem is identical in nature to the problem entrepreneurs face in BGG who show the optimal debt contract has the property that the default rate and external finance premium move inversely with net-worth. In this model, the net-worth component is replaced with the collateral value, implying that $\partial \bar{\omega}_{t+1}^j / \partial p_t^n < 0$ - finance premiums and default rates will move in the opposite direction of collateral prices.

⁴ r_t^e is explicitly defined in the description of the banking sector in the appendix using the approach laid out in Hafstead and Smith (2012)

⁵Notice the entrepreneur's income can be re-written as $\int_{\bar{\omega}_{t+1}^j}^{\infty} \omega_{t+1}^j dF(\omega_{t+1}^j) r_{t+1}^k k_t^j q_t - (1 - F_t(\bar{\omega}_{t+1}^j)) r_t^b b_t^j = (1 - \Gamma_t(\bar{\omega}_{t+1}^j)) r_{t+1}^k k_t^j q_t$ where I use (4) and (8).

⁶The first order conditions for this problem are in the appendix.

Aggregate Goods Production

The previous section describes the firm-level behavior in the goods producing sector, specifically it describes the debt-contract problem faced by each producer. In this section, I describe the industry wide behavior. Each entrepreneur (in the second period of their life) has access to the production technology, $y_t^j = \omega_t^j z_t (k_{t-1}^j)^{\alpha_g} (l_t^{g,j})^{1-\alpha_g}$, which can be aggregated over due to constant returns to scale. The aggregate goods production technology in any given period t is specified as

$$y_t = z_t (k_{t-1})^{\alpha_g} (l_t^g)^{1-\alpha_g} \quad (10)$$

where z_t is an exogenous technology process which affects all entrepreneurs equally. I assume this technology follows a first-order autoregressive process.

$$\ln(z_t) = (1 - \rho_z) \bar{z} + \rho_z \ln(z_{t-1}) + \varepsilon_t^z \quad \varepsilon_t^z \sim \mathcal{N}(0, \sigma_z) \quad (11)$$

The gross aggregate real return on holding a unit of capital from period $t - 1$ to period t is defined by

$$r_t^k = \frac{\alpha_g \frac{y_t}{k_{t-1}} + (1 - \delta^k) q_t}{q_{t-1}}, \quad (12)$$

where I utilize the aggregate marginal product of capital from the Cobb-Douglas specification above - $mp_k = \alpha_g \frac{y_t}{k_{t-1}}$.

The labor aggregate in the production function is a composite of labor supplied by the household, l_t , and labor supplied by this periods young entrepreneurs, l_t^e ,

$$l_t^g = (l_t^e)^{\alpha_e} (l_t)^{1-\alpha_e}. \quad (13)$$

This implies the wage paid to the household's labor and the wage paid to entrepreneurial labor are given by,

$$w_t = (1 - \alpha_g)(1 - \alpha_e) \frac{y_t}{l_t} \quad (14)$$

$$w_t^e = (1 - \alpha_g) \alpha_e \frac{y_t}{l_t^e} \quad (15)$$

I calibrate $\alpha_e = .01$ so that in equilibrium the household receives the majority of wages and variations in collateral values are the primary sources of movement in entrepreneur's balance sheets. The aggregate income of entrepreneurs in period t is $(1 - \Gamma_{t-1}(\bar{\omega}_t)) r_t^k k_{t-1} q_{t-1}$. I assume entrepreneurs, like the household, receive utility from consuming both the consumption good and housing services. Unlike households, entrepreneurs have the ability to transform their endowment of 'land' - \bar{n}^j - into non-tradable housing. Recall however, this endowment was leveraged last period to secure a loan in the amount $p_{t-1}^n \bar{n}^j$. Hence, entrepreneurs who are able, choose to payback the secured loan with interest $p_{t-1}^n \bar{n}^j r_{t-1}^d$ and then convert \bar{n}^j into housing services one for one. If they don't payback the secured loan then they default on this contract and the bank takes possession of the collateral \bar{n}^j .

I assume in the aggregate, all the entrepreneurs who did not default on their unsecured loan, payback their secured loan and use the rest of their income on the consumption good. Those who defaulted on the unsecured loan have lost all income and hence do not consume anything. More specifically, the aggregate real consumption of entrepreneurs is given by

$$c_t^e = (1 - \Gamma_{t-1}(\bar{\omega}_t)) r_t^k k_{t-1} q_{t-1} - (1 - F_{t-1}(\bar{\omega}_t)) p_{t-1}^n \bar{n}^j r_{t-1}^d. \quad (16)$$

“What micro-level preferences would give rise to this aggregate consumption behavior?” is an interesting question. In the appendix I describe one possible micro-structure that would lead to this aggregate consumption behavior. An appealing aspect of this description is the existence of a single default rate in the economy.⁷

2.2.3 New Housing Production

I assume new housing is produced in a purely competitive market and free from financial frictions. In particular, housing producers combine labor l_t^h with housing specific technology, z_t^h in the production technology,

$$h_t^{new} = z_t^h (l_t^h)^{1-\alpha_h} \quad (17)$$

where

$$\ln(z_t^h) = (1 - \rho_{z^h}) \bar{z}^h + \rho_{z^h} \ln(z_{t-1}^h) + \varepsilon_t^{z^h} \quad \varepsilon_t^{z^h} \sim \mathcal{N}(0, \sigma_{z^h}). \quad (18)$$

I model housing specific technology independent of technology in the goods producing sector since much of the economic growth over the last two decades has been IT-driven and housing production is a non IT-intensive industry. Moreover, this specification allows for goods technology process, z_t , to play a significant role in determining output without implying a counterfactual negative correlation between home prices and GDP (see for example Davis and Heathcote (2005)). The resulting demand for labor from the housing sector takes the form

$$w_t^h = (1 - \alpha_h) p_t^h \frac{h_t^{new}}{l_t^h}. \quad (19)$$

2.2.4 Banking Sector: The Supply Side Financial Friction

There are a unit measure of banks in the model each belonging to one of two types. I distinguish bank types by a superscript “P” for productive banks and a superscript “U” for unproductive banks (who make up ν share of the population). Productive banks represent the *Large* commercial banks in the data. These banks are more productive with repossessed collateral pledged by entrepreneurs to secure loans and hence value these housing-secured assets more than their unproductive counterparts. However, this efficiency creates a moral hazard problem for borrowers due to the possibility of productive banks wrongfully repossessing collateral and absconding with the profits. If this occurs, the entrepreneur’s only recourse is to take the productive banks accumulated capital. To this extent, bank-capital

⁷That is to say, the default rate on unsecured loans is the same as the default rate on secured loans. I choose this as a starting point although this assumption can be relaxed.

mitigates the moral hazard concerns and allows the productive banks to hold more of these collateralized assets. An amplification effect emerges from the endogenous tightening and loosening of this moral hazard constraint which forces productive banks to adjust their holding of collateralized assets in response to movements in home prices.

For ease of exposition I describe factors common to both types of bank before describing each type's optimizing behavior. In particular, all banks have some degree of market power, face a balance sheet constraint and remit a fraction of profits each period back to the household in the form of dividends and various transfers. In what follows I generically refer to bank i to reference one of the infinitely many identical banks within either type.

Each bank possesses a degree of market power which is captured by assuming a Dixit-Stiglitz type aggregator function. As Hafstead and Smith (2012) point out, this has the simplifying feature that all banks serve all entrepreneurs and therefore face the same ex-ante and ex-post default rates. More specifically, aggregate loans are a CES index

$$b_t = \left(\int_0^1 b_t(i)^{\frac{\theta_b-1}{\theta_b}} \right)^{\frac{\theta_b}{\theta_b-1}} \quad (20)$$

where θ_b is the elasticity of substitution between different bank loans and is calibrated to match aggregate lending rates. The corresponding price index which is dual⁸ to this quantity index is given by

$$r_t^b = \left(\int_0^1 r_t^b(i)^{1-\theta_b} \right)^{\frac{1}{1-\theta_b}}. \quad (21)$$

This specification of the aggregate indexes implies each bank i of type $T \in \{P, U\}$ faces the downward sloping demand for loans,

$$b_t^T(i) = \left(\frac{r_t^{b,T}(i)}{r_t^b} \right)^{-\theta_b} b_t. \quad (22)$$

Each bank i must not only satisfy their demand for loans, but they must also abide to the balance sheet constraint,

$$p_t b_t^T(i) + p_t^n n_t^T(i) = p_t d_t^T(i) + p_{t-1} b k_{t-1}^T(i) \quad (23)$$

which simply states that assets (bank loans) must equal liabilities (bank deposits) plus bank capital, respectively.

Since banks use share holder's retained earnings to fund risky loans, I assume shareholders (households) require compensation. More specifically, each period the bank is allowed (by the central bank) to expose a fraction ψ_t of bank capital to cover *expected* losses on unsecured

⁸Duality here refers to the price and quantity indexes which satisfy Fisher's factor reversal test, $\int_0^1 r_t^b(i) b_t(i) di = r_t^b b_t$.

defaulted loans. Each period t , the fraction of loans that actually default is given by $F_{t-1}(\bar{\omega}_t)$. Hence, each period the bank transfers the nominal payment

$$p_t trans_t^T(i) = F_{t-1}(\bar{\omega}_t) p_{t-1} \psi_{t-1} b k_{t-1}^T(i) \quad (24)$$

to shareholders in order to compensate them for the capital that was exposed to covering losses on loans originated in period $t - 1$. In this sense, the transfer to shareholders occurs only on realized, or ex-post, loan losses. Combining this transfer payment with dividend payments, bank capital evolves according to the following law of motion.

$$p_t b k_t^T(i) = \gamma_t^T p_t \Pi_t^T(i) - p_t trans_t^T(i) + (1 - \delta^{bk}) p_{t-1} b k_{t-1}^T(i) \quad (25)$$

To summarize this, banks of type T pay out a time varying fraction γ_t^T of period t profits as dividends and invest the remaining fraction in bank capital. Additionally, banks compensate shareholders for exposing retained earnings to potential losses via $p_t trans_t^T$ and lose a fraction of bank capital to depreciation. Following Gerali, Neri, Sessa, and Signoretti (2010), I assume bank investment decisions are made independently from bank profit maximization, however, I assume this fraction is time varying. In particular, I assume that $\gamma_t^T = \frac{\bar{\gamma}^T}{p_t \Pi_t^T}$ so that each period a constant amount of new equity is injected into the banks from shareholders. This implies realistically that banks respond to falling profits by paying out a smaller share of profits in dividends. Before proceeding to a specific description of each type of bank's problem, it useful to summarize these transfers by defining net investment in the banking sector.

$$i_t^{bk} = \sum_{T \in \{P, U\}} s_T (\gamma_t^T p_t \Pi_t^T - p_t trans_t^T) \quad \text{where } s_T = \begin{cases} \nu & \text{if } T = u \\ 1 - \nu & \text{if } T = p \end{cases} \quad (26)$$

Productive Bank

The productive bank enters each period t with inflows consisting of maturing unsecured loans $r_{t-1}^{b,p}(i) p_t b_{t-1}^p(i)$ and maturing secured loans $p_{t-1}^n n_{t-1}^p r_{t-1}^d$, of which, $(1 - F_{t-1}(\bar{\omega}_t))$ will be repaid in full. Denote the real income of all borrowers who are unable to repay last periods loan by $\Phi_{t-1}(\bar{\omega}_t)$. The productive bank will receives the fraction $\frac{b_{t-1}^p(i)}{b_{t-1}}$ of $\phi_{t-1}(\bar{\omega}_t)$ net of auditing costs μ for the unsecured loan defaults. Additionally, the productive bank repossesses $F_{t-1}(\bar{\omega}_t) n_{t-1}^p(i)$, which is the collateral posted on the secured loans who defaulted. This repossessed collateral is transformed in to housing using the technology common to all banks, $h_t^r(i) = z^r n_{t-1}^p(i)$. Finally, the productive bank also has incoming deposits totaling $p_t d_t^p(i)$. At the same time, the productive bank has outflows of newly originated unsecured and secured loans totaling $p_t b_t^p(i) + p_t^n n_t^p(i)$ and maturing deposits from period $t - 1$ totaling $p_{t-1} d_{t-1}^p(i) r_{t-1}^d$. This is stated more concisely below in (30) which defines the productive bank's period t nominal profits.

$$\begin{aligned} p_t \Pi_t^p(i) &= (1 - F_{t-1}(\bar{\omega}_t)) r_{t-1}^{b,p}(i) p_t b_{t-1}^p(i) + (1 - \mu) \frac{b_{t-1}^p(i)}{b_{t-1}} p_t \Phi_{t-1}(\bar{\omega}_t) \\ &\quad + (1 - F_{t-1}(\bar{\omega}_t)) p_{t-1}^n n_{t-1}^p(i) r_{t-1}^d + F_{t-1}(\bar{\omega}_t) p_t^h z^r n_{t-1}^p(i) \\ &\quad - p_t b_t^p(i) - p_t^n n_t^p(i) - p_{t-1} d_{t-1}^p(i) r_{t-1}^d + p_t d_t(i) \end{aligned} \quad (27)$$

The productive bank's ability to liquidate repossessed collateral - n_t^p at zero marginal cost raises a moral hazard. In particular, if the productive bank were to claim default on all the secured loans originated in period t and repossess the collateral the following period, they would earn a gross real return totaling $n_t^p \mathbb{E}_t \left\{ \frac{z^r p_{t+1}^h - (1 - F_t(\bar{\omega}_{t+1}) r_t^d p_t^n)}{p_t^n} \right\}$. The first term represents income from the selling the unlawfully repossessed collateral and the second term subtracts the foregone income that would have been received from entrepreneurs paying back their loans. I assume a fraction of this return will be lost when taken so that productive banks only net a fraction $\psi_t^{n,P}$ of this return. This varies stochastically according to the AR(1) process.

$$\ln(\psi_t^{n,P}) = \rho_{\psi^{n,P}} \ln(\psi_{t-1}^{n,P}) + \varepsilon_t^{\psi^{n,P}} \quad \varepsilon_t^{\psi^{n,P}} \sim \mathcal{N}(0, \sigma_{\psi^{n,P}}) \quad (28)$$

These disturbances provide a model equivalent to the large bank share shock from that will be analyzed in the VAR.

If the productive bank chooses to abscond with the assets, entrepreneurs are entitled to the remaining equity of the bank after preferred shareholders (households) receive their risk premium. Hence, entrepreneurs would be entitled to a claim of $(1 - \psi_t F_t(\bar{\omega}_{t+1})) b k_t^p(i)$. Thus, the incentive for productive banks to claim default and abscond with these housing-secured assets is eliminated when the equity claims of exploited entrepreneurs exceeds the gross return on unlawful liquidations.

$$\underbrace{(1 - \psi_t F_t(\bar{\omega}_{t+1})) b k_t^p(i)}_{\text{Equity Claim of Exploited Entrepreneurs}} \geq \underbrace{n_t^p \mathbb{E}_t \left\{ \frac{z^r p_{t+1}^h - (1 - F_t(\bar{\omega}_{t+1}) r_t^d p_t^n)}{p_t^n} \right\}}_{\text{Gross Return on Unlawful Repossessions}} \psi_t^{n,P} \quad (29)$$

When (29) holds with equality, the productive bank will be limited in how many housing-secured assets it can hold. Moreover, this constraint will endogenously loosen and tighten in response to various macroeconomic shocks which affect home prices or default rates. Let Λ_t denote the household's stochastic discount factor used for valuing future real payments. The problem faced by the productive bank is then defined below.

$$\max_{\{r_{t+j}^{b,p}(i), b_{t+j}^p(i), n_{t+j}^p(i), d_{t+j}^p(i)\}_{j=0}^{\infty}} \sum_{j=0}^{\infty} \mathbb{E}_t \{ \Lambda_{t+j} \Pi_{t+j}^p(i) \} \quad \text{subject to} \quad (22), (23), (29)$$

Due to the complications that arise from solving a model with an occasionally binding constraint, I calibrate the model so that the productive bank's moral hazard constraint binds in the non-stochastic steady-state.

