DO CREDIT CONSTRAINTS AMPLIFY MACROECONOMIC FLUCTUATIONS?

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Abstract. Credit constraints can potentially be an amplification and propagation mechanism that transforms the shocks hitting the economy into the observed business cycle fluctuations. This article demonstrates, in contrast to previous studies, that the transmission mechanism through credit constraints is quantitatively important. In the context of a dynamic stochastic general equilibrium model with heterogeneous agents and credit constraints, we obtain two key findings essential for this financial mechanism to work. First, we identify shocks that impact directly on asset prices and thus trigger strong amplification effects. Second, allowing firms to be constrained by the value of their collateral assets is crucial to generate ripple effects on the persistent comovements between the prices of collateral assets and aggregate quantities.

I. Introduction

If an investor is credit-constrained, then movements in asset prices will change the investor's borrowing capacity and investment. Changes in investment drive changes in future output, which in turn feedbacks to the current asset prices. This two-way feed-back generates a financial multiplier that can potentially transform economic shocks

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into large and persistent fluctuations in investment and output. The theoretical argument here is well established by Kiyotaki and Moore (1997) and many subsequent works. The empirical importance of such a financial multiplier remains an open issue. Some studies find weak amplification from credit constraints (Kocherlakota, 2000; Cordoba and Ripoll, 2004). Some other studies report negative comovements between asset prices and business investment following shocks that drive fluctuations in the value of collateral (Iacoviello and Neri, 2009). These studies present challenges for the empirical relevance of models with credit constraints.

This article demonstrates that, unlike the previous studies, credit constraints produce strong amplification of macroeconomic fluctuations and generate positive comovements between asset prices and business investment. The key to getting amplification is to identify economic shocks that directly impact upon the price of collateral assets. The movements in asset prices and therefore in collateral value kick-start the financial multiplier: a decline in asset prices lowers the collateral value and contracts the entrepreneur's borrowing capacity so that business investment falls; a fall in investment lowers future output, which depresses the current asset prices and reduces the collateral value. Thus, if an economic shock can move the prices of collateral assets, it can also generate large fluctuations on investment and output. Previous studies focus on total factor productivity (TFP) shocks (Cordoba and Ripoll, 2004). But a TFP shock does not have large impacts on asset prices because it moves future dividends and the risk-free interest rate in the same direction. In our model, as in Kiyotaki and Moore (1997), Kiyotaki (1998), and Kocherlakota (2000), land serves both as a collateral for borrowing and an input factor of production. And the shock that has direct impact on land prices is the housing demand shock that shifts the marginal utility of housing (i.e., the "dividends" from housing services). Our empirical results suggest that, through the financial multiplier, the housing demand shock alone accounts for over 90% of the observed fluctuations in the growth rate of land prices.

The credit constraint in our model not only amplifies land price fluctuations, it also propagates the housing demand shock and transform the shock into fluctuations in business investment and output. In the data, the land price and business investment are positively correlated.[1] Figure 1 displays the impulse responses of the land price and business investment estimated from a Bayesian vector autoregression (BVAR) model with the Sims and Zha (1998) prior. These impulse responses provide further evidence

[1]The correlation between the land price and business investment is 0.54 for the band-pass filtered series and 0.58 for the Hodrick-Prescott (HP) filtered series.

that land prices and business investment move together following shocks that drive changes in land prices. We find that the key to getting this positive comovement is to have the investing agent to face credit constraints. Previous studies, notably Iacoviello and Neri (2009), find negative comovement between housing prices and business investment because their investing agent does not face credit constraints (although a subset of the households do). In our model, the investing agent (i.e., the entrepreneur) is credit constrained. As the housing demand shock raises the land price, it also raises the entrepreneur's borrowing capacity to finance business investment. The positive comovement is not only empirically relevant, but also theoretically important because the amplification mechanism of the financial multiplier relies on the comovements between land prices and business investment. Through the two-way feedback between the land price and investment, the housing demand shock gets propagated and it accounts for $30-40\%$ of the fluctuations in the growth rates of investment and output.

We make these points in the context of a dynamic stochastic general equilibrium (DSGE) model with heterogeneous agents and credit constraints. The model consists of two types of agents: the representative household and the representative entrepreneur. The household consumes a homogeneous good, land services (housing) and leisure, and supplies labor and loanable funds in competitive markets. The entrepreneur consumes and produces the homogeneous good. Production of the good requires labor, capital, and land (commercial structures) as inputs. To finance consumption, production, and investment in land and capital, the entrepreneur borrows loanable funds in the competitive market subject to a credit constraint. In particular, the borrowing capacity is constrained by a fraction of the present value of land and the accumulated capital stock. Thus, land and capital serve as both inputs for production and collateral for borrowing.[2]

The amplification mechanism of the model is illustrated in Figure 8. Suppose the economy starts from the steady state (point A) and consider the effects of a positive housing demand shock. Without the credit constraint, the shock shifts the household's land demand curve upward and has no impact on the entrepreneur's land demand curve. The land price increases and the land gets re-distributed from the entrepreneur to the household (from point A to point B). If the entrepreneur is credit constrained,

[2]The land in our model can be a proxy for any fixed-supply asset or an asset that grows at a much slower rate than the capital. As Davis and Heathcote (2007) show, land grows at a very slow rate and land prices are the main driving force of housing prices observed in the U.S. We therefore interchange the terms "land" and "housing" in the paper, as does Kocherlakota (2008).

however, the rise in the land price (through the shift in the household's land demand curve) increases the entrepreneur's net worth and expands its borrowing capacity. The expansion of credit shifts up the entrepreneur's land demand curve, which reinforces the household's response and results in a further rise in the land price and a further expansion of credit, generating a (static) multiplier. The rise in entrepreneur's net worth and the expansion of credit also produces a dynamic multiplier: more credit allows for more business investment in period t and thus higher capital stocks in the future; since capital and land are complementary factors of production, higher capital stocks raise the future marginal products of land, which increase the current land price further. Thus, in the credit-constrained economy, the housing demand shock has a much bigger bite on the land price (point C) than in the unconstrained economy (point B).

To evaluate the empirical significance of the credit constraints, we estimate the model using the Bayesian methods and U.S. time series data. We obtain two main findings. First, credit constraints provide strong amplification. The estimated dynamic responses of consumption and investment in our model can be more than three times as large as those implied by a model in which we turn off the response of the entrepreneur's borrowing capacity to changes in the collateral value. Thus, the magnitude of a financial multiplier can be as large as three. Second, shocks that account for most of fluctuations in the housing price generate important dynamic interactions between the collateral value and business investment. In consequence, our model generates co-movements among consumption, investment, hours, and housing price.

Our results help understand why the existing literature has been unable to establish the amplification mechanism through which a financial multiplier can be important. If there is no economic shock that generates large movements in the prices of collateral assets, the financial multiplier will have weak effects. One such example is the neutral technology shock: the shock moves current and future dividends as well as the loan rate in the same direction. As a result, it does not move the asset price much. The inability of moving the asset price explains why Kocherlakota (2000) and Cordoba and Ripoll (2004) find weak multiplier effects of technology shocks in their calibrated models with credit constraints. Their findings are consistent with our estimated results: while technology shocks can be important sources of fluctuations in output as in a standard real business cycle model, they do not generate large fluctuations in the prices of collateral assets so that their impact on output does not work through credit constraints on firms' ability to borrow. Instead of modeling credit constraints on firms, Iacoviello and Neri (2009) study credit constraints on households' ability to borrow to finance their houses. Housing shocks in their model shift resources from the non-housing sector to the housing sector and thus generate opposite movements between housing prices and business investment. Because these results are inconsistent with the data, the financial multiplier is unimportant. If there is an significant financial multiplier in the data, the model must be able to generate comovements between housing prices and business investment.

In our model, financial shocks such as those to housing demand not only have a large impact on the housing price but also generate comovements among consumption, investment, hours, and housing prices. These comovements are necessary for strong amplification through the financial multiplier. A positive shock to housing demand directly drives up the land price. The increase in the land price expands the entrepreneur's borrowing capacity and raises production and labor demand. The rise in labor input in turn raises the marginal product of land and capital, hence the entrepreneur's demand for land rises. As the household and the entrepreneur both compete for land while the land supply is limited, the housing demand shock generates large fluctuations in the land price. The fluctuations in the land price change firms' credit constraints endogenously, which influence their decisions on investment in a quantitatively significant way. Our estimates indicate that housing demand shocks alone account for about 90% of land price fluctuations, $20-35\%$ of output fluctuations, and $35-45\%$ of investment fluctuations at various forecast horizons.

II. Related Literature

Our model builds on the standard real business cycle (RBC) model and generalizes the RBC model by introducing heterogeneous agents and credit constraints. As the standard RBC model focuses on fluctuations in aggregate quantities and abstracts from the two-way feedback between asset prices and quantities, it has difficulties to confront the observed asset price fluctuations.[3] In our model with borrowing constraints, asset

[3]The challenge to explain asset-price movements in the standard RBC framework is first documented by Mehra and Prescott (1985). To meet the challenge, the subsequent literature has extended the RBC model in various directions. For example, some researchers emphasize the importance of habit persistence (Constantinides, 1990; Abel, 1990), some argue for the role of non-expected utility functions (Epstein and Zin, 1989, 1991), and some others study the importance of adjustment costs in capital (Jermann, 1998; Boldrin, Christiano, and Fisher, 2001) or rigidities in the labor market (Uhlig, 2007) along with habit formation.

prices can directly interact with investment and other aggregate quantities. Such interactions, as we find in the current paper, prove to be important for understanding the observed fluctuations in both asset prices and aggregate output.

The idea that borrowing constraints play a critical role in amplifying business cycles can be traced back at least to Fisher (1933). Our model builds on the recent literature that focuses on the costly contract enforcement problem (i.e., the problem of controlling over assets). Examples in this literature include Kiyotaki and Moore (1997), Kiyotaki (1998), Krishnamurthy (2003), Cordoba and Ripoll (2004), Iacoviello (2005), Pintus and Wen (2008), and Iacoviello and Neri (2009).[4] In this class of models, the borrowing capacity is constrained by the value of the collateral assets. We follow the literature and assume that the household (creditor) is more patient than the entrepreneur (debtor) so that a positive first-order excess return exists in steady state. Given the excess return, the borrower assigns a positive value to existing loans and borrows up to the limit. The binding credit constraint allows asset prices to interact with the debt level and therefore with investment and output. Such interactions can, in theory, generate a financial multiplier that amplifies business cycle shocks.

Establishing the quantitative importance of the financial multiplier in the Kiyotaki and Moore (1997) framework has been a challenge in the literature. For example, Kocherlakota (2000) and Cordoba and Ripoll (2004) report weak financial multiplier effects following technology shocks. Our work suggests a reason for their findings: technology shocks move the dividend flows and the risk-free interest rate in the same direction and therefore do not move asset prices much. To get strong amplification effects from the financial multiplier, one needs to identify economic mechanisms that generate large asset price fluctuations. Our model is able to generate large asset price fluctuations because an important component of the collateral assets is land, which is fixed in supply. With the supply of the collateral asset fixed, financial shocks that drive the asset demand (such as the housing demand shock in our model) directly translate into fluctuations in the price of the collateral asset, providing rooms for asset prices to interact with investment and output.[5] This insight implies that, if the collateral assets could be endogenously adjusted at the business cycle frequencies (as in Iacoviello

[4]Open-economy extensions of this class of models include Aoki, Benigno, and Kiyotaki (2007) and Mendoza (2008), among others.

[5]The economic mechanism for amplifying asset price fluctuations works the same way as long as the collateral assets are fixed in supply (at least at the business cycle frequencies). The land in our model is just a metaphor for such assets. Another example of such assets is the intangible capital emphasized by Bond and Cummins (2000) and Hall (2001).

and Neri (2009)), then it would be harder to generate asset price movements and the financial multiplier would be weaker.

Our work is related to another strand of literature that builds on the work by Townsend (1979) and Gale and Hellwig (1985) and focuses on the costly state verification problem caused by asymmetric information between creditors and debtors. Examples includes Carlstrom and Fuerst (1997), Bernanke, Gertler, and Gilchrist (1999), Cooley, Marimon, and Quadrini (2004), De Fiore and Uhlig (2005), Gertler, Gilchrist, and Natalucci (2007), Christiano, Motto, and Rostagno (2008), and Gilchrist, Ortiz, and Zakrajsek (2009). This class of models emphasizes the interactions between interest rate spreads and aggregate quantities. Unlike Kiyotaki and Moore (1997), loans in the model of Bernanke, Gertler, and Gilchrist (1999) are priced to take into account default risks and debtors optimally choose the amount of borrowing, taking the loan rate as given. Thus, although agency costs contribute to a positive external financing premium (i.e., the spread between the loan rate and the risk-free deposit rate), no borrowers are constrained by credit in equilibrium and there is no steady-state excess return relative to the loan rate. This class of models generates a "financial accelerator" effect that is similar to the financial multiplier effect in Kiyotaki and Moore (1997): an increase in the credit spread reduces entrepreneurs's net worth and raises the default probability and the external finance premium; as the cost of loans rises, entrepreneurs choose to reduce borrowing and investment and this action raises the spread further.

There are few studies of the empirical importance of the financial accelerator effect emphasized by Bernanke, Gertler, and Gilchrist (1999), with the notable exception of Christiano, Motto, and Rostagno (2008), who estimate an expanded version of the Bernanke, Gertler, and Gilchrist (1999) model using the time series data from the United States and the Euro Area. Christiano, Motto, and Rostagno (2008) identify certain financial shocks that can drive both the fluctuations in the external finance premium and investment. Their empirical work focuses on the dynamic interactions between the credit spread and investment. The focus of our paper is on the dynamic interactions between the asset price itself and investment. These two approaches reinforce each other, lending support to our view that the key to generating a strong financial multiplier (or accelerator) is to identify economic mechanisms that move asset prices.

III. The Model

The economy is populated by two types of agents—households and entrepreneurs—with a continuum and unit measure of each type. There are four types of commodities: labor, goods, land, and loanable bonds. Goods production requires labor, capital, and land as inputs. The output can be used for consumption (by both types of agents) and for capital investment (by the entrepreneurs). The representative household's utility depends on consumption goods, land services (housing), and leisure; the representative entrepreneur's utility depends on consumption goods only.

