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ARTICLE

Financial frictions and uncertainty shocks

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Abstract
This paper examines how credit constraints shape the transmission of uncertainty shocks in business cycles. Standard models struggle to capture the simultaneous declines in output, consumption, investment, and labor hours during uncertainty spikes. We introduce collateral-based credit constraints for impatient households and entrepreneurs, linking their borrowing capacity to asset values. As uncertainty rises, higher risk premia reduce the demand for collateral assets, prompting impatient households to cut labor supply, leading to an output decline. Our model generates macroeconomic co-movements without relying on nominal rigidities. Lowering the loan-to-value (LTV) ratio, particularly for households, helps mitigate these adverse effects.

Keywords: uncertainty; co-movement problem; financial friction

JEL classifications: E21; E32; E44

1. Introduction

In recent years, a growing body of literature has explored the macroeconomic implications of uncertainty shocks. Several empirical studies show that heightened uncertainty leads to simultaneous declines in output, consumption, investment, and labor hours (Jurado et al. 2015; Fernández-Villaverde et al. 2015; Baker et al. 2016; Basu and Bundick, 2017; Carriero et al. 2018; Oh, 2020; Cross et al. 2023). However, when researchers incorporate uncertainty shocks into standard business cycle models, the resulting predictions often diverge from the empirical evidence outlined above. This discrepancy arises because increased uncertainty amplifies precautionary motives among households, causing them to reduce consumption while increasing labor supply. With technology and capital stock unchanged, the additional labor supply boosts output. The rise in output, coupled with reduced consumption, implies an increase in investment. These predictions, however, stand in stark contrast to observed macroeconomic dynamics, where heightened uncertainty consistently coincides with contractions across key aggregates.[1]

This disconnect, widely recognized as the "co-movement problem," highlights a significant limitation in traditional business cycle models. Given technology and capital remain constant when uncertainty rises, the core challenge lies in explaining why labor hours decline as empirical evidence suggests. The existing literature primarily focuses on factors affecting labor demand, such as irreversible hiring (Leduc and Liu, 2016), non-convex adjustment costs (Bloom et al. 2018), risky hiring (Arellano et al. 2019), and precautionary pricing (Basu and Bundick, 2017; Born and Pfeifer, 2021), to explain the reduction in labor hours during uncertain times. While these mechanisms provide useful insights, they leave a gap in understanding the supply-side factors behind the decline in labor hours following uncertainty shocks.

Recent work by Lee et al. (2024) highlights the need to consider both demand-side and supply-side factors in explaining fluctuations in labor market outcomes over the business cycle. A key distinction between these channels lies in their respective effects on real wages and labor hours: demand shocks typically lead to a positive co-movement between the two, whereas supply shocks result in a negative co-movement following economic shocks. While the decline in average hours is a relatively robust empirical finding, the literature offers more mixed evidence on wage responsesseveral earlier studies report confidence intervals for real wages that include zero, indicating greater uncertainty on this margin.[2] A recent study by Cross et al. (2023), using a Bayesian vector autoregression framework, finds that average hours decline and nominal hourly earnings rise significantly in response to uncertainty shocks (see Figure 7, p. 13 of Cross et al. (2023)).[3] These results point to a critical role for supply-side mechanisms in the propagation of uncertainty shocks. Yet, much of the literature continues to emphasize demand-side channels, leaving the supply-side largely underexplored. This paper addresses that gap by proposing a supply-side transmission mechanism in which heightened uncertainty interacts with the procyclicality of household debt to reduce labor supply, in line with the evidence presented by Campbell and Hercowitz (2011).

Complementing this focus, a growing body of research highlights the important role of financial frictions in shaping labor market dynamics. Mumtaz and Zanetti (2015) employ a time-varying VAR model to trace how technology shocks propagate through the labor market. Building on this, Mumtaz and Zanetti (2016) show that models combining financial and search frictionsespecially those featuring nominal debt contractsfit the data better than models incorporating only one type of friction. Similarly, Zanetti (2019) develops a general equilibrium framework linking firms' financial decisions to labor outcomes, demonstrating that financial shocks affect not only debt and dividends but also wages and employment. Although these studies do not directly address uncertainty shocks, they collectively underscore the importance of jointly modeling financial and labor market frictions to better understand employment and wage dynamics over the business cycle.

Our paper builds on these insights by adopting the framework of Iacoviello (2005), which features heterogeneous agentspatient households, impatient households, and entrepreneursand the use of durable assets, such as housing or physical capital, as collateral. We extend this model to examine how uncertainty shocks exacerbate financial frictions and reshape macroeconomic dynamics. In our setting, increases in uncertainty raise risk premiums, tightening borrowing constraints and prompting adjustments in labor supply, entrepreneurial investment, and housing demand. By explicitly modeling the interaction between uncertainty, collateral constraints, and labor decisions, our analysis sheds new light on the supply-side mechanisms through which uncertainty shocks influence the macroeconomy.

In our model, patient and impatient households respond differently to uncertainty shocks due to their distinct financial positions. Patient households, similar to the representative agent in standard business cycle models, increase their labor supply and reduce consumption in response to rising uncertainty. In contrast, impatient households reduce their work hours and downsize their housing holdings due to tighter borrowing constraints and increased risks associated with collateral. This behavior arises because impatient households rely on mortgages to acquire larger properties with smaller down payments, leaving them more exposed to financial risk. Increased uncertainty amplifies the volatility of housing resale values, prompting these households to downsize their housing and reallocate expenditures to other consumption categories. This downsizing, in turn, leads to a reduction in their labor supply. When the decline in labor supply among impatient households outweighs the increase by patient households, aggregate labor hours and overall production decrease.

The reduction in aggregate labor hours lowers the marginal product of housing and capital, prompting entrepreneurs to scale back their demand for both. Additionally, heightened uncertainty reduces the attractiveness of using these assets as collateral, further reducing their demand.

As a result, investment in housing and physical capital declines. Consequently, our model demonstrates that a flexibly priced business cycle framework incorporating collateral constraints can reproduce boom-bust cycles triggered by uncertainty shocks.

Finally, uncertainty shocks in our model incorporate the financial labor supply accelerator mechanisms proposed by Campbell and Hercowitz (2011), which establish a negative relationship between the minimum down payment required for collateral and household labor supply in the representative agent framework. In our model, patient households and impatient households face different down payment requirements when purchasing housing. Specifically, patient households face higher down payment requirements because they purchase properties without relying on housing loans, while impatient households depend on borrowing. During periods of heightened uncertainty, the redistribution of housing from impatient to patient households effectively raises the overall down payment required for housing purchases. This transition contributes to a decline in aggregate labor hours, reinforcing the negative relationship between down payments and labor supply in an economy with both patient and impatient households.

A recent paper by Chatterjee, Gunawan and Kohn (2025) also examines the interaction between credit constraints and uncertainty shocks. However, our work differs in both the nature of the second-moment shock and the primary transmission mechanism. While their analysis focuses on credit uncertainty shocks, we study TFP uncertainty shocks. Moreover, in their framework, uncertainty influences labor demand through firms' borrowing capacity. In contrast, our model emphasizes how uncertainty affects households' collateral demand, thereby altering labor supply decisions. These distinctions yield different implications for aggregate responses to uncertainty.

A broader body of work also explores how various financial frictions help resolve the co-movement problem and amplify business cycle volatility. For instance, Christiano et al. (2014) introduce agency costs related to financial intermediation, emphasizing the pivotal role of volatility shocks in driving business cycle fluctuations. Arellano et al. (2019) show that uncertainty shocks increase default risk and credit spreads, prompting firms to reduce their labor demand. Gilchrist, Sim and Zakrajšek (2014) examine the relationship between uncertainty, investment, and credit spreads, underscoring how financial frictions amplify the effects of uncertainty through credit markets. Ottonello and Winberry (2020) further explore the role of financial frictions in shaping heterogeneous firm responses to monetary policy.

In line with this literature, our paper incorporates household heterogeneity and demonstrates that financial frictions associated with household indebtedness are a critical factor in the transmission of uncertainty shocks. Our model also complements the existing studies by showing how financing frictions may amplify or propagate output fluctuations in response to different types of aggregate shocks. Bernanke and Gertler (1989); Kiyotaki and Moore (1997); and Carlstrom and Fuerst (1997) show that financial frictions can amplify the output fluctuation in response to technology shocks. Iacoviello (2005), Tsai (2016), Dey and Tsai (2017), and Iacoviello and Neri (2010) show that financial frictions can amplify and propagate policy shocks. In our research, we propose that financial frictions can exacerbate and transmit uncertainty shocks.

In terms of resolving the co-movement problem associated with the uncertainty shocks, most existing studies require nominal rigidity to generate co-movement among key macroeconomic aggregates in response to an uncertainty shock.[4] However, our model can reproduce the boom-bust business cycles without relying on nominal rigidity. Born and Pfeifer (2021) show that sticky price setting is inconsistent with empirical responses to uncertainty shocks, suggesting that the common reliance on nominal price rigidity may be misplaced.[5] Katayama and Kim (2018) further show that standard two-sector sticky price models with freely mobile factors predict counterfactual increases in investment and output. By introducing imperfect intersectoral factor mobility, they demonstrate that real rigiditiesnot nominal price stickinessare essential for realistic dynamics. We further compare the effects of uncertainty shocks in two settings: our baseline model with financial frictions and flexible prices, and a model with nominal price rigidity but no financial frictions. The contraction in aggregate output is more pronounced in the former, underscoring the importance of financial frictions and real rigidities in transmitting uncertainty shocks.

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The remainder of the paper is structured as follows. Section 2 presents our baseline model, outlining its key components and the mechanisms through which financial frictions propagate uncertainty shocks. Section 3 provides a quantitative analysis, including the calibration of model parameters and simulation results. In Section 4, we conduct comparative analyses to evaluate the robustness of our findings against alternative modeling approaches, such as those with nominal rigidities. Finally, Section 5 concludes.

2. The model

Our model builds upon the framework established by Iacoviello (2005) to examine the impacts of uncertainty shocks. Within this model, time is discrete and indexed by t. There are three types of agents: patient households, impatient households, and entrepreneurs. Impatient households and entrepreneurs possess lower discount factors in comparison to patient households, leading them to borrow from the latter. Consequently, we refer to impatient households and entrepreneurs as "borrowers" and patient households as "savers." These borrowers encounter credit constraints similar to the framework proposed by Kiyotaki and Moore (1997), utilizing durable assets such as housing or physical capital as collateral to address repayment concerns that arise due to costly enforcement. Our analysis investigates the behaviors of these economic agents to examine the transmission mechanisms associated with uncertainty shocks within the model. Below, we introduce the problems faced by each agent in turn.

2.1 Patient households

There is a continuum of mass one of savers that choose consumption, $c_{s,t}$, bonds, $b_{s,t}$, housing, $h_{s,t}$, and working hours, $n_{s,t}$, to maximize their lifetime utility:[6]

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_s^t \left[\Gamma_{c,s} \cdot \frac{(c_{s,t} - \phi_c c_{s,t-1})^{1-\sigma_c} - 1}{1-\sigma_c} + J \cdot \frac{h_{s,t}^{1-\sigma_h} - 1}{1-\sigma_h} - \kappa \cdot \frac{n_{s,t}^{1+\eta}}{1+\eta} \right],$$

where E_0 represents the expectation operator conditional on information in period 0, β_s is the savers' discount factor, σ_c, σ_h and η determine the curvature of the utility function with respect to consumption, housing, and labor hours, respectively. Parameters J and κ reflect the preferences associated with housing and work. Additionally, ϕ_c measures the strength of consumption habit, and $\Gamma_{c,s} \equiv (1-\phi_c)/(1-\beta_s\phi_c)$ is a scaling factor ensuring the patient households' marginal utility of consumption is $1/c_s$ in the steady state.

Savers face a budget constraint given by:

$$c_{s,t} + q_t h_{s,t} + b_{s,t} \leq w_{s,t} n_{s,t} + q_t h_{s,t-1} + \frac{R_{t-1}}{\Pi_t} \cdot b_{s,t-1} + div_t, \tag{1}$$

where $b_{s,t}$ represents the bond holdings of savers, $w_{s,t}$ represents the real wage rate, q_t represents the relative price of housing, R_t is the nominal interest rate, Π_t is the inflation rate, and div_t is the dividend earned from owning retailers' businesses.