Unproductive Bank

The unproductive bank is identical to the productive bank with one noticeable exception - they are less productive. To make matters more concrete, when a secured loan defaults the

unproductive bank repossesses collateral $F_{t-1}(\bar{\omega}_t)n_{t-1}^u(i)$. Unlike their productive counterparts, the unproductive bank liquidates this collateral while bearing an increasing marginal cost. On defaulted secured loans, the unproductive bank transforms repossessed collateral into housing yielding revenue $p_t^h z^r n_{t-1}^u(i)$ at a resource cost of $p_t \mu^{r,u} (n_{t-1}^u(i))^{x^{r,u}}$. This captures the heterogeneity between commercial banks (empirically found by (Wheelock and Wilson, 2012; Bos and Kolari, 2013)) with regards to their ability to evaluate and trade off-balance sheet assets. Most notably, as unproductive banks increase their holding of these assets, the value of the assets will fall due to the increasing marginal cost. Hence, the market liquidity of such assets depends on the distribution of these assets (i.e. it depends on who is holding the assets). A point first made by KM and applied to here to housing backed securities within this model.

With this exception, the unproductive bank's profit function is very similar to the productive bank's stated below.

$$\begin{aligned}
p_t \Pi_t^u(i) &= (1 - F_{t-1}(\bar{\omega}_t)) r_{t-1}^{b,u}(i) p_t b_{t-1}^u(i) + (1 - \mu) \frac{b_{t-1}^u(i)}{b_{t-1}} p_t \Phi_{t-1}(\bar{\omega}_t) \\
&+ (1 - F_{t-1}(\bar{\omega}_t)) p_{t-1}^n n_{t-1}^u(i) r_{t-1}^{D,U} \\
&+ F_{t-1}(\bar{\omega}_t) \left[p_t^h z^r n_{t-1}^u(i) - p_t \mu^{r,u} (n_{t-1}^u(i))^{x^{r,u}} \right] \\
&- p_t b_t^u(i) - \chi^{b,u} b_t^u(i) - p_t^n n_t^u(i) - p_{t-1} d_{t-1}^u(i) r_{t-1}^d + p_t d_t^u(i)
\end{aligned} \tag{30}$$

Notice the lack of productivity spills over to unsecured loans. The parameter $\chi^{b,u}$ is calibrated to match the average share of resources allocated to financial intermediation. The increasing resource cost of repossessing collateral implies the unproductive bank is *not* subject to a moral hazard constraint. In particular, if any single unproductive bank i attempted to purchase a large amount of these assets at a given market price p_t^n and falsely claim default, their cost of liquidating the assets would exceed what they paid for them. Therefore the existence of these increasing marginal cost eliminates any incentive to steal away these assets.

Let Λ_t denote the household's stochastic discount factor used for valuing future real payments. The problem faced by the unproductive bank is then defined below.

$$\max_{\{r_{t+j}^{b,u}(i), b_{t+j}^u(i), n_{t+j}^u(i), d_{t+j}^u(i)\}_{j=0}^{\infty}} \sum_{j=0}^{\infty} \mathbb{E}_t \{ \Lambda_{t+j} \Pi_{t+j}^u(i) \} \quad \text{subject to (22), (23)}$$

2.2.5 Central Bank

The central bank is charged with setting a *macroprudential* policy rule and a monetary policy rule. The macroprudential policy instrument is the regulatory maximum share of capital that can be allocated to loan losses. This essentially controls the amount of owners equity the bank can allocate to cover loan losses. Here, I assume the central bank simply sets this to a constant level,

$$\psi_t = \bar{\psi}. \tag{31}$$

As for the monetary policy instrument I assume the central bank follows the simple interest rate rule whereby the rate on one-period deposits adjusts to itself lagged, the inflation rate, and the growth rate of real GDP:

$$\left(\frac{r_t^d}{\bar{r}^d}\right) = \left(\frac{r_{t-1}^d}{\bar{r}^d}\right)^{\rho_r} \left(\frac{\pi_t}{\bar{\pi}}\right)^{\psi_\pi} \left(\frac{gdp_t}{gdp_{t-1}}\right)^{\psi_{gdp}}. \quad (32)$$

2.2.6 Market Clearing

Sections 2.2.1 - 2.2.5 describe the optimal behavior of all agents in the economy. A symmetric competitive equilibrium is defined as a sequence of quantities, prices and Lagrange multipliers (shadow prices) which satisfy all optimality conditions, policy rules and market clearing conditions. In particular, the demand for housing must equate the supply of housing on the market which consists of newly built homes, repossessed collateral being liquidated on the housing market and non-depreciated housing from last period. Put more simply,

$$h_t = h_t^{new} + F_{t-1}(\bar{\omega}_t)z^r (\nu n_{t-1}^u + (1 - \nu)n_{t-1}^p) + (1 - \delta^h)h_{t-1}. \quad (33)$$

The above expression can be further simplified by noting that the market for secured lending (or more narrowly, land) clears when

$$\bar{n} = \nu n_t^u + (1 - \nu)n_t^p, \quad (34)$$

where the left hand side is the aggregate endowment of entrepreneurs. By the ex-ante symmetry among entrepreneurs this is required to equal $\bar{n} = \bar{n}^j$ for all entrepreneurs j . Similarly, this ex-ante symmetry also implies the demand for capital by entrepreneurs is identical, or $k_t = k_t^j$ for all entrepreneurs j . I assume that capital can be transformed one for one from the final good and depreciates at rate δ^k . Therefore, capital evolves according to,

$$k_t = i_t + (1 - \delta^k)k_{t-1}. \quad (35)$$

Since I do not include adjustment costs, the price of capital equals the price of the final good at all times, $q_t = p_t$. Adjustment costs in the production of capital could easily be added, as in BGG. However, in this model, they are not needed to generate an amplification effect. Instead, the asset price spirals occur from the redistribution of assets between agents as in KM. With this description of the model, the goods market clearing condition is satisfied whenever,

$$y_t = c_t + c_t^e + i_t + i_t^{bk} + \mu\Phi_{t-1}(\bar{\omega}_t) + \nu\mu^{r,u} (n_{t-1}^u(i))^{X^{r,u}} + \nu\chi^{b,u}b_t^u, \quad (36)$$

which stipulates that the consumption good must be either consumed by the household or the entrepreneur, invested in bank capital, or used to audit or repossess the collateral of defaulting entrepreneurs. It is useful for the purpose of calibration and model inference to define GDP in this multi-sector model.

$$gdp_t = c_t + i_t + p_t^h h_t^{new} \quad (37)$$

2.3 Calibration

The model is calibrated to match characteristics of the U.S. economy from 1998 to 2012 and each time period is interpreted as one quarter. In order to numerically solve the model, there are 23 non-shock parameters and 15 shock parameters which must first be assigned values. Beginning with the household’s parameters I calibrate $\beta = .9875$ as to match up the steady state deposit rate in the model with the average rate on 3-Month U.S. Treasury Bills. I set the utility on non-housing leisure and housing leisure, $\eta^h = 4.6034$ and $\eta^l = 1.43$ which matches the share of labor supplied in housing equal to 5%, the U.S. average using data from the BLS and the total share of time spent working equal to 1/3. Finally, the last of the preference parameters $\bar{\eta}^h = .2219$ calibrates the steady state real price of housing so that consumption’s share of GDP = $\frac{c}{GDP} = .80$, which is the average ratio of personal consumption expenditures to personal consumption expenditures and private investment for the U.S. Similarly, setting $\delta^h = .0189$ implies the share of housing wealth to annual GDP, $\frac{p^h h}{4 \times GDP} = 1.4$.

On the production side, I set the share of income going to labor in the goods producing sector, $1 - \alpha_g = .7$ and the same share in the housing sector $1 - \alpha_h = .8$ following Iacovello and Neri (2010). I normalize the ‘land’ endowment of entrepreneurs, $\bar{n} = 1$. As for the financial accelerator parameters, I collectively set $\mu^M = .135$ and $\bar{\sigma}^{\omega} = .18$. The auditing cost parameter falls between the value from Christiano, Motto, and Rostagno (2013) and BGG and the steady state value of the variance of the idiosyncratic productivity shock implies an annual steady state default rate of $F(\bar{\omega}) = .01$ which is the average default rate on C & I loans secured by real-estate using data obtained from the St. Louis Fed’s FRED database.

With regards to the banking sector, I set the share of capital allocated to loan losses, $\psi = .25$, the average of loan-loss allocations to the equity of commercial banks over this period according to data obtained from FRED. I normalize each bank’s share of the population to be equal by setting $\nu = \frac{1}{2}$. The depreciation rate on bank capital is set at $\delta^{bk} = .04$ which implies the leverage ratio of large banks is 14.⁹ The value for $\nu \chi^{b,u} = .0004954$ is obtained from Hafstead and Smith (2012) who create a time series of banking productivity in loan intermediation. I set the steady-state rate of return on entrepreneurial loans equal to the average prime loan rate, $r^e = 1.017$. This pins down the elasticity of substitution between bank loans, $\theta_b = 263.75$.¹⁰ There is little agreement over the real return on capital, I set it equal to equal to 10% per annum which is slightly below the real return on capital in the U.S. estimated by Oulton and Rincon-Aznar (2009).¹¹ This value also matches the annualized

⁹This value also implies the first order autocorrelation of bank capital in the model is 0.99, the same value it has in the data. For a point of reference, Gerali, Neri, Sessa, and Signoretti (2010) set the depreciation rate on bank capital to 0.08.

¹⁰Hafstead and Smith (2012) find a similarly high value for $\theta_b = 260$.

¹¹Oulton and Rincon-Aznar (2009) estimate the average annual real return on capital to be 13%, however they acknowledge this estimate is potentially biased upwards. Therefore, I follow Hafstead and Smith (2012) and set the annual return to 10%.

return on small-cap stocks, representing firms who are likely to be financially constrained, using data from Morningstar.

I set $\bar{\gamma}^p = 0.0063$ which ensures the share of housing-secured assets held by the productive banks, $\frac{n^p}{n^p+n^u} = 0.92$, the average share of total credit exposure concentrated in large banks, as explained in Section (3.2). Similarly, setting $\bar{\gamma}^u = 0.0261$ ensures the leverage ratio of unproductive banks is 0.3, the average value in the data according to the Office of the Comptroller of the Currency’s (OCC) Quarterly Derivatives Report. Additionally, I set $\chi^{r,u} = 1.07$, implying strictly convex cost of repossessing/liquidating collateral for the unproductive bank. This together with setting $\mu^{r,u} = 0.0871$ calibrates the steady state price of the housing-secured assets so that $\frac{p^n \bar{n} + b}{p^n \bar{n}} = 2.5$, or the average ratio of C&I loans plus total credit exposure to total credit exposure. Finally, normalizing $z^r = 1$ and setting $\bar{z}^h = 1.14$ implies the real-estate owned share, or REO share, $\frac{F(\bar{\omega})z^r \bar{n}}{F(\bar{\omega})z^r \bar{n} + h^{new}} = 0.1775$ which is the value in the data according to RealtyTrac.

As for the remaining policy parameters, steady state gross inflation is set equal to unity and $\rho_r = 0.85$, $\psi_\pi = 1.5$, $\psi_{gdp} = 0.125$. The remaining shock parameters can not be pinned down by matching steady state values. The exogenous process, $\psi_t^{n,P}$, which governs the productive bank’s moral hazard constraint is used to highlight the impact of asset redistribution between banks, and is largely not structural. Therefore, I set $\rho_{\psi^{n,P}} = .9$ and $\sigma_{\psi^{n,P}} = .01$.

The remaining exogenous processes are calibrated using a moments matching exercise. In particular, I choose $\rho_z = 0.99$, $\sigma_z = 0.0052$, $\rho_{\eta^h} = 0.8952$, $\sigma_{\eta^h} = 0.000015$, $\rho_{\sigma^\omega} = 0.9526$ and $\sigma_{\sigma^\omega} = 0.0466$ to match the model’s standard deviation and first-order autocorrelation of: the external finance premium (proxied by the spread between BAA corporate bond-rate and 10-year treasuries), real GDP¹², real private investment and real home prices. This exercise not only pins down values for the model’s driving shocks, but since I do not restrict the calibration strategy to match the model’s implied correlation matrix, it allows for an empirical examination of the model’s performance.

The model fits the data reasonably well with nearly all the moments in the confidence interval. Comparing this model to the baseline BGG model augmented with a housing sector, it becomes clear why the celebrated BGG financial accelerator must be adjusted to analyze the financial crisis. The BGG financial contract assumes the borrowers wealth is liquid, therefore (real-estate) secured debt is absent in the model. This explains why BGG has difficulty capturing the dynamics between the EFP and both p^h and Investment. BGG’s counterfactual correlation between GDP and the EFP stems largely from the documented puzzle that BGG’s debt-contract generates an increases in the EFP following a positive technology shock. (Shen, 2011). These issues are absent in the model presented here since housing secured debt, and therefore home prices, play a critical role in the financial contract.¹³ As a

¹²The standard deviation of housing supply shocks were consistently pushed to 0 in the moments matching exercise. Real GDP is measured as the model equivalent. Hence, I sum personal consumption expenditures and private investment and deflate the resulting series by the civilian population over the age of 16 and the personal consumption expenditures excluding food and energy price deflator.

¹³For the BGG model correlations, I include investment adjustment costs of the form: $k_t = (i_t -$

Table 1: Cyclical Properties of the Model

Correlation	5 Percent	Median	95 Percent	Model	BGG (1999)
EFP, GDP	-0.89	-0.68	-0.45	-0.78	0.25
EFP, p^h	-0.87	-0.60	-0.32	-0.66	0.30
EFP, Investment	-0.89	-0.63	-0.32	-0.89	-0.06
GDP, p^h	0.50	0.76	0.93	0.93	0.93
GDP, Investment	0.93	0.96	0.99	0.87	0.83
p^h , Investment	0.57	0.81	0.95	0.65	0.87

^a The data correlations and confidence intervals are computed using Jeffery’s Prior and a non-informative prior on an estimated VAR(2).

robustness check I also performed the moments matching exercises with nominal price and wage rigidities standard in DSGE models such as Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007) and reached a similar conclusion with these added frictions.

2.4 The Model’s Amplifying Effect of Asset Redistribution

In this section I analyze the behavior of the following four variables:

1. External Finance Premium (EFP) = $\mu \frac{\phi_{t-1}(\bar{\omega}_t)}{b_{t-1}}$
2. Real GDP = gdp_t
3. Real house prices = p_t^h
4. The share of housing-secured assets held by large banks = $\frac{(1-\nu)n_t^p}{\bar{n}}$

in response to the model’s structural shocks. For each shock, I present the model’s response when the productive bank’s moral hazard constraint binds (the solid lines) and when this constraint is relaxed (the dashed lines). Notice that when the constraint is relaxed, the productive banks hold all of the housing-secured assets since they are significantly more productive. Hence, for this model, the *Large Bank Share* variable is constant.

Figure 2 displays the equilibrium model’s response of the endogenous variables to a detrimental risk, technology and housing demand shock. The dynamics are noticeably different when the moral hazard constraint binds compared to the efficient allocation whereby large banks hold all of the housing-secured assets. In particular, the response of all the variables are *amplified*. Changes in the risk-characteristics of borrowers or the household’s preferences towards housing are magnified by 50% when assets are redistributed between large and small

$S(i_t/i_{t-1}) + (1 - \delta^k)k_{t-1}$ where $S(1) = S'(1) = 0$ and $S''(1) > 0$. I set $S''(1) = 0.5$ as larger values further deteriorated the model fit highlighted in Table 1. Interestingly, without adjustment cost the BGG model fits the data much better in the sense highlighted in Table 1; however, this effectively “turns-off” the financial accelerator mechanism.