III.1. **The representative household.** Similar to Iacoviello (2005), the household has the utility function

$$\mathrm{E}\sum_{t=0}^{\infty}\beta^t A_t\left\{\log(C_{ht}-\gamma_h C_{h,t-1})+\varphi_t\log L_{ht}-\psi_t N_{ht}\right\}, \tag{1}$$

where C_{ht} denotes consumption, L_{ht} denotes land holdings, and N_{ht} denotes labor hours. The parameter $\beta \in (0,1)$ is a subjective discount factor, the parameter γ_h measures the degree of habit persistence, and the term E is a mathematical expectation operator. The terms A_t, φ_t, and ψ_t are preference shocks. We assume that the intertemporal preference shock A_t follows the stochastic process

$$A_t = A_{t-1}(1+\lambda_{at}), \quad \ln\lambda_{at} = (1-\rho_a)\ln\bar{\lambda}_a + \rho_a\ln\lambda_{a,t-1} + \varepsilon_{at}, \tag{2}$$

where $\bar{\lambda}_a > 0$ is a constant, $\rho_a \in (-1,1)$ is the persistence parameter, and ε_{at} is an identically and independently distributed (i.i.d.) white noise process with mean zero and variance σ_a^2. The housing preference shock φ_t follows the stationary process

$$\ln\varphi_t = (1-\rho_\varphi)\ln\bar{\varphi} + \rho_\varphi\ln\varphi_{t-1} + \varepsilon_{\varphi t}, \tag{3}$$

where $\bar{\varphi} > 0$ is a constant, $\rho_\varphi \in (-1,1)$ measures the persistence of the shock, and $\varepsilon_{\varphi t}$ is a white noise process with mean zero and variance σ_φ^2. The labor supply shock ψ_t follows the stationary process

$$\ln\psi_t = (1-\rho_\psi)\ln\bar{\psi} + \rho_\psi\ln\psi_{t-1} + \varepsilon_{\psi t}, \tag{4}$$

where $\bar{\varphi} > 0$ is a constant, $\rho_\psi \in (-1,1)$ measures the persistence, and $\varepsilon_{\psi t})$ is a white noise process with mean zero and variance σ_ψ^2.

Denote by q_{lt} the relative price of housing (in consumption units), R_t the gross real loan rate, and w_t the real wage; denote by S_t the household's purchase in period t of the loanable bond that pays off one unit of consumption good in all states of nature in period $t+1$. In period 0, the household begins with $L_{h,-1} > 0$ units of housing and

$S_{-1} > 0$ units of the loanable bond. The flow of funds constraint for the household is given by

$$C_{ht} + q_{lt}(L_{ht} - L_{h,t-1}) + \frac{S_t}{R_t} \leq w_t N_{ht} + S_{t-1}. \tag{5}$$

The household chooses C_{ht}, $L_{h,t}$, N_{ht}, and S_t to maximize (1) subject to (2)-(5) and the borrowing constraint $S_t \geq -\bar{S}$ for some large number $\bar{S}$.

III.2. **The representative entrepreneur.** The entrepreneur has the utility function

$$\mathrm{E} \sum_{t=0}^{\infty} \beta^t \left[\log(C_{et} - \gamma_e C_{e,t-1})\right], \tag{6}$$

where C_{et} denotes the entrepreneur's consumption and γ_e is the habit persistence parameter.

The entrepreneur produces goods using capital, labor, and land as inputs. The production function is given by

$$Y_t = Z_t [L_{e,t-1}^{\phi} K_{t-1}^{1-\phi}]^{\alpha} N_{et}^{1-\alpha}, \tag{7}$$

where Y_t denotes output, K_{t-1}, N_{et}, and $L_{e,t-1}$ denote the inputs capital, labor, and land, respectively, and the parameters $\alpha \in (0,1)$ and $\phi \in (0,1)$ measure the output elasticities of these production factors. We assume that the total factor productivity Z_t is composed of a permanent component Z_t^p and a transitory component ν_t such that $Z_t = Z_t^p \nu_{zt}$, where the permanent component Z_t^p follows the stochastic process

$$Z_t^p = Z_{t-1}^p \lambda_{zt}, \quad \ln \lambda_{zt} = (1-\rho_z) \ln \bar{\lambda}_z + \rho_z \ln \lambda_{z,t-1} + \varepsilon_{zt}, \tag{8}$$

and the transitory component follows the stochastic process

$$\ln \nu_{zt} = \rho_{\nu_z} \ln \nu_{z,t-1} + \varepsilon_{\nu_z t}. \tag{9}$$

The parameter $\bar{\lambda}_z$ is the steady-state growth rate of Z_t^p; the parameters ρ_z and ρ_{ν_z} measure the degree of persistence. The innovations ε_{zt} and $\varepsilon_{\nu_z t}$ are i.i.d. white noise processes that are mutually independent with mean zero and variances given by σ_z^2 and $\sigma_{\nu_z}^2$, respectively.

The entrepreneur is endowed with K_{-1} units of initial capital stock and $L_{-1,e}$ units of initial land. Capital accumulation follows the law of motion

$$K_t = (1-\delta) K_{t-1} + \left[1 - \frac{\Omega}{2} \left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)^2\right] I_t, \tag{10}$$

where I_t denotes investment, $\bar{\lambda}_I$ denotes the steady-state growth rate of investment, and $\Omega > 0$ is the adjustment cost parameter.

The entrepreneur faces the flow of funds constraint

$$C_{et} + q_{lt}(L_{et} - L_{e,t-1}) + B_{t-1} = Z_t[L_{e,t-1}^{\phi} K_{t-1}^{1-\phi}]^{\alpha} N_{et}^{1-\alpha} - \frac{I_t}{Q_t} - w_t N_{et} + \frac{B_t}{R_t}, \tag{11}$$

where B_{t-1} is the amount of matured debt and B_t/R_t is the value of new debt. Following Greenwood, Hercowitz, and Krusell (1997), we interpret Q_t as the investment-specific technological change. Specifically, we assume that $Q_t = Q_t^p \nu_{qt}$, where the permanent component Q_t^p follows the stochastic process

$$Q_t^p = Q_{t-1}^p \lambda_{qt}, \quad \ln \lambda_{qt} = (1 - \rho_q) \ln \bar{\lambda}_q + \rho_q \ln \lambda_{q,t-1} + \varepsilon_{qt}, \tag{12}$$

and the transitory component μ_t follows the stochastic process

$$\ln \nu_{qt} = \rho_{\nu_q} \ln \nu_{q,t-1} + \varepsilon_{\nu_q t}. \tag{13}$$

The parameter $\bar{\lambda}_q$ is the steady-state growth rate of Q_t^p; the parameters ρ_q and ρ_{ν_q} measure the degree of persistence. The innovations ε_{qt} and $\varepsilon_{\nu_q t}$ are i.i.d. white noise processes that are mutually independent with mean zero and variances given by σ_q^2 and $\sigma_{\nu_q}^2$, respectively.

The entrepreneur faces the credit constraint

$$B_t \leq \theta_t E_t[q_{l,t+1} L_{et} + q_{k,t+1} K_t], \tag{14}$$

where $q_{k,t+1}$ is the shadow price of capital in consumption units.[6] Under this credit constraint, the amount that the entrepreneur can borrow is limited by a fraction of the value of the collateral assets—land and capital. Following Kiyotaki and Moore (1997), we interpret this type of credit constraints as reflecting the problem of costly contract enforcement: if the entrepreneur fails to pay the debt, the creditor can seize the land and the accumulated capital; since it is costly to liquidate the seized land and capital stock, the creditor can recoup up to a fraction θ_t of the total value of the collateral assets. We interpret θ_t as a "collateral shock" that reflects the uncertainty in the tightness of the credit market. We assume that θ_t follows the stochastic process

$$\ln \theta_t = (1 - \rho_\theta) \ln \bar{\theta} + \rho_\theta \ln \theta_{t-1} + \varepsilon_{\theta t}, \tag{15}$$

where $\bar{\theta}$ is the steady-state value of θ_t, $\rho_\theta \in (0, 1)$ is the persistence parameter, and $\varepsilon_{\theta t}$ is an i.i.d. white noise process with mean zero and variance σ_θ^2.

The entrepreneur chooses C_{et}, N_{et}, I_t, $L_{e,t}$, K_t, and B_t to maximize (6) subject to (7) through (15).

[6]Since the price of new capital is $1/Q_t$, Tobin's q in this model is given by $q_{kt} Q_t$, which is the ratio of the value of installed capital to the price of new capital.

III.3. **Market clearing conditions and equilibrium.** In a competitive equilibrium, the markets for goods, labor, land, and loanable bonds all clear. The goods market clearing condition implies that

$$C_t + \frac{I_t}{Q_t} = Y_t, \tag{16}$$

where $C_t = C_{ht} + C_{et}$ denotes aggregate consumption. The labor market clearing condition implies that labor demand equals labor supply:

$$N_{et} = N_{ht} \equiv N_t. \tag{17}$$

The land market clearing condition implies that

$$L_{ht} + L_{et} = \bar{L}, \tag{18}$$

where $\bar{L}$ is the fixed aggregate land endowment. Finally, the bond market clearing condition implies that

$$S_t = B_t. \tag{19}$$

A competitive equilibrium consists of sequences of prices $\{w_t, q_{lt}, R_t\}_{t=0}^{\infty}$ and allocations $\{C_{ht}, C_{et}, I_t, N_{ht}, N_{et}, L_{ht}, L_{et}, S_t, B_t, K_t, Y_t\}_{t=0}^{\infty}$ such that (i) taking the prices as given, the allocations solve the optimizing problems for the household and the entrepreneur and (ii) all markets clear.

III.4. **Some key properties of the equilibrium.** Following Kiyotaki and Moore (1997), we assume that the household are more patient than the entrepreneur.[7] The patience factor in our model is important because it leads to two related characteristics of the equilibrium: there exists a first-order excess return and the collateral constraint is binding in the steady-state equilibrium.

The first-order excess return exists because the patient household's savings depress the equilibrium loan rate and the less patient entrepreneur chooses to borrow up to the credit limits to finance investment and production. As the credit constraint is binding, the entrepreneur assigns a positive shadow value to existing loans.[8] The binding credit

[7]In an disaggregated environment with heterogeneous households and heterogenous entrepreneurs who all have an identical subjective discount factor, the aggregate patience factor arises if entrepreneurs face an exogenous death or exit rate as assumed by Bernanke, Gertler, and Gilchrist (1999) or if households face persistent and uninsurable idiosyncratic income risks and their precautionary savings make them appear patient in aggregation (Liu, Wang, and Zha, 2009).

[8]In Appendix B.1, we derive the first-order excess return for our model. The first-order excess return represents a key distinction between Kiyotaki and Moore (1997)'s model with costly contract enforcement and Bernanke, Gertler, and Gilchrist (1999)'s model with costly state verification. In Bernanke, Gertler, and Gilchrist (1999), the intermediary sets the loan rate to break even, taking into

constraint allows for two-way interactions between asset prices and investment, giving rise to a financial multiplier effect, the empirical importance of which we evaluate in the following sections.

IV. Econometric Methodology

We use the Bayesian method to fit our model to quarterly U.S. time series data from 1976:Q1 through 2009:Q1. The time series that we use include the relative price of land, the inverse of the quality-adjusted relative price of investment, real per capita consumption, real per capita investment (in consumption units), real per capita nonfarm and nonfinancial business debt, and per capita hours worked (as a fraction of total time endowment). Appendix A describes the details of our data.[9]

We partition the model parameters into three subsets. The first subset of parameters includes the structural parameters on which we have agnostic priors. This set of parameters, $\Psi_1 = \{\gamma_h, \gamma_e, \Omega, , g_\gamma, \bar{\lambda}_q\}$, consists of the household's and entrepreneur's habit persistence parameters γ_h and γ_e, investment-adjustment cost parameter Ω, the growth rate of per capita output g_γ, and the growth rate of per capita investment $\bar{\lambda}_q$. These parameters are listed in the top panel of Table 1. We assume that the priors for γ_h and γ_e follow the beta distribution with the shape parameters given by $a = 1$ and $b = 2$. Thus, we assign positive density to $\gamma_h = \gamma_e = 0$ and let the probability density decline linearly as the value of γ_h (or γ_e) increases from 0 to 1. These hyper-parameter values imply that a lower probability (5%) bound for γ_h and γ_e is 0.0256 and an upper probability (95%) bound is 0.7761. This 90% probability interval covers most calibrated values for the habit persistence parameter used in the literature (e.g., Boldrin, Christiano, and Fisher (2001) and Christiano, Eichenbaum, and Evans (2005)). The prior for the investment adjustment cost parameter Ω follows the gamma distribution with the shape parameter $a = 1$ and the rate parameter $b = 0.5$. These hyper-parameters imply that the probability density is positive at $\Omega = 0$ and that the 90% prior probability interval for Ω ranges from 0.1 to 6, which covers most values used

account the default risks; an entrepreneur optimally chooses the amount of loans, taking the loan rate as given. The equilibrium loan rate is the same as the return on risky assets and thus the first-order excess return is always zero.

[9]The data on investment-specific technology are needed to get the sizes of standard deviations of investment technology shocks in line with those in Krusell, Ohanian, Ríos-Rull, and Violante (2000) and Fisher (2006). By using an explicit measure of investment-specific technology shocks (i.e., biased technology shocks) in our estimation, we will be able to assess the importance of biased technology shocks relative to neutral technology shocks.

in the DSGE literature (e.g., Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2007), and Liu, Waggoner, and Zha (2009)). The priors for the steady-state growth rates of output and of capital follow the gamma distribution with the 90% probability interval covering the range between 0.1 and 1.5, corresponding to annual growth rates between 0.4% and 6%.

The second subset of parameters includes the structural parameters for which we can use the steady-state relations for constructing informative priors. This set of parameters, $\Psi_2 = \{\beta, \bar{\lambda}_a, \bar{\varphi}, \bar{\psi}, \phi, \alpha, \theta, \delta\}$, consists of the subjective discount factor β, the patience factor $\bar{\lambda}_a$, the housing preference parameter $\bar{\varphi}$, the leisure preference parameter $\bar{\psi}$, the elasticity parameters in the production function ϕ and α, the average loan-to-asset ratio θ, and the capital depreciation rate δ. To construct the prior distributions for the parameters in Ψ_2, we first simulate the parameters in Ψ_1 from their prior distributions and then, for each simulation, we impose the steady-state restrictions on both Ψ_1 and Ψ_2 such that the model matches the following moment conditions: (1) the average labor income share is 70% ($\alpha = 0.3$); (2) the average real prime loan rate is 4% per annum (Huggett, Ventura, and Yaron, 2009); (3) the capital-output ratio is on average 1.15 at the annual frequency; (4) the investment-capital ratio is on average 0.209 at the annual frequency; (5) the average land-output ratio is 0.65 at the annual frequency; (6) the average nonfarm and nonfinancial businesses' loan-asset ratio is 0.75 at the annual frequency ($\theta = 0.75$); (7) the average housing-output ratio is 1.45 at the annual frequency; and (8) the average market hours is 25% of time endowment.[10] Since the prior distributions for the parameters in Ψ_2 are of unknown form, the 90% probability bounds, reported in Table 1 (the lower panel), are generated through simulations. As shown in the table, the steady-state restrictions lead to informative probability intervals for the marginal prior distributions of the parameters and thus help identify

[10]Since we have a closed-economy model with no government spending, we measure private domestic output by the sum of personal consumption expenditures and private domestic investment, where consumption is the expenditures on nondurable goods and non-housing services, and investment is the expenditures on consumer durable goods and fixed investment in equipment and software. These time series are provided by the Bureau of Economic Analysis (BEA) through Haver Analytics. Capital and housing stock are in annual rates. Capital stock includes the annual stocks of equipment, software, and consumer durable goods. The land-output ratio is the ratio of the nominal value of land input and the nominal value of output in the private nonfarm and nonfinancial business sector for the period 1987-2007 taken from the Bureau of Labor Statistics (BLS).

the structural parameters in Ψ_2.[11] Our method for constructing the prior distributions for Ψ_2 is similar to the approach studied by Del Negro and Schorfheide (2008), which combines the Baynesian approach and the standard calibration approach for eliciting priors.