The first-order conditions associated with consumption, labor hours, housing, and bond holdings are as follows:

$$\lambda_{s,t} = uc_{s,t}, \tag{2}$$

$$\lambda_{s,t} w_{s,t} = -un_{s,t}, \tag{3}$$

$$\lambda_{s,t} q_t = \beta_s \mathrm{E}_t \left(\lambda_{s,t+1} q_{t+1}\right) + uh_{s,t}, \tag{4}$$

$$\lambda_{s,t} = \beta_s \mathrm{E}_t \left(\lambda_{s,t+1} \frac{R_t}{\Pi_{t+1}}\right), \tag{5}$$

where $\lambda_{s,t}$ is the Lagrange multiplier associated with the savers' budget constraints, Eq. (1), $uc_{s,t}$, $uh_{s,t}$, and $un_{s,t}$ are the first-order derivatives of the savers' utility function with respect to $c_{s,t}$, $h_{s,t}$, and $n_{s,t}$, respectively, which can be expressed as follows:

$$
\begin{aligned}
uc_{s,t} &= \Gamma_{c,s}\left\{(c_{s,t}-\phi_c c_{s,t-1})^{-\sigma_c} - \beta_s\phi_c \mathrm{E}_t\left[(c_{s,t+1}-\phi_c c_{s,t})^{-\sigma_c}\right]\right\},\\
uh_{s,t} &= Jh_{s,t}^{-\sigma_h},\\
un_{s,t} &= -\kappa n_{s,t}^{\eta}.
\end{aligned}
$$

Combing Eqs. (2) and (3) yields the optimal labor-leisure condition as follows:

$$uc_{s,t}w_{s,t} = -un_{s,t}. \tag{6}$$

Combing Eqs. (2) and (4), we obtain the optimal condition of housing for patient households as follows:

$$q_t = \mathrm{E}_t(\Lambda^s_{t+1,t}q_{t+1}) + mrs^s_{hc,t}, \tag{7}$$

where $\Lambda^s_{t+1,t} \equiv \beta_s\lambda_{s,t+1}/\lambda_{s,t}$ is savers' stochastic discount factor (SDF) and $mrs^s_{hc,t} \equiv uh_{s,t}/\lambda_{s,t}$ is savers' marginal rate of substitution (MRS) for housing with respect to non-durable goods. Because housing is a durable good, patient households select their housing so that the current housing purchase cost equals the combined benefit of the expected discounted resale value and the MRS between housing and non-durable goods.

Since the patient household can utilize both housing and bonds as savings instruments, the no-arbitrage condition dictates that the one-period return on bonds must be equal to the return from holding housing, that is,

$$\mathrm{E}_t\left(\frac{\Lambda^s_{t+1,t}R_t}{\Pi_{t+1}}\right) = \mathrm{E}_t\left(\frac{\Lambda^s_{t+1,t}q_{t+1}}{q_t}\right) + \frac{mrs^s_{hc,t}}{q_t}. \tag{8}$$

2.2 Impatient households

There is a continuum of impatient households with mass one who choose consumption, $c_{b,t}$, bonds, $b_{b,t}$, housing, $h_{b,t}$, and working hours, $n_{b,t}$, to maximize their expected lifetime utility:

$$\mathrm{E}_0\sum_{t=0}^{\infty}\beta_b^t\left[\Gamma_{c,b}\cdot\frac{(c_{b,t}-\phi_c c_{b,t-1})^{1-\sigma_c}-1}{1-\sigma_c} + J\cdot\frac{h_{b,t}^{1-\sigma_h}-1}{1-\sigma_h} - \kappa\cdot\frac{n_{b,t}^{1+\eta}}{1+\eta}\right],$$

where β_b is the discount factor of impatient households. We assume $\beta_b < \beta_s$ to ensure that the credit constraints for impatient households are binding in equilibrium. In addition, $\Gamma_{c,b} \equiv (1-\phi_c)/(1-\beta_b\phi_c)$ denotes the scaling factor that ensures the impatient households' marginal utility of consumption is $1/c_b$ in the steady state.

The budget constraint for impatient households is:

$$c_{b,t} + q_t h_{b,t} + b_{b,t} \le w_{b,t}n_{b,t} + q_t h_{b,t-1} + \frac{R_{t-1}}{\Pi_t}\cdot b_{b,t-1}, \tag{9}$$

where $b_{b,t}$ represents the bond holdings of the impatient households, and $w_{b,t}$ is the wage rate for the impatient households.

Furthermore, houses have a dual role for impatient households, serving as both residences and collateral assets. Specifically, the impatient households face borrowing limits, which are related to a fraction $m_b \in [0, 1]$ of their housing value:

$$-b_{b,t} \le m_b \mathrm{E}_t\left(\frac{\Pi_{t+1}}{R_t}\cdot q_{t+1}\right)h_{b,t}, \tag{10}$$

where m_b represents the loan-to-value (LTV) ratio.

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We then derive the first-order conditions associated with impatient households' problems for $c_{b,t}$, $n_{b,t}$, $h_{b,t}$, and $b_{b,t}$:

$$\lambda_{b,t} = uc_{b,t}, \tag{11}$$

$$\lambda_{b,t} w_{b,t} = -un_{b,t}, \tag{12}$$

$$\lambda_{b,t} q_t = \mathrm{E}_t(\beta_b \lambda_{b,t+1} q_{t+1} + \rho_{b,t} m_b q_{t+1} \Pi_{t+1}) + uh_{b,t}, \tag{13}$$

$$\lambda_{b,t} = \beta_b \mathrm{E}_t \left(\lambda_{b,t+1} \frac{R_t}{\Pi_{t+1}} \right) + \rho_{b,t} R_t, \tag{14}$$

where $\lambda_{b,t}$ denotes the Lagrange multiplier associated with the budget constraint, Eq. (9), and $\rho_{b,t}$ is Lagrange multiplier associated with the collateral constraint, Eq. (10). $uc_{b,t}$, $uh_{b,t}$, and $un_{b,t}$ denote respectively the first derivatives of the impatient households' utility with respect to $c_{b,t}$, $h_{b,t}$, and $n_{b,t}$, which can be expressed as follows:

$$uc_{b,t} = \Gamma_{c,b} \left\{ (c_{b,t} - \phi_c c_{b,t-1})^{-\sigma_c} - \beta_b \phi_c \mathrm{E}_t [(c_{b,t+1} - \phi_c c_{b,t})^{-\sigma_c}] \right\}, \tag{15}$$

$$uh_{b,t} = J h_{b,t}^{-\sigma_h}, \tag{16}$$

$$un_{b,t} = -\kappa n_{b,t}^{\eta}. \tag{17}$$

The main difference between the optimal conditions of the patient households and the impatient households lies in their housing choices. Combining Eqs. (13) and (14), we can derive the optimal housing condition for impatient households as follows:

$$q_t = \mathrm{E}_t(\Lambda_{t+1,t}^{b} q_{t+1}) + m_b \mathrm{E}_t \left(\frac{\Pi_{t+1}}{R_t} \cdot q_{t+1} \right) - m_b \mathrm{E}_t \left(\frac{\Lambda_{t+1,t}^{b}}{\Pi_{t+1}} \right) \mathrm{E}_t(\Pi_{t+1} q_{t+1}) + mrs_{hc,t}^{b}, \tag{18}$$

where $\Lambda_{t+1,t}^{b} \equiv \beta_b \lambda_{b,t+1} / \lambda_{b,t}$ is impatient households' SDF and $mrs_{hc,t}^{b} \equiv uh_{b,t} / \lambda_{b,t}$ is their MRS for housing with respect to non-durable goods. Using $\mathrm{E}_t(\frac{\Lambda_{t+1,t}^{b}}{\Pi_{t+1}}) \mathrm{E}_t(\Pi_{t+1} q_{t+1}) \approx \mathrm{E}_t(\Lambda_{t+1,t}^{b} q_{t+1})$, we can approximate Eq. (18) as:

$$q_t \approx \mathrm{E}_t \left[\left((1 - m_b) \cdot \Lambda_{t+1,t}^{b} + m_b \cdot \frac{\Pi_{t+1}}{R_t} \right) \cdot q_{t+1} \right] + mrs_{hc,t}^{b}.^{7} \tag{19}$$

Similar to the optimal housing condition for patient households in Eq. (7), impatient households choose housing such that the current price equals the sum of the discounted resale value and the MRS between housing and non-durable goods. However, unlike patient households, who rely solely on their SDF to evaluate the expected resale value, impatient households use a weighted average of their SDF and the inverse of the real interest rate. This distinction arises because impatient households purchase housing with only a down payment, using the property as collateral for borrowing. As a result, they receive only a fraction of the housing's resale value in the next period, corresponding to their initial out-of-pocket contribution. In contrast, the saver does not borrow, so they receive the full amount of resale value for housing in the next period.

Combing Eqs. (12) and (11) yields the optimal labor-leisure condition as follows:

$$uc_{b,t} w_{b,t} = -un_{b,t}. \tag{20}$$

Although the borrowing constraint does not directly affect the optimal labor-leisure trade-off, it plays a significant role in shaping labor supply and non-durable consumption choices. When impatient households use housing as collateral to borrow, they are required to pay only a fraction of the housing price upfront, that is, the down payment. By imposing borrowing limits, the

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consolidated budget constraint for impatient households can be expressed as follows:

$$c_{b,t} + \underbrace{\left[q_t - m_b \cdot \mathrm{E}_t\left(\frac{\Pi_{t+1}}{R_t} \cdot q_{t+1}\right)\right] \cdot h_{b,t}}_{\text{down payments for housing}}$$

$$\leq w_{b,t} n_{b,t} + \underbrace{\left[q_t - m_b \cdot \frac{\mathrm{E}_{t-1}(\Pi_t q_t)}{\Pi_t}\right] \cdot h_{b,t-1}}_{\text{initial housing wealth}}, \tag{21}$$

where the "down payment" faced by impatient households is defined as the difference between the current housing price and the discounted value of the collateralized portion.[8] Changes in relative housing expenditures, which affect borrowing limits, lead to shifts in the consolidated budget constraint. These shifts impact decisions regarding labor and consumption, illustrating how financial frictions tied to housing propagate throughout the economy.

2.3 The entrepreneurs

There is a continuum of mass one of entrepreneurs who produce homogeneous wholesale goods according to the following Cobb–Douglas production function:

$$y_t = A_t k_{t-1}^{\mu} h_{e,t-1}^{\nu} n_t^{1-\mu-\nu}, \tag{22}$$

where A_t represents the aggregate TFP, k_{t-1} represents the capital stock, $h_{e,t-1}$ represents the entrepreneurs' real estate holdings, n_t denotes the aggregate labor input, μ measures the share of capital, ν measures the share of housing, and $1-\mu-\nu$ represents the share of aggregate labor hours in the production function. Furthermore, the aggregate labor input, $n_t = n_{s,t}^{\alpha} n_{b,t}^{1-\alpha}$, is a combination of labor inputs from both patient households, $n_{s,t}$, and impatient households, $n_{b,t}$. Accordingly, the aggregate wage is given by: $w_t = \frac{w_{s,t}^{\alpha} w_{b,t}^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}$.

Entrepreneurs encounter credit constraints similar to those faced by impatient households. Entrepreneurs have the flexibility to use both houses and physical capital as collateral, relative to impatient households. Moreover, we allow different LTV ratios for housing and capital, denoted as $m_e^h \in [0,1]$ for housing loans and $m_e^k \in [0,1]$ for capital loans. Consequently, the borrowing limit can be expressed as follows:

$$-b_{e,t}^h \leq m_e^h \mathrm{E}_t\left(\frac{\Pi_{t+1}}{R_t} \cdot q_{t+1}\right) h_{e,t}, \tag{23}$$

$$-b_{e,t}^k \leq m_e^k \mathrm{E}_t\left(\frac{\Pi_{t+1}}{R_t}\right) k_t. \tag{24}$$

In Eq. (23), $b_{e,t}^h$ represents the loans secured by the value of housing, while in Eq. (24), $b_{e,t}^k$ represents the loans secured by the value of capital. Entrepreneurs' overall loan position is defined as $b_{e,t} \equiv b_{e,t}^h + b_{e,t}^k$.[9] These borrowing constraints reflect the limitations on entrepreneurs' borrowing capacity based on the expected discounted value of their collateral and the applicable LTV ratios.