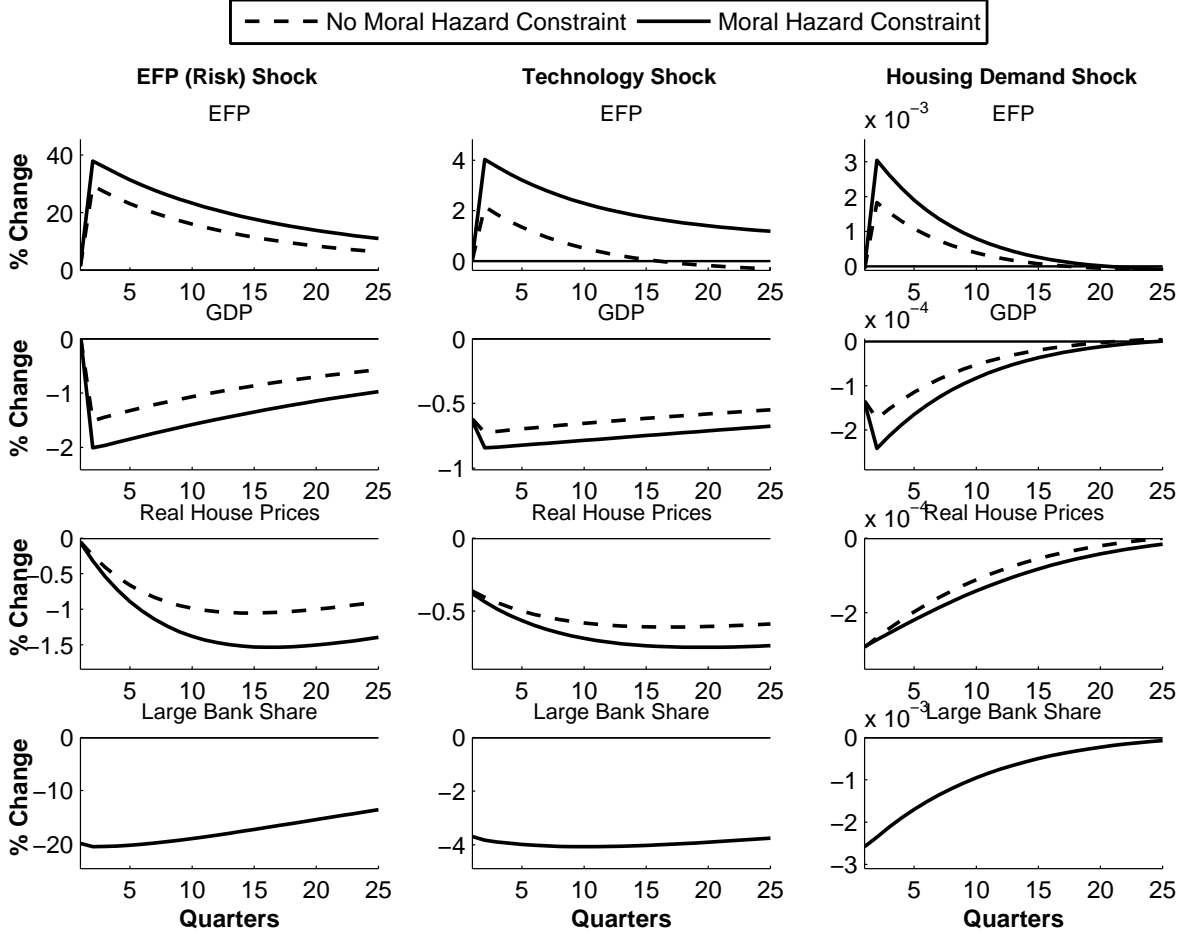


Figure 2: Impulse response functions from the equilibrium model. The solid lines denote the dynamic responses when the productive bank's moral hazard constraint binds and the dashed lines are the dynamics when this constraint is relaxed.

banks. Even technology shocks raise GDP by 25% more at peak when large banks are able to expand their housing-secured asset holdings. The key factor driving these changes are movements in home prices, which are themselves amplified.

I highlight this amplification effect in figure 3 which illustrates the differences between the two models simulated in the IRFs. The diagram shows the effect of a drop in home prices on the price of \bar{n} . In particular, the equation determining the price of housing-secured assets is given by the unproductive banks first order condition for n_t^u ,

$$p_t^n = \frac{1}{r_t^d} \mathbb{E}_t \left\{ z^r p_{t+1}^h - \chi^{r,u} \mu^{r,u} n_t^{U(\chi^{r,u}-1)} \right\} \quad (38)$$

which for $\chi^{r,u} > 1$ looks like a typical demand curve. If expected home prices fall, this will shift down the demand curve for these assets. Without any redistribution effect, asset prices fall from p_1^n to $p_1^{n'}$ - this is the dynamic captured in the figure on the left.

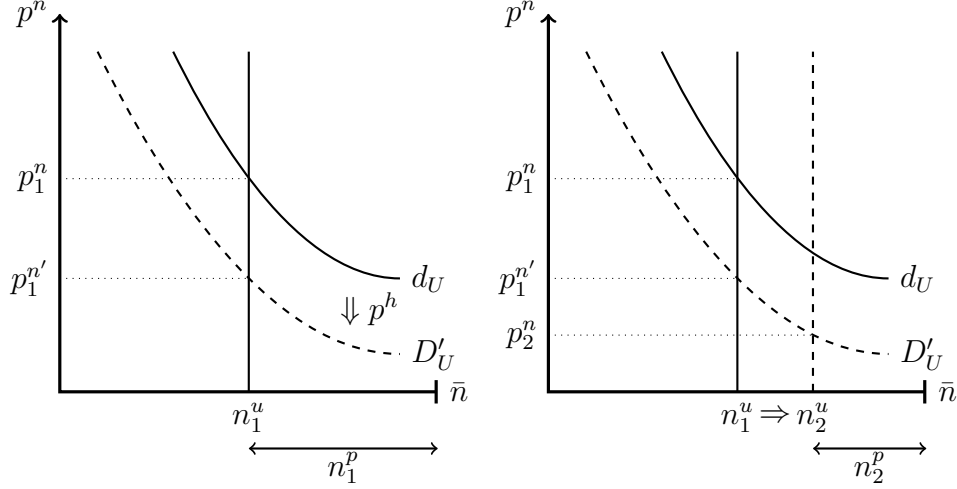


Figure 3: The graph on the left illustrates the impact on asset prices when home prices drop, without any redistribution effect. The graph on the right highlights the additional fall in asset prices that results when the productive bank must reduce its share of housing-secured secured assets due to the endogenously tightening moral hazard constraint.

To understand the amplification effect stemming from the redistribution of housing-secured assets, notice two things. (i) First, due to the positive marginal cost of liquidating collateral, asset prices fall by *more* (in percentage terms) than expected home prices. That is, $\mathcal{E}_{p_t^n, \mathbb{E}_t\{p_{t+1}^h\}} > 1$.

$$\mathcal{E}_{p_t^n, \mathbb{E}_t\{p_{t+1}^h\}} = \frac{\partial p_t^n}{\partial \mathbb{E}_t\{p_{t+1}^h\}} \frac{\mathbb{E}_t\{p_{t+1}^h\}}{p_t^n} = \frac{z^r \mathbb{E}_t\{p_{t+1}^h\}}{z^r \mathbb{E}_t\{p_{t+1}^h\} - \chi^{r,u} \mu^{r,u} n_t^{U(\chi^{r,u}-1)}} > 1 \quad (39)$$

(ii) Second, the debt contract described in section 2.2.2 shows that as the value of the entrepreneur's pledgeable assets falls, the probability of default increases.¹⁴

$$\frac{\partial F_t(\bar{\omega}_{t+1}^j)}{\partial p_t^n} = \frac{\partial F_t(\bar{\omega}_{t+1}^j)}{\partial \bar{\omega}_{t+1}^j} \frac{\partial \bar{\omega}_{t+1}^j}{\partial p_t^n} < 0 \quad (40)$$

These two effects, (i) and (ii) (Eqs. 39 and 40), both act to tighten the binding moral hazard constraint for the productive bank (Eq. (29)) and hence the large bank share falls.

¹⁴The first partial derivative is positive due to the monotonicity of CDFs and the second partial derivative is negative due to the structure of the optimal debt contract.

This is illustrated in the graph on the right of figure 3. In particular, a drop in home prices induces not only a direct fall in asset prices from p_1^n to $p_1^{n'}$ but a further drop to p_2^n due to an endogenous reduction in n_t^p (and the downward sloping demand for n_t^u due to the strictly convex costs). This is the beginning a multiplier effect of sorts. As p_t^n falls by more than $\mathbb{E}_t \{p_{t+1}^h\}$, the moral hazard constraint tightens further inducing further reductions in n_t^p . All the while, as these forces act to push down the value of secured debt, borrower's face an increasing external finance premium. This is the amplification effect highlighted by the difference between the 2 sets of IRFs in figure 2.

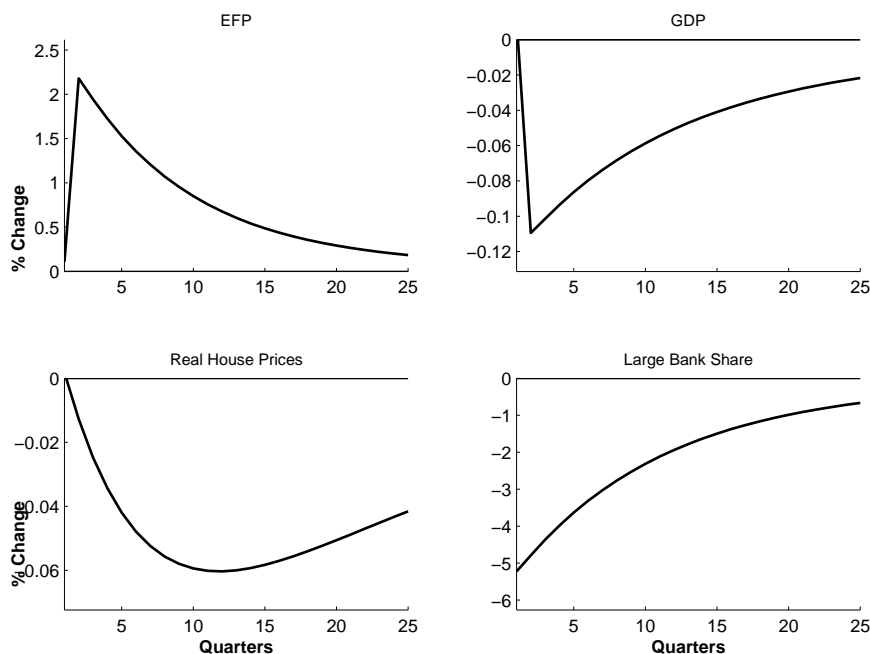


Figure 4: Impulse response function from the equilibrium model to an exogenous 1% drop in the share of housing-backed assets held by productive banks.

This static multiplier effect from asset redistribution may be easiest to spot when I exogenously increase the share of assets held by the productive bank in figure 4. The dynamics following this exogenous shock are shown in the the last column of IRFs in figure 2. Although, the shock is set to decrease n_t^p by only 1% the period the shock hits, n_t^p decreases *more than 5 times as much*, more than 5%. Again, this amplified response is driven by the asset redistribution illustrated in figure 3. When n_t^p decreases there are two immediate effects, as explained by equations 39 and 40, both of which act to expound this decrease in the productive bank's share of housing-secured assets.

One common theme through all the impulse response functions is an amplification effect stemming from asset redistribution. Although, I have highlighted the static amplification, there is also a dynamic feature at work which makes the moral-hazard constrained model more persistent. Since repossessed collateral ultimately is liquidated on the real-estate market, this increase in supply lowers home prices into the future to the extent that housing does not depreciate immediately. These effects re-enforce one another over time. Ultimately though, these dynamic amplification effects are powered by restarting, period by period, the engine that drives the static multiplier.

3 VAR Tests of the Model’s Amplification Mechanism

In this section, I estimate a series of VAR models to examine the empirical plausibility of the model’s predictions. The variables included in the VARs are the same variables examined in the model’s impulse response functions: the external finance premium, real GDP, real home prices and the share of total credit exposure concentrated in large banks. All variables are available at a quarterly frequency from 1998:Q2 to 2012:Q4.¹⁵ As specified in log-levels, the Schwarz Bayesian information criterion selects 2 lags for the VAR. In what follows I first lay-out the model’s testable predictions, then I go on to describe the data and the structural identification before presenting the impulse response functions for the various models.

3.1 The Model’s Empirical Implications

The DSGE model developed in the previous section posits an amplification effect stemming from the redistribution of assets between large and small banks. In particular, the amplification mechanism posits that an initial economic downturn, in which home prices fall, causes the credit exposure of large banks to fall which in turn causes finance premiums to rise.

1. A decrease in real home prices decreases the concentration of housing-secured assets in big banks.
2. A decrease in the concentration of housing-secured assets in big banks causes finance premiums to rise.
3. A rise in finance premiums lowers home prices and output.

This mechanism is self re-enforcing, 1. → 2. → 3. → 1. → 2. → 3. → 1. and so forth. At each completion of the cycle output falls; therefore, as the cycle feeds back on itself output falls further and further which deepens the recession. To test this qualitative aspect of the model, I use a factor structural vector auto-regression. The results provide further empirical support for the integrated housing and financial structure I put forth in the equilibrium model.

¹⁵The time series is limited by the availability of net credit exposure data from the OCC’s Quarterly Derivatives Report. However, for the removal of trends, I use data going back to 1975:Q1

3.2 Data Description

One of the model’s key variables, the external finance premium is unobservable. However, following the recent strategy of Christiano, Motto, and Rostagno (2013) and Carlstrom, Fuerst, Ortiz, and Paustian (2012), I use the spread between BAA corporate bonds and 10-year Treasuries to proxy this unobservable variable. As for real GDP, I use the model equivalent definition. I sum personal consumption expenditures and private investment (the sum of residential and non-residential investment in the model) and divide the resulting series by the personal consumption expenditures excluding food and energy price deflator. I measure real home prices using the Case-Shiller National Composite Home Price Index divided by the personal consumption expenditures excluding food and energy price deflator. Both real GDP and real home prices reveal evidence of a unit root at the 10% confidence level using an ADF test. I therefore, remove any deterministic and/or stochastic trend by taking the difference between the log of the original series and a 25 quarter centered moving average of the logged series.

Finally, I follow Breuer (2000) and construct the large bank share variable using the Office of the Comptroller of the Currency’s (OCC) Quarterly Derivatives Report which tracks the derivative activity of the 25 largest U.S. commercial banks (in terms of notional derivatives held) and the commercial banking sector as a whole. Specifically, I sum the total credit exposure of the largest commercial banks and divide this by the total credit exposure of all commercial banks. The banks I deem as ‘large’ are the six financial firms which consistently hold the largest amount of notional derivatives. These six banks include: JP Morgan Chase, Citibank, Bank of America, HSBC, Wachovia and Wells Fargo.¹⁶ In the baseline model, the variable Large Bank Share refers to the share of total credit risk held by these six banks relative to all U.S. commercial banks. These derivatives contracts are dominated by interest rate contracts, which were often secured by MBSs.¹⁷

As a robustness check, I also compute the large bank share using data obtained directly from the *FR Y-9C Consolidated Financial Statements for Bank Holding Companies* collected quarterly by the Federal Reserve.¹⁸ One advantage of using this data is the highly detailed handling of mergers and acquisitions by the National Information Center.

Ideally, I would like to obtain a time series of the amount of debt securities issued by bank holding companies which are secured by mortgage backed securities, as this most closely aligns with the interpretation of these variables in the model. For example, the Asset-Backed Commercial Paper market provides an ideal example of the type of debt banks issued on

¹⁶One challenge to tracking these firms over time is dealing with mergers, acquisitions and the financial crisis. I handle these issues by adding the off-balance sheet asset’s of acquired banks to the acquiring bank’s assets to create (as much as is possible) a consistent time series. See Table (3) for more details on how this group evolves over time.

¹⁷See for example: <http://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/short-term-markets/Repo-Markets/frequently-asked-questions-on-repo/6-what-types-of-asset-are-used-as-collateral-in-the-repo-market/>

¹⁸I am indebted to Bob DeYoung for recommending this data source.

the behalf of firms/investment banks holding MBSs. Unfortunately this data has only been collected as of 2008. To get a rough measure of the debt banks have extended which are secured, either directly or indirectly, by housing I use the reported level of loans secured by real-estate. In the following IRF estimates which refer to ‘Alternative Data,’ the variable Large Bank Share refers to the share of loans secured by real estate held by the six banks listed above relative to all bank holding companies which file the Y-9C report.