The third subset of parameters consists of those describing the shock processes displayed in Table 2. These parameters are summarized by $\Psi_3 = \{\rho_i, \sigma_i\}$ for $i \in \{a, z, \nu_z, q, \nu_q, \varphi, \psi, \theta\}$, where ρ_i and σ_i denote the persistence parameters and the standard deviations of the eight structural shocks. We adopt agnostic priors for these parameters. Specifically, the priors for the persistent parameters follow the beta distribution with the 90% probability interval given by $[0.0256, 0.7761]$; the priors for the standard deviations follow the inverse gamma distribution with the 90% probability interval given by $[0.0001, 1.0]$. We have examined the sensitivity of our estimates by extending both the lower and the upper bounds of this interval and found that the results are not sensitive.

V. Empirical results

We now present and discuss our empirical findings. Section V.1 reports the estimated values of structural parameters, Section V.2 presents variance decompositions from the estimated model, Section V.3 presents evidence that the dynamic interactions between asset prices and investment have played a quantitatively important role in generating aggregate fluctuations throughout our sample period, and Section V.4 further discusses the importance of endogenous credit constraints based on impulse responses of several key macroeconomic and distributional variables.

V.1. **Parameter estimates.** Tables 1 and 2 report the posterior mode estimates of the parameters. The maximum log posterior density (MLPD) for our DSGE model is 2232.68. The MLPD for the Bayesian vector autoregression with four lags is 2145.64.[12]

[11]Even with a subset of deep parameters well identified, the posterior density function is still very non-Gaussian and has many local peaks. We randomly simulate 100000 starting points and select the converged result that gives the highest posterior density. Among these starting points, many converge to the point that has the highest peak. The computing time is about 4-5 days on a cluster of 24 2.5GHz computers.

[12]We use the prior settings provided by Sims and Zha (1998). Specifically, we set the hyperparameter values as, in their notation, $\lambda_0 = 1, \lambda_1 = 0.5, \lambda_3 = 0.1, \lambda_4 = 0.1$, and $\mu_5 = \mu_6 = 1$. The MLPD is sensitive to the prior and its value can differ by 50-100 in log for different but reasonable hyperparameter values.

By the Schwarz criterion, the fit from our structural model is competitive with an atheoretical statistical model.

Our estimates suggest that habit persistence is moderately important for both agents, with the entrepreneur's habit parameter larger than the household's (0.55 vs.0.32). The estimated value of the investment-adjustment cost parameter is 0.18, much smaller than those obtained in the literature.[13] Since credit constraints impede the adjustments of investment and amplify the responses of the asset price, our model relies less on explicit investment adjustment costs to fit the data. Further, unlike Smets and Wouters (2007) and Justiniano and Primiceri (2008) who treat the investment-specific shock as a latent series, we fit our model to the time series of the relative price of investment and our estimated size of the investment-specific shock is small (see Table 2), so is the adjustment cost parameter.

The estimated growth rate of per capita output is about 1.26% per annum, consistent with the average growth rate of real per capita GDP in the United States for the postwar period. The estimated growth rate of the investment-specific technology is higher than that calibrated by Greenwood, Hercowitz, and Krusell (1997) (4.8% vs. 3.2% per annum), mainly because they use a shorter sample that ends in 1990, whereas, for the sub-sample after the early 1990s, the United States economy experienced even more rapid declines in the quality-adjusted relative price of equipment, software, and consumer durable goods. The lower panel of Table 1 reports the estimated values of the parameters in Ψ_2. All parameters lie within the 90% probability intervals of the priors. In this sense, it helps identify this set of parameters by imposing the steady-state relations in the model and matching the appropriate first moments in the data. The estimated value of the patience factor (0.005) implies that the first-order excess return is about 1.94% per annum (see the discussion in Section III.4 and Appendix B.1). Thus, the entrepreneur assigns a substantial value to the existing loans as the credit constraint is binding in the steady state equilibrium.

Table 2 displays the estimates of the parameters in the shock processes. Four shocks turn out to be persistent, with the estimated AR(1) coefficients above 0.9. These shocks are the patience shock, the housing demand shock, the labor supply shock, and the collateral shock. The size of the patience shock measured by the estimated standard deviation is the largest (0.19) among all shocks, followed by the housing demand shock (0.05) and the collateral shock (0.013). The sizes of the technology shocks are small.

[13]The literature reports estimates of the investment-adjustment cost parameters between 2.5 and 5 (Christiano, Eichenbaum, and Evans, 2005; Smets and Wouters, 2007).

In particular, the estimated standard deviations of the investment-specific technology shock (to both the growth rate and the level) are the smallest among all shocks. This result stands in contrast to those obtained by Justiniano and Primiceri (2008), who treat changes in the investment-specific technology shock as an unobservable and find its volatility much larger than that of any other shock. Our result, however, is consistent with Krusell, Ohanian, Ríos-Rull, and Violante (2000) and Liu, Waggoner, and Zha (2009), who use direct measures of investment-specific technology.

V.2. **Variance decompositions.** Whether an exogenous economic shock has significant impact on the dynamics of asset prices and aggregate quantities does not necessarily depend on the size or the persistence of the shock itself; rather it depends on the model's internal transmission mechanism, which transforms the shocks into the fluctuations in prices and quantities. To gauge the relative importance of each shock when the model's transmission mechanism is taken into account, we now examine the variance decompositions of asset prices and aggregate quantities across the eight shocks. Tables 3 and 4 report these results at forecasting horizons between the impact period (1Q) and four years after the shock (24Q).

We begin with the patience shock, which is persistent and has the largest standard deviation (almost four times the size of the second largest shock). Despite its persistence and large size, the patience shock has little impact on the dynamics of the asset prices measured by the land price, the capital price, and the excess returns. It has a modest impact on investment (about 20%) and output (about 10%). Similarly, the neutral technology shocks (or TFP shocks) account for little of the fluctuations in the asset prices but these technology shocks, especially the shock to the growth rate, account for a substantial fraction of fluctuations in consumption (about 65%) and in output $(15-45\%)$ at the business cycle frequencies. Our findings here are consistent with Kocherlakota (2000) and Cordoba and Ripoll (2004), who report weak financial multiplier effects following TFP shocks in a model with credit constraints. TFP shocks do drive business cycle fluctuations, but they do not work through the credit constraints because these shocks do not move the asset prices much.

In contrast, the housing demand shock, which has the second largest standard deviation and is very persistent, stands out as the most important source of the business cycle dynamics of the land price: it accounts for about 90% of the land price fluctuations. Working through the binding credit constraint, the housing demand shock also drives a substantial fraction of fluctuations in investment $(35-45\%)$ and output $(20-35\%)$.

It does not follow, however, that a shock that drives the asset prices will necessarily influence the dynamics of aggregate quantities. The permanent shock to the investment-specific technology, for example, has negligible impact on investment itself even though it drives most of the fluctuations in the capital price. Nor does it follow that an economic shock directly influencing the borrowing capacity will have an important impact on both asset prices and investment fluctuations. The collateral shock is the case in point: the shock is very persistent and has the third largest standard deviation, but it has little impact on the dynamics of the land price and the capital price and that its impact on output is modest (about 10%).

In the context of our heterogenous agent model, one should take caution interpreting the intertemporal shock (such as the investment specific shock) as an "intertemporal wedge." Unlike the representative agent model in Chari, Kehoe, and McGrattan (2007), a source of intertemporal distortion in our model comes naturally from the credit constraint. Although explicit intertemporal shocks do not account for a large fraction of output fluctuations, the intertemporal distortion through the credit constraint help amplify and propagate the dynamic effects of other shocks. A primary example is the housing demand shock, which accounts for about 20% to 35% of output fluctuations at business-cycle frequencies. The housing demand shock gets amplified through credit constraints as it drives most of the movements in the land price. Since land is an important collateral, changes in the land price lead to changes in the borrowing capacity and therefore investment and future output, which feeds back to changes in the current asset price and the collateral value. Our results suggest that this financial multiplier is empirically important.

V.3. **Land prices and macroeconomic fluctuations: a historical perspective.** Variance decompositions reported in Section V.2 indicate the average importance of a particular type of shock relative to other types of shocks. As Sims and Zha (2006) point out, however, variance decompositions give no indication of whether a sequence of shocks account for fluctuations in macroeconomic variables at particular points of time through the sample. As a way to quantify the historical importance of dynamic interactions between land prices and real aggregate variables, our structural model makes it an internally coherent exercise to calculate what would have happened if only housing demand shocks had occurred *throughout the history*. We turn off all the estimated structural shocks bar housing demand shocks and use our estimated model to generate the time paths of the land price, consumption, and investment by conditioning on the estimated initial state variables and the sequence of estimated housing demand shocks. We then compare the simulation to the data.

Figure 2 displays these counterfactual histories by comparing the actual quarterly growth rates of the land price, consumption, and investment (represented by dashed lines) and the corresponding simulated paths generated by housing demand shocks alone (represented by thick solid lines). By construction, were all the other shocks left in place, the simulations would have matched the observed data exactly. Thus, in these graphs, the gap between the observed time series and the counterfactual histories captures the collective contributions of all shocks other than the housing demand shock.

The top panel of Figure 2 shows that the simulated path of land prices tracks the actual data almost perfectly, indicating that housing demand shocks are the dominant source of fluctuations in the observed land prices throughout the sample. Since housing demand shocks cause most of the observed fluctuations in the land price, any dynamic interactions between land prices and business cycles, if they exist, should be driven mainly by these shocks as well. The middle panel of Figure 2 reports the simulated path of consumption. The simulated path is smoother than the observed path and shows strong asymmetric effects on consumption: it tracks observed consumption in expansion periods such as late 1980s, late 1990s, and 2000s, but misses all downturns in consumption.

While housing demand shocks do not generate downturns in consumption, they do generate both the upturns and the downturns in investment. As shown in the bottom panel of Figure 2, the counterfactual path of investment tracks the data well. Comparing the top and bottom panels of Figure 2, one can see that the land price and investment move together for the most part of the history. These comovements, driven by housing demand shocks, are the result of the internal transmission mechanism working through endogenous credit constraints.

V.4. **Importance of endogenous credit constraints.** In our model, the entrepreneur's credit limit is endogenous and depends on the value of collateral and therefore on asset prices. A shock can be amplified through the credit constraint if it can move asset prices, resulting in a financial multiplier effect. To examine the importance of endogenous credit limits, we now plot impulse responses of several key macroeconomic variables in our estimated model and compare these responses to those in a counterfactual economy in which the credit limit is exogenously fixed at the steady-state level of our model.

Our analysis suggests that the strength of the amplification depends on how responsive asset prices are to the shock. Some shocks drive business cycle fluctuations, but not through the credit constraint because they do not move the asset prices much. One such example is the TFP shock, which, as shown by Kocherlakota (2000) and Cordoba and Ripoll (2004), generates a weak financial multiplier effect. Since TFP shocks move the dividends (i.e., the rental values of land) and the discount rate (i.e., the risk-free loan rate) in the same direction, they do not generate large fluctuations in asset prices and therefore do not have significant effects on the borrowing capacity. Figure 3 displays the impulse responses of four macroeconomic variables following a positive, one-standard-deviation, shock to neutral technology growth for two models: our estimated model with endogenous credit limit (solid lines) and the alternative model in which the credit limit is exogenously fixed at the steady state value (dashed lines). As shown in the figure, differences between the two sets of impulse responses (solid vs. dashed lines) are negligible, as the credit limit respond little to technology shocks.

The borrowing capacity, however, is influenced considerably by two sources of economic shocks: the collateral shock that directly affects the borrowing capacity and the housing demand shock that indirectly affects the borrowing capacity by moving the land price. To assess the quantitative importance of the transmission mechanism provided by the credit constraint, we plot the impulse responses of several key variables following each of these two shocks for our model in which the credit limit responds to changes in asset prices and for the alternative model in which the credit limit does not respond to asset prices.

Figure 4 plots the impulse responses of four macroeconomic variables to a positive, one-standard-deviation, collateral shock. The amplification effect through the endogenous credit constraint is evident: compared to the alternative model with the fixed credit limit, the peak response of output in our model is more than three times as large. The responses of the land price, consumption, and investment are all amplified under the endogenous credit constraint. Figure 5 displays the distributional effects in response to the collateral shock. The shock leads to an initial drop and a subsequent persistent increase in household consumption and an initial rise and a subsequent persistent decline in entrepreneur consumption. It also leads to a shift of land holdings from the household to the entrepreneur. As the collateral shock expands the entrepreneur's borrowing capacity, the entrepreneur's demand for land increases while the loan liability reduces the entrepreneur's net worth and consumption. On the other hand, the household is induced to save more, leading to a rise in the growth rate of household consumption. Compared to the results for our model with the endogenous credit limit (solid lines), the responses of consumption and land holdings are much less pronounced when the credit limit is held fixed (dashed lines).

Similar to the collateral shock, the housing demand shock also generates persistent and hump-shaped responses of macroeconomic variables and has distributional effects, as shown in Figures 6 and 7. The key difference, however, is that housing demand shock has a much larger impact on the land price than does the collateral shock, as is evident by comparing the scales in Figure 4 and Figure 6. Indeed, the peak effect of a housing demand shock on the land price is greater than that of a collateral shock by an order of magnitude (0.042 vs. 0.003). As land is an important part of collateral, the housing demand shock generates large and persistent responses of investment and output through the credit constraint. Compared to the case where the credit limit is exogenously fixed (dashed lines), the responses of investment and output to the housing demand shock are at least three times as large (solid lines).

The responses of macroeconomic variables to both financial shocks are qualitatively the same. Why is the housing demand shock quantitatively more important than the collateral shock in propagating macroeconomic fluctuations? The economic reason is that the housing demand shock directly impacts upon the land price whereas the collateral shock affects the land price only indirectly. Thus, through the financial multiplier, the housing demand shock is capable of generating larger dynamic effects than does the collateral shock on the housing price, the firm's net worth, labor demand, and business investment.

In summary, a positive housing demand shock raises the land price and thus the collateral value. As a result, the credit limit is expanded. With a larger borrowing capacity, the entrepreneur is able to increase investment in land and capital, which raises future output and marginal products of both capital and land. The rise in future marginal products raises the current asset price further, which continues to expand the credit limit. Our exercises suggest that the endogenous credit constraint provides a quantitatively important financial multiplier mechanism of housing demand shocks.

VI. Conclusion

How much credit constraints amplify and propagate macroeconomic fluctuations is an important question, as the answer to this question can change the way of macroeconomic modeling as well as our understanding of macroeconomic policy. We find that the economic mechanism generating the comovements between the price of a collateral asset and business investment is essential to the amplification effects provided by credit constraints. While technology shocks and some other shocks such as the labor supply shock contribute to output fluctuations through the usual propagation channels as documented in the literature and in this paper, our findings show that housing demand shocks, through the credit constraints channel, play an important role in generating comovements among consumption, investment, hours, and housing prices.

Our work builds an empirical foundation on which one can extend our model in several dimensions in future research. One extension is to confront the model with the capital price data (or Tobin's q). This task is challenging because, unlike land, aggregate supply of physical capital is not limited and changes in response to economic shocks. The works by Bond and Cummins (2000) and Hall (2001) suggest that intangible capital be an important part of capital. Since the supply of intangible capital is fixed in the short run, extending our model by incorporating intangible capital can be promising for matching the capital price data.