The entrepreneur starts each period with an initial loan of $b_{e,t-1}$ and earns $\frac{P_t^w}{P_t} \cdot y_t$, by selling their output to retailers. Entrepreneurs then acquire new debt of $b_{e,t}$, consume $c_{e,t}$, invest i_t, adjust their real estate holdings $q_t(h_{e,t} - h_{e,t-1})$, and repay their previous debt $(R_{t-1}/\Pi_t) \cdot b_{e,t-1}$. Additionally, they pay wages to both patient households $w_{s,t} n_{s,t}$ and impatient households $w_{b,t} n_{b,t}$. Therefore, entrepreneurs' budget constraints can be expressed as:

$$c_{e,t} + i_t + q_t(h_{e,t} - h_{e,t-1}) + w_{s,t} n_{s,t} + w_{b,t} n_{b,t} + b_{e,t} = \frac{P_t^w}{P_t} \cdot y_t + \frac{R_{t-1}}{\Pi_t} \cdot b_{e,t-1}, \tag{25}$$

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The law of motion for capital is:

$$k_t = i_t + (1-\delta)k_{t-1}, \tag{26}$$

where k_t represents the capital stock, and δ is the depreciation rate.

Let β_e be the discount factor for entrepreneurs. We assume the entrepreneurs' discount factor satisfies $\beta_e < \beta_s$ to ensure that the credit constraints for the entrepreneurs are binding in equilibrium. Additionally, their lifetime utility function is given by:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_e^t \left[\Gamma_{c,e} \cdot \frac{(c_{e,t} - \varepsilon_c c_{e,t-1})^{1-\sigma_c} - 1}{1-\sigma_c} \right].$$

where $\Gamma_{c,e} \equiv (1-\phi_c)/(1-\beta_e\phi_c)$ is the scaling factor that ensures the marginal utility of consumption equals $1/c_e$ in the steady state.

Finally, entrepreneurs maximize their lifetime utility subject to the budget constraint, Eq. (25), the law of motion of the capital stock, Eq. (26), and the credit constraints, Eqs. (23)–(24). The associated first-order conditions are as follows:

$$\lambda_{e,t} = uc_{e,t}, \tag{27}$$

$$\lambda_{e,t} q_t = \mathrm{E}_t \left[\beta_e \lambda_{e,t+1} \left(\frac{\nu y_{t+1}}{X_{t+1} h_{e,t}} + q_{t+1} \right) + m_e^h \rho_{e,t}^h q_{t+1} \Pi_{t+1} \right], \tag{28}$$

$$\lambda_{e,t} = \mathrm{E}_t \left(\beta_e \lambda_{e,t+1} \frac{R_t}{\Pi_{t+1}} \right) + \rho_{e,t}^h R_t, \tag{29}$$

$$\lambda_{e,t} = \beta_e \mathrm{E}_t \left\{ \lambda_{e,t+1} \left[\frac{\mu y_{t+1}}{X_{t+1} k_t} + (1-\delta) \right] + m_e^k \rho_{e,t}^k \Pi_{t+1} \right\}, \tag{30}$$

$$\lambda_{e,t} = \mathrm{E}_t \left(\beta_e \lambda_{e,t+1} \frac{R_t}{\Pi_{t+1}} \right) + \rho_{e,t}^k R_t, \tag{31}$$

$$w_{s,t} = \frac{\alpha(1-\mu-\nu) y_t}{X_t n_{s,t}}, \tag{32}$$

$$w_{b,t} = \frac{(1-\alpha)(1-\mu-\nu) y_t}{X_t n_{b,t}}, \tag{33}$$

where $\lambda_{e,t}$ denotes the Lagrange multiplier for budget constraint, Eq. (25). $\rho_{e,t}^h$ and $\rho_{e,t}^k$ stand for the Lagrange multipliers associated with credit constraints, Eqs. (23)–(24), respectively. $uc_{e,t}$ represents the marginal utility of consumption of entrepreneurs, which is defined as

$$uc_{e,t} \equiv \Gamma_{c,e} \left\{ (c_{e,t} - \phi_c c_{e,t-1})^{-\sigma_c} - \beta_e \phi_c \mathrm{E}_t [(c_{e,t+1} - \phi_c c_{e,t})^{-\sigma_c}] \right\}.$$

In contrast to a standard model without borrowing constraints, the first-order conditions for an entrepreneur's housing and capital now include terms that account for the shadow value associated with relaxing the borrowing constraint through an additional unit of housing or capital, respectively. As a result, the entrepreneur's optimal choice of capital and housing equates today's prices of capital and housing to the sum of their discounted resale values and the discounted marginal product of each factor. Similar to impatient households, the entrepreneur can use housing and capital as collateral for borrowing. Consequently, the effective discounted resale value is influenced by both the SDF and the real interest rate, which determine the repayment amount. Specifically, the entrepreneur's optimal conditions are approximately expressed as:

$$q_t \approx \mathrm{E}_t \left\{ \Lambda_{t+1,t}^e \cdot \nu y_{t+1}/(X_{t+1} h_{e,t}) + \left[\left(1 - m_e^h\right) \cdot \Lambda_{t+1,t}^e + m_e^h \cdot \frac{\Pi_{t+1}}{R_t} \right] q_{t+1} \right\}, \tag{34}$$

$$1 \approx \mathrm{E}_t \left\{ \Lambda_{t+1,t}^e \cdot \mu y_{t+1}/(X_{t+1} k_{e,t}) + \left[\left(1 - \delta - m_e^h\right) \cdot \Lambda_{t+1,t}^e + m_e^h \cdot \frac{\Pi_{t+1}}{R_t} \right] \right\}, \tag{35}$$

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where $\nu y_{t+1}/(X_{t+1}h_{e,t})$ and $\mu y_{t+1}/(X_{t+1}k_{e,t})$ stand for the marginal product of housing and the marginal product of capital, respectively. $\Lambda^{e}_{t+1,t} \equiv \beta_e \lambda_{e,t+1}/\lambda_{e,t}$ is entrepreneurs' SDF.[10]

The next subsection introduces the final goods producer and the monopolistically competitive retailers. The inclusion of monopolistically competitive retailers enables a seamless transition between a flexible-price and a sticky-price economy by adjusting the parameter associated with price stickiness. Although our model does not rely on price stickiness to address the co-movement puzzle, we consider it for the purpose of model comparison.

2.4 Final goods producer

The representative final goods producer purchases a continuum of differentiated intermediate goods from retailers and transforms them into final products. The production process follows a constant elasticity of substitution technology, represented as:

$$Y_t = \left(\int_0^1 Y_t(z)^{\frac{\eta_y - 1}{\eta_y}} \mathrm{d}z \right)^{\frac{\eta_y}{\eta_y - 1}}, \tag{36}$$

where Y_t denotes the quantity of final goods, $Y_t(z)$ represents the quantity of intermediate good z purchased from retailer z, and η_y is the elasticity of substitution between different intermediate goods.

Let $P_t(z)$ denote the price of intermediate good z. The aggregate price level of the final good, P_t, can be expressed as:

$$P_t = \left(\int_0^1 P_t(z)^{1-\eta_y} \mathrm{d}z \right)^{1/(1-\eta_y)}. \tag{37}$$

Assuming that the market for final goods is competitive, the final goods producer solves the following problem:

$$\max_{Y_t(z)} P_t Y_t - \int_0^1 P_t(z) Y_t(z) \mathrm{d}z,$$

where the objective is to maximize profits.

The resulting optimality condition for the demand of intermediate goods is given by:

$$Y_t(z) = \left[\frac{P_t(z)}{P_t} \right]^{-\eta_y} Y_t. \tag{38}$$

2.5 Retailers

In our benchmark model, a continuum of monopolistically competitive retailers, indexed by $z \in [0, 1]$, each purchase homogeneous goods from entrepreneurs at price $P^w_t \equiv P_t/X_t$, transform them into differentiated goods $Y_t(z)$ at no cost, and sell $Y_t(z)$ to the final goods firm at price $P_t(z)$.

We assume that retailers can adjust their prices every period without incurring any costs. Later, when we extend the analysis to include price stickiness, we will introduce a quadratic adjustment cost. For now, retailer z's optimization problem is given by:

$$\max_{\{P_t(z)\}_{j=t}^{\infty}} \left[\frac{P_t(z) - P^w_t}{P_t} \cdot Y_t(z) \right],$$

subject to the demand function in Eq. (38).

The first-order condition for retailer z's problem is:

$$(1-\eta_y) \cdot \left[\frac{P_t(z)}{P_t} \right]^{1-\eta_y} + \eta_y \cdot \frac{P^w_t}{P_t} \cdot \left[\frac{P_t(z)}{P_t} \right]^{-\eta_y} = 0. \tag{39}$$

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Since all retailers face the same profit maximization problem, they choose the same price, $P_t(z) = P_t$, and produce the same quantity, $Y_t(z) = Y_t$. This leads to the following condition:

$$0 = (1 - \eta_y) + \frac{\eta_y}{X_t}. \tag{40}$$

2.6 Source of the uncertainty

We assume that the log of TFP shock A_t follows an AR(1) process, which takes the form:

$$\log A_t = \rho_a \log A_{t-1} + \exp(V_t)\sigma_A \varepsilon_{A,t}, \tag{41}$$

where $\varepsilon_{A,t} \sim N(0,1)$, ρ_a is the persistence of stochastic process to A_t, and σ_A is the standard deviation of innovations to A_t. Furthermore, the autoregressive process of productivity features time-varying volatility. In particular, the log of the standard deviation, V_t, of the innovations to productivity follows the autoregressive process:

$$V_t = \rho_v V_{t-1} + \sigma_V \varepsilon_{V,t}, \tag{42}$$

where $\varepsilon_{V,t} \sim N(0,1)$, ρ_v is the persistence of stochastic process to V_t, and σ_V is the standard deviation of innovations to V_t.

Two independent innovations, $\varepsilon_{A,t}$ and $\varepsilon_{V,t}$, affect the productivity. The first innovation denotes the productivity shocks, which change the productivity itself, while the second innovation denotes the volatility shock, which affects the spread of values for productivity. The volatility shock in the productivity implies that all firms are affected by more volatile shocks. Given the timing assumption, firms learn in advance the dispersion of shocks from which they will draw in the next period. This timing assumption captures the notion of uncertainty that firms face about future business conditions.

2.7 Monetary policy and market-clearing conditions

We assume that the monetary authority follows a simple interest rate rule, which responds to changes in inflation as follows:[11]

$$\frac{R_t}{R} = \left(\frac{\Pi_t}{\Pi}\right)^{\phi_\Pi}, \tag{43}$$

where R and Π are, respectively, the steady-state nominal interest rate and inflation rate, and ϕ_Π is the policy parameter.

Housing market equilibrium requires

$$h_{s,t} + h_{b,t} + h_{e,t} = 1, \tag{44}$$

Bonds market equilibrium requires

$$b_{s,t} + b_{b,t} + b_{e,t} = 0, \tag{45}$$

Goods market equilibrium requires

$$c_t + i_t = Y_t \tag{46}$$

where $c_t = c_{s,t} + c_{b,t} + c_{e,t}$ denotes the aggregate consumption.

We define the gross domestic product of this economy, $\widetilde{Y}_t$, as the sum of aggregate output and the imputed housing services of owner-occupied homes:

$$\widetilde{Y}_t \equiv Y_t + h_{s,t} \cdot mrs^s_{hc,t} + h_{b,t} \cdot mrs^b_{hc,t}. \tag{47}$$

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3. Quantitative analysis

This section is divided into four parts. First, we describe the solution method used to solve the model. Second, we estimate the exogenous process of uncertainty shocks. Third, we calibrate the model parameters to accurately replicate the fundamental characteristics of the U.S. economy. Finally, we use the calibrated model to analyze the impacts of uncertainty shocks.

3.1 Solution method

We employ the third-order perturbation approximation with the pruning method introduced by Andreasen et al. (2017) to address our dynamic stochastic general equilibrium model. This choice stems from the need for at least a third-order approximation of the policy functions to analyze the impulse response to a second-moment shock, as indicated by Fernández-Villaverde et al. (2011). In addition, we prune terms with higher-order effects beyond the third order to prevent higher-order approximations from generating explosive sample paths.