3.3 Model A: A Factor Structural VAR

The model’s implications described above calls for the identification of 3 distinct structural shocks using four variables. Since the number of desired structural shocks is less than the number of variables for which there are model implications, I employ a factor structural vector auto-regression following Gorodnichenko (2005). This approach is appropriately fitting here for a couple of reasons.

First, the four variables in the VAR behave qualitatively similar to technology and housing demand shocks in the equilibrium model as shown in Figure 2. For this reason, imposing timing restrictions at any horizon to distinguish these shocks proves difficult. Moreover, there is no need to disentangle these shocks to test the model’s predictions that an aggregate expansion which increases real home prices, loosens both the supply and demand side financial frictions. Therefore, I choose to simply recognize macroeconomic disturbances as a single factor, which allows me to test the model’s prediction along this dimension without imposing arbitrary timing restrictions on the behavior of output and real home prices. Blanchard and Quah (1989) make a similar argument that shocks can be aggregated when they elicit qualitatively similar dynamics.¹⁹ Second, the external finance premium in the model is unobservable. Hence, by using a factor-structural VAR, I can explicitly include measurement error terms to ensure this proxy for the external finance premium does not contaminate the structural shocks of study.

In addition to the macroeconomic factor discussed above, I identify a ‘risk’ shock, an increase in the cross sectional dispersion of borrowers in the model $\ln(\sigma_t^\omega)$ and an exogenous increase in the share of housing-secured assets held by large banks. The latter shock is the model equivalent of a decrease in $\ln(\psi_t^{n,P})$ which exogenously improves the moral hazard problem between large banks and borrowers. To summarize, I identify an exogenous tightening of the demand-side financial friction (the ‘risk’ shock), a beneficial macroeconomic shock and an exogenous loosening of the supply-side financial friction. Identifying these three shocks is sufficient to test the three model predictions laid out above.

To identify these three shocks, I impose a recursive scheme that ensures global identification is achieved²⁰ and allows for home prices and real GDP to behave symmetrically to all

¹⁹Their argument is a bit more formal. To summarize, they show that so long as the dynamic responses of the variables in the VAR to the aggregated shocks differ up to a scalar lag distribution (The responses need not be identical nor proportional) then the shocks can be aggregated.

²⁰Since the 3×3 sub-matrix of A excluding the last row is lower triangular, we can ensure global identification (Anderson, 2003; Anderson and Rubin, 1956).

the shocks. In the model, the ex-post observable external finance premium in period t is determined by fundamentals in period $t - 1$. For this reason, I order the spread, which proxies the external finance premium first in the VAR to match this feature of the model. Next I order real GDP and then home prices. The ordering between these two variables is innocuous since they are treated symmetrically in the identification scheme. Finally, I order the share of total credit exposure held by large banks. This recursive ordering is consistent with the equilibrium model. The macroeconomic factor shocks in the DSGE model do not have a contemporaneous effect on the external finance premium but they do contemporaneously impact real GDP, real home prices and the large bank share. Additionally, the supply-side financial shock affects all variables (other than the large bank share) with a lagged response.

To summarize the identification scheme, let e_t denote the 4×1 vector of reduced form VAR residuals. Let ϵ_t denote the 3×1 vector of structural shocks and let v_t denote the 4×1 vector of measurement errors which ensures the rank between the reduced form shocks and the identify structure match. The matrix A , is a 4×3 loading matrix which relates the structural factors to the reduced form residuals. Summarizing this,

$$e_t = A\epsilon_t + v_t \quad (41)$$

where

$$A = \begin{bmatrix} a_{1,1} & 0 & 0 \\ a_{2,1} & a_{2,2} & 0 \\ a_{3,1} & a_{3,2} & 0 \\ a_{4,1} & a_{4,2} & a_{4,3} \end{bmatrix} \quad (42)$$

I assume the measurement error terms, v_t are independent of the structural factors ϵ_t at all leads and lags and I also assume the covariance matrix of the measurement errors, Ψ , is diagonal. Equation (41) is estimated using maximum likelihood techniques.²¹

3.4 Models for Robustness Checks: VAR Models B and C

To ensure the results obtained from the factor structural vector auto-regression are not driven by the reduced rank identification scheme, I examine the empirical implications of two alternative VAR models. Model B tests for the DSGE model's amplification mechanism using the approach employed in Ludvigson's 1998 *Journal of Money Credit and Banking* paper. The idea is similar to Model A in that the econometric strategy aims to sequentially identify shocks which trace out the steps of the financial accelerator mechanism. In what follows, I explain how I apply Ludvigson's (1998) procedure to test the financial amplification mechanism in this paper.

²¹In particular, assuming e_t are *i.i.d. Normal*, the log-likelihood equation is given by,

$$\log(\mathcal{L}) = -\frac{4T\ln(\pi)}{2} - \frac{T}{2}\ln(|AA' + \Psi|) - \frac{1}{2}\sum_{t=1}^T e_t'(AA' + \Psi)^{-1}e_t.$$

The first step in testing the amplification mechanism using Model B is to identify the impact an expansionary housing demand disturbance (i.e. the shock to home prices) has on the large bank share variable. If this share falls with home prices, I then proceed to step two which estimates the response of the external finance premium to an exogenous decrease in the large bank share when home prices are removed from the VAR. The idea is to examine how a change in the share of loans intermediated by large banks impacts the external finance premium independent of the endogenous response of home prices to this change in the composition of lending. Finally, if the finance premium increases when the large bank share decreases, I estimate the response of real GDP and real home prices to an exogenous increase in the external finance premium, excluding the large bank share.²² Again, the idea is to trace out the steps in the amplification mechanism while controlling for the endogenous reaction of home prices and the share of credit held by large banks respectively.

Model C takes this idea one step further and estimates a series of bivariate VARs. The first VAR has home prices and the large bank share. If falling home prices causes large banks to withdraw relatively more credit than smaller banks, then I estimate a second bivariate VAR which includes the external finance premium and the share of credit held by large banks. If reductions in the large bank share drive-up finance premiums, then I estimate a third bivariate VAR with the external finance premium and GDP. If this VAR indicates that rising finance premiums causes real GDP to fall, then this provides evidence in support of the equilibrium model’s amplification mechanism spelled out in Section (3.1).

Throughout all of these VAR models, I order variables as follows: the external finance premium, real GDP, real home prices and the large bank share. The motivation for this ordering follows from the equilibrium model’s impulse response functions in Figure (2). The most delicate issue of this ordering lies in the decision of whether to place real GDP before real home prices or vis-a-versa. The equilibrium model implies both have a non-zero response to housing demand and technology shocks. All of the results for the recursive models used in Model B and Model C are robust to reversing the ordering of real GDP and real home prices. Model A treats these variables symmetrically and for this reason is the preferred model.

3.5 Model A: Impulse Response Functions

Impulse response functions trace out the path of the variables in periods $t = 0, 1, 2, \dots$ in response to a one time structural disturbance in period $t = 0$. The rows of figure 5 correspond to variables while the columns correspond to the structural factors described above. Confidence bands are computed using Monte Carlo integration techniques assuming a normal likelihood and uninformative prior.

In order to test the model’s amplification prediction the first step is to examine if a drop in home prices caused by an aggregate downturn tightens the large banks’ moral hazard constraint forcing them to shed assets relative to their smaller counterparts. This macroeconomic

²²The results are robust to alternatively removing *both* home prices and the large bank share from the VAR and estimating the impact an increase in the external finance premium has on real GDP.

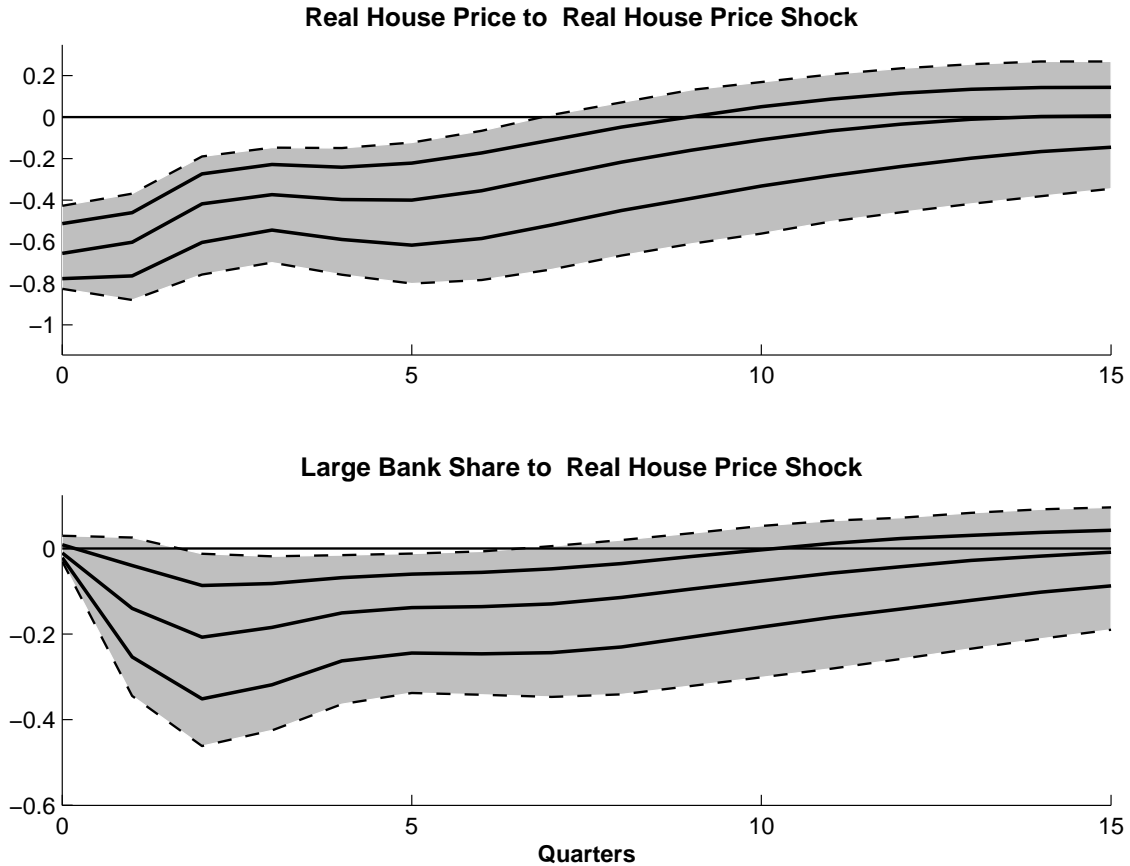


Figure 5: Baseline Model: Median Impulse Response to a contractionary aggregate shock with 68% and 90% confidence bounds.

factor which simultaneously decreases real home prices and real GDP has the interpretation of either a housing demand disturbance or a technology shock in the DSGE model. Both shocks have been attributed as playing a driving role in the evolution of the real economy (See for example Liu, Wang, and Zha (2013) or Kydland and Prescott (1982)). As the model predicts, this aggregate downturn tightens the large banks' moral hazard constraint forcing them to shed assets relative to their smaller counterparts as shown in Figure (5).

The second step in the accelerator mechanism, and in fact the model's key prediction is that changes in the distribution of assets between productive and unproductive banks alters the finance terms offered to borrowers. For example, if the assets shift to less productive banks, which are the small banks in equilibrium, finance premiums will rise as the liquid value of the borrowers collateral falls when it is held by these unproductive intermediaries. The data confirms this prediction in Figure (6). An exogenous decrease in the share of assets

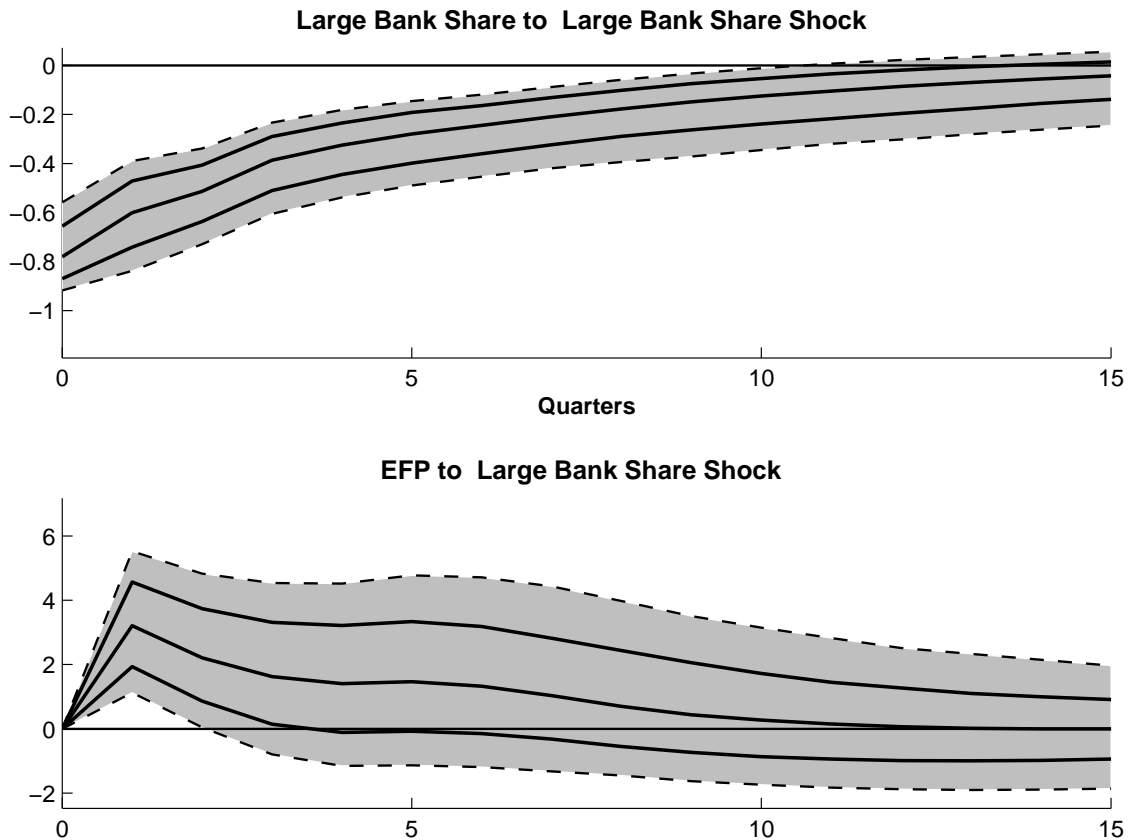


Figure 6: Baseline Model: Median Impulse Response to an exogenous decrease in the large bank share with 68% and 90% confidence bounds.

held by large banks increases the external finance premium, suggesting financing conditions are worsening.