Another ambitious extension is to merge our work with Christiano, Motto, and Rostagno (2008) by incorporating both credit constraints and the external finance premium due to bankruptcy costs in the model. This extension allows us to identify certain periods in which whether credit (liquidity) constraints or the finance premium is more important in the amplification and propagation of economic shocks. A third challenging extension is to make the DSGE model with financial multipliers useful for policy analysis. Recent theoretical literature has made some progress in identifying externalities that call for policy interventions in the presence of credit and liquidity constraints (Lorenzoni, 2008; Kiyotaki and Moore, 2008). Extending the DSGE framework with credit and liquidity constraints like ours to empirical evaluations of monetary and fiscal policies is an important task.

Table 1. Prior distributions and posterior modes of structural parameters

	Prior					Posterior
Parameter	Distribution	a	b	Low	High	Mode
γ_h	Beta(a,b)	1.00	2.00	0.025	0.776	0.3288
γ_e	Beta(a,b)	1.00	2.00	0.025	0.776	0.5517
Ω	Gamma(a,b)	1.00	0.50	0.102	5.994	0.1810
$100(g_\gamma - 1)$	Gamma(a,b)	1.86	3.01	0.100	1.500	0.3157
$100(\bar{\lambda}_q - 1)$	Gamma(a,b)	1.86	3.01	0.100	1.500	1.2121
β	Simulated			0.9563	0.9946	0.9885
$\bar{\lambda}_a$	Simulated			0.0000	0.0509	0.0048
$\bar{\varphi}$	Simulated			0.0000	0.0697	0.0536
ϕ	Simulated			0.0655	0.0701	0.0698
δ	Simulated			0.0291	0.0485	0.0378

Note: "Low" and "High" denote the bounds of the 90% probability interval for the prior distribution.

Table 2. Prior Distributions and posterior modes of shock parameters

	Prior					Posterior
Parameter	Distribution	a	b	Low	High	Mode
ρ_a	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.9246
ρ_z	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.4374
ρ_{ν_z}	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.0091
ρ_q	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.6016
ρ_{ν_q}	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.3532
ρ_φ	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.9998
ρ_ψ	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.9810
ρ_θ	Beta(a,b)	1.0000	2.0000	0.0256	0.7761	0.9819
σ_a	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.1876
σ_z	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.0046
σ_{ν_z}	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.0042
σ_q	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.0037
σ_{ν_q}	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.0028
σ_φ	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.0545
σ_ψ	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.0065
σ_θ	Inverse gamma(a,b)	0.3543	0.0002	0.0001	1.0000	0.0129

Note: "Low" and "High" denote the bounds of the 90% probability interval for the prior distribution.

Table 3. Variance decompositions of asset prices

Horizon	Patience	Ngrowth	Nlevel	Bgrowth	Blevel	Housing	Labor	Collateral
				Land price				
1Q	4.91	1.63	1.24	0.01	0.02	90.83	1.36	0.01
4Q	4.12	2.75	0.32	0.04	0.01	91.45	1.22	0.08
8Q	3.73	3.40	0.21	0.06	0.00	91.09	1.32	0.18
16Q	3.07	4.40	0.16	0.04	0.00	90.60	1.47	0.25
24Q	2.46	5.19	0.13	0.10	0.00	90.45	1.48	0.20
				Capital price				
1Q	9.09	0.58	24.51	46.30	1.28	12.20	3.31	2.73
4Q	4.01	0.44	7.20	75.93	0.86	7.53	1.34	2.70
8Q	1.83	0.21	3.28	88.99	0.40	3.44	0.61	1.24
16Q	0.82	0.09	1.47	95.04	0.18	1.55	0.27	0.56
24Q	0.53	0.06	0.95	96.82	0.12	1.00	0.18	0.36
				Excess Returns				
1Q	2.79	0.26	2.79	2.04	0.14	63.45	0.92	27.62
4Q	2.50	0.17	2.93	2.38	0.12	64.42	0.84	26.64
8Q	2.32	0.14	3.01	2.71	0.11	65.35	0.80	25.56
16Q	2.21	0.12	3.09	3.02	0.11	66.52	0.78	24.15
24Q	2.18	0.11	3.12	3.12	0.11	67.02	0.78	23.56

Note: Columns 2 to 9 correspond to contributions made by the intertemporal preference shock (Patience), the permanent shock to neutral technology (Ngrowth), the transitory shock to neutral technology (Nlevel), the permanent shock to biased technology (Bgrowth), the transitory shock to biased technology (Blevel), the housing demand shock (Housing), the labor supply shock (Labor), and the collateral shock (Collateral).

Table 4. Variance decompositions of aggregate quantities

Horizon	Patience	Ngrowth	Nlevel	Bgrowth	Blevel	Housing	Labor	Collateral
Consumption								
1Q	5.76	49.76	9.99	0.62	0.21	3.15	28.53	1.98
4Q	2.05	68.49	1.72	0.37	0.06	1.00	25.85	0.45
8Q	1.48	66.05	1.28	0.55	0.03	5.54	23.13	1.93
16Q	3.10	63.54	1.10	0.39	0.01	9.12	19.90	2.83
24Q	3.09	66.92	0.87	1.20	0.01	7.62	18.20	2.10
Investment								
1Q	20.33	0.77	13.47	3.19	1.81	39.89	6.99	13.56
4Q	20.30	4.82	4.75	0.85	0.37	45.04	7.07	16.82
8Q	19.46	8.53	3.60	2.89	0.27	42.48	7.59	15.18
16Q	17.54	12.40	3.09	8.25	0.24	37.49	7.97	13.02
24Q	16.11	14.33	2.83	11.88	0.22	34.50	7.78	12.35
Output								
1Q	12.74	8.06	19.03	4.46	0.41	29.72	16.13	9.44
4Q	12.81	17.79	5.08	1.65	0.08	35.40	14.04	13.15
8Q	11.80	26.20	3.41	0.93	0.06	31.84	14.56	11.20
16Q	9.69	37.98	2.47	1.38	0.04	24.82	15.59	8.01
24Q	8.00	46.09	1.99	2.17	0.04	19.90	15.49	6.31

Note: Columns 2 to 9 correspond to contributions made by the intertemporal preference shock (Patience), the permanent shock to neutral technology (Ngrowth), the transitory shock to neutral technology (Nlevel), the permanent shock to biased technology (Bgrowth), the transitory shock to biased technology (Blevel), the housing demand shock (Housing), the labor supply shock (Labor), and the collateral shock (Collateral).

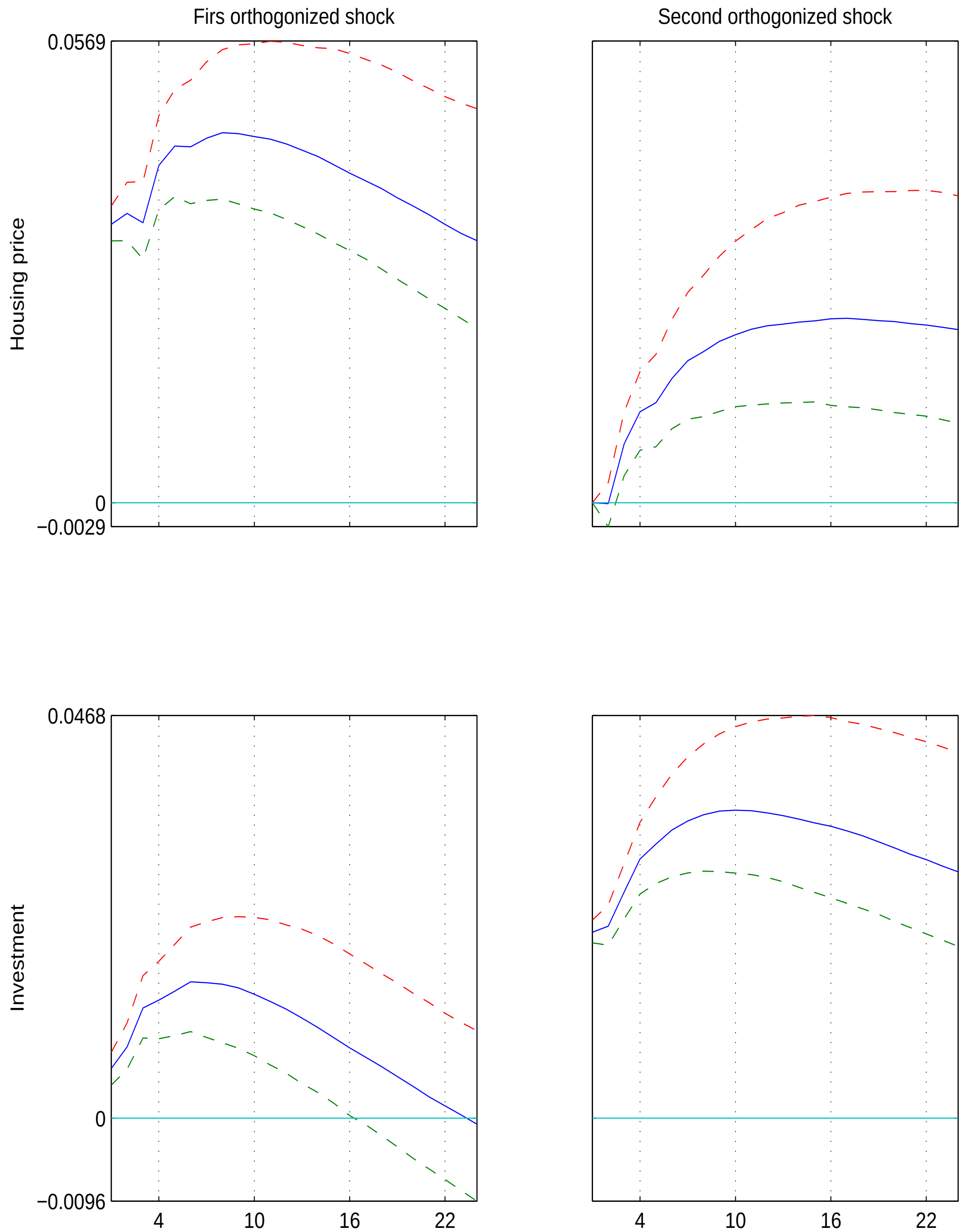

FIGURE 1. Impulse responses from a BVAR model. Solid lines represent the estimated responses and dashed lines represent .68 error bands.

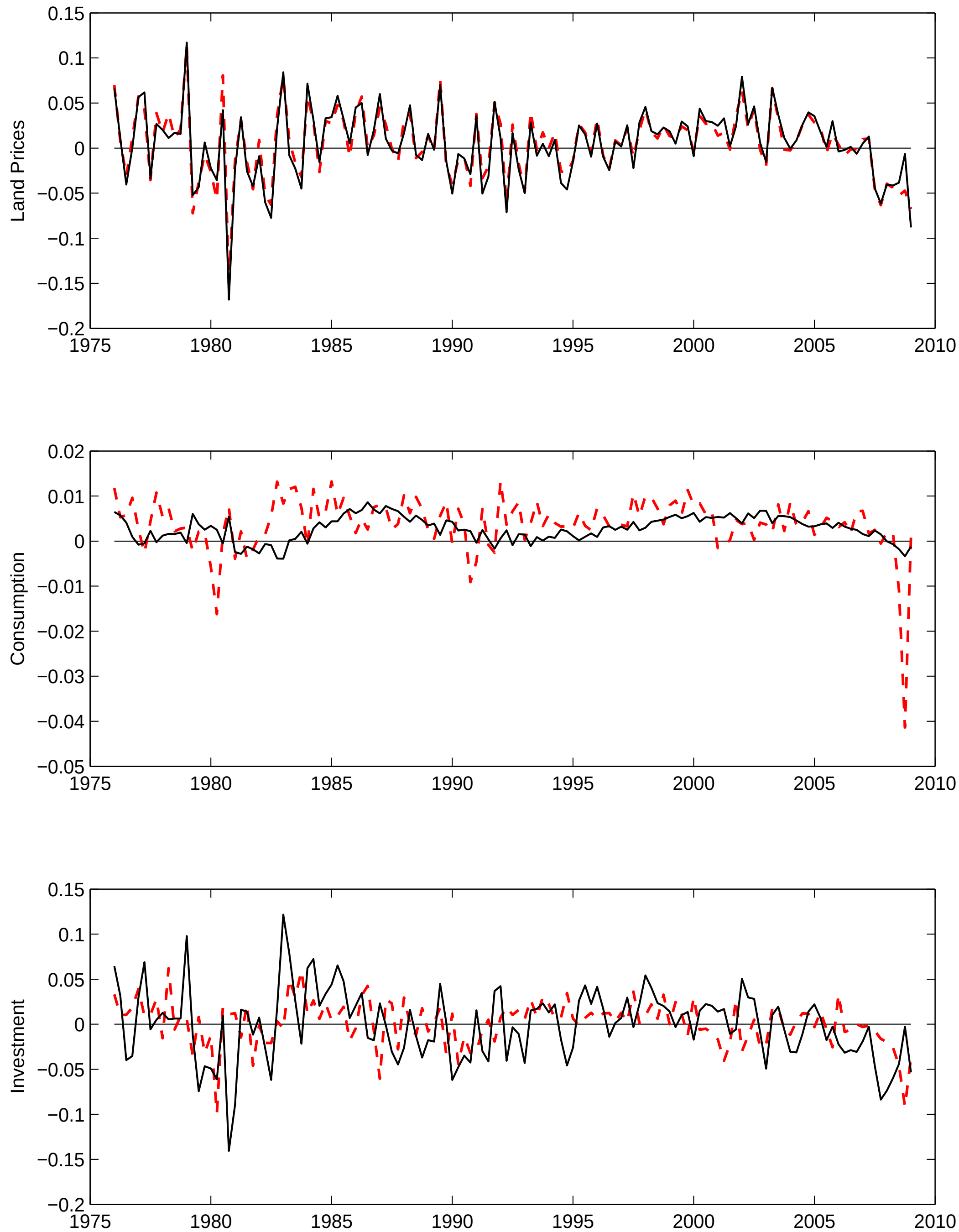

FIGURE 2. Historical paths of the land price, consumption, and investment: counterfactual versus data. Thin dashed lines represent the quarterly growth rates in the data; thick solid lines represent the simulations generated by housing demand shocks alone.