Following the approach of Basu and Bundick (2017), we set the exogenous shocks to zero and stimulate the economy for a sufficiently long period until all endogenous variables have converged to their stochastic steady state. Then, we introduce the uncertainty shock and compute its impulse responses as a percentage deviation from the steady state. Specifically, we implement the simulation using Dynare software.

3.2 Estimation of exogenous processes

An important aspect of our analysis is the estimate of the key parameters associated with the stochastic process of uncertainty shocks, including ρ_A, ρ_V, σ_A, and σ_V. Following Cesa-Bianchi and Fernandez-Corugedo (2018), we estimate the process of productivity and uncertainty shocks using the time series data of aggregate TFP for the U.S. business sector. The sample periods ranges from 1947Q1 to 2024Q3.[12]

By fitting an AR(1) process to the log-deviations of TFP from a linear trend, we estimate the parameter that captures the persistence of the productivity process, ρ_A, and the standard deviation of its innovations, σ_A, which are 0.9780 and 0.0089, respectively. These values are in line with the findings of Cesa-Bianchi and Fernandez-Corugedo (2018) and Fernández-Villaverde et al. (2011).

We then compute the standard deviations of the TFP innovations with an eight quarter rolling window to get the proxy for the time-varying volatility of the TFP innovations. By fitting an AR(1) process to the log of the standard deviations of the TFP innovations from a linear trend, we estimate the parameter that captures the persistence of the uncertainty process, which yields the value of ρ_V being 0.9110 and σ_V being 0.1643. These parameter values are similar to the estimation from Cesa-Bianchi and Fernandez-Corugedo (2018) and Caldara et al. (2012).[13]

Figure 1 plots the standard deviation and cyclical component associated with σ_t^{TFP}, with NBER recession periods shown as shaded areas. The top panel of Figure 1 presents the standard deviations of σ_t^{TFP}, which tends to spike during recessionary periods. We use the log-deviations of σ_t^{TFP} from a linear trend as a proxy for V_t. These cyclical components of σ_t^{TFP} are displayed in the lower panel of Figure 1.

3.3 Calibration

We now calibrate the key parameters of our model. Since our model is quarterly, we choose a savers' discount factor of $\beta_s = 0.9925$, which corresponds to a 3% annual real interest rate. The impatient households' and entrepreneurs' discount factors are set to $\beta_b = 0.94$ and $\beta_e = 0.94$, respectively, as in Iacoviello (2015). We also follow Choa and Francis (2011) in setting the parameters $\sigma_c = 3.0$ and $\sigma_h = 1.5$ to match the increasing ratio of housing to non-housing consumption as income increases. Furthermore, when σ_h exceeds σ_c, changes in the housing stock have a milder

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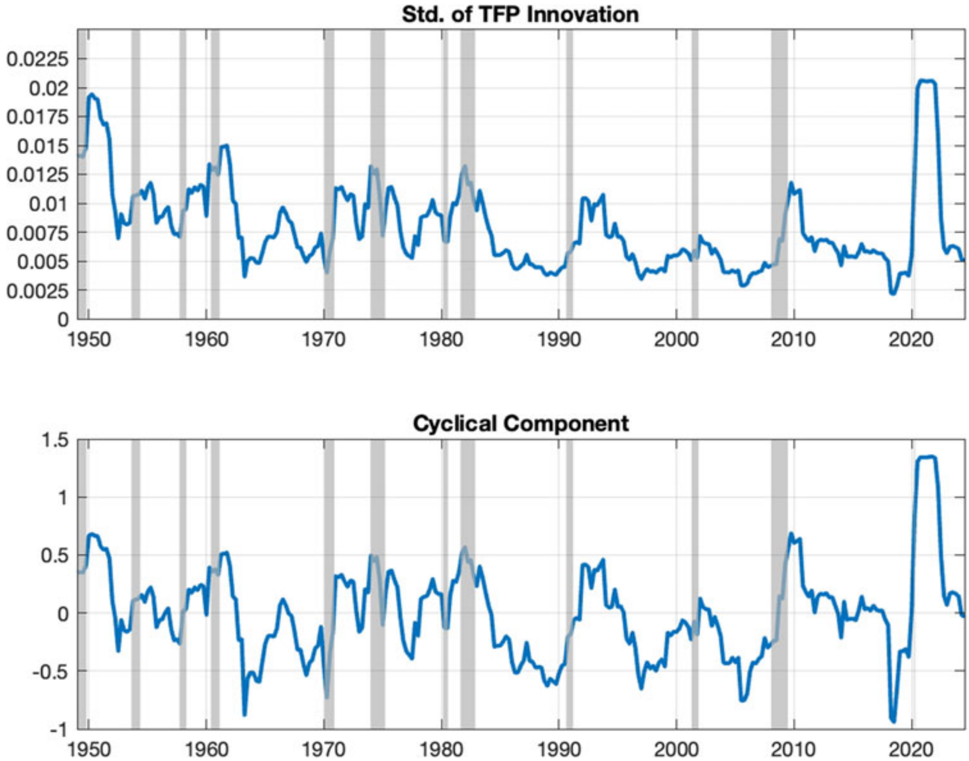

Figure 1. Time-varying volatility of TFP innovations.

effect on utility compared to changes in consumption. Such a feature allows households use housing stocks as a buffer against unexpected shocks. For a detailed discussion, please refer to Zanetti (2014). Both the inverse of the Frisch elasticity of labor supply, η, and the weight of work, κ, are chosen as 1, based on Guerrieri and Iacoviello (2017).

The weight of housing, J, is set to 0.0757, which gives a real estate wealth to annual output ratio of 3.1, consistent with Iacoviello (2015). The maximum LTV ratios for borrowers and entrepreneurs are both set to 0.9, in line with Iacoviello (2015), and Guerrieri and Iacoviello (2017). The strength of consumption habit, ϕ_c, is set to 0.6842, following the research of Guerrieri and Iacoviello (2017).

We choose a depreciation rate of $\delta = 0.025$, corresponding to an annual depreciation rate of 10%. The shares of capital and real estate to output are fixed at $\mu = 0.3$ and $\nu = 0.03$, respectively, as in Iacoviello (2005). Savers' wage share, α, is set to 0.67, consistent with Iacoviello (2015). Finally, the monetary policy rule is set to $\phi_\Pi = 1.5$, a standard choice in the literature akin to Monacelli (2009). To enhance clarity, we provide a summary of all parameter values in Table 1.

3.4 Quantitative analysis

To analyze the impacts of uncertainty shocks, we follow Fernández-Villaverde et al. (2011) to compute impulse response functions (IRFs) to a mean preserving shock to the variance of TFP. IRFs are expressed as percentage deviations from the stochastic steady state in response to a one-standard deviation uncertainty shock. For nominal interest rates and inflation, we report deviations from their stochastic steady-state levels. Since we are interested in investigating which model ingredients are key to propagating the uncertainty shocks during the business cycles, we

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Table 1. Parameters values

Parameter	Description	Value	Source/target
β_s	Discount factor for savers	0.9925	3% annual real interest rate
β_b	Discount factor for impatient households	0.94	Iacoviello (2015)
β_e	Discount factor for entrepreneurs	0.94	Iacoviello (2015)
σ_c	Risk aversion for consumption	3.0	Choa and Francis (2011)
σ_h	Risk aversion for housing	1.5	Choa and Francis (2011)
η	Inverse of Frisch elasticity	1	Guerrieri and Iacoviello (2017)
J	housing preference	0.0723	Steady-state housing wealth to annual output ratio of 3.1
m_b, m_e^h, m_e^k	LTV ratio	0.9	Iacoviello (2015)
δ	Depreciation rate	0.025	10% annual depreciation rate
μ	Capital share	0.3	Iacoviello (2005)
ν	Housing share	0.03	Iacoviello (2005)
α	Savers wage share	0.67	Iacoviello (2015)
ϕ_c	Habit in consumption	0.6842	Guerrieri and Iacoviello (2017)
ϕ_Π	Response of inflation	1.5	Monacelli (2009)
ρ_A	AR(1) TFP shock	0.9780	Data
σ_A	Std. TFP shock	0.0089	Data
ρ_V	AR(1) TFP uncertainty shock	0.9110	Data
σ_V	Std. TFP uncertainty shock	0.1643	Data

focus on the responses of output, consumption, investment, housing holdings, employment, real wage, and total loans throughout our analysis.

3.4.1 A frictionless economy with a representative agent

We first consider a frictionless economy consisting solely of patient households, where borrowing constraints are absent. This setup mirrors a representative agent model, with patient households owning a representative entrepreneur who produces homogeneous goods according to the technology outlined in Eq. (22). The entrepreneur accumulates capital and housing for production without collateral constraints, with market-clearing conditions given as: $h_{s,t} + h_{e,t} = 1$, $b_{s,t} = 0$, and $c_{s,t} + i_t = Y_t$. For a detailed presentation of the model without collateral constraints, please refer to Appendix A.

In this economy, precautionary saving motives shape household responses to uncertainty shocks. When uncertainty rises, patient households reduce consumption and increase labor supply. Given fixed capital and unchanged TFP, the additional labor input raises aggregate production and investment while lowering real wages. Although the model predicts a decline in real wages alongside rising output and investment, this contrasts with empirical findings, which typically show that uncertainty shocks lead to an increase in real wages and broad-based declines in output, consumption, and investment. As a result, this alternative model without collateral constraints fails to replicate the co-movement patterns seen in the data. Figure 2 presents the IRFs for the frictionless economy following a one-standard-deviation increase in TFP uncertainty.

3.4.2 The baseline model with financial frictions

We then transition to our baseline model, which incorporates financial frictions, including collateral constraints on both impatient households and entrepreneurs, with LTV ratios set at

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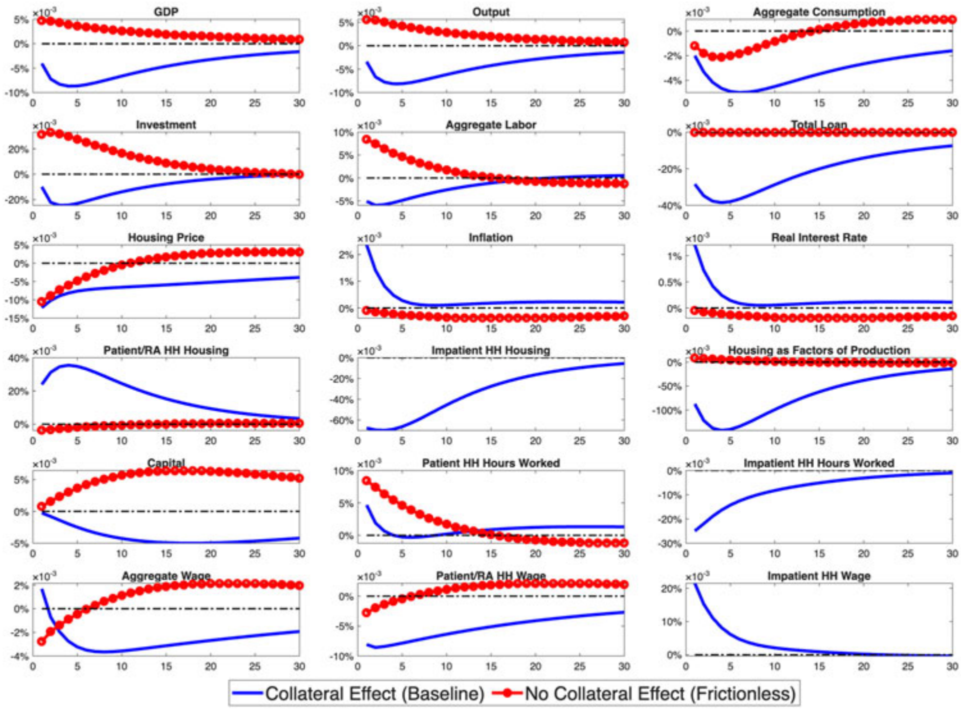

Figure 2. IRFs to a TFP uncertainty shock: baseline model versus frictionless economy.
Notes: IRFs are expressed as percentage deviations from the stochastic steady state in response to a one-standard deviation uncertainty shock.

$m_b = m_e^h = m_e^k = 0.9$. This framework introduces both patient and impatient households, allowing us to explore how credit constraints amplify or dampen the effects of uncertainty shocks. Unlike the frictionless model, the baseline model captures co-movement across macroeconomic aggregates by accounting for the distinct behaviors of patient and impatient households.