Since the VAR has confirmed the first two steps of the accelerator mechanism, I proceed to the third step to examine how rising finance premiums affect the macroeconomy. In particular, the model predicts that rising financing costs will lead to an increase in defaults and ultimately lower home price due to the increased supply of homes on the market. Moreover, the existence of higher financing costs leads to less investment. Both of these movements exact a negative effect on real GDP. This is confirmed in Figure (7) As home prices fall so too does real GDP due to both the direct effect home prices have on GDP and through the indirect effect. Therefore the impulse response functions show that when home prices fall, credit exposure shifts from large banks which magnifies the movement of finance premiums and, in turn, amplifies the movement of output and home prices, starting the cycle over. *In summary, the results above provide evidence which supports the hypothesis that the redistri-*

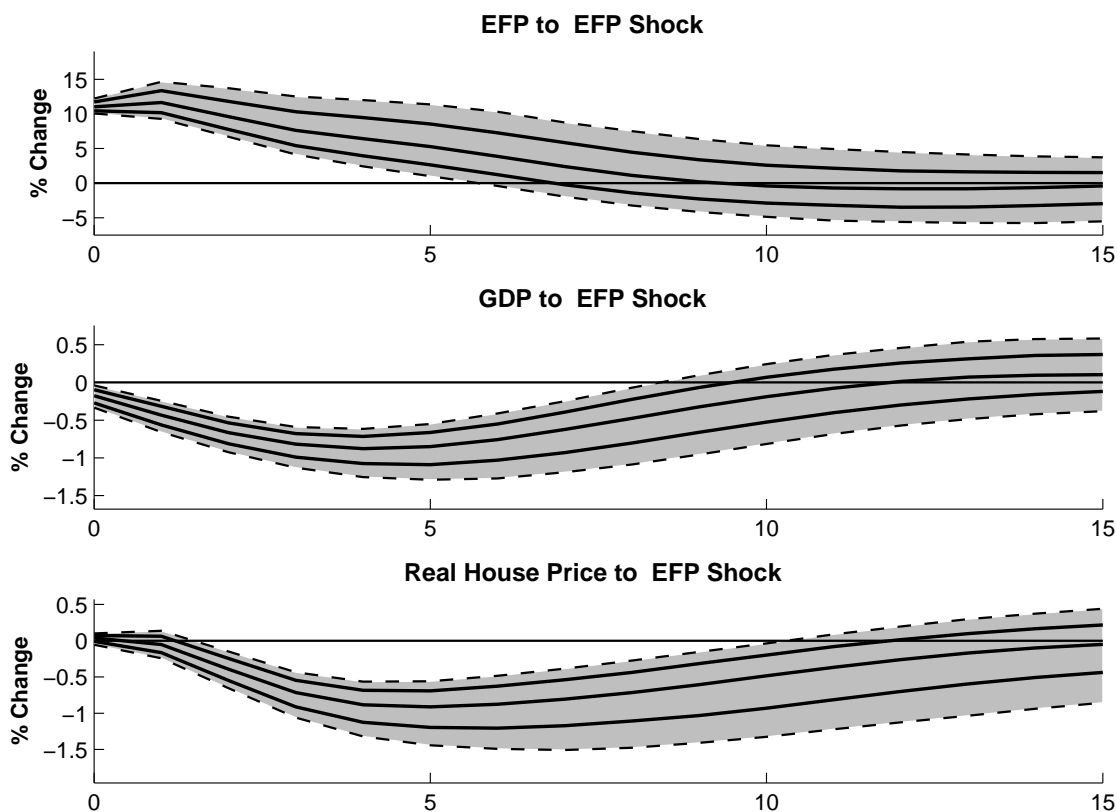


Figure 7: Baseline Model: Median Impulse Response to an exogenous increase in the external finance premium with 68% and 90% confidence bounds.

bution of housing-secured assets magnifies the movement of finance premiums, house prices and output across the business cycle, supporting the model's predictions.

3.6 Model A: Impulse Response Functions with Alternative Data

As mentioned above, I perform a robustness check of the above results by estimating the same factor-structural VAR with the large bank share variable measured by the share of loans secured by real estate from the Federal Reserve's Y-9C report. The results below show that both models behave qualitatively similar. The response of the finance premium to an exogenous decrease in the share of real estate secured loans issued by large banks loses some statistical significance in this version. However, the median response is still positive for 8 quarters as is the majority of the posterior density for the first 6 quarters.

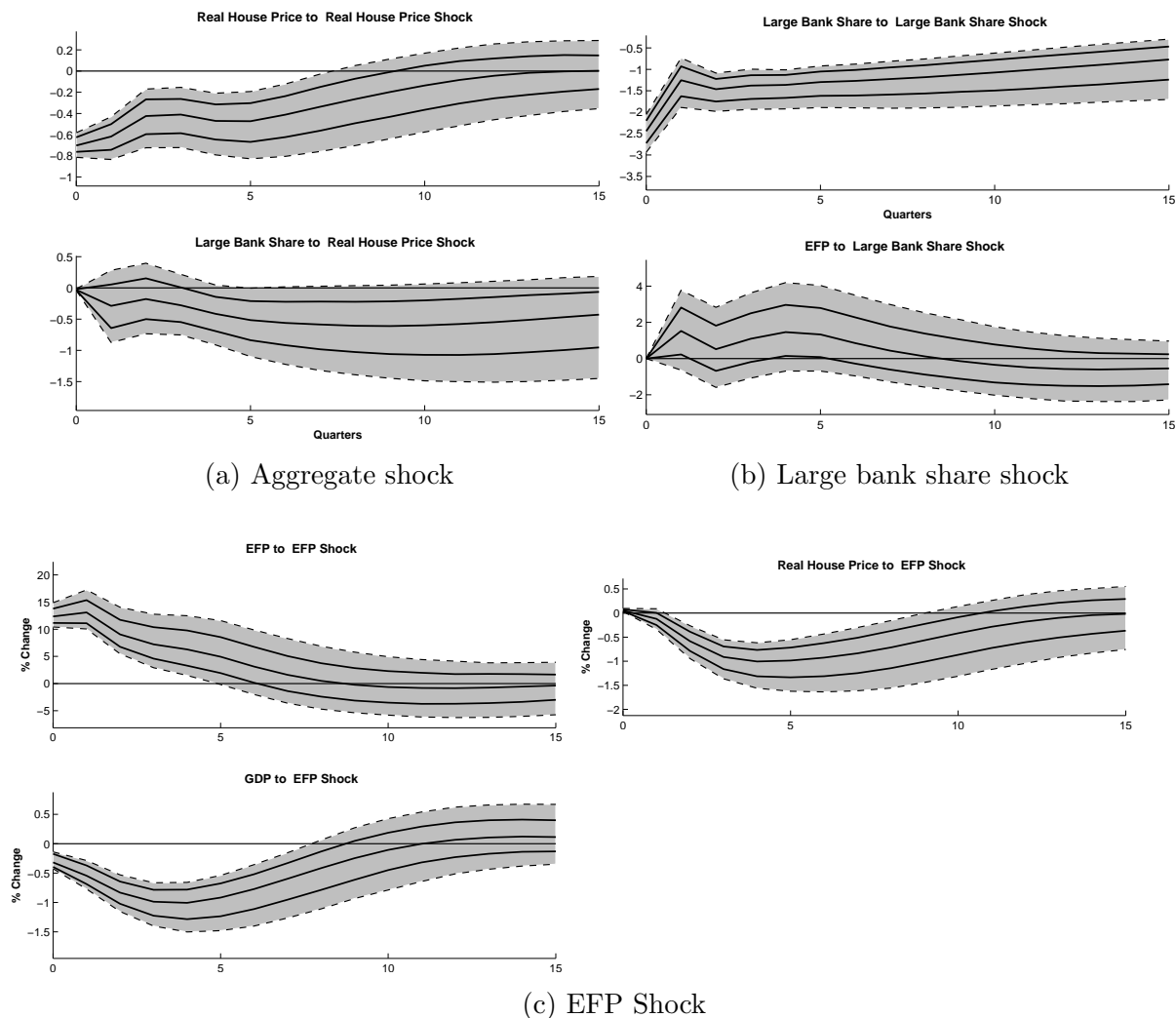


Figure 8: Alternative Data: Median Impulse Response to various contractionary shocks with 68% and 90% confidence bounds.

3.7 Model B: Impulse Response Functions

Model A uses a reduced rank identification scheme, which may be driving the results from the previous section. To examine the implications of the reduced rank identification strategy, I also test the model by estimating a sequence of VAR models where the response variables are restricted from the next model (Ludvigson, 1998). I call these sequence of VARs Model B. The results confirm the equilibrium model's amplification mechanism is a robust feature of the data, even when the VAR model has full rank and the sequence of estimated models restricts endogenous responses of real home prices and the large bank share.

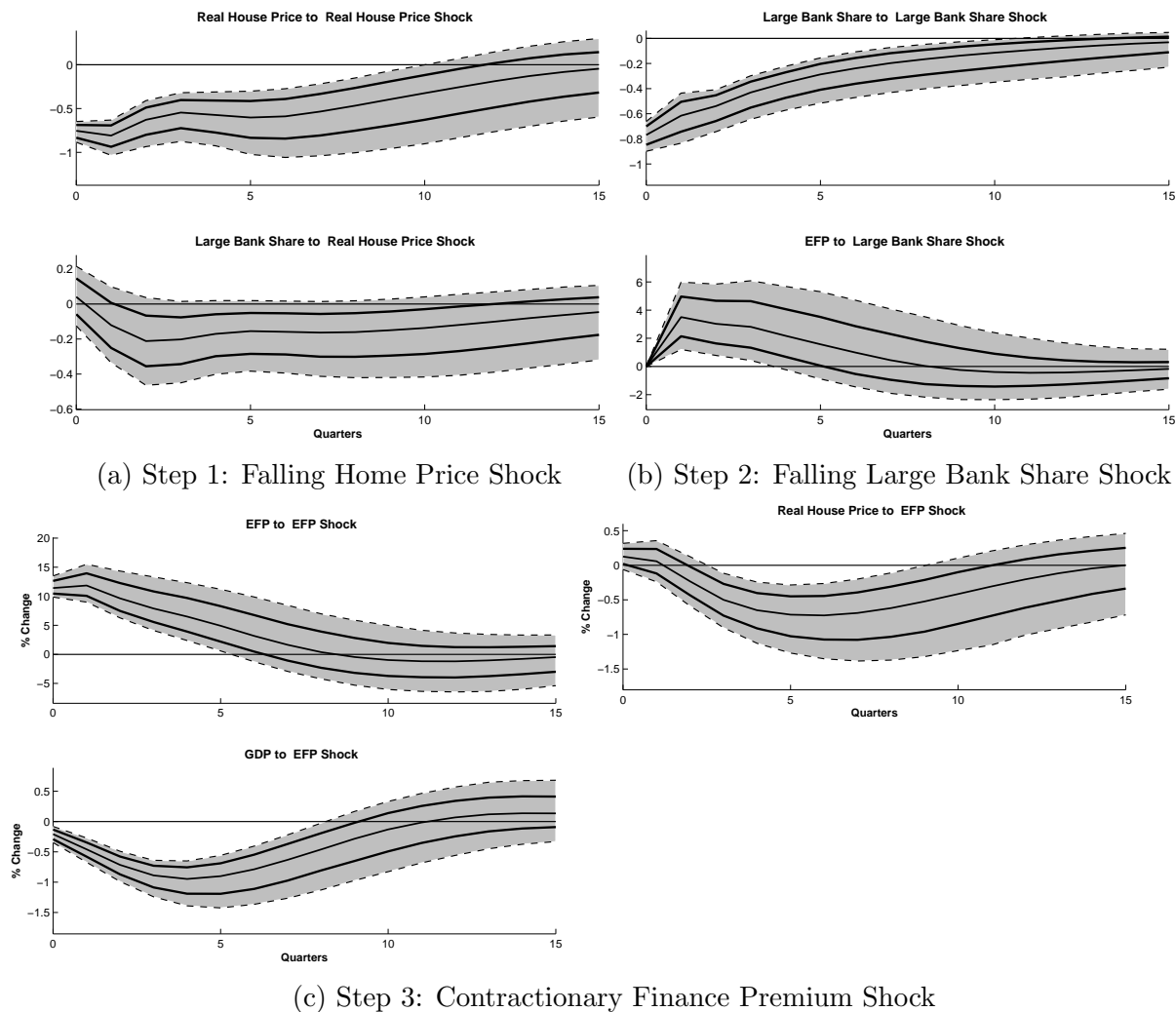


Figure 9: Model B: Median Impulse Response to various contractionary shocks with 68% and 90% confidence bounds.

3.8 Model B: Impulse Response Functions with Alternative Data

In this section, I repeat Ludvigson's (1998) approach to testing for a financial accelerator mechanism using the alternative measure of the large bank share variable measured by the share of loans secured by real estate from the Federal Reserve's Y-9C report. The results below show that both models behave qualitatively similar. Given the similar behavior of Model A with both measures of the large bank share variable, this section further confirms the empirical results are not excessively fragile to the measure of large bank asset concentration.

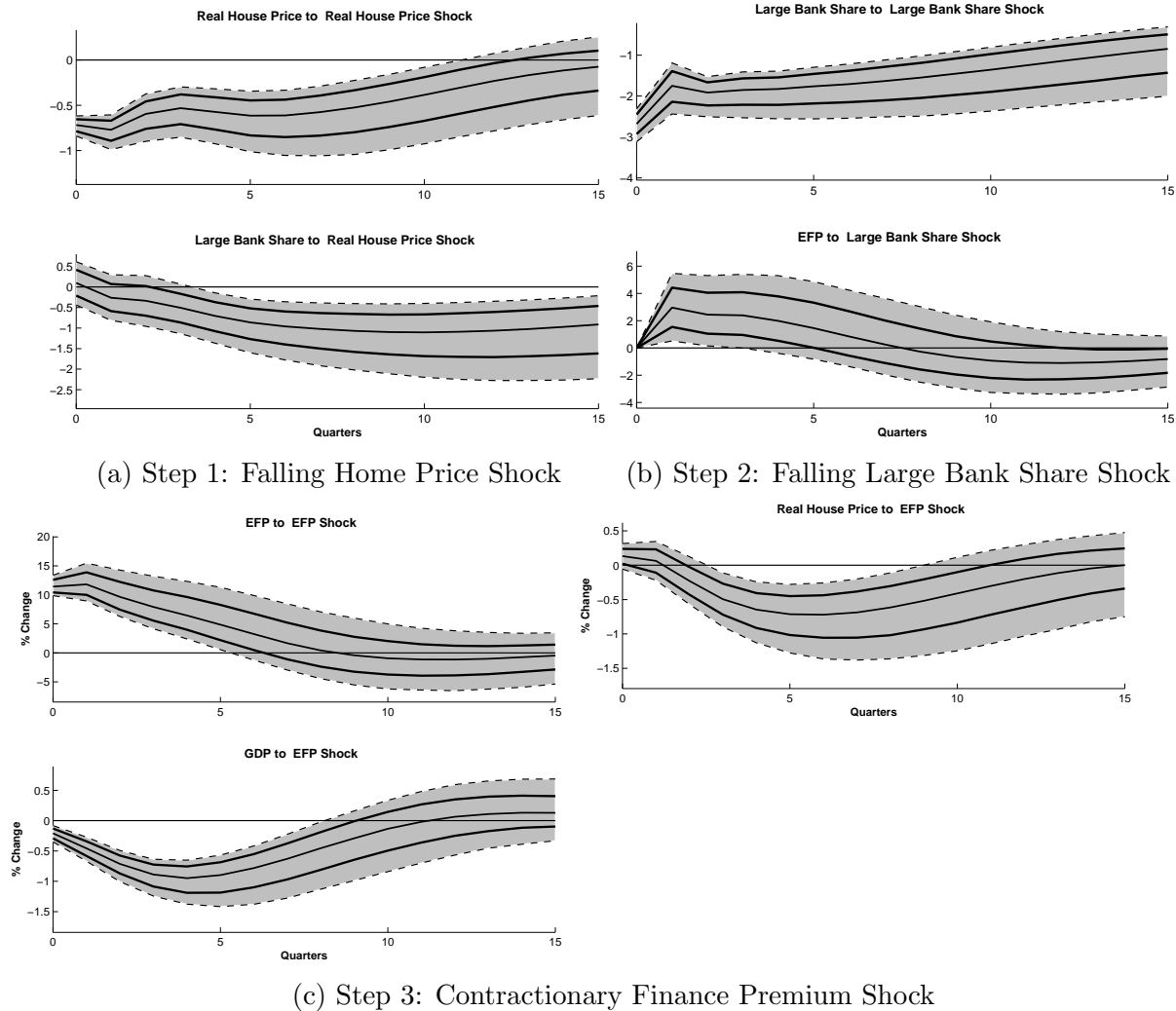
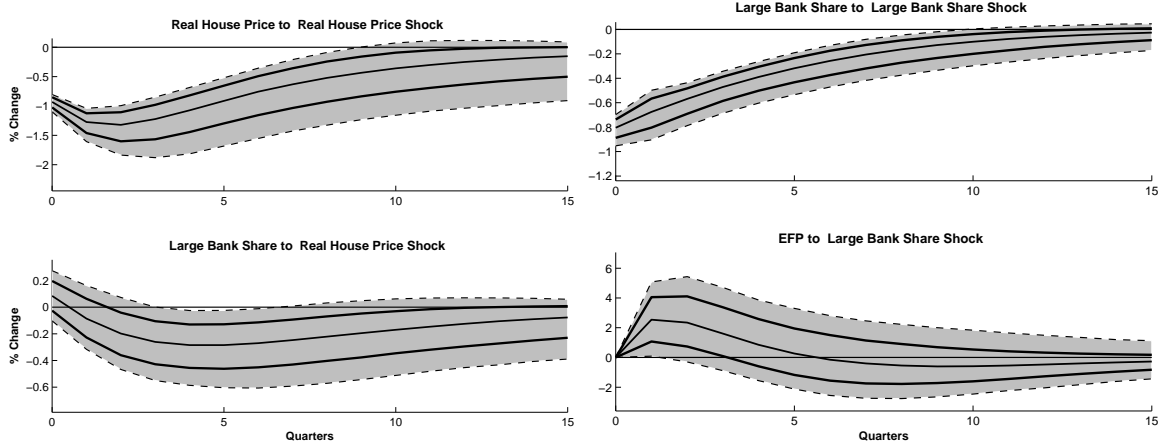


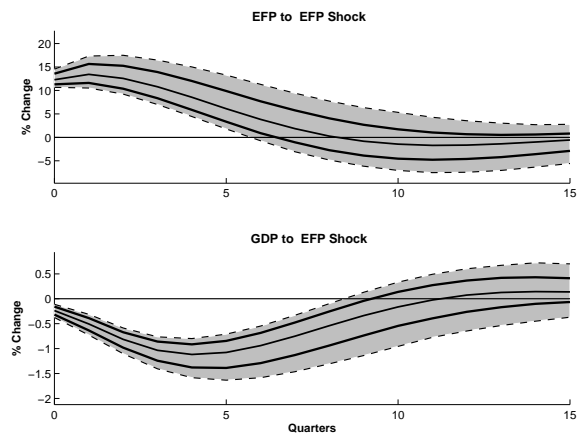
Figure 10: Model B Alternative Data: Median Impulse Response to various contractionary shocks with 68% and 90% confidence bounds.