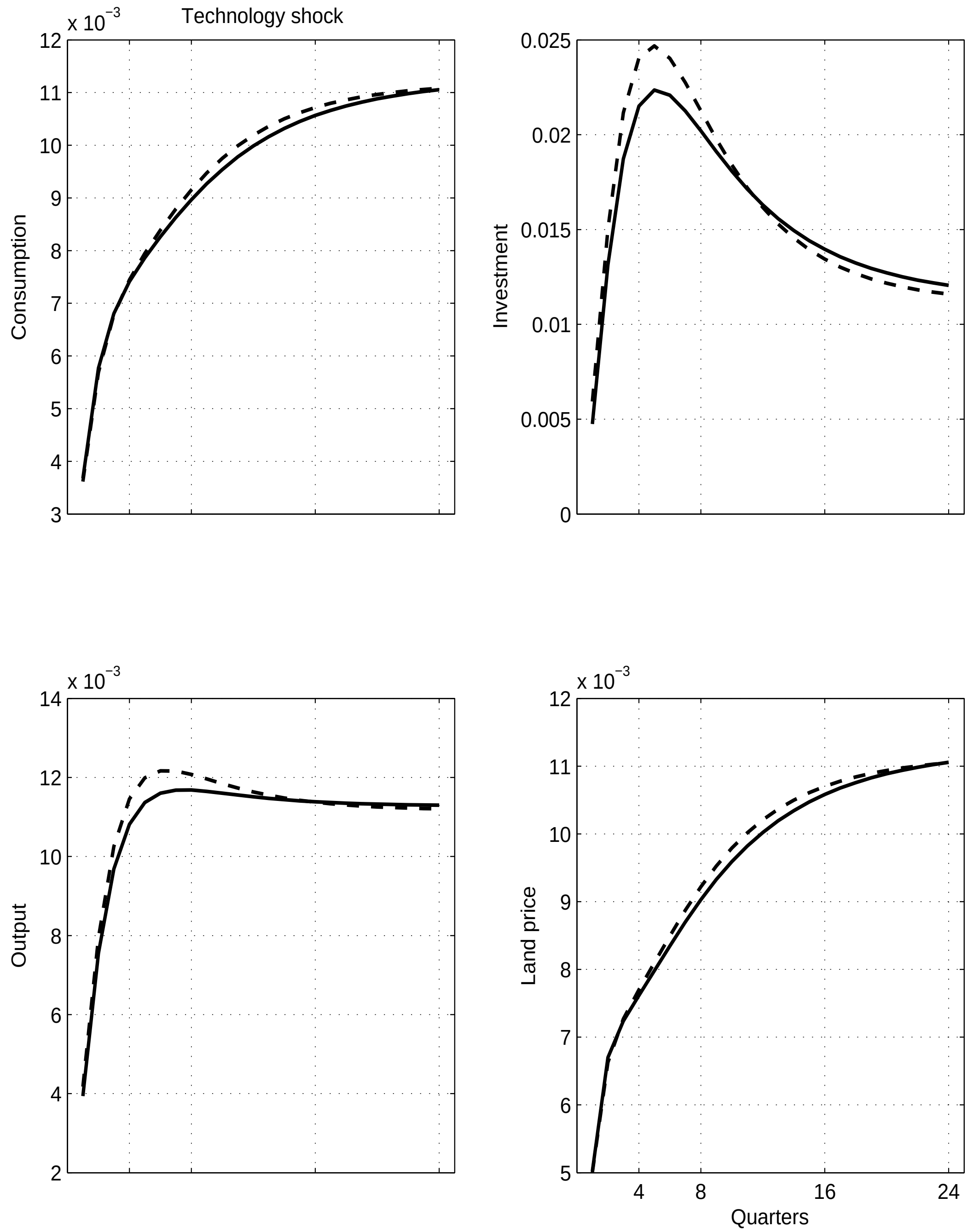

FIGURE 3. Impulse responses to a shock to neutral technology growth. Solid lines represent the model with endogenous credit limit; dashed lines represent the case with fixed credit limit.

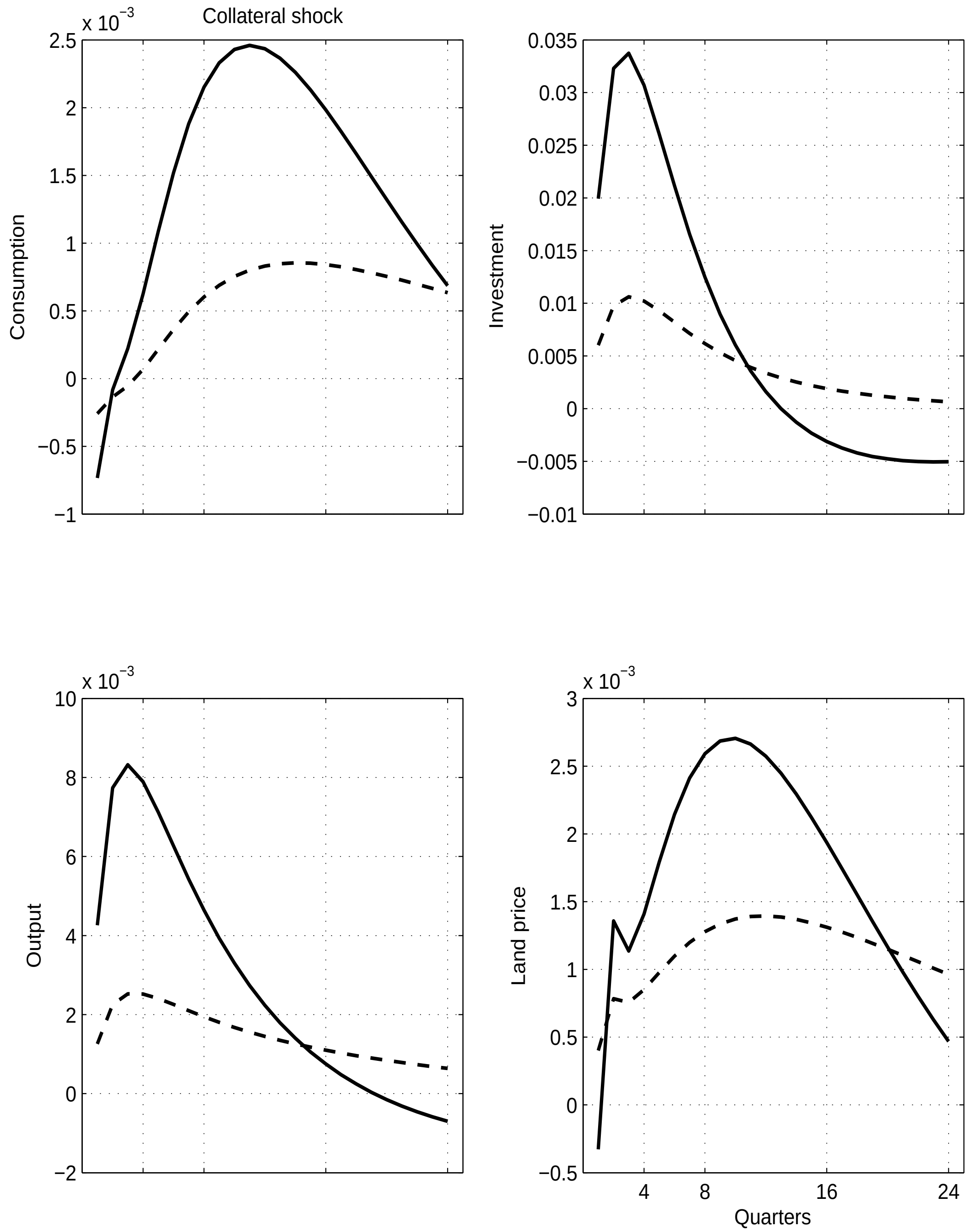

FIGURE 4. Impulse responses to a collateral shock. Solid lines represent the model with endogenous credit limit; dashed lines represent the case with fixed credit limit.

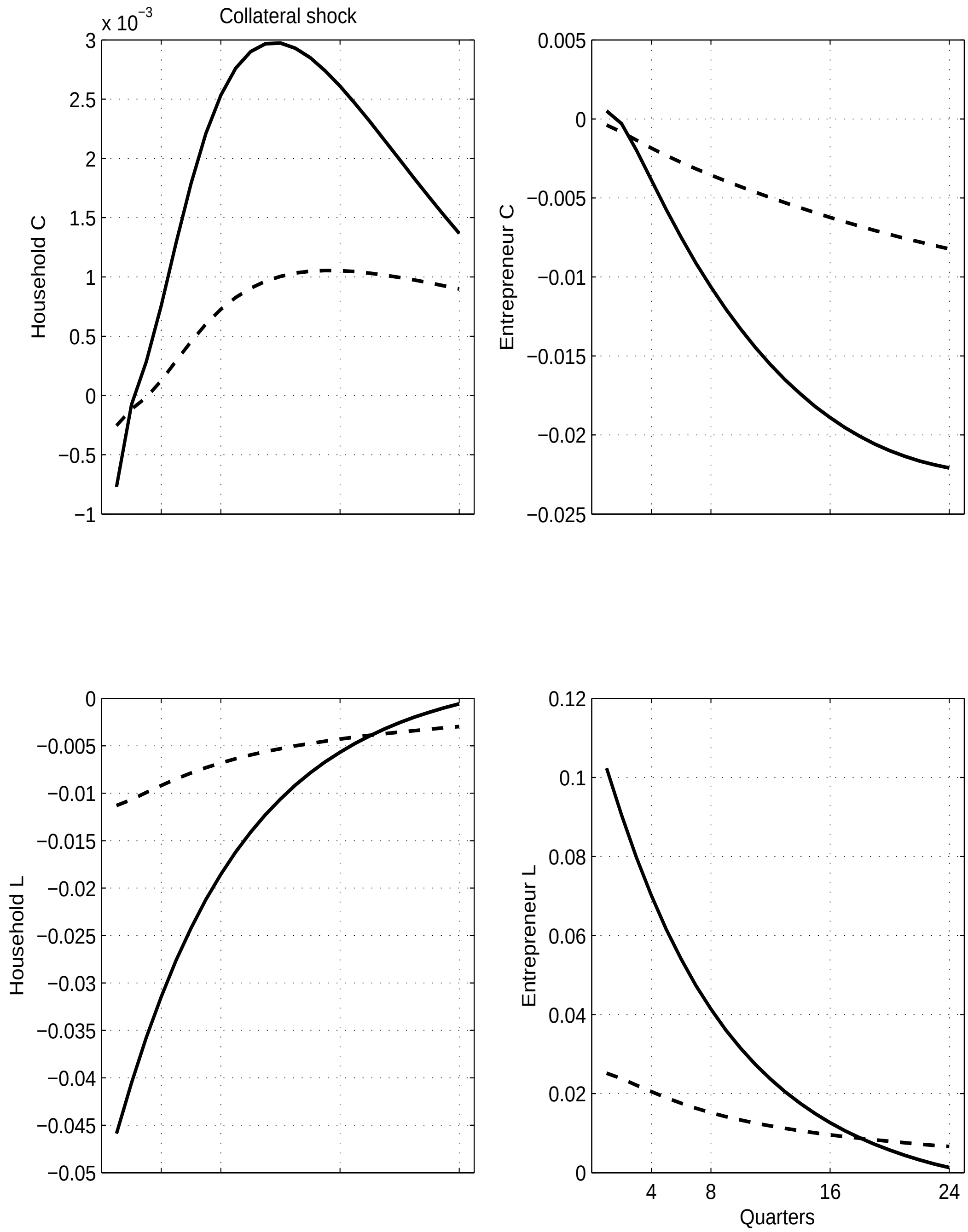

FIGURE 5. Impulse responses to a collateral shock. The letter "C" stands for "Consumption" and "L" stands for "Land." Solid lines represent the model with endogenous credit limit; dashed lines represent the case with fixed credit limit.

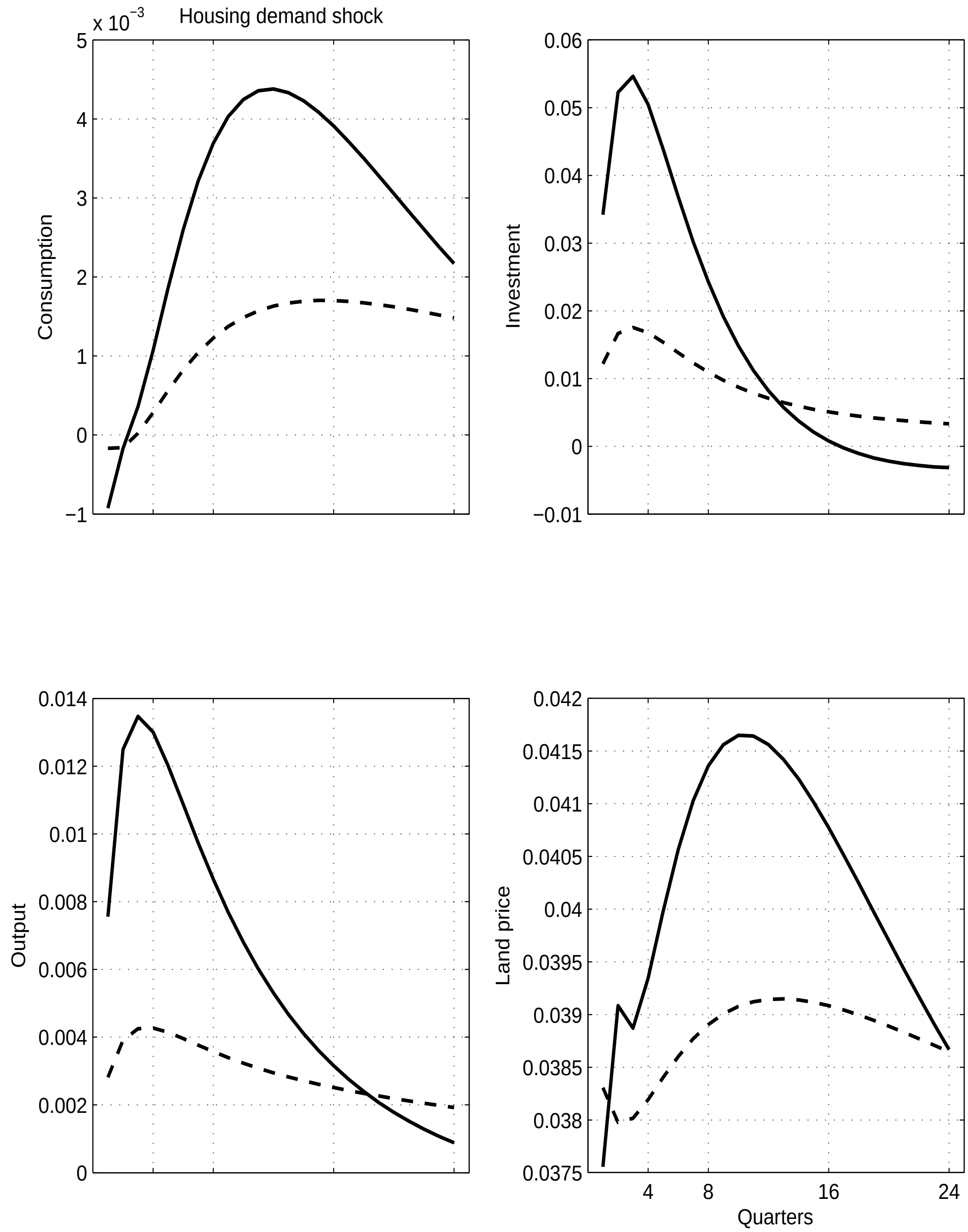

Figure 6. Impulse responses to a housing demand shock. Solid lines represent the model with endogenous credit limit; dashed lines represent the case with fixed credit limit.