In our benchmark model, the behavior of patient households largely mirrors that observed in a frictionless economy, driven primarily by precautionary saving motives. In response to uncertainty shocks, patient households reduce their non-durable consumption and increase their labor supply. In contrast, the optimal decisions regarding non-durable consumption and labor for impatient households are closely tied to their housing decisions, which are influenced by both their SDF and the prevailing real interest rate when selling their collateral, as shown in Eq. (19). Specifically, the SDF term reflects the precautionary saving motive, while the real interest rate captures the resale risk associated with housing. The relative importance of these factors is determined by their respective weights.

To further illustrate the risks associated with borrowing, we decompose Eq. (19) as follows:

$$q_t \approx \left[(1-m_b)\mathrm{E}_t(\Lambda^b_{t+1,t}) + m_b \mathrm{E}_t(\Pi_{t+1})/R_t\right] \cdot \mathrm{E}_t(q_{t+1}) + (1-m_b)\mathrm{Cov}_t(\Lambda^b_{t+1,t}, q_{t+1}) + m_b \mathrm{Cov}_t(\Pi_{t+1}, q_{t+1})/R_t + mrs^b_{hc,t}. \quad (48)$$

This decomposition includes four main components of the risk associated with borrowing: (1) the product of the inverse of the expected real interest rate and the expected housing resale price, (2) the product of the expected SDF and the expected housing resale price, (3) the covariance terms between the housing resale price and the inverse of the real interest rate, and (4) the covariance terms between the housing resale price and the SDF. With a LTV ratio of $m_b = 0.9$, the precautionary saving motive has a relatively minor influence on housing decisions, as its weight is $(1 - m_b) = 0.1$. In contrast, the real interest rate plays a significantly greater role, with a weight of $m_b = 0.9$. This disparity in weights underscores that the housing decisions of impatient households are primarily driven by the resale risk associated with the real interest rate, rather than by precautionary saving motives. For the subsequent analysis, we disregard the expected and covariance terms associated with the precautionary saving motive (i.e., the SDF term), as their impacts, characterized by $1 - m_b$, are comparatively smaller.

Based on the decomposition in Eq. (48), the housing decision is primarily influenced by the dynamics of the real interest rate (future inflation rate) and housing resale prices. In response to uncertainty shocks, future inflation rises, and housing resale prices decline. While inflation generally benefits borrowers by reducing the real value of repayments in terms of goods, this advantage diminishes when inflation and housing prices move in opposite directions. Specifically, if housing prices fall more than inflation rises, borrowers become less willing to take on debt, reducing their housing holdings and transitioning from larger to smaller homes. Additionally, the covariance term captures the risk premiums associated with housing purchases.[14] A decline in this covariance term reduces borrowers' willingness to pay, thereby lowering housing demand.

To analyze this dynamic, we follow Koop et al. (1996) to simulate IRFs for the covariance between inflation and housing prices. The simulation results, shown in Figure 3, indicate that heightened uncertainty amplifies the negative correlation between future inflation and housing prices, leading impatient households to reduce their housing holdings. In contrast, patient households, viewing housing as both a durable good and an investment, are less sensitive to the timing of purchases due to the stable shadow value of durable goods. Consequently, when the relative price of housing declines, patient households increase their housing holdings. This divergence in behavior drives a significant reallocation of housing consumption from impatient to patient households, reflecting their distinct responses to changes in inflation, housing prices, and associated risks. To deepen our understanding of this redistribution, we examine the empirical relationship between inflation and housing prices, utilizing the All-Transactions House Price Index (USSTHPI) and the Personal Consumption Expenditures Chain-type Price Index (PCECTPI) for the period spanning 1959:Q1 to 2023:Q4. Following the FRED-QD methodology, we transform the USSTHPI using first differences of natural logarithms and the PCECTPI using second differences of natural logarithms. The resulting correlation coefficient of −0.055 highlights a negative relationship between inflation and housing prices, underscoring the role of changing economic conditions in shaping housing consumption patterns.

Housing prices decline following uncertainty shocks due to differences in financing methods and the redistribution of housing between impatient and patient households. Impatient households rely on leverage to finance housing purchases, making them more sensitive to risk. In contrast, patient households, who purchase housing without loans, are less constrained by borrowing costs. This redistribution leads to a sharper decline in housing demand among impatient households compared to the corresponding increase among patient households. With aggregate housing supply fixed, the overall reduction in demand drives housing prices downward.

Inflation rises in response to uncertainty shocks, driven primarily by increasing labor costs in production. These higher costs stem from a decline in labor supply among impatient households, which outweighs the modest increase from patient households. The reduction in labor supply among impatient households is closely linked to their housing demand. To lower their risk exposure, impatient households reduce their housing holdings, which alters their choice set of non-durable consumption and leisure, as captured in Eq. (21). This decrease in housing reallocates resources from down payments to non-durable consumption and leisure, ultimately leading to a reduction in their labor supply.

Despite the contraction in aggregate labor supply, labor demandlargely determined by the marginal product of laborremains stable due to fixed housing and capital stocks. This imbalance results in higher aggregate wages and fewer hours worked, consistent with the findings of Cross et al. (2023), which show that average hours decrease while hourly earnings rise modestly during

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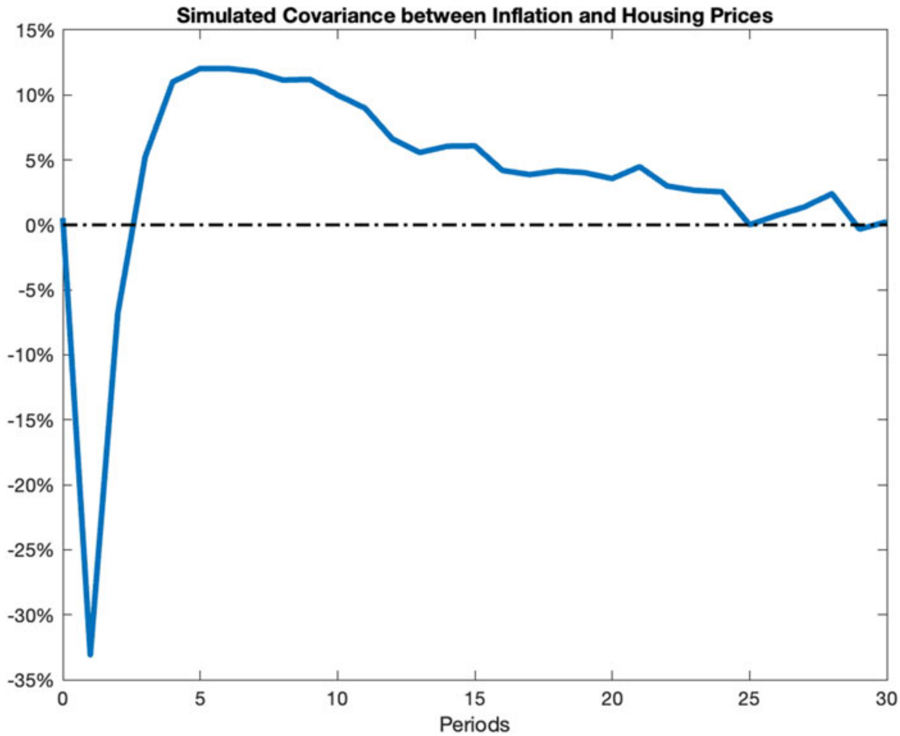

Figure 3. Percentage deviation in simulated covariance between inflation and housing prices over 25,000 simulations.

periods of heightened uncertainty. The increase in aggregate wages further amplifies inflationary pressures. The modest increase in real wages is consistent with our supply-side mechanism, whereby tighter collateral constraints reduce labor supply, raising the marginal product of labor despite the broader contraction in hours and output.

This reduction in labor supply also explains the observed positive correlation between household debt and labor supply, as documented by Fortin (1995) and Del Boca and Lusardi (2003). This relationship aligns with the financial labor supply accelerator proposed by Campbell and Hercowitz (2011), which links higher minimum down payments to reduced labor supply. While Campbell and Hercowitz (2011) examines this relationship within a representative agent framework, we extend the analysis to a two-agent household model. In our model, patient and impatient households differ in their financial approaches to housing purchases. Patient households buy houses without loans, requiring higher down payments, while impatient households use leverage, resulting in lower down payment requirements. Consequently, when housing transitions from impatient to patient households, the total down payment required for housing purchases increases. This mechanism highlights a positive relationship between leverage and labor supply and a negative relationship between down payments and labor supply.

With housing and capital stocks fixed, the reduction in aggregate labor hours leads to a decline in overall output. Furthermore, as heightened uncertainty is expected to persist over multiple periods, the reduction in labor supply is likely to continue. This sustained contraction in labor hours leads to a prolonged decline in the expected marginal productivity of capital and housing, resulting in an extended decrease in investment in both assets. Additionally, entrepreneurs reduce their demand for housing and physical capital as collateral values become increasingly uncertain due to uncertainty shocks. This further decreases investment and housing demand.

In summary, this increase in uncertainty leads to a decrease in consumption, investment, aggregate labor hours, and output. Consequently, our baseline model effectively reproduces the

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co-movement among key macroeconomic aggregates following heightened uncertainty. These findings are illustrated in Figure 2, where we also present the dynamics associated with the frictionless economy. It's worth noting that our model with financial frictions can address the co-movement puzzle, even in the absence of nominal rigidities.

3.4.3 The importance of the risk premium channel

To highlight the importance of the risk premium in addressing the co-movement puzzle, we examine an alternative scenario where both patient households and entrepreneurs employ the steady-state housing price, denoted as $\overline{q}$, to evaluate the collateral value. Consequently, the borrowing constraints associated with housing are modified as follows:

$$b_{b,t} \le m_b \mathrm{E}_t \left(\frac{\Pi_{t+1}}{R_t} \cdot \overline{q} \right) h_{b,t},$$

$$b^h_{e,t} \le m^h_e \mathrm{E}_t \left(\frac{\Pi_{t+1}}{R_t} \cdot \overline{q} \right) h_{e,t}.$$

When housing prices are held constant, the risk premium channel becomes effectively inactive, as $\mathrm{Cov}_t(\Lambda^b_{t+1,t}, \overline{q}) = \mathrm{Cov}_t(\Lambda^e_{t+1,t}, \overline{q}) = \mathrm{Cov}_t(\Pi_{t+1}, \overline{q})/R_t = 0$. As the risk premium terms associated with housing resale prices vanish, the incentive for impatient households to decrease their demand for housing following uncertainty shocks also disappears. Consequently, their labor supply will not decrease as it did previously. Therefore, the increase in aggregate labor hours among patient and impatient households leads to an overall rise in aggregate labor hours, which in turn leads to the higher aggregate production, given that current technology and capital stock remain unchanged. This boost in output, combined with reduced consumption, results in an increase in investment, a pattern similar to the outcomes in the frictionless economy model. Figure 4 presents the simulation results of the case with and without risk premium in our baseline model.

4. Understanding the key features of the model

In this section, we further examine a series of quantitative exercises to better understand how the various elements of our model contribute to our results. Specifically, credit constraints affect activities of both entrepreneurs and impatient households. We first evaluate the relative importance of households' and entrepreneurs' credit constraint in resolving the puzzle. We also examine the stringency of credit constraints to see how these shocks influence the dynamics adjustment following the shocks. Furthermore, we examine targeted macroprudential policies within the model. Finally, we compare our quantitative results with that in the typical sticky price model.

4.1 The relative importance of households' and entrepreneurs' credit constraints

In this subsection, we examine the relative importance of the financial frictions associated with impatient households and entrepreneurs. In particular, we examine scenarios where only one of these economic agents faces these constraints, as opposed to situations where both patient households and entrepreneurs encounter borrowing restrictions.

4.1.1 The economy with entrepreneurs' credit constraints only

We start by analyzing the scenario in which only the entrepreneurs are subject to the borrowing constraints. The behavior of the entrepreneurs in this model economy is identical to that in our baseline model.