3.9 Model C: Impulse Response Functions

In this section, I perform a third robustness check to the VAR model used to test for the accelerator mechanism spelled out in Section (3.1). In Model C, I estimate a sequence of bivariate VARs. Although this provides a simplistic interpretation of the data, the bivariate models ensure the IRFs are not influenced by the endogenous responses of variables. For example, these results confirm the drop in the large bank share following a drop in home prices is not driven by real GDP. Similarly, the response of the EFP to an exogenous drop in the large bank share is independent of the behavior of real GDP. Finally, real GDP falls in response to rising finance premiums even when there is no explicit real home price channel.



(a) Step 1: Falling Home Price Shock (b) Step 2: Falling Large Bank Share Shock

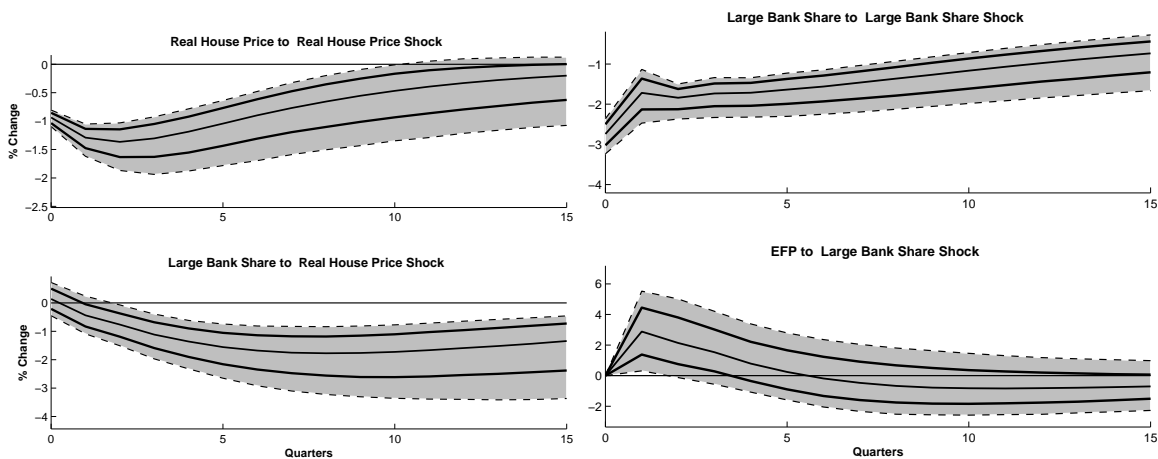


(c) Step 3: Contractionary Finance Premium Shock

Figure 11: Model C: Median Impulse Response to various contractionary shocks with 68% and 90% confidence bounds.

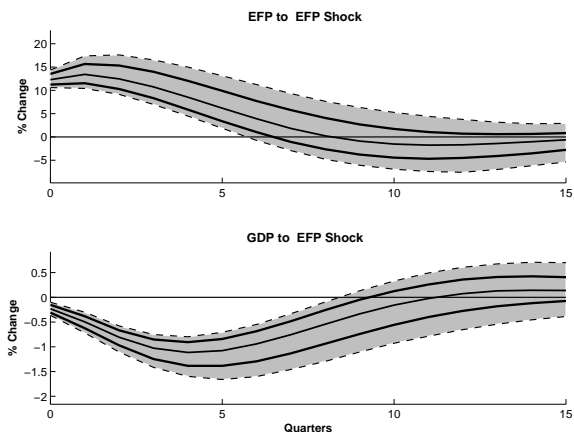
3.10 Model C: Impulse Response Functions with Alternative Data

This section performs one final robustness check by re-estimating Model C with the alternative measure of the large bank share. As was the case for Model A and Model B, the results are not sensitive to how the large bank share variable is measured. The cumulative evidence of these alternative models shows that over the last 14 years, there has been a tight relationship between home prices, the concentration of assets in the largest financial firms, finance premiums and the real economy. The following section returns to the equilibrium model to study the impact of actions taken by policy makers to break this relationship.



(a) Step 1: Falling Home Price Shock

(b) Step 2: Falling Large Bank Share Shock



(c) Step 3: Contractionary Finance Premium Shock

Figure 12: Model C Alternative Data: Median Impulse Response to various contractionary shocks with 68% and 90% confidence bounds.

4 Unconventional Monetary Policy

I now turn the focus to analyzing the unprecedented actions taken by policy makers in the wake of the 2007 Financial Crisis through the lens of this empirically verified model. Since the model features large financial firms ('Too Big to Fail' banks) and housing secured debt (Mortgage Backed Securities), it can be used to analyze the relative effectiveness of:

- (i) Equity injections into big banks similar to TARP
- (ii) Central Bank purchases of mortgage backed securities such as QE1 and QE3

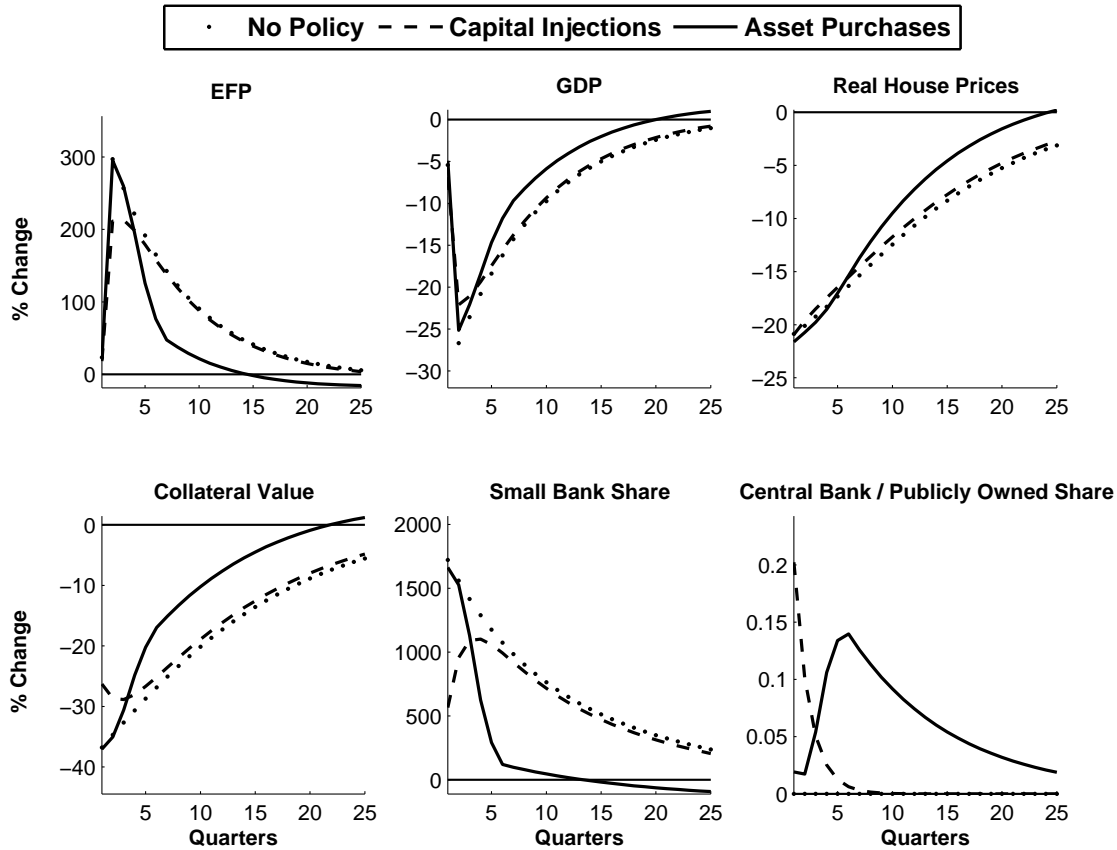


Figure 13: Impulse responses to large contraction in housing demand. The dashed lines represent the dynamics under no policy response, the solid lines are the dynamics following a short-term equity injection and the dotted line displays the dynamics under a persistent central bank asset purchase policy.

To simulate these policies I hit the economy with a large decrease in housing demand which generates a 20% drop in real home prices, real GDP and a 3 to 4 fold increase in the external finance premium – all similar to the magnitude of the Great Recession with the exception of output which fell by less during the recession, although I am disregarding any expansionary effects of fiscal policy in the model. I consider three alternative unconventional monetary policy regimes including no policy as simulated in Figure (2). The alternative two regimes are described below.

Equity Injections To simulate equity injections into ‘Too Big to Fail’ banks I assume the Central Bank uses a lump-sum tax, τ_t , to raise money from the household and provide an equity injection, INJ_t^{CB} , to the productive banks. The banks can use the capital immediately but must pay it back in its entirety. This policy is modeled by

adding/augmenting the following equations to the model.

$$INJ_t^{CB} = \theta_{bk} \varepsilon_t^{\eta^h} \quad (43)$$

$$\tau_t = INJ_t^{CB} - \delta^{CB} \frac{bk_{t-1}^{CB}}{\pi_t} \quad (44)$$

$$bk_t^{CB} = INJ_t^{CB} + (1 - \delta^{CB}) \frac{bk_{t-1}^{CB}}{\pi_t} \quad (45)$$

In any period t , the productive banks now have total capital equal to $bk_t^p + bk_t^{CB}$. This policy rule only has two parameters to calibrate. I set $\theta_{bk} = .18$ which calibrates the size of the initial equity injection and $\delta^{CB} = .5$. This calibration is set so that the equity injections comprise 20

Quantitative Easing: To simulate large scale asset purchases of mortgage backed securities (MBS) I assume the Central Bank uses a lump-sum tax, τ_t , to raise money from the household and then purchases $p_t^n n_t^{CB}$ units of collateral. As the policy persists, the household will be responsible for any losses or profits from the central bank's holding of these assets. This policy is modeled by adding/augmenting the following equations to the model.

$$n_t^{CB} = \rho^n n_{t-1}^{CB} + \sum_{j=0}^4 \theta_j^n \varepsilon_{t-j}^{\eta^h} \quad (46)$$

$$\tau_t = p_t^n n_t^{CB} - (1 - F_{t-1}(\bar{\omega}_t)) p_{t-1}^n n_{t-1}^{CB} r_{t-1}^d - F_{t-1}(\bar{\omega}_t) p_t^h z^r n_{t-1}^{CB} \quad (47)$$

In any period t , the market clearing condition for secured lending is now given by,

$$\bar{n} = \nu n_t^u + (1 - \nu) n_t^p + n_t^{CB}. \quad (48)$$

This policy rule has six parameters to calibrate. I set $\theta_0^n = \theta_4^n = .5$, $\theta_1^n = \theta_3^n = 1$ and $\theta_2^n = 1.4$ which calibrates the flow of central bank asset purchases to have a hump-shaped pattern with the flow of purchases of Mortgage-Backed Securities held outright by the central bank (using data from the Flow of Funds H.4.1, Factors Affecting Reserve Balances) peaking at 14% of the total credit exposure of all commercial banks.²³ and I set $\rho^n = .9$ to capture the prolonged nature of the Quantitative Easing policies implemented by the Federal Reserve. In particular, with $\rho^n = .9$ the purchases last for more than 8 years. In the welfare section I vary this.

Equity Injections vs. Quantitative Easing

The simulations of the large fall in housing demand are illustrated in Figure (13) under all three unconventional policy regimes – including no policy intervention. The results reveal that *both* equity injections and large-scale asset purchases (LSAP's) mitigate the crisis on

²³Credit exposure is computed as explained in Section (3.2) using data from the OCC's Quarterly Derivatives Reports

impact. However, the duration of the unconventional policies plays a critical role in determining the time it takes to recover from the recession. Since the equity injections are paid back after 7 quarters, the dynamics under this regime converge towards the no-policy regime. The length of the recession is essentially unchanged – although the initial severity is lessened. Comparing equity injections to LSAP’s, the equity injections better mitigate the initial impact of the crisis; however, the persistence of the LSAP policy serve to speed-up the recovery.

Which policy is preferred? To answer this question, I analyze *(i)* the total costs of the policies and importantly *(ii)* the welfare rankings of the policies using the household’s utility function. Table (2) reveals that although both unconventional policy regimes are preferred

Table 2: Equity Injections vs. Quantitative Easing

Policy Rule	Length of Recession (Quarters)	Taxpayer Revenue (% of GDP)	Welfare Cost ¹ (% of Consumption)
No Policy	33	0.000%	0.71%
Equity Injections	31	0.000%	0.63%
QE, 5 Quarters	32	0.016%	0.63%
QE, 6 Quarters	31	0.022%	0.61%
QE, 7 Quarters	31	0.025%	0.59%
QE, 8 Quarters	31	0.029%	0.57%
QE, 9 Quarters	30	0.036%	0.55%
QE, 11 Quarters	29	0.046%	0.51%
QE, 13 Quarters	28	0.064%	0.44%
QE, 18 Quarters	25	0.107%	0.32%
QE, 34 Quarters	18	0.300%	0.00%

¹ Welfare is computed by evaluating $\frac{\partial \mathcal{W}_t}{\partial \varepsilon_t^h}$ where $\mathcal{W}_t = u_t + \beta \mathbb{E}_t \{ \mathcal{W}_{t+1} \}$ and u_t is the household’s period utility function. the cost is the % of steady-state consumption under the optimal policy the household would have give-up under a prolonged QE policy to be indifferent to the inferior policy.

to no policy intervention, the quantitative easing policy outperforms the equity injections in terms of *both* cost and welfare. The central bank’s asset purchases actually result in profits for tax-payers – consistent with the U.S. experience in which the Federal Reserve has made record transfers to Treasury in light of its balance-sheet expansion. Moreover, this policy is preferred from a welfare standpoint. Independent of the transfers to the household resulting from the QE policy, the persistence of the policy speeds-up the recovery from the recession which improves welfare.

In addition to these quantitative factors, there is a political aspect to the comparison of these policies as well. Although not modeled here, equity injections carry a stigma of *(i)*

Directly benefiting Wall Street as opposed to Main Street and (ii) The government taking an ownership stake in a private firm. For example, in Figure (13) the variable ‘Publicly Owned Share’ captures the government’s equity stake in the big banks. One could easily argue the welfare rankings between equity injections and QE could reverse if the equity injections are larger or more persistent. However, the political ramifications of equity injections makes such adjustments unrealistic. In totality, QE policies are preferred as they provide sufficient stimulus to offset the crisis without carrying political costs.

Were equity injections necessary?