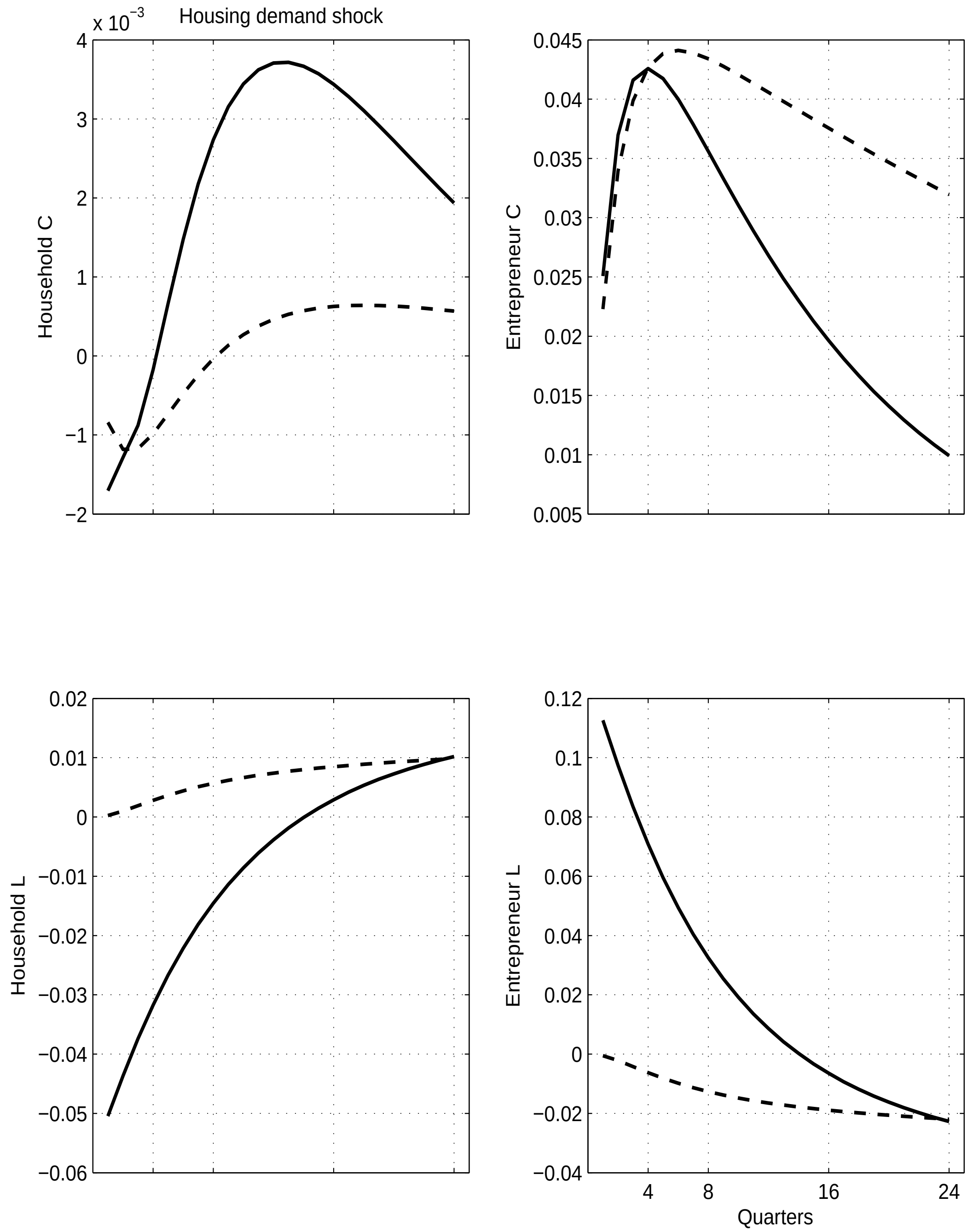

FIGURE 7. Impulse responses to a housing demand shock. The letter "C" stands for "Consumption" and "L" stands for "Land." Solid lines represent the model with endogenous credit limit; dashed lines represent the case with fixed credit limit.

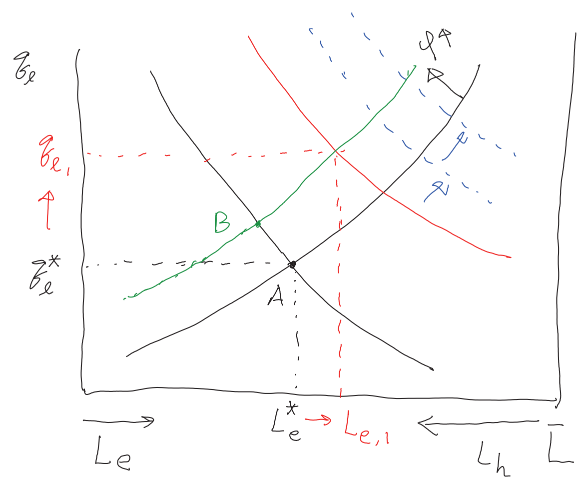

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Figure 8. Dynamic multiplier of housing prices: an illustration.

Appendix A. Data Description

All data are either taken directly from the Haver Analytics Database or constructed by Patrick Higgins at the Federal Reserve Bank of Atlanta. The construction methods are described below.

The model estimation is based on six U.S. aggregate variables: the relative price of land (q_{lt}^{Data}), the inverse of the relative price of investment (Q_t^{Data}), real per capita consumption (C_t^{Data}), real per capita investment in consumption units (I_t^{Data}), real per capita nonfinancial business debt (B_t^{Data}), and per capita hours (L_t^{Data}).

These series are derived as follows.

- $q_{lt}^{\text{Data}} = \frac{\text{LiqLAND\_PI\_OFHEO}}{\text{PriceNonDurPlusServExHous}}$;
- $Q_t^{\text{Data}} = \frac{\text{PriceNonDurPlusServExHous}}{\text{GordonPriceCDplusES}}$;
- $C_t^{\text{Data}} = \frac{(\text{NomConsNHSplusND})/\text{PriceNonDurPlusServExHous}}{\text{LNNReviseQtr}}$;
- $I_t^{\text{Data}} = \frac{(\text{CD@USECON} + \text{FNE@USECON})/\text{PriceNonDurPlusServExHous}}{\text{LNNReviseQtr}}$;
- $B_t^{\text{Data}} = \frac{(\text{PL10TCR5@FFUNDS} + \text{PL11CRE5@FFUNDS})/\text{PriceNonDurPlusServExHous}}{\text{LNNReviseQtr}}$;
- $L_t^{\text{Data}} = \frac{\text{LXNFH@USECON}}{\text{LNNReviseQtr}}$.

The original data, the constructed data, and their sources are described as follows.

LNNReviseQtr: civilian noninstitutional population with ages 16 years and over (NSA, Thous) by eliminating breaks in population from 10-year censuses and post 2000 American Community Surveys using "error of closure" method. This fairly simple method is used by the Census Bureau to get a smooth monthly population series to reduce the unusual influence of drastic demographic changes. The detailed explanation can be found in http://www.census.gov/popest/archives/methodology/intercensal_nat_meth.html. Source: BLS.

PriceNonDurPlusServExHous: the consumption deflator. The Tornqvist procedure is used to construct this deflator as a weighted aggregate index from nondurables consumption and services consumption excluding housing services. Source: BEA.

LiqLAND_PI_OFHEO: the liquidity-adjusted price index for residential land from Davis and Heathcote (2007) (http://www.marginalq.com/morris/landdata.html). The adjustment methods of Quart and Quigley (1989, 1991) are used to be consistent with the volatility measure provided by Lin and Liu (2008).

GordonPriceCDplusES: the quality-adjusted price index for consumer durable goods, equipment investment, and software investment. This index is a weighted one from a number of individual price series within this category. For each individual price series from 1947 to 1983, we use Gordon (1990)'s quality-adjusted price index. Following Cummins and Violante (2002), we estimate an econometric model of Gordon's price series as a function of a time trend and a few macroeconomic indicators in the National Income and Product Account (NIPA), including the current and lagged values of the corresponding NIPA price series; the estimated coefficients are then used to extrapolate the quality-adjusted price index for each individual price series for the sample from 1984 to 2008. These constructed price series are annual. We use Denton (1971)'s method to interpolate these annual series on a quarterly frequency. We then use the Tornquist procedure to construct the quality-adjusted price index from the interpolated individual quarterly price series. Source: BEA.

NomConsNHSplusND: nominal personal consumption expenditures: non-housing services and nondurable goods. Source: BEA.

CD@USECON: nominal personal consumption expenditures: durable goods. Source: BEA.

FNE@USECON: nominal private nonresidential investment: equipment & software. Source: BEA.

PL10TCR5@FFUNDS: nonfarm nonfinancial corporation business liabilities: credit market debt. Source: BEA.

PL11CRE5@FFUNDS: nonfarm nonfinancial noncorporate business liabilities: credit market instruments. Source: BEA.

LXNFH@USECON: nonfarm business sector: hours of all persons (1992=100). Source: BLS.

Appendix B. Detailed derivations

B.1. **The excess returns.** In this section, we provide an intuitive derivation of the first-order excess returns in the presence of binding credit constraints.

The representative entrepreneur has two types of assets: land and capital. Each asset can be intuitively thought of as a Lucas tree bearing fruits and growing at a gross rate of g_γ. The entrepreneur can trade a portion of the tree in the market, and the return on this tree depends on the price of a unit of the tree as well as the marginal product (fruit) of the remaining tree. In steady state, it should be g_γ/β. To see if this intuition works in the model when the entrepreneur faces the borrowing constraint, we first derive the expected return on each of these assets. We begin with the return on land.

Suppose the entrepreneur purchases one unit of land at the price q_{lt} in period t. Since she can pledge a fraction θ_t of the present value of the land as a collateral, the net out-of-pocket payment (i.e., the down payment) to purchase the land is given by

$$u_t \equiv q_{lt} - \theta_t \mathrm{E}_t \frac{q_{l,t+1}}{R_t}, \tag{A1}$$

where R_t is the loan rate. The land is used for period $t+1$ production and yields $\phi\alpha Y_{t+1}/L_{et}$ units of extra output. In addition, the entrepreneur can keep the remaining value of the land in period $t+1$ after repaying the debt so that the total payoff from the land is $\phi\alpha Y_{t+1}/L_{et} + q_{l,t+1} - \theta_t \mathrm{E}_t q_{l,t+1}$. The return on the land from period t to $t+1$ is thus given by

$$R_{l,t+1} = \frac{\phi\alpha Y_{t+1}/L_{et} + q_{l,t+1} - \theta_t \mathrm{E}_t q_{l,t+1}}{q_{lt} - \theta_t \mathrm{E}_t \frac{q_{l,t+1}}{R_t}}. \tag{A2}$$

We can similarly derive the return on capital, which is given by

$$R_{k,t+1} = \frac{\phi\alpha Y_{t+1}/K_t + q_{k,t+1}(1-\delta) - \theta_t \mathrm{E}_t q_{k,t+1}}{q_{kt} - \theta_t \mathrm{E}_t \frac{q_{k,t+1}}{R_t}}. \tag{A3}$$

To see how these returns relate to the entrepreneur's optimal decisions, we denote by μ_{et} the Lagrangian multiplier for the flow of funds constraint (11), μ_{kt} the multiplier for the capital accumulation equation (10), and μ_{bt} the multiplier for the credit constraint (14). With these notations, the shadow price of capital in consumption units is given by

$$q_{kt} = \frac{\mu_{kt}}{\mu_{et}},$$

and the marginal utility of income, μ_{et}, is equal to the marginal utility of consumption:

$$\mu_{et} = \frac{1}{C_{et} - \gamma_e C_{e,t-1}} - \mathrm{E}_t \frac{\beta\gamma_e}{C_{e,t+1} - \gamma_e C_{et}}.$$

The optimal decision on the entrepreneur's borrowing can be described by

$$\frac{1}{R_t} = \beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} + \frac{\mu_{bt}}{\mu_{et}}. \tag{A4}$$

The above Euler equation implies that the credit constraint is binding (i.e., $\mu_{bt} > 0$) if and only if the interest rate is lower than the entrepreneur's intertemporal marginal rate of substitution. The entrepreneur's optimal decisions on land and capital can be described by the following two Euler equations:

$$q_{lt} = \beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} \left[\alpha\phi \frac{Y_{t+1}}{L_{et}} + q_{l,t+1} \right] + \frac{\mu_{bt}}{\mu_{et}} \theta_t \mathrm{E}_t q_{l,t+1}, \tag{A5}$$

$$q_{kt} = \beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} \left[\alpha(1-\phi) \frac{Y_{t+1}}{K_t} + q_{k,t+1}(1-\delta) \right] + \frac{\mu_{bt}}{\mu_{et}} \theta_t \mathrm{E}_t q_{k,t+1}. \tag{A6}$$

Using (A4), we can rewrite Equations (A5) and (A6) as

$$1 = \beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} R_{j,t+1}, \quad j \in \{l, k\}. \tag{A7}$$

Since consumption grows at the rate g_λ in equilibrium and the utility function is of logarithmic form, (A7) implies that $R_j = g_\lambda / \beta$.

On the other hand, the loan rate R_t is determined by the household's intertemporal Euler equation:

$$\frac{1}{R_t} = \beta \mathrm{E}_t \frac{\mu_{h,t+1}}{\mu_{ht}}, \tag{A8}$$

where μ_{ht} is the Lagrangian multiplier for the flow of funds constraint (5). It represents the marginal utility of income and is equal to the marginal utility of consumption:

$$\mu_{ht} = A_t \left[\frac{1}{C_{ht} - \gamma_h C_{h,t-1}} - \mathrm{E}_t \frac{\beta \gamma_h}{C_{h,t+1} - \gamma_h C_{ht}} (1 + \lambda_{a,t+1}) \right].$$

It follows from (A8) that in steady state, $R = \frac{g_\gamma}{\beta(1+\bar{\lambda}_a)}$, where $\bar{\lambda}_a > 0$ measures the extent to which the household is more patient than the entrepreneur. The steady state excess return is then given by

$$R_j^e \equiv R_j - R = \frac{g_\gamma}{\beta} \frac{\bar{\lambda}_a}{1 + \bar{\lambda}_a}, \quad j \in \{l, k\}. \tag{A9}$$

Clearly, the steady-state excess return is positive if and only if the patience factor, $\bar{\lambda}_a$, is positive.

To see how a positive first-order excess return is related to the entrepreneur's credit constraint, one can derive from (A4) the following steady state relationship:

$$\frac{\beta \bar{\lambda}_a}{g_\gamma} = \frac{\tilde{\mu}_b}{\tilde{\mu}_e}.$$

Thus, the credit constraint is binding (i.e., $\tilde{\mu}_b > 0$) if and only if the household is more patient than the entrepreneur (i.e., $\bar{\lambda}_a > 0$).

This result carries over to the dynamics of excess returns. Denote by $R^e_{j,t+1} \equiv R_{j,t+1} - R_t$ the excess return for asset $j \in \{l, k\}$. By combining the bond Euler equation (A4) and the asset-pricing equation (A7), we obtain

$$\beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} R^e_{j,t+1} = \frac{\mu_{bt}}{\mu_{et}} R_t, \quad j \in \{l, k\}. \tag{A10}$$

As in the standard asset-pricing model, the mean excess return depends on the asset's riskiness measured by the covariance between the return and the marginal utility of consumption. Unlike the standard model, however, the excess return in our model contains a first-order term that is positive if and only if the borrowing constraint is binding (i.e., $\mu_{bt} > 0$).