However, when we remove the credit constraints for impatient households, we set their discount factors at the same level as that of patient households, that is, $\beta_b = \beta_s$. Consequently, patient

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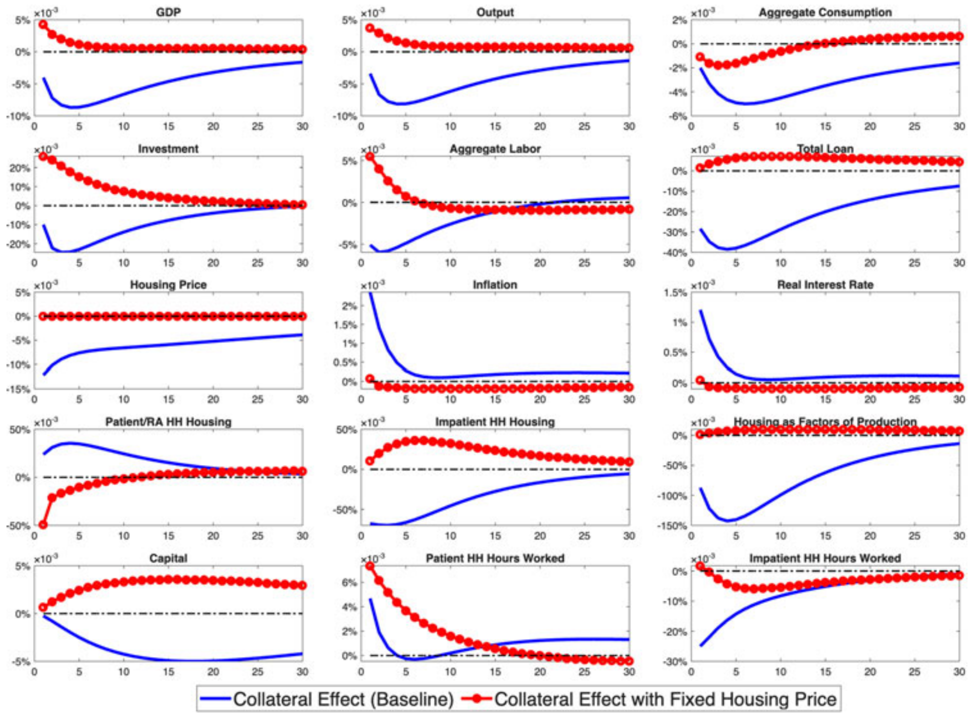

Figure 4. IRFs to a TFP uncertainty shock in alternative credit constraint with a fixed price of q.
Notes: IRFs are expressed as percentage deviations from the stochastic steady state in response to a one-standard deviation uncertainty shock.

and impatient households become indistinguishable and can be effectively merged into a single category of patient households. This change leads to an aggregate labor input of $n_t = n_{s,t}$. Therefore, the setting of the patient household is very similar to its counterpart in the frictionless economy we introduce earlier. One key difference is that the entrepreneur is not owned by the patient households, and thus their valuation for future profits is different than their counterparts in the frictionless economy setting. The new market-clearing conditions now become $h_{s,t} + h_{e,t} = 1$, $b_{s,t} + b_{e,t} = 0$, and $c_{s,t} + c_{e,t} + i_t = Y_t$.

In this economy, the uncertainty shock triggers an increase in labor supply due to precautionary saving motives, resulting in a rise in aggregate production. Since labor is complementary to capital, the increased labor supply also boosts the marginal productivity of capital, consequently increasing entrepreneurs' demand for capital. Additionally, the financial accelerator effect further amplifies this demand for capital, leading to an increase in investment. Regarding the demand for housing by entrepreneurs, the augmented labor supply elevates the marginal product of housing, thereby increasing the demand for housing. However, the heightened uncertainty surrounding the resale value of housing diminishes their demand for it. Together, the decrease in housing demand resulting from increased uncertainty outweighs the demand increase due to its complementary relationship with production, leading to a net reduction in housing demand for entrepreneurs. The IRFs for this scenario are depicted by the red dotted lines in Figure 5. It's important to note that the model without the credit constraints for impatient households incorrectly predicts an expansionary effect from the uncertainty shock and fails to resolve the co-movement puzzle.

4.1.2 The economy with impatient households' credit constraints only

Next, we shift our focus to an economy in which entrepreneurs' credit constraints have been removed, while impatient households still encounter credit constraints. Here, the behavior of

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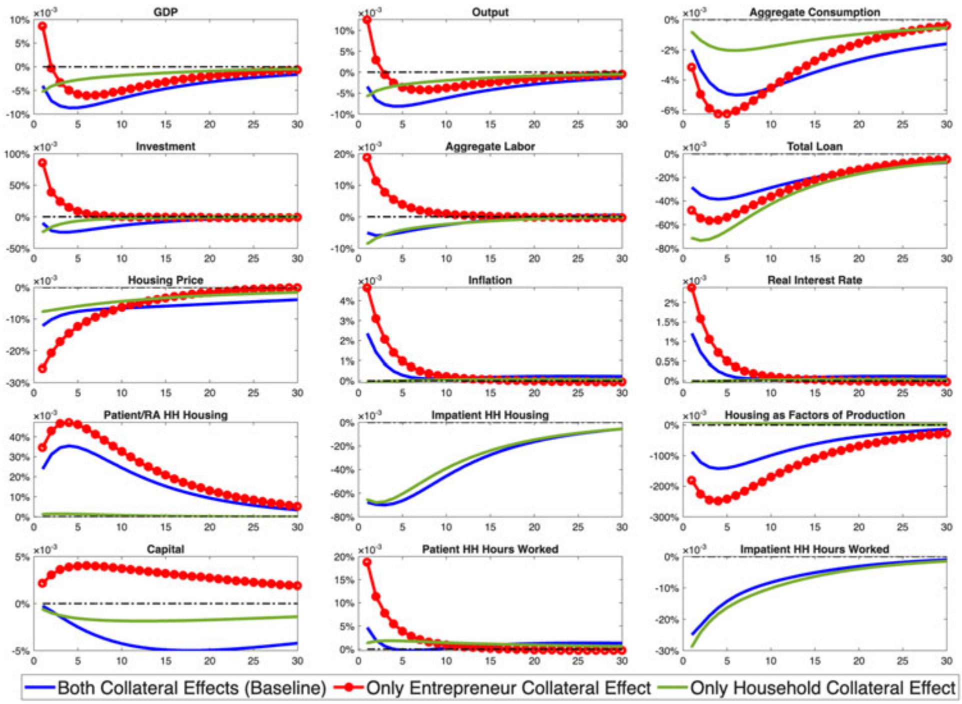

Figure 5. IRFs to a TFP uncertainty shock under different types of collateral constraints.
Notes: IRFs are expressed as percentage deviations from the stochastic steady state in response to a one-standard deviation uncertainty shock.

patient and impatient households is identical to our baseline model. However, the behavior of entrepreneurs is identical to our previous frictionless economy model setting. This setting assumes that entrepreneurs use the same technology described in Eq. (22) and are owned by the patient households. Furthermore, in this case, entrepreneurs are not subject to any borrowing constraints when accumulating capital and housing. Additionally, new market-clearing conditions now becomes $h_{s,t} + h_{b,t} + h_{e,t} = 1$, $b_{s,t} + b_{b,t} = 0$, and $c_{s,t} + c_{b,t} + i_t = y_t$.

During times of heightened uncertainty, the resale housing value becomes more volatile, prompting impatient households to downsize their homes in an effort to reduce their housing exposure. This downsizing leads to a reduction in working hours among impatient households, which in turn causes a decrease in aggregate labor hours, resulting in a decline in aggregate production.

Since the fall in aggregate labor hours also leads to a decrease in the expected marginal productivity of capital, investment will fall in response. However, in the absence of the financial frictions associated with entrepreneurs, the decline in investment is less severe, leading to a milder recession. The simulation results for this scenario are depicted by the green lines in Figure 5.

In summary, financial frictions related to impatient households play a crucial role in addressing the co-movement issue following uncertainty shocks. In contrast, financial frictions associated with entrepreneurs only act as a mechanism that amplifies the reduction in investment, thereby intensifying the recession when compared to scenarios without these financial constraints.

4.2 Varying degrees of financial frictions and their effects

In this exercise, we manipulate the stringency of borrowing constraints for both impatient households and entrepreneurs by adjusting their LTV ratios. Our objective is to gain insight into how these constraints influence the amplification of uncertainty shocks and their subsequent impact on

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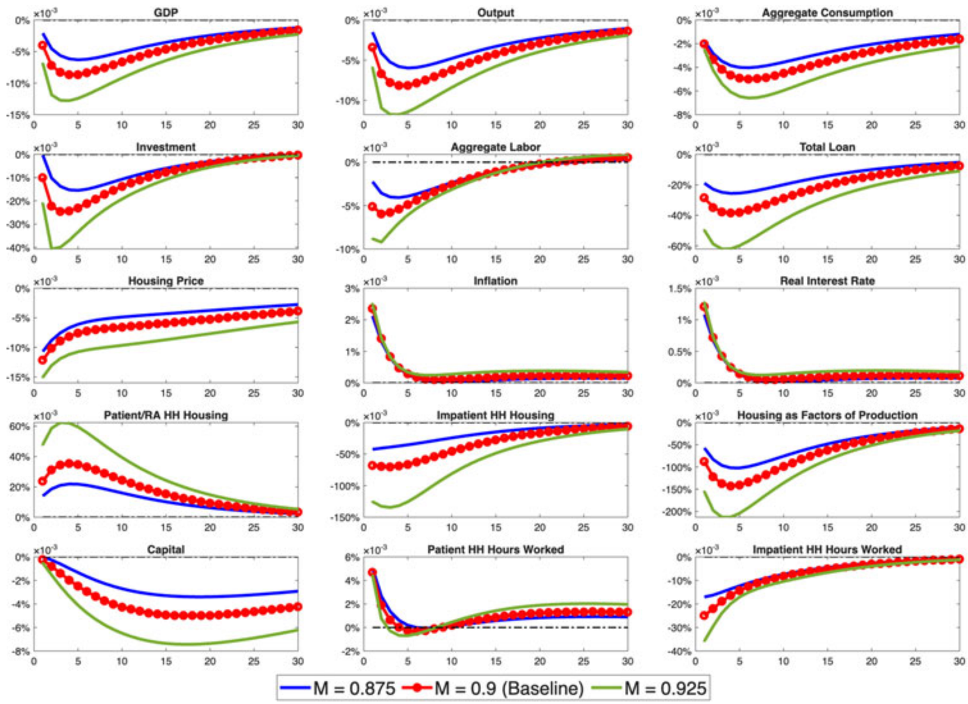

Figure 6. IRFs to a TFP uncertainty shock under varying *M*.
Notes: IRFs are expressed as percentage deviations from the stochastic steady state in response to a one-standard deviation uncertainty shock.

macroeconomic dynamics. Without loss of generality, we examine a scenario in which LTV ratios are uniform across agents, denoted as $m_b = m_e^k = m_e^h = M$. In this context, a higher M value signifies more relaxed borrowing constraints, allowing both impatient households and entrepreneurs to access greater collateral with a relatively smaller initial down payment, thereby increasing leverage. Consequently, when impatient households respond to heightened uncertainty by reducing their housing holdings, the resulting decline in aggregate labor supply becomes more pronounced at higher LTV ratios, leading to a deeper recession.

Figure 6 presents the IRFs under three different levels of financial friction, specifically with M values set at 0.875, 0.9, and 0.925. The simulation results demonstrate that a lower LTV ratio corresponds to smaller fluctuations in aggregate output, whereas a higher LTV ratio leads to a more substantial decline in aggregate production. From this perspective, deregulation amplifies fluctuations in aggregate production, aligning with prior studies by Liou (2013); Born (2011), and Chang (2011). Consequently, policymakers may consider regulating LTV ratios to mitigate excessive fluctuations in aggregate production.

4.3 Targeted macroprudential policies

In this subsection, we further investigate a targeted macroprudential policy by selectively tightening LTV ratios for different types of collateral. Specifically, we focus on three distinct borrowing constraints: (1) households' housing collateral (M_b), (2) entrepreneurs' housing collateral (M_e^h), and (3) entrepreneurs' capital collateral (M_e^k). Since our previous findings suggest that reducing LTV ratios can stabilize the economy, we now assess which specific constraint should be tightened to achieve the most effective stabilization. To this end, we conduct a policy experiment in which we lower each LTV ratio individually to 0.875 while keeping the other two constant at 0.9.