The above conclusion that a persistent QE policy outperforms a short-lived equity injection into big banks raises a natural question: Were the equity injections necessary? In other words, the results above suggest the economy would be in roughly the same condition with or without the TARP injections. Recall however the circumstances under which TARP was passed.²⁴ The economy was quickly deteriorating and urgent action was required to prevent a total collapse of the financial system. Chairman Ben Bernanke’s reply to a weekend extension for congress to debate the equity injections was famously recounted as, “If we don’t do this [pass TARP] tomorrow, we won’t have an economy on Monday.” This paper’s inclusion of heterogeneous banks allows me to analyze the stabilizing role of capitalizing big banks.

In particular, the strength of the asset-price spiral from the redistribution of assets is calibrated by the slope of the unproductive bank’s demand for housing-backed assets, $\chi^{r,u}$. The baseline calibration is set to $\chi^{r,u} = 1.06$. As this value increases the impact of asset redistribution is strengthened. In fact, for slightly larger values of $\chi^{r,u}$ the model becomes indeterminate so that no unique rational expectations equilibrium exists. The amplification effect becomes so strong that without counter-cyclical policy there are multiple equilibria.

Interestingly, this indeterminacy can be remedied with counter-cyclical equity injections. In particular,

$$INJ_t^{CB} = \theta_{bk} (\log(p_t^n) - \log(\bar{P}^n))$$

with $\theta_{bk} < 0$ is sufficient to restore determinacy. This systematic recapitalization of big banks eliminates the multiple equilibria induced by a strong asset-price spiral. In this sense, the ranking provided in Table (2) should serve as a lower bound of the value of various unconventional policies.

²⁴Outlined nicely in Andrew Ross Sorkin’s book, *Too Big to Fail*

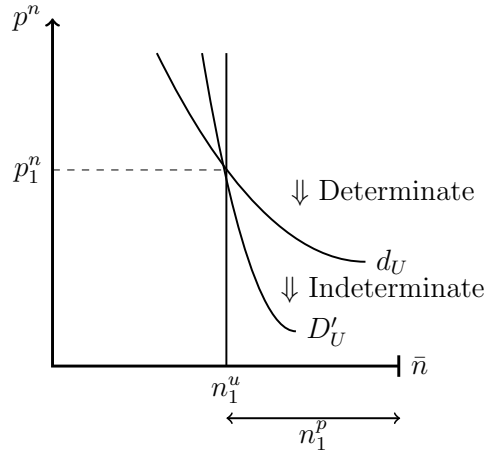


Figure 14: If the asset-price spiral is strong enough, the economy becomes indeterminate. Determinacy can be restored with counter-cyclical equity injections.

5 Conclusion

The paper presents a financial mechanism which is able to capture salient features of the U.S. economy stemming from the interconnectedness of housing and financial markets. The interaction between the two sectors allows for a more natural interpretation of what set-off the Great Recession, a drop in housing demand, as opposed to the “Financial Shocks” that other papers consider. Beyond simply being the source of the initial downturn, the housing market also plays a fundamental role in prolonging the downturn. Since housing is a durable, when defaults begin rising due to a drop in home prices, the future price of housing will remain depressed as it takes time for the stock of homes to return to normal levels. This mechanism captures the observed empirical relationship between the external finance premium and home prices, output and investment; a relationship which the traditional Bernanke, Gertler, and Gilchrist (1999) financial accelerator fails to capture.

In addition to integrating housing and financial markets, in this paper I provide insights for policy makers regarding the treatment of “Too Big to Fail” banks. By eschewing the assumption that all banks are the same (or similarly, banks face no agency problems), I am able to show why big banks withdrew relatively more credit during the Great Recession. The model’s qualitative predictions for the joint behavior of the asset concentration in large banks, home prices, output and finance premiums are confirmed using an estimated VAR.

Beyond capturing this empirical observation, the model shows the differential behavior between big banks and their smaller counter parts served to strengthen the Great Recession. Therefore, the equity injections into the largest financial firms in 2008 are well justified as they mitigated the severity of the downturn and prevented a potential collapse. Although this thwarted the initial downturn, policies such as “QE 1/3,” the Fed’s Mortgage Backed Security purchase programs, play an important role in the model by speeding up the recovery.

Future Work

Although this paper explains why big banks withdrew relatively more credit when home prices plunged in 2007 and provides a transmission channel for unconventional monetary policy, much work lies ahead. In particular, the policy options in this paper are designed to clean-up after the crash instead of preventing it in the first place. Moving beyond crisis management, the empirically validated financial structure presented in this paper can be used to explore the efficacy of macroprudential policy in preventing a build-up of assets in large financial firms when home prices rise.

A question of empirical importance arises as well from the model. Christiano, Motto, and Rostagno (2013) show that “risk shocks” have played a substantial role in shaping the business cycle for the last 20 years. However, they point out their finding is driven by the ability of risk shocks to generate the empirical observation that credit contracts during recessions. Due to the novel debt contract I introduce in this paper, credit contracts following adverse technology and demand shocks – the usual business cycle suspects. Given the policy implications, it is worth while to examine the robustness of their results in this housing-centered financial structure.

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A VAR Data and Complete Results

Table 3: Bank Mergers and Acquisitions

Banks Included in the set of <i>Large</i> Commercial Banks							
1998:Q2-1999:Q2	1999:Q3 ¹	1999:Q4 ²	2000:Q1-2001:Q3 ³	2001:Q4 - 2002:Q1 ⁴	2002:Q2 - 2004:Q3 ⁵	2004:Q4 - 2009:Q1 ⁶	2009:Q2 - 2012:Q4 ⁹
Citibank	Citibank	Citibank	Citibank	Citibank	Citibank	Citibank	Citibank
Wells Fargo Bank NA	Wells Fargo Bank NA	Wells Fargo Bank NA	Wells Fargo Bank NA	Wells Fargo Bank NA	Wells Fargo Bank NA	Wells Fargo Bank NA	Wells Fargo Bank NA
First Union NB	First Union NB	First Union NB	First Union NB	First Union NB	Wachovia Bank NA	Wachovia Bank NA	JP Morgan Chase Bank
Wachovia Bank NA	Wachovia Bank NA	Wachovia Bank NA	Wachovia Bank NA	Wachovia Bank NA	JP Morgan Chase Bank	JP Morgan Chase Bank ⁸	HSBC Bank USA
Chase Manhattan Bank	Chase Manhattan Bank	Chase Manhattan Bank	Chase Manhattan Bank	JP Morgan Chase Bank	Bank One Natl. ASSN	HSBC Bank USA	Bank of America NA
Morgan Guaranty NY	Morgan Guaranty NY	Morgan Guaranty NY	Morgan Guaranty NY	Bank One Natl. ASSN	HSBC Bank USA	Bank of America NA	
First NB of Chicago	First NB of Chicago	First NB of Chicago	Bank One Natl. ASSN	HSBC Bank USA	Bank of America NA		
Bank One NA	Bank One NA	Bank One of NA	HSBC Bank USA	Bank of America NA			
Republic NB NY	Republic NB NY	HSBC Bank USA	Bank of America NA				
Bank of America NT&SA	Bank of America NA	Bank of America NA					
Nationsbank NA							
Banks Excluded from the set of Commercial Banks							
2008:Q4 - 2012:Q4 ⁷							
Goldman Sachs							

¹ Bank of America NT and SA merges with Nationsbank NA

² HSBC enters the U.S. commercial bank market by acquiring Republic NB of New York

³ Bank One of NA based in Ohio merges with First NB of Chicago, forming Bank One National ASSN based in Chicago, Illinois.

⁴ Chase Manhattan Bank and Morgan Guaranty TR CO of NY merge to form JP Morgan Chase Bank

⁵ Wachovia acquires First Union National Bank

⁶ JP Morgan Chase acquires Bank One National ASSN

⁷ Goldman Sachs becomes a commercial bank

⁸ JP Morgan Chase acquired Bear Sterns due to extreme financial distress. Beginning in 2008:Q1 JP Morgan Chase experienced increase exposure through repo transactions with Bear Sterns and the ultimate acquisition of Bear Sterns and all exposures. This is very difficult to account for since Q-10 SEC filings report Notional values, not total credit exposure. Hence, from 2008:Q1-2008:Q4 I use a linear interpolation to assess JP Morgan Chase's total credit exposure.

⁹ HSBC Bank USA acquires Wachovia Bank NA under financial distress.

Below, in Figure (15) I provide the complete set of impulse response functions for the VAR model described in Section (3). I also provide historical decompositions of all three structural shocks. Since the model is under-identified in the sense that there are less shocks than variables, projecting the variables on to the space of structural shocks does not yield the full set of variables. However, this serves as a useful tool to diagnose the extent to which the structural shocks can explain the observed movement of the endogenous variables. The inability to explain much of the variation in these variables would seriously call in to question the identification scheme. The results of this exercise are reported in Figure (16) below which show the three structural shocks can explain nearly all of the movement of the endogenous variables in the VAR.

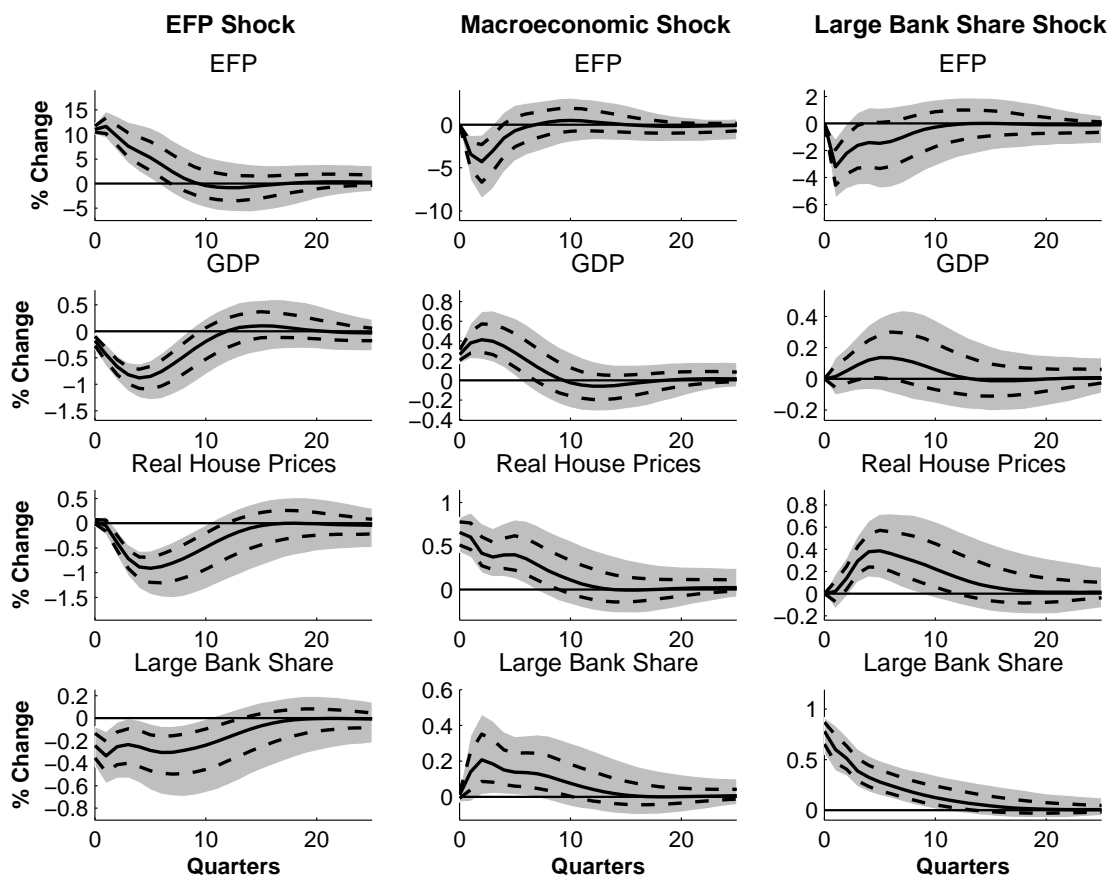


Figure 15: Median Impulse Response Functions with 68% and 90% confidence bounds computed with 5000 draws from the posterior distribution using Jeffery's Prior.

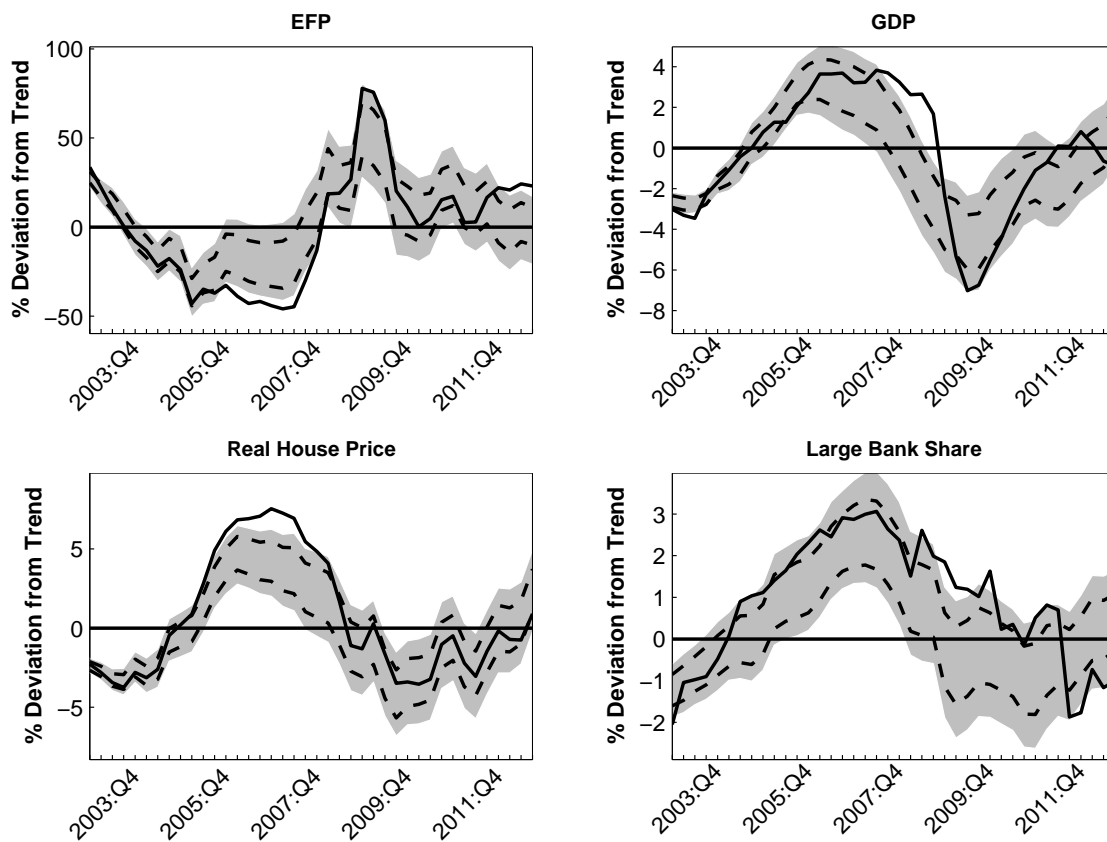


Figure 16: Projected historical decompositions with 68% and 90% confidence bounds computed with 5000 draws from the posterior distribution using Jeffery's Prior. Solid lines denote the actual data.

B Equilibrium Model

In this section I provide the full set of equations which defines the dynamic equilibrium model. All upper case variables are real and lower case variables are nominal - including interest rates. In particular for any nominal interest rate r_t , the real interest rate is given via the Fisher equation, $R_t = \mathbb{E}_t \left\{ \frac{r_t}{\pi_{t+1}} \right\}$.