B.2. **Euler equations.** Denote by μ_{ht} the Lagrangian multiplier for the flow of funds constraint (5). The first-order conditions for the household's optimizing problem are given by

$$\mu_{ht} = A_t \left[\frac{1}{C_{ht} - \gamma_h C_{h,t-1}} - \mathrm{E}_t \frac{\beta \gamma_h}{C_{h,t+1} - \gamma_h C_{ht}} (1 + \lambda_{a,t+1}) \right], \tag{A11}$$

$$w_t = \frac{A_t}{\mu_{ht}} \psi_t, \tag{A12}$$

$$q_{lt} = \beta \mathrm{E}_t \frac{\mu_{h,t+1}}{\mu_{ht}} q_{l,t+1} + \frac{A_t \varphi_t}{\mu_{ht} L_{ht}}, \tag{A13}$$

$$\frac{1}{R_t} = \beta \mathrm{E}_t \frac{\mu_{h,t+1}}{\mu_{ht}}. \tag{A14}$$

Equation (A11) equates the marginal utility of income and of consumption; equation (A12) equates the real wage and the marginal rate of substitution (MRS) between leisure and income; equation (A13) equates the current relative price of land to the marginal benefit of purchasing an extra unit of land, which consists of the current utility benefits (i.e., the MRS between housing and consumption) and the land's discounted future resale value; and equation (A14) is the standard Euler equation for the loanable bond.

Denote by μ_{et} the Lagrangian multiplier for the flow of funds constraint (11), μ_{kt} the multiplier for the capital accumulation equation (10), and μ_{bt} the multiplier for the borrowing constraint (14). With these notations, the shadow price of capital in consumption units is given by

$$q_{kt} = \frac{\mu_{kt}}{\mu_{et}}. \tag{A15}$$

The first-order conditions for the entrepreneur's optimizing problem are given by

$$\mu_{et} = \frac{1}{C_{et} - \gamma_e C_{e,t-1}} - \mathrm{E}_t \frac{\beta \gamma_e}{C_{e,t+1} - \gamma_e C_{et}}, \tag{A16}$$

$$w_t = (1 - \alpha) Y_t / N_{et}, \tag{A17}$$

$$\begin{aligned} \frac{1}{Q_t} = {} & q_{kt} \left[1 - \frac{\Omega}{2} \left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I \right)^2 - \Omega \left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I \right) \frac{I_t}{I_{t-1}} \right] \\ & + \beta \Omega \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} q_{k,t+1} \left(\frac{I_{t+1}}{I_t} - \bar{\lambda}_I \right) \left(\frac{I_{t+1}}{I_t} \right)^2, \end{aligned} \tag{A18}$$

$$q_{kt} = \beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} \left[\alpha (1 - \phi) \frac{Y_{t+1}}{K_t} + q_{k,t+1} (1 - \delta) \right] + \frac{\mu_{bt}}{\mu_{et}} \theta_t \mathrm{E}_t q_{k,t+1}, \tag{A19}$$

$$q_{lt} = \beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} \left[\alpha \phi \frac{Y_{t+1}}{L_{et}} + q_{l,t+1} \right] + \frac{\mu_{bt}}{\mu_{et}} \theta_t \mathrm{E}_t q_{l,t+1}, \tag{A20}$$

$$\frac{1}{R_t} = \beta \mathrm{E}_t \frac{\mu_{e,t+1}}{\mu_{et}} + \frac{\mu_{bt}}{\mu_{et}}. \tag{A21}$$

Equation (A16) equates the marginal utility of income to the marginal utility of consumption since consumption is the numéraire; equation (A17) is the labor demand equation which equates the real wage to the marginal product of labor; equation (A18) is the investment Euler equation, which equates the cost of purchasing an additional unit of investment good and the benefit of having an extra unit of new capital, where the benefit includes the shadow value of the installed capital net of adjustment costs and the present value of the saved future adjustment costs; equation (A19) is the capital Euler equation, which equates the shadow price of capital to the present value of future marginal product of capital and the resale value of the un-depreciated capital, plus the value of capital as a collateral asset for borrowing; equation (A20) is the land Euler equation, which equates the price of the land to the present value of the future marginal product of land and the resale value, plus the value of land as a collateral asset for borrowing; equation (A21) is the bond Euler equation for the entrepreneur, which reveals that the borrowing constraint is binding (i.e., $\mu_{bt} > 0$) if and only if the interest rate is lower than the entrepreneur's intertemporal marginal rate of substitution.

B.3. **Stationary equilibrium.** We are interested in studying the fluctuations around the balanced growth path. For this purpose, we focus on a stationary equilibrium by appropriately transforming the growing variables. Specifically, we make the following transformations of the variables

$$\tilde{Y}_t \equiv \frac{Y_t}{\Gamma_t}, \quad \tilde{C}_{ht} \equiv \frac{C_{ht}}{\Gamma_t}, \quad \tilde{C}_{et} \equiv \frac{C_{et}}{\Gamma_t}, \quad \tilde{I}_t \equiv \frac{I_t}{Q_t\Gamma_t}, \quad \tilde{K}_t \equiv \frac{K_t}{Q_t\Gamma_t}, \quad \tilde{B}_t \equiv \frac{B_t}{\Gamma_t},$$

$$\tilde{w}_t \equiv \frac{w_t}{\Gamma_t}, \quad \tilde{\mu}_{ht} \equiv \frac{\mu_{ht}\Gamma_t}{A_t}, \quad \tilde{\mu}_{et} \equiv \mu_{et}\Gamma_t, \quad \tilde{\mu}_{bt} \equiv \mu_{bt}\Gamma_t, \quad \tilde{q}_{lt} \equiv \frac{q_{lt}}{\Gamma_t}, \quad \tilde{q}_{kt} \equiv q_{kt}Q_t, \tag{A22}$$

where $\Gamma_t \equiv [Z_t Q_t^{(1-\phi)\alpha}]^{\frac{1}{1-(1-\phi)\alpha}}$. In Appendix B, we describe the stationary equilibrium and derive the log-linearized equilibrium conditions around the steady state for solving the model. To solve the log-linearized equilibrium system requires the input of several key steady-state values. These include the shadow value of the loanable funds $\frac{\tilde{\mu}_b}{\tilde{\mu}_e}$, the ratio of commercial real estate to aggregate output $\frac{\tilde{q}_l L_e}{\tilde{Y}}$, the ratio of residential land to commercial real estate $\frac{L_h}{L_e}$, the ratio of loanable funds to output $\frac{\tilde{B}}{\tilde{Y}}$, the capital-output ratio $\frac{\tilde{K}}{\tilde{Y}}$, and the "big ratios" $\frac{\tilde{C}_h}{\tilde{Y}}$, $\frac{\tilde{C}_e}{\tilde{Y}}$, and $\frac{\tilde{I}}{\tilde{Y}}$. The model implies a set of restrictions between these steady-state ratios and the parameters, and we will use these restrictions along with the first moments of selected time series in the data to sharpen our priors and to help identify a subset of the parameters in our estimation.

Denote by $g_{\gamma t} \equiv \frac{\Gamma_t}{\Gamma_{t-1}}$ and $g_{qt} \equiv \frac{Q_t}{Q_{t-1}}$ the growth rates for the exogenous variables Γ_t and Q_t. Denote by g_γ the steady-state value of $g_{\gamma t}$ and $\lambda_k \equiv g_\gamma \bar{\lambda}_q$ the steady-state growth rate of capital stock. On the balanced growth path, investment grows at the same rate as does capital, so we have $\bar{\lambda}_I = \lambda_k$.

The stationary equilibrium is the solution to the following system of equations:

$$\tilde{\mu}_{ht} = \frac{1}{\tilde{C}_{ht} - \gamma_h \tilde{C}_{h,t-1}\Gamma_{t-1}/\Gamma_t} - \mathrm{E}_t \frac{\beta\gamma_h}{\tilde{C}_{h,t+1}\Gamma_{t+1}/\Gamma_t - \gamma_h \tilde{C}_{ht}}(1+\lambda_{a,t+1}), \tag{A23}$$

$$\tilde{w}_t = \frac{\psi_t}{\tilde{\mu}_{ht}}, \tag{A24}$$

$$\tilde{q}_{lt} = \beta \mathrm{E}_t \frac{\tilde{\mu}_{h,t+1}}{\tilde{\mu}_{ht}}(1+\lambda_{a,t+1})\tilde{q}_{l,t+1} + \frac{\varphi_t}{\tilde{\mu}_{ht} L_{ht}}, \tag{A25}$$

$$\frac{1}{R_t} = \beta \mathrm{E}_t \frac{\tilde{\mu}_{h,t+1}}{\tilde{\mu}_{ht}} \frac{\Gamma_t}{\Gamma_{t+1}}(1+\lambda_{a,t+1}). \tag{A26}$$

$$\tilde{\mu}_{et} = \frac{1}{\tilde{C}_{et} - \gamma_e \tilde{C}_{e,t-1}\Gamma_{t-1}/\Gamma_t} - \mathrm{E}_t \frac{\beta\gamma_e}{\tilde{C}_{e,t+1}\Gamma_{t+1}/\Gamma_t - \gamma_e \tilde{C}_{et}}, \tag{A27}$$

$$\tilde{w}_t = (1-\alpha)\tilde{Y}_t / N_t, \tag{A28}$$

$$\begin{aligned} 1 = {} & \tilde{q}_{kt}\left[1 - \frac{\Omega}{2}\left(\frac{\tilde{I}_t}{\tilde{I}_{t-1}}\frac{Q_t\Gamma_t}{Q_{t-1}\Gamma_{t-1}} - \bar{\lambda}_I\right)^2 - \Omega\left(\frac{\tilde{I}_t}{\tilde{I}_{t-1}}\frac{Q_t\Gamma_t}{Q_{t-1}\Gamma_{t-1}} - \bar{\lambda}_I\right)\frac{\tilde{I}_t}{\tilde{I}_{t-1}}\frac{Q_t\Gamma_t}{Q_{t-1}\Gamma_{t-1}}\right] \\ & + \beta\Omega \mathrm{E}_t \frac{\tilde{\mu}_{e,t+1}}{\tilde{\mu}_{et}}\frac{Q_t\Gamma_t}{Q_{t+1}\Gamma_{t+1}}\tilde{q}_{k,t+1}\left(\frac{\tilde{I}_{t+1}}{\tilde{I}_t}\frac{Q_{t+1}\Gamma_{t+1}}{Q_t\Gamma_t} - \bar{\lambda}_I\right)\left(\frac{\tilde{I}_{t+1}}{\tilde{I}_t}\frac{Q_{t+1}\Gamma_{t+1}}{Q_t\Gamma_t}\right)^2, \end{aligned} \tag{A29}$$

$$\tilde{q}_{kt} = \beta \mathrm{E}_t \frac{\tilde{\mu}_{e,t+1}}{\tilde{\mu}_{et}}\left[\alpha(1-\phi)\frac{\tilde{Y}_{t+1}}{\tilde{K}_t} + \tilde{q}_{k,t+1}\frac{Q_t\Gamma_t}{Q_{t+1}\Gamma_{t+1}}(1-\delta)\right] + \frac{\tilde{\mu}_{bt}}{\tilde{\mu}_{et}}\theta_t \mathrm{E}_t \tilde{q}_{k,t+1}\frac{Q_t}{Q_{t+1}}, \tag{A30}$$

$$\tilde{q}_{lt} = \beta \mathrm{E}_t \frac{\tilde{\mu}_{e,t+1}}{\tilde{\mu}_{et}}\left[\alpha\phi\frac{\tilde{Y}_{t+1}}{L_{et}} + \tilde{q}_{l,t+1}\right] + \frac{\tilde{\mu}_{bt}}{\tilde{\mu}_{et}}\theta_t \mathrm{E}_t \tilde{q}_{l,t+1}\frac{\Gamma_{t+1}}{\Gamma_t}, \tag{A31}$$

$$\frac{1}{R_t} = \beta \mathrm{E}_t \frac{\tilde{\mu}_{e,t+1}}{\tilde{\mu}_{et}}\frac{\Gamma_t}{\Gamma_{t+1}} + \frac{\tilde{\mu}_{bt}}{\tilde{\mu}_{et}}. \tag{A32}$$

$$\tilde{Y}_t = \left(\frac{Z_t Q_t}{Z_{t-1}Q_{t-1}}\right)^{-\frac{(1-\phi)\alpha}{1-(1-\phi)\alpha}} [L_{e,t-1}^{\phi}\tilde{K}_{t-1}^{1-\phi}]^{\alpha} N_t^{1-\alpha}, \tag{A33}$$

$$\tilde{K}_t = (1-\delta)\tilde{K}_{t-1}\frac{Q_{t-1}\Gamma_{t-1}}{Q_t\Gamma_t} + \left[1 - \frac{\Omega}{2}\left(\frac{\tilde{I}_t}{\tilde{I}_{t-1}}\frac{Q_t\Gamma_t}{Q_{t-1}\Gamma_{t-1}} - \bar{\lambda}_I\right)^2\right]\tilde{I}_t, \tag{A34}$$

$$\tilde{Y}_t = \tilde{C}_{ht} + \tilde{C}_{et} + \tilde{I}_t, \tag{A35}$$

$$\bar{L} = L_{ht} + L_{et}, \tag{A36}$$

$$\alpha \tilde{Y}_t = \tilde{C}_{et} + \tilde{I}_t + \tilde{q}_{lt}(L_{et} - L_{e,t-1}) + \tilde{B}_{t-1}\frac{\Gamma_{t-1}}{\Gamma_t} - \frac{\tilde{B}_t}{R_t}, \tag{A37}$$

$$\tilde{B}_t = \theta_t \mathrm{E}_t \left[\tilde{q}_{l,t+1}\frac{\Gamma_{t+1}}{\Gamma_t} L_{et} + \tilde{q}_{k,t+1}\tilde{K}_t \frac{Q_t}{Q_{t+1}} \right]. \tag{A38}$$

We solve these 16 equations for 16 variables summarized in the vector

$$[\tilde{\mu}_{ht}, \tilde{w}_t, \tilde{q}_{lt}, R_t, \tilde{\mu}_{et}, N_t, \tilde{I}_t, \tilde{Y}_t, \tilde{C}_{ht}, \tilde{C}_{et}, \tilde{q}_{kt}, L_{et}, L_{ht}, \tilde{K}_t, \tilde{B}_t, \tilde{\mu}_{bt}]'.$$

B.4. **Steady state.** To get the steady-state value for $\frac{\tilde{\mu}_b}{\tilde{\mu}_e}$, we use the stationary bond Euler equations (A26) for the household and (A32) (described in the Appendix) to obtain

$$\frac{1}{R} = \frac{\beta(1+\bar{\lambda}_a)}{g_\gamma}, \quad \frac{\tilde{\mu}_b}{\tilde{\mu}_e} = \frac{\beta\bar{\lambda}_a}{g_\gamma}. \tag{A39}$$

Since $\bar{\lambda}_a > 0$, we have $\tilde{\mu}_b > 0$ and the borrowing constraint is binding in the steady-state equilibrium.