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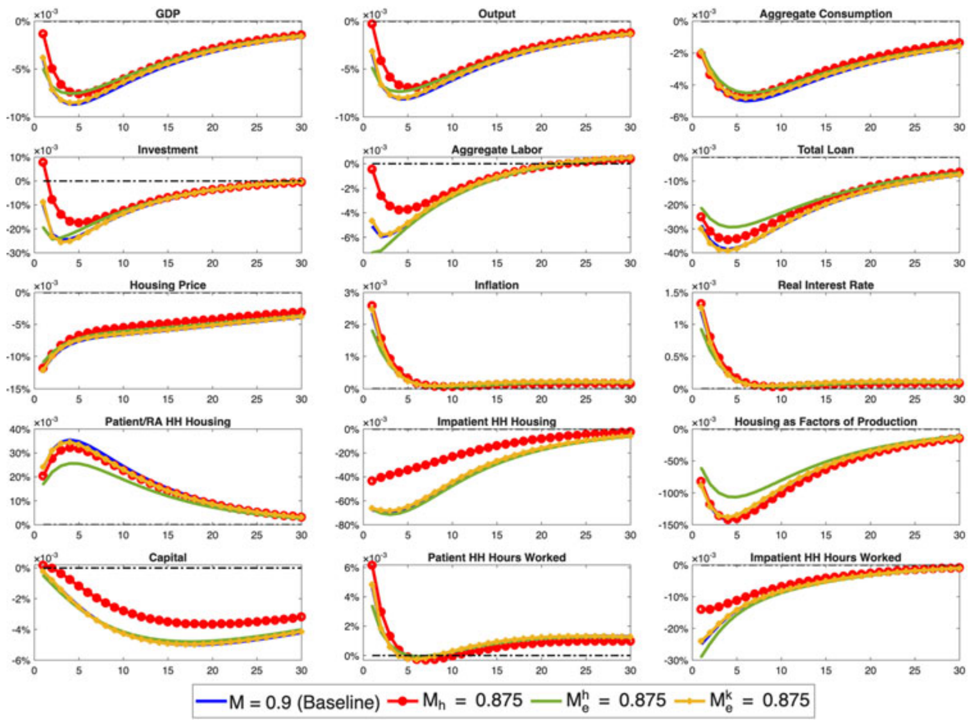

Figure 7. IRFs to a TFP uncertainty shock targeting different collateral constraints.
Notes: IRFs are expressed as percentage deviations from the stochastic steady state in response to a one-standard deviation uncertainty shock.

This approach allows us to isolate the effects of tightening borrowing constraints on different economic agents and identify the most effective policy intervention in stabilizing the economy.

Figure 7 illustrates the macroeconomic effects of targeted LTV tightening. Comparing the baseline case (blue solid line) to the scenario where $M_b = 0.875$ (red dotted line), we find that tightening borrowing constraints for households serves as the most effective macroprudential policy tool. By limiting household leverage, this policy dampens the amplification of uncertainty shocks, as the reduction in housing held by impatient households is smaller. Consequently, the decline in their labor supply is less pronounced, leading to a milder economic downturn relative to the baseline.

In contrast, adjusting borrowing constraints for entrepreneurs has little to no stabilizing effect. Tightening M_e^k, which governs entrepreneurs' capital collateral, has virtually no impact on macroeconomic dynamics. Since the real price of capital remains fixed at 1, the risk premium term in Eq. (34) remains unchanged, preventing financial tightening from influencing the broader economy. As a result, IRFs remain nearly identical across scenarios, suggesting that adjusting M_e^k is an ineffective macroprudential tool. Similarly, tightening M_e^h has little effect on macroeconomic dynamics. This is because entrepreneurs primarily use housing as a factor of production and as collateral for borrowing. However, the share of housing in the production function is relatively small, accounting for only 3% of total inputs. As a result, regulating LTV ratios associated with entrepreneurial housing has only a mild impact on macroeconomic fluctuations.

These findings underscore that macroprudential policies targeting household borrowing constraints are the most effective in mitigating economic volatility. While tightening entrepreneurial borrowing constraints has limited or no effect, restricting household leverage directly curtails the transmission of financial shocks, reducing economic instability and preventing excessive fluctuations in aggregate output.

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4.4 Comparison with sticky price model

In this subsection, our primary objective is to conduct a quantitative comparison between our baseline model and the conventional sticky price model concerning their respective responses to uncertainty shocks. To address this, we introduce a theoretical framework that encompasses nominal frictions in the context of representative households. This model also incorporates real frictions like consumption habits and investment adjustment costs, which are extensively discussed in the literature. Following this, the section delves into a comparison of the IRFs between our baseline model and the one featuring price stickiness.

4.4.1 The model with sticky price and investment adjustment cost

In the model with price stickiness, there is a representative household that maximizes its lifetime utility by choosing consumption, housing, labor hours and saving just like the patient households in our baseline model. Moreover, the setting of entrepreneur is almost identically to our frictionless economy model. However, due to the investment adjustment cost, the law of motion for capital, Eq. (26), now becomes:

$$k_t = (1-\delta)k_{t-1} + \left[1 - \frac{\phi_k}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2\right] i_t,$$

where $\phi_k \geq 0$ represents the investment adjustment cost parameter.

Regarding the behavior of retailers, they purchase wholesale goods at the price $P_t^w \equiv P_t/X_t$ from entrepreneurs. These goods are then transformed into various intermediate goods, which are subsequently sold to the final goods producer. However, in contrast to our baseline model setting where retailers can freely change their prices each period without incurring any expenses, they now encounter quadratic adjustment costs in their price-setting behavior, akin to Rotemberg (1982). Specifically, these adjustment costs take the form $\Phi_{y,t} \equiv \frac{\phi_p}{2}\left[\frac{P_t(z)}{P_{t-1}(z)} - \Pi\right]^2 Y_t$, where ϕ_p is the adjustment cost parameter that determines the level of nominal price rigidity, and Π represents the steady-state inflation level. Therefore, retailer z's problem now becomes:

$$\max_{\{P_{t+j}(z)\}_{j=t}^{\infty}} \mathrm{E}_t \sum_{j=0}^{\infty} \frac{\beta^j \lambda_{s,t+j}}{\lambda_{s,t}} \cdot \left[\frac{P_{t+j}(z) - P_{t+j}^w}{P_{t+j}} \cdot Y_{t+j}(z) - \Phi_{y,t}\right],$$

subject to its demand function Eq. (38).

The first-order condition associated with retailer z's problem is:

$$(1-\eta_y) \cdot \left[\frac{P_t(z)}{P_t}\right]^{1-\eta_y} + \eta_y \cdot \frac{P_t^w}{P_t} \cdot \left[\frac{P_t(z)}{P_t}\right]^{-\eta_y} - \phi_p\left[\frac{P_t(z)}{P_{t-1}(z)} - \Pi\right] \cdot \frac{P_t(z)}{P_{t-1}(z)}$$
$$+ \mathrm{E}_t\left\{\frac{\beta_s \lambda_{s,t+1}}{\lambda_{s,t}} \cdot \frac{Y_{t+1}}{Y_t} \cdot \phi_p\left[\frac{P_{t+1}(z)}{P_t(z)} - \Pi\right] \cdot \frac{P_{t+1}(z)}{P_t(z)}\right\} = 0. \quad (49)$$

Since all retailers face the same profit maximization problem, they all choose the same price, $P_t(z) = P_t$, and produce the same quantity, $Y_t(z) = Y_t$. Hence, we get:

$$\phi_p(\Pi_t - \Pi) \cdot \Pi_t = (1-\eta_y) + \frac{\eta_y}{X_t} + \mathrm{E}_t\left[\frac{\beta_s \lambda_{s,t+1}}{\lambda_{s,t}} \cdot \frac{Y_{t+1}}{Y_t} \cdot \phi_p(\Pi_{t+1} - \Pi) \cdot \Pi_{t+1}\right]. \quad (50)$$

Furthermore, the wholesale goods market-clearing condition implies that

$$y_t = \int_0^1 Y_t(z)dz = Y_t.$$

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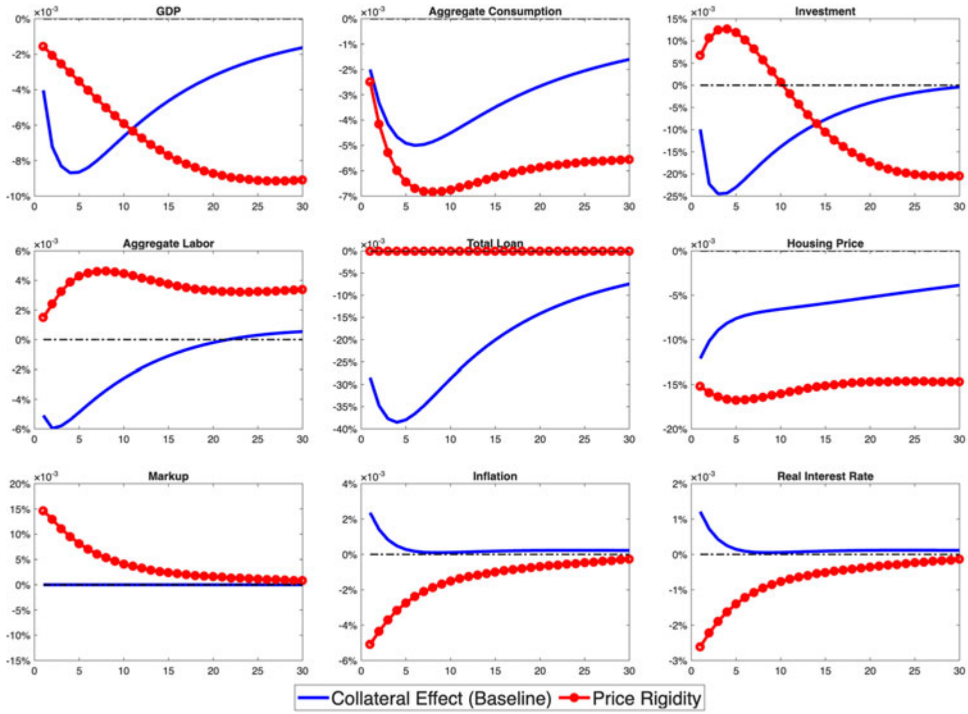

Figure 8. IRFs to a TFP uncertainty shock—collateral effect versus nominal rigidity.
Notes: IRFs are expressed as percentage deviations from the stochastic steady state in response to a one-standard deviation uncertainty shock.

4.4.2 The quantitative comparison

We select the price adjustment cost parameter (ϕ_p) to match the slope of the New Keynesian Phillips Curve typically found in a Calvo model with an average price duration of three quarters. Additionally, we fix the investment adjustment cost parameter (ϕ_k) at a value of 2.5. Figure 8 illustrates a comparison of the IRFs between our baseline model and the RA model with sticky price and investment adjustment costs.

As explained by Basu and Bundick (2017), uncertainty shocks lead households to reduce their consumption and increase their labor supply due to precautionary saving motives. The subsequent increase in labor supply exerts downward pressure on wages and firms' marginal costs, ultimately causing prices to decrease in a flexible-price model to maintain constant markups. However, in the presence of sticky prices, the adjustment of prices is sluggish, resulting in an increase in markups. Additionally, as noted by Born and Pfeifer (2021), uncertainty shocks lead to heightened variability in aggregate productivity. This variability prompts retailers to set higher prices, driven by a precautionary pricing motive when they have the flexibility to adjust their prices. This is because lowering prices under these circumstances could result in significant losses due to rising marginal costs and the inability to adapt prices accordingly. Through both setting higher prices when they have the opportunity and the increase in the markup channel, uncertainty shocks diminish the demand for output and labor, ultimately leading to a recession, as illustrated in Figure 8.

In the sticky price model, this markup channel generates a fall in aggregate production mainly by lowering labor demand. However, when households' precautionary labor supply is strong, the reduction in hours worked is limited, resulting in relatively small uncertainty shock effects. In contrast, the financial labor supply accelerator channel in our baseline model resolves the co-movement puzzle by reducing labor supply. As entrepreneurs' housing and physical capital are predetermined, the current labor demand remains fixed. Consequently, a decrease in labor supply can readily translate into a reduction in hours worked, leading to larger uncertainty shock effects.

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5. Conclusion

This study explores the role of credit constraints in amplifying and propagating uncertainty shocks within a business cycle framework. By introducing collateral-based borrowing constraints for both impatient households and entrepreneurs, we offer a novel approach to addressing the co-movement puzzle, which has long challenged standard business cycle models. Unlike many traditional frameworks that emphasize nominal rigidities, our model demonstrates that financial frictions alone can effectively explain the simultaneous declines in output, consumption, investment, and labor hours during periods of heightened uncertainty.