Household - 5

$$\frac{w_t^h}{c_t} = \frac{\eta^h}{1 - l_t^{new}} \quad (\text{B.1})$$

$$\frac{w_t^{g,C}}{c_t} = \frac{\eta^l}{1 - l_t^{g,C}} \quad (\text{B.2})$$

$$\frac{\eta_t^h}{h_t} = \frac{p_t^h}{c_t} - \beta \mathbb{E}_t \left\{ \frac{(1 - \delta^h) p_{t+1}^h}{c_{t+1}} \right\} \quad (\text{B.3})$$

$$\frac{1}{r_t^d} = \mathbb{E}_t \{ \Lambda_{t+1} \} \quad (\text{B.4})$$

$$\Lambda_t = \beta \frac{c_{t-1}}{\pi_t c_t} \quad (\text{B.5})$$

Aggregate Goods Production - 7

$$y_t = z_t (k_{t-1})^{\alpha_g} (l_t^g)^{1-\alpha_g} \quad (\text{B.6})$$

$$l_t^g = (l_t)^{(1-\alpha_e)} (l_t^e)^{\alpha_e} \quad (\text{B.7})$$

$$w_t = (1 - \alpha_g)(1 - \alpha_e) \frac{y_t}{l_t} \quad (\text{B.8})$$

$$w_t^e = (1 - \alpha_g) \alpha_e \frac{y_t}{l_t^e} \quad (\text{B.9})$$

$$r_t^k = \frac{\alpha_g \frac{y_t}{k_t} + (1 - \delta^k) q_t}{q_{t-1}} \quad (\text{B.10})$$

$$c_t^e = (1 - \alpha_t^n) (1 - \Gamma_{t-1}(\bar{\omega}_t)) R_t^k k_{t-1} \quad (\text{B.11})$$

$$\alpha_t^n = \frac{(1 - F_{t-1}(\bar{\omega}_t)) p_{t-1}^n r_{t-1}^d \bar{n}}{(1 - \Gamma_{t-1}(\bar{\omega}_t)) r_t^k q_{t-1} k_{t-1}} \quad (\text{B.12})$$

Capital Producers - 1

$$i_t = k_t - (1 - \delta^k) k_{t-1} \quad (\text{B.13})$$

goods Production: Firm-level Debt Contract - 9

In this section I provide the equations which determine the debt contract. Moreover, I provide a description of the individual entrepreneur's problem which leads to the aggregate entrepreneur's consumption rule defined in equation (16). In particular, suppose entrepreneur j has preferences over consumption and housing given by a Cobb-Douglas utility function,

$$U_t(j) = c_t(j)^{1-\alpha_t^n} N_t(j)^{\alpha_t^n}$$

with

$$\alpha_t^n = \frac{(1 - F_{t-1}(\bar{\omega}_t)) p_{t-1}^n r_{t-1}^d \bar{n}}{(1 - \Gamma_{t-1}(\bar{\omega}_t)) r_t^k q_{t-1} k_{t-1}}.$$

Since entrepreneur j takes the aggregate default rate $F_{t-1}(\bar{\omega}_t)$ and the aggregate choice of capital, k_t as given, this Walrasian demand bundles given these preferences has the well-known property of constant expenditure shares on consumption and housing.

$$c_t(j) = (1 - \alpha_t^n) (1 - \Gamma_{t-1}(\bar{\omega}_t^j)) r_t^k k_{t-1}^j q_{t-1}$$

Aggregating over this equation implies

$$\begin{aligned} c_t &= \int_0^\infty (1 - \alpha_t^n) (1 - \Gamma_{t-1}(\bar{\omega}_t^j)) r_t^k k_{t-1}^j q_{t-1} dj \\ &= (1 - \alpha_t^n) (1 - \Gamma_{t-1}(\bar{\omega}_t)) r_t^k k_{t-1} q_{t-1} \\ &= (1 - \Gamma_{t-1}(\bar{\omega}_t)) r_t^k k_{t-1} q_{t-1} - (1 - F_{t-1}(\bar{\omega}_t)) p_{t-1}^n r_{t-1}^d \bar{n}. \end{aligned}$$

The second equality follows from the ex-ante homogeneity among entrepreneurs implying they all will choose the same default cut-off, $\bar{\omega}_t^j$, and the same level of capital expenditures, k_t^j .

$$\mathbb{E}_t \{ \Gamma_t'(\bar{\omega}_{t+1}) R_{t+1}^k q_t k_t \} = \lambda_t^e \mathbb{E}_t \{ (\Gamma_t'(\bar{\omega}_{t+1}) - \mu^M G_t'(\bar{\omega}_{t+1})) R_{t+1}^k q_t k_t \} \quad (\text{B.14})$$

$$\begin{aligned} \mathbb{E}_t \{ [1 - \Gamma_t(\bar{\omega}_{t+1})] R_{t+1}^k \} &= \lambda_t^e \mathbb{E}_t \{ R_t^e - \Gamma_t(\bar{\omega}_{t+1}) R_{t+1}^k \} \\ &\quad + \lambda_t^e \mathbb{E}_t \{ \mu^M G_t(\bar{\omega}_{t+1}) R_{t+1}^k \} \end{aligned} \quad (\text{B.15})$$

$$R_t^e (q_t k_t - p_t^n \bar{n} - w_t^e) = \mathbb{E}_t \{ (\Gamma_t(\bar{\omega}_{t+1}) - \mu^M G_t(\bar{\omega}_{t+1})) R_{t+1}^k q_t k_t \} \quad (\text{B.16})$$

$$b_t = q_t k_t - p_t^n \bar{n} - w_t^e \quad (\text{B.17})$$

$$z_{t+1} = \frac{\ln(\bar{\omega}_{t+1}) + .5 (\sigma_t^\omega)^2}{\sigma_t^\omega} \quad (\text{B.18})$$

$$G_t(\bar{\omega}_{t+1}) = \Phi^{\mathcal{N}}(z_{t+1} - \sigma_t^\omega) \quad (\text{B.19})$$

$$\Gamma_t(\bar{\omega}_{t+1}) = \Phi^{\mathcal{N}}(z_{t+1} - \sigma_t^\omega) + \bar{\omega}_{t+1} (1 - \Phi^{\mathcal{N}}(z_{t+1})) \quad (\text{B.20})$$

$$G_t'(\bar{\omega}_{t+1}) = \left(\frac{1}{\sigma_t^\omega \sqrt{2\pi}} \right) e^{-\frac{z_{t+1}^2}{2}} \quad (\text{B.21})$$

$$\Gamma_t'(\bar{\omega}_{t+1}) = 1 - \Phi^{\mathcal{N}}(z_{t+1}) \quad (\text{B.22})$$

Housing Production: Aggregate Behavior - 2

$$h_t^{new} = z_t^h (l_t^h)^{(1-\alpha_h)} \quad (\text{B.23})$$

$$w_t^h = p_t^h (1 - \alpha_h) \frac{h_t^{new}}{l_t^h} \quad (\text{B.24})$$

Productive Bank - 10

$$\{(1 - \psi_t F_t(\bar{\omega}_{t+1})) b k_t^p\} = N_t^p \mathbb{E}_t \left\{ \frac{z^r p_{t+1}^h - (1 - F_t(\bar{\omega}_{t+1})) p_t^n r_t^d}{p_t^n} \right\} \quad (\text{B.25})$$

$$\mathbb{E}_t \left\{ \Lambda_{t+1} \bar{r}_t^{e,P} \right\} = \mathbb{E}_t \left\{ \Lambda_{t+1} r_t^d \right\} \quad (\text{B.26})$$

$$\begin{aligned} \mathbb{E}_t \left\{ \Lambda_{t+1} \bar{r}_t^{e,P} \right\} &= \left(\frac{\theta_b - 1}{\theta_b} \right) \mathbb{E}_t \left\{ \Lambda_{t+1} (1 - F_t(\bar{\omega}_{t+1})) \right\} r_t^{b,p} \\ &+ \mathbb{E}_t \left\{ \Lambda_{t+1} \pi_{t+1} \frac{(1 - \mu^M) \Phi_t(\bar{\omega}_{t+1})}{b_t} \right\} \end{aligned} \quad (\text{B.27})$$

$$b_t^p = \left(\frac{r_t^{b,p}}{r_t^b} \right)^{-\theta_b} b_t \quad (\text{B.28})$$

$$b_t^p = d_t^p + \frac{b k_{t-1}^p}{\pi_t} - p_t^n n_t^p \quad (\text{B.29})$$

$$\begin{aligned} \Pi_t^p &= (1 - F_{t-1}(\bar{\omega}_t)) \frac{r_{t-1}^{b,p}}{\pi_t} b_{t-1}^p \\ &+ (1 - \mu^M) \frac{b_{t-1}^p}{b_{t-1}} \Phi_t(\bar{\omega}_{t+1}) \\ &+ (1 - F_{t-1}(\bar{\omega}_t)) r_{t-1}^d p_{t-1}^n N_{t-1}^p \\ &+ F_{t-1}(\bar{\omega}_t) p_t^h z^r N_{t-1}^p - p_t^n N_t^p \\ &- R_{t-1}^d d_{t-1}^p + d_t^p - b_t^p \end{aligned} \quad (\text{B.30})$$

$$DIV_t^p = \Pi_t^p \quad (\text{B.31})$$

$$TRANS_t^p = F_{t-1}(\bar{\omega}_t) \psi_{t-1} \frac{b k_{t-1}^p}{\pi_t} \quad (\text{B.32})$$

$$INV_t^p = T^{b,p} - TRANS_t^p \quad (\text{B.33})$$

$$b k_t^p = INV_t^p + (1 - \delta^{b k, P}) \frac{b k_{t-1}^p}{\pi_t} \quad (\text{B.34})$$

Unproductive Bank - 10

$$p_t^n = \frac{1}{r_t^d} \mathbb{E}_t \left\{ z^r p_{t+1}^h - \chi^{r,u} \mu^{r,u} n_t^U (\chi^{r,u-1}) \right\} \quad (\text{B.35})$$

$$\mathbb{E}_t \left\{ \Lambda_{t+1} \bar{r}_t^{e,U} \right\} = \mathbb{E}_t \left\{ \Lambda_{t+1} r_t^d + \chi^{b,u} \right\} \quad (\text{B.36})$$

$$\begin{aligned} \mathbb{E}_t \left\{ \Lambda_{t+1} \bar{r}_t^{e,U} \right\} &= \left(\frac{\theta_b - 1}{\theta_b} \right) \mathbb{E}_t \left\{ \Lambda_{t+1} (1 - F_t(\bar{\omega}_{t+1})) \right\} r_t^{b,u} \\ &+ \mathbb{E}_t \left\{ \Lambda_{t+1} \pi_{t+1} \frac{(1 - \mu^M) \Phi_t(\bar{\omega}_{t+1})}{b_t} \right\} \end{aligned} \quad (\text{B.37})$$

$$b_t^u = \left(\frac{r_t^{b,u}}{r_t^b} \right)^{-\theta_b} b_t \quad (\text{B.38})$$

$$b_t^u = d_t^u + \frac{b k_{t-1}^u}{\pi_t} - p_t^n n_t^p \quad (\text{B.39})$$

$$\begin{aligned} \Pi_t^u &= (1 - F_{t-1}(\bar{\omega}_t)) \frac{r_{t-1}^{b,u}}{\pi_t} b_{t-1}^u \\ &+ (1 - \mu^M) \frac{b_{t-1}^u}{b_{t-1}} \Phi_t(\bar{\omega}_{t+1}) \\ &+ (1 - F_{t-1}(\bar{\omega}_t)) r_{t-1}^d p_{t-1}^n N_{t-1}^u \\ &+ F_{t-1}(\bar{\omega}_t) \left[p_t^h z^r N_{t-1}^u - \mu^{r,u} (n_{t-1}^u)^{\chi^{r,u}} \right] \\ &- p_t^n N_t^u - R_{t-1}^d d_{t-1}^u + d_t^u - b_t^u (1 + \chi^{b,u}) \end{aligned} \quad (\text{B.40})$$

$$DIV_t^u = \Pi_t^u \quad (\text{B.41})$$

$$TRANS_t^u = F_{t-1}(\bar{\omega}_t) \psi_{t-1} \frac{b k_{t-1}^u}{\pi_t} \quad (\text{B.42})$$

$$INV_t^u = T^{b,u} - TRANS_t^u \quad (\text{B.43})$$

$$b k_t^u = INV_t^u + (1 - \delta^{bk,U}) \frac{b k_{t-1}^u}{\pi_t} \quad (\text{B.44})$$

Aggregate Bank - 10

$$\bar{r}_t^e = \left[\nu \left(\bar{r}_t^{e,U} \right)^{1-\theta_b} + (1 - \nu) \left(\bar{r}_t^{e,P} \right)^{1-\theta_b} \right]^{\frac{1}{1-\theta_b}} \quad (\text{B.45})$$

$$r_t^e = \left(\frac{\theta_b}{\theta_b - 1} \right) \bar{r}_t^e - \left(\frac{1}{\theta_b - 1} \right) (1 - \mu^M) \frac{\mathbb{E}_t \left\{ \pi_{t+1} \Phi_{t+1}^{H.B.} \right\}}{b_t} \quad (\text{B.46})$$

$$R_t^e = \frac{r_t^e}{\pi_{t+1}} \quad (\text{B.47})$$

$$R_t^d = \frac{r_t^d}{\pi_{t+1}} \quad (\text{B.48})$$

$$r_t^b = \left[\nu \left(r_t^{b,u} \right)^{1-\theta_b} + (1-\nu) \left(r_t^{b,p} \right)^{1-\theta_b} \right]^{\frac{1}{1-\theta_b}} \quad (\text{B.49})$$

$$d_t = \nu d_t^u + (1-\nu) d_t^p \quad (\text{B.50})$$

$$\text{div}_t = \nu \text{DIV}_t^u + (1-\nu) \text{DIV}_t^p \quad (\text{B.51})$$

$$\text{trans}_t = \nu \text{TRANS}_t^u + (1-\nu) \text{TRANS}_t^p \quad (\text{B.52})$$

$$\text{INV}_t = \nu \text{INV}_t^u + (1-\nu) \text{INV}_t^p \quad (\text{B.53})$$

$$\Phi_{t-1}(\bar{\omega}_t) = G_{t-1}(\bar{\omega}_t) R_t^k q_{t-1} k_{t-1} \quad (\text{B.54})$$

Market Clearing - 4

$$h_t = h_t^{\text{new}} + F_{t-1}(\bar{\omega}_t) z^r \bar{n} + (1-\delta^h) h_{t-1} \quad (\text{B.55})$$

$$\bar{n} = \nu N_t^p + (1-\nu) N_t^u \quad (\text{B.56})$$

$$y_t = c_t + c_t^e + i_t + i_t^{bk} + \mu^M \Phi_{t-1}(\bar{\omega}_t) + \nu F_{t-1}(\bar{\omega}_t) \mu^{r,u} \left(N_{t-1}^u \right)^{\chi^{r,u}} + \nu \chi^{b,u} b_t^u \quad (\text{B.57})$$

$$\text{gdp}_t = c_t + i_t + p_t^h h_t^{\text{INV}} \quad (\text{B.58})$$

Monetary Policy - 2

$$\psi_t = \bar{\psi} \quad (\text{B.59})$$

$$\left(\frac{r_t^d}{\bar{r}^d} \right) = \left(\frac{r_{t-1}^d}{\bar{r}^d} \right)^{\rho_r} \left(\frac{\pi_t}{\bar{\pi}} \right)^{\psi_\pi} \left(\frac{\text{gdp}_t}{\text{gdp}_{t-1}} \right)^{\psi_{\text{gdp}}} \quad (\text{B.60})$$

Exogenous Shocks - 5

$$\ln(\eta_t^h) = (1-\rho_{\eta^h}) \bar{\eta}^h + \rho_{\eta^h} \ln(\eta_{t-1}^h) + \varepsilon_t^{\eta^h} \quad (\text{B.61})$$

$$\ln(z_t) = (1-\rho_z) \bar{z} + \rho_z \ln(z_{t-1}) + \varepsilon_t^z \quad (\text{B.62})$$

$$\ln(\sigma_t^\omega) = (1-\rho_{\sigma^\omega}) \bar{\sigma}^\omega + \rho_{\sigma^\omega} \ln(\sigma_{t-1}^\omega) + \varepsilon_t^{\sigma^\omega} \quad (\text{B.63})$$

$$\ln(z_t^h) = (1-\rho_{z^h}) \bar{z}^h + \rho_{z^h} \ln(z_{t-1}^h) + \varepsilon_t^{z^h} \quad (\text{B.64})$$

$$\ln(\psi_t^{n,P}) = \rho_{\psi^{n,P}} \ln(\psi_{t-1}^{n,P}) + \varepsilon_t^{\psi^{n,P}} \quad (\text{B.65})$$