To get the ratio of commercial real estate to output, we use the land Euler equation (A31) for the entrepreneur, the definition of $\tilde{\mu}_e$ in (A27), and the solution for $\frac{\tilde{\mu}_b}{\tilde{\mu}_e}$ in (A39). In particular, we have

$$\frac{\tilde{q}_l L_e}{\tilde{Y}} = \frac{\beta\alpha\phi}{1-\beta-\beta\bar{\lambda}_a\bar{\theta}}. \tag{A40}$$

To get the investment-output ratio, we first solve for the investment-capital ratio by using the law of motion for capital stock in (A34) and then solve for the capital-output ratio using the capital Euler equation (A30). Specifically, we have

$$\frac{\tilde{I}}{\tilde{K}} = 1 - \frac{1-\delta}{\lambda_k}, \tag{A41}$$

$$\frac{\tilde{K}}{\tilde{Y}} = \left[1 - \frac{\beta}{\lambda_k}(\bar{\lambda}_a\bar{\theta} + 1 - \delta)\right]^{-1} \beta\alpha(1-\phi), \tag{A42}$$

where we have used the steady-state condition that $\tilde{q}_k = 1$, as implied by the investment Euler equation (A29). The investment-output ratio is then given by

$$\frac{\tilde{I}}{\tilde{Y}} = \frac{\tilde{I}}{\tilde{K}}\frac{\tilde{K}}{\tilde{Y}} = \frac{\beta\alpha(1-\phi)[\lambda_k - (1-\delta)]}{\lambda_k - \beta(\bar{\lambda}_a\bar{\theta} + 1 - \delta)}. \tag{A43}$$

Given the solution for the ratios $\frac{\tilde{q}_l L_e}{\tilde{Y}}$ and $\frac{\tilde{K}}{\tilde{Y}}$ in (A40) and (A42), the binding borrowing constraint (A38) implies that

$$\frac{\tilde{B}}{\tilde{Y}} = \bar{\theta} g_\gamma \frac{\tilde{q}_l L_e}{\tilde{Y}} + \frac{\bar{\theta}}{\bar{\lambda}_q}\frac{\tilde{K}}{\tilde{Y}}. \tag{A44}$$

The entrepreneur's flow of funds constraint (A37) implies that

$$\frac{\tilde{C}_e}{\tilde{Y}} = \alpha - \frac{\tilde{I}}{\tilde{Y}} - \frac{1-\beta(1+\bar{\lambda}_a)}{g_\gamma}\frac{\tilde{B}}{\tilde{Y}}. \tag{A45}$$

The aggregate resource constraint (A35) then implies that

$$\frac{\tilde{C}_h}{\tilde{Y}} = 1 - \frac{\tilde{C}_e}{\tilde{Y}} - \frac{\tilde{I}}{\tilde{Y}}. \tag{A46}$$

To solve for $\frac{L_h}{L_e}$, we first use the household's land Euler equation (i.e., the housing demand equation) (A25) and the definition for the marginal utility (A23) to obtain

$$\frac{\tilde{q}_l L_h}{\tilde{C}_h} = \frac{\bar{\varphi}(g_\gamma - \gamma_h)}{g_\gamma(1-g_\gamma/R)(1-\gamma_h/R)}, \tag{A47}$$

where the steady-state loan rate is given by (A39).

Taking the ratio between (A47) and (A40) results in the solution

$$\frac{L_h}{L_e} = \frac{\bar{\varphi}(g_\gamma - \gamma_h)(1-\beta-\beta\bar{\lambda}_a\bar{\theta})}{\beta\alpha\phi g_\gamma(1-g_\gamma/R)(1-\gamma_h/R)}\frac{\tilde{C}_h}{\tilde{Y}}. \tag{A48}$$

Finally, we can solve for the steady-state hours by combining the labor supply equation (A24) and the labor demand equation (A28) to get

$$N = \frac{(1-\alpha)g_\gamma(1-\gamma_h/R)}{\bar{\psi}(g_\gamma - \gamma_h)}\frac{\tilde{Y}}{\tilde{C}_h}. \tag{A49}$$

B.5. **Log-linearized equilibrium system.** Upon obtaining the steady-state equilibrium, we log-linearize the equilibrium conditions (A23) through (A38) around the steady state. We define the constants $\Omega_h \equiv (g_\gamma - \beta(1+\bar{\lambda}_a)\gamma_h)(g_\gamma - \gamma_h)$ and $\Omega_e \equiv (g_\gamma - \beta\gamma_e)(g_\gamma - \gamma_e)$. The log-linearized equilibrium conditions are given by

$$\begin{aligned}
\Omega_h\hat{\mu}_{ht} &= -[g_\gamma^2 + \gamma_h^2\beta(1+\bar{\lambda}_a)]\hat{C}_{ht} + g_\gamma\gamma_h(\hat{C}_{h,t-1} - \hat{g}_{\gamma t}) \\
&\quad -\beta\bar{\lambda}_a\gamma_h(g_\gamma - \gamma_h)\mathrm{E}_t\hat{\lambda}_{a,t+1} + \beta(1+\bar{\lambda}_a)g_\gamma\gamma_h\mathrm{E}_t(\hat{C}_{h,t+1} + \hat{g}_{\gamma,t+1}), && \text{(A50)}\\
\hat{w}_t + \hat{\mu}_{ht} &= \hat{\psi}_t, && \text{(A51)}\\
\hat{q}_{lt} + \hat{\mu}_{ht} &= \beta(1+\bar{\lambda}_a)\mathrm{E}_t\left[\hat{\mu}_{h,t+1} + \hat{q}_{l,t+1}\right] \\
&\quad +[1-\beta(1+\bar{\lambda}_a)](\hat{\varphi}_t - \hat{L}_{ht}) + \beta\bar{\lambda}_a\mathrm{E}_t\hat{\lambda}_{a,t+1}, && \text{(A52)}\\
\hat{\mu}_{ht} - \hat{R}_t &= \mathrm{E}_t\left[\hat{\mu}_{h,t+1} + \frac{\bar{\lambda}_a}{1+\bar{\lambda}_a}\hat{\lambda}_{a,t+1} - \hat{g}_{\gamma,t+1}\right], && \text{(A53)}\\
\Omega_e\hat{\mu}_{et} &= -(g_\gamma^2 + \beta\gamma_e^2)\hat{C}_{e,t} + g_\gamma\gamma_e(\hat{C}_{e,t-1} - \hat{g}_{\gamma t}) + \beta g_\gamma\gamma_e\mathrm{E}_t(\hat{C}_{e,t+1} + \hat{g}_{\gamma,t+1}), && \text{(A54)}\\
\hat{w}_t &= \hat{Y}_t - \hat{N}_t, && \text{(A55)}\\
\hat{q}_{kt} &= (1+\beta)\Omega\lambda_k^2\hat{I}_t - \Omega\lambda_k^2\hat{I}_{t-1} + \Omega\lambda_k^2(\hat{g}_{\gamma t} + \hat{g}_{qt})
\end{aligned}$$

$$-\beta\Omega\lambda_k^2 \mathrm{E}_t[\hat{I}_{t+1}+\hat{g}_{\gamma,t+1}+\hat{g}_{q,t+1}], \tag{A56}$$

$$\begin{aligned}\hat{q}_{kt}+\hat{\mu}_{et} &= \frac{\tilde{\mu}_b}{\tilde{\mu}_e}\frac{\bar{\theta}}{\bar{\lambda}_q}(\hat{\mu}_{bt}+\hat{\theta}_t)+\frac{\beta(1-\delta)}{\lambda_k}\mathrm{E}_t(\hat{q}_{k,t+1}-\hat{g}_{q,t+1}-\hat{g}_{\gamma,t+1})+\left(1-\frac{\tilde{\mu}_b}{\tilde{\mu}_e}\frac{\bar{\theta}}{\bar{\lambda}_q}\right)\mathrm{E}_t\hat{\mu}_{e,t+1}\\ &\quad +\frac{\tilde{\mu}_b}{\tilde{\mu}_e}\frac{\bar{\theta}}{\bar{\lambda}_q}\mathrm{E}_t(\hat{q}_{k,t+1}-\hat{g}_{q,t+1})+\beta\alpha(1-\phi)\frac{\tilde{Y}}{\tilde{K}}\mathrm{E}_t(\hat{Y}_{t+1}-\hat{K}_t),\end{aligned} \tag{A57}$$

$$\begin{aligned}\hat{q}_{lt}+\hat{\mu}_{et} &= \frac{\tilde{\mu}_b}{\tilde{\mu}_e}g_\gamma\bar{\theta}(\hat{\theta}_t+\hat{\mu}_{bt})+\left(1-\frac{\tilde{\mu}_b}{\tilde{\mu}_e}g_\gamma\theta\right)\mathrm{E}_t\hat{\mu}_{e,t+1}+\frac{\tilde{\mu}_b}{\tilde{\mu}_e}g_\gamma\bar{\theta}\mathrm{E}_t(\hat{q}_{l,t+1}+\hat{g}_{\gamma,t+1})\\ &\quad +\beta\mathrm{E}_t\hat{q}_{l,t+1}+(1-\beta-\beta\bar{\lambda}_a\bar{\theta})\mathrm{E}_t[\hat{Y}_{t+1}-\hat{L}_{et}],\end{aligned} \tag{A58}$$

$$\hat{\mu}_{et}-\hat{R}_t = \frac{1}{1+\bar{\lambda}_a}\left[\mathrm{E}_t(\hat{\mu}_{e,t+1}-\hat{g}_{\gamma,t+1})+\bar{\lambda}_a\hat{\mu}_{bt}\right], \tag{A59}$$

$$\hat{Y}_t = \alpha\phi\hat{L}_{e,t-1}+\alpha(1-\phi)\hat{K}_{t-1}+(1-\alpha)\hat{N}_t-\frac{(1-\phi)\alpha}{1-(1-\phi)\alpha}[\hat{g}_{zt}+\hat{g}_{qt}], \tag{A60}$$

$$\hat{K}_t = \frac{1-\delta}{\lambda_k}[\hat{K}_{t-1}-\hat{g}_{\gamma t}-\hat{g}_{qt}]+\left(1-\frac{1-\delta}{\lambda_k}\right)\hat{I}_t, \tag{A61}$$

$$\hat{Y}_t = \frac{\tilde{C}_h}{\tilde{Y}}\hat{C}_{ht}+\frac{C_e}{\tilde{Y}}\hat{C}_{e,t}+\frac{\tilde{I}}{\tilde{Y}}\hat{I}_t, \tag{A62}$$

$$0 = \frac{L_h}{\bar{L}}\hat{L}_{ht}+\frac{L_e}{\bar{L}}\hat{L}_{et}, \tag{A63}$$

$$\begin{aligned}\alpha\hat{Y}_t &= \frac{\tilde{C}_e}{\tilde{Y}}\hat{C}_{e,t}+\frac{\tilde{I}}{\tilde{Y}}\hat{I}_t+\frac{\tilde{q}_l L_e}{\tilde{Y}}(\hat{L}_{et}-\hat{L}_{e,t-1})\\ &\quad +\frac{1}{g_\gamma}\frac{\tilde{B}}{\tilde{Y}}(\hat{B}_{t-1}-\hat{g}_{\gamma t})-\frac{1}{R}\frac{\tilde{B}}{\tilde{Y}}(\hat{B}_t-\hat{R}_t),\end{aligned} \tag{A64}$$

$$\begin{aligned}\hat{B}_t &= \hat{\theta}_t+g_\gamma\bar{\theta}\frac{\tilde{q}_l L_e}{\tilde{B}}\mathrm{E}_t(\hat{q}_{l,t+1}+\hat{L}_{et}+\hat{g}_{\gamma,t+1})\\ &\quad +\left(1-g_\gamma\bar{\theta}\frac{\tilde{q}_l L_e}{\tilde{B}}\right)\mathrm{E}_t(\hat{q}_{k,t+1}+\hat{K}_t-\hat{g}_{q,t+1}).\end{aligned} \tag{A65}$$

The terms $\hat{g}_{zt}$, $\hat{g}_{qt}$, and $\hat{g}_{\gamma t}$ are given by

$$\hat{g}_{zt} = \hat{\lambda}_{zt}+\hat{\nu}_{zt}-\hat{\upsilon}_{z,t-1}, \tag{A66}$$

$$\hat{g}_{qt} = \hat{\lambda}_{qt}+\hat{\nu}_{qt}-\hat{\upsilon}_{q,t-1}, \tag{A67}$$

$$\hat{g}_{\gamma t} = \frac{1}{(1-(1-\phi)\alpha)}\hat{g}_{zt}+\frac{(1-\phi)\alpha}{(1-(1-\phi)\alpha)}\hat{g}_{qt}. \tag{A68}$$

The technology shocks follow the processes

$$\hat{\lambda}_{zt} = \rho_z\hat{\lambda}_{z,t-1}+\hat{\varepsilon}_{zt}, \tag{A69}$$

$$\hat{\nu}_{zt} = \rho_{\nu_z}\hat{\nu}_{z,t-1}+\hat{\varepsilon}_{\nu_z t}, \tag{A70}$$

$$\hat{\lambda}_{qt} = \rho_q\hat{\lambda}_{q,t-1}+\hat{\varepsilon}_{qt}, \tag{A71}$$

$$\hat{\nu}_{qt} = \rho_{\nu_q}\hat{\nu}_{q,t-1} + \hat{\varepsilon}_{\nu_q t}. \tag{A72}$$

$$\tag{A73}$$

There preference shocks follow the processes

$$\hat{\lambda}_{at} = \rho_a\hat{\lambda}_{a,t-1} + \hat{\varepsilon}_{at}, \tag{A74}$$

$$\hat{\varphi}_t = \rho_\varphi\hat{\varphi}_{t-1} + \hat{\varepsilon}_{\varphi t}, \tag{A75}$$

$$\hat{\psi}_t = \rho_\psi\hat{\psi}_{t-1} + \hat{\varepsilon}_{\psi t}. \tag{A76}$$

The liquidity shock follows the process

$$\hat{\theta}_t = \rho_\theta\hat{\theta}_{t-1} + \hat{\varepsilon}_{\theta t}. \tag{A77}$$

We solve the 19 equations (A50) through (A68) for the 19 unknowns in the vector

$$x_t = [\hat{\mu}_{ht}, \hat{w}_t, \hat{q}_{lt}, \hat{R}_t, \hat{\mu}_{et}, \hat{\mu}_{bt}, \hat{N}_t, \hat{I}_t, \hat{Y}_t, \hat{C}_{ht}, \hat{C}_{et}, \hat{q}_{kt}, \hat{L}_{ht}, \hat{L}_{et}, \hat{K}_t, \hat{B}_t, \hat{g}_{\gamma t}, \hat{g}_{zt}, \hat{g}_{qt}]'.$$

The state variables consist of the predetermined variables and the exogenous forcing processes summarized in the vector

$$s_t = [\hat{C}_{h,t-1}, \hat{C}_{e,t-1}, \hat{I}_{t-1}, \hat{L}_{e,t-1}, \hat{K}_{t-1}, \hat{B}_{t-1}, \hat{\lambda}_{zt}, \hat{\nu}_t, \hat{\lambda}_{qt}, \hat{\mu}_t, \hat{\lambda}_{at}, \hat{\varphi}_t, \hat{\psi}_t, \hat{\theta}_t]'$$

We use Chris Sims's gensys algorithm to solve the model.

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