A key innovation of our model lies in its emphasis on the interplay between collateral risk and labor supply adjustments. Heightened uncertainty increases the risk premium for collateralized assets, prompting impatient households to reduce their housing holdings and reallocate expenditures from housing to non-durable consumption. This reallocation affects their labor-leisure choices, leading to a decline in labor supply. If this reduction in labor hours by impatient households surpasses the increase in hours worked by patient households, the aggregate labor supply contracts, resulting in declines in both output and aggregate production.

Furthermore, our findings highlight the significant role of financial constraints in shaping macroeconomic dynamics. By adjusting LTV ratios, policymakers can influence the severity of the economic impact of uncertainty shocks. For instance, a lower LTV ratio reduces leverage, mitigating fluctuations in labor supply and aggregate output, while higher ratios amplify these fluctuations, deepening recessions.

This research enriches our understanding of the complex relationship between financial frictions and macroeconomic dynamics. It offers a robust alternative to models that rely on nominal rigidities, shedding light on the mechanisms through which uncertainty shocks propagate in the presence of credit constraints. The insights from our study carry important implications for the design of macroprudential policies aimed at stabilizing economic fluctuations during periods of heightened uncertainty. Future research could extend this analysis by exploring the interaction of financial frictions with other types of shocks or incorporating additional heterogeneities among economic agents.

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Notes

1 The co-movement problem is linked to the insights of Barro and King (1984), who show that the one-sector growth model generates business-cycle-like co-movement patterns only when contemporaneous shocks to total factor productivity (TFP) occur. Other types of shocks struggle to replicate the observed patterns of positive co-movement in the data.

2 Fernández-Villaverde et al. (2015), Katayama and Kim (2018), and Carriero et al. (2018) similarly find a decline in labor hours but do not report a statistically significant response in real wages, as their confidence intervals include zero.

3 Although the original results pertain to nominal wages, we obtained the replication code from the authors and extended the analysis to real wages. Using an updated sample through 2020Q4, we find that real wages also increase in response to uncertainty shocks, and the corresponding 68% confidence intervals, consistent with Cross et al. (2023), exclude zero.

4 For example, Basu and Bundick (2017), Born and Pfeifer (2014), Leduc and Liu (2016), and Cesa-Bianchi and Fernandez-Corugedo (2018) all rely on nominal rigidity to reproduce the boom-bust business cycles following the uncertainty shocks.

5 Born and Pfeifer (2021) find that uncertainty shocks align with sticky wages but not sticky prices.

6 See, for example, Chambers et al. (2009), Choa and Francis (2011), and Cao and Nie (2017).
7 In our simulations, the approximation error, defined as:

$$\left[\frac{\mathrm{E}_t\left(\frac{\Lambda^b_{t+1,t}}{\Pi_{t+1}}\right)\mathrm{E}_t(\Pi_{t+1}q_{t+1})}{\mathrm{E}_t(\Lambda^b_{t+1,t}q_{t+1})}-1\right]\times 100\%,$$

is less than 0.05%. Alternatively, $\mathrm{Cov}_t(\frac{\Lambda^b_{t+1,t}}{\Pi_{t+1}},\Pi_{t+1}q_{t+1})\approx 0$.
8 An alternative way to express the optimal housing condition for impatient households is:

$$\lambda_{b,t}\left[q_t-m_b\mathrm{E}_t\left(\frac{\Pi_{t+1}}{R_t}\cdot q_{t+1}\right)\right]\approx\beta_b(1-m_b)\mathrm{E}_t(\lambda_{b,t+1}q_{t+1})+uh_{b,t},$$

where the term $[q_t-m_b\mathrm{E}_t(\Pi_{t+1}/R_t\cdot q_{t+1})]$ represents the "down payment" faced by impatient households.
9 For the case where $m^h_e=m^k_e=m_e$, Eqs. (23)–(24) can be combined into a single credit constraint, $b_{e,t}=m_e\mathrm{E}_t\Big[\Pi_{t+1}/R_t(q_{t+1}h_{e,t}+k_t)\Big]$.
10 To derive these two equations, we combine Eqs. (28)–(31) and use the following approximation:

$$\mathrm{E}_t\left(\Lambda^e_{t+1,t}/\Pi_{t+1}\right)\mathrm{E}_t\left(\Pi_{t+1}q_{t+1}\right)\approx\mathrm{E}_t\left(\Lambda^e_{t+1,t}q_{t+1}\right);$$
$$\mathrm{E}_t\left(\Lambda^e_{t+1,t}/\Pi_{t+1}\right)\mathrm{E}_t(\Pi_{t+1})\approx\mathrm{E}_t(\Lambda^e_{t+1,t}).$$

11 See Monacelli (2009) and Mendicino and Punzi (2014).
12 The data is available at https://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp/ (see Fernald, 2014; Fernald and Matoba, 2009; Basu et al. 2006).
13 An alternative way to construct a measure of uncertainty shocks is based on a Bayesian approach that computes the likelihood function with flat priors and samples from the posterior with a Markov Chain Monte Carlo method. The details can be found in Fernández-Villaverde et al., (2015).
14 While the covariance between the SDF and housing prices also contributes to risk premiums, its effect is smaller and excluded from the current analysis.

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Appendix A. A model of a frictionless economy

In this appendix, we explain how to modify our baseline model into a frictionless economy. Specifically, we eliminate the credit constraints for both impatient households and entrepreneurs while setting their discount factors to be equal to that of patient households, denoted as $\beta_b = \beta_e = \beta_s$. Consequently, patient and impatient households become indistinguishable and can be collectively represented as patient households. This leads to an aggregate labor input of $n_t = n_{s,t}$. Furthermore, we assume entrepreneurs are owned by savers. Below, we introduce the problems faced by patient households and entrepreneurs in turn.

A.1 Patient households

There is a continuum of mass one of patient households that choose consumption, $c_{s,t}$, housing, $h_{s,t}$, and working hours, $n_{s,t}$, to maximize their lifetime utility:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_s^t \left[\Gamma_{c,s} \cdot \frac{(c_{s,t} - \phi_c c_{s,t-1})^{1-\sigma_c} - 1}{1-\sigma_c} + J \cdot \frac{h_{s,t}^{1-\sigma_h} - 1}{1-\sigma_h} - \kappa \cdot \frac{n_{s,t}^{1+\eta}}{1+\eta} \right].$$

Patient households are subject to a budget constraint represented by:

$$c_{s,t} + q_t h_{s,t} + b_{s,t} \leq w_{s,t} n_{s,t} + q_t h_{s,t-1} + \frac{R_{t-1}}{\Pi_t} \cdot b_{s,t-1} + div_t + \pi_t,$$

where π_t represents profits earned from the wholesale goods firm.

The first-order conditions associated with savers' problems with consumption, labor hours, housing, and bond holdings are:

$$\begin{aligned}
\lambda_{s,t} &= uc_{s,t}, \\
\lambda_{s,t} w_{s,t} &= -un_{s,t}, \\
\lambda_{s,t} q_t &= \beta_s \mathrm{E}_t \left(\lambda_{s,t+1} q_{t+1}\right) + uh_{s,t}, \\
\lambda_{s,t} &= \beta_s \mathrm{E}_t \left(\lambda_{s,t+1} \frac{R_t}{\Pi_{t+1}}\right),
\end{aligned}$$

where $\lambda_{s,t}$ is the Lagrange multiplier associated with savers' budget constraint. $uc_{s,t}$, $uh_{s,t}$, and $un_{s,t}$ are the first-order derivatives of the savers' utility function with respect to $c_{s,t}$, $h_{s,t}$, and $n_{s,t}$:

$$\begin{aligned}
uc_{s,t} &\equiv \Gamma_{c,s} \left\{ (c_{s,t} - \phi_c c_{s,t-1})^{-\sigma_c} - \beta_s \phi_c \mathrm{E}_t \left[(c_{s,t+1} - \phi_c c_{s,t})^{-\sigma_c} \right] \right\}, \\
uh_{s,t} &\equiv J h_{s,t}^{-\sigma_h}, \\
un_{s,t} &\equiv -\kappa n_{s,t}^{\eta}.
\end{aligned}$$

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A.2 The entrepreneur

There is an entrepreneur that produces homogeneous wholesale goods according to the Cobb–Douglas production function, Eq. (22). The entrepreneur's period profit is defined as:

$$\pi_t \equiv \frac{P_t}{X_t} \cdot y_t - i_t - q_t(h_{e,t} - h_{e,t-1}) - w_{s,t} n_{s,t}.$$

We assume patient households own this entrepreneur. This modification leads entrepreneurs to use patient households' SDF to evaluate their profits. Therefore, the entrepreneur's problem is to maximize

$$\max \mathrm{E}_0 \sum_{t=0}^{\infty} \beta_s^t \cdot \lambda_{s,t} \cdot \pi_t,$$

subject to the Cobb–Douglas production function, Eq. (22), and the law of motion for capital. The associated first-order conditions are:

$$\lambda_{s,t} q_t = \mathrm{E}_t \left[\beta_s \lambda_{s,t+1} \left(\frac{\nu y_{t+1}}{X_{t+1} h_{e,t}} + q_{t+1} \right) \right],$$

$$\lambda_{s,t} = \beta_s \mathrm{E}_t \left\{ \lambda_{s,t+1} \left[\frac{\mu y_{t+1}}{X_{t+1} k_t} + (1 - \delta) \right] \right\},$$

$$w_{s,t} = \frac{(1 - \mu - \nu) y_t}{X_t n_{s,t}}.$$

A.3 Market-clearing conditions

The new market-clearing conditions become:

$$h_{s,t} + h_{e,t} = 1,$$

$$c_{s,t} + i_t = y_t.$$

Appendix B. Translation of Calvo Price duration into implied Rotemberg adjustment cost parameter

This section first introduces retailers who reoptimize prices à la Calvo, deriving its associated New Keynesian Phillips Curve. Then we show how to translate Calvo price duration into implied Rotemberg adjustment cost parameter by comparing their New Keynesian Phillips Curves.

B.1 Calvo price setting

Building on the work of Calvo (1983) and Yun (1996), we assume that retailers can reset their price with probability $1 - \tilde{\phi}_p$. Retailer z's problem is:

$$\max_{P_t^\star(z)} \mathrm{E}_t \sum_{j=0}^{\infty} \frac{(\beta \tilde{\phi}_p)^j \lambda_{s,t+j}}{\lambda_{s,t}} \cdot \left[\frac{P_{t+j}^\star(z) - P_{t+j}^w}{P_{t+j}} \cdot Y_{t+j}(z) \right],$$

subject to its demand function Eq. (38). The first-order condition associated with retailer z's problem is:

$$\mathrm{E}_t \sum_{j=0}^{\infty} \frac{(\beta \tilde{\phi}_p)^j \lambda_{s,t+j}}{\lambda_{s,t}} \cdot \left\{ (1 - \eta_y) \cdot \left[\frac{P_t^\star(z)}{P_{t+j}} \right]^{1-\eta_y} + \eta_y \cdot \frac{P_{t+j}^w}{P_{t+j}} \cdot \left[\frac{P_t^\star(z)}{P_{t+j}} \right]^{-\eta_y} \right\} \cdot Y_{t+j} = 0. \tag{51}$$

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Given that all retailers face the same profit maximization problem, they all choose the same price, $P_t^\star(z) = P_t^\star$. Hence, we get:

$$P_t^\star = \frac{\eta_y}{\eta_y - 1} \cdot \frac{\mathrm{E}_t \sum_{j=0}^{\infty} (\beta\tilde{\phi}_p)^j \lambda_{s,t+j} \cdot \frac{P_{t+j}^{\eta_y}}{X_{p,t+j}} \cdot Y_{t+j}}{\mathrm{E}_t \sum_{j=0}^{\infty} (\beta\tilde{\phi}_p)^j \lambda_{s,t+j} \cdot P_{t+j}^{\eta_y - 1} \cdot Y_{t+j}}. \tag{52}$$

Finally, the price for the final goods, Eq. (37), can be rewritten as the following equation:

$$P_t = \left[(1 - \tilde{\phi}_p) \cdot (P_t^\star)^{1-\eta_y} + \tilde{\phi}_p \cdot P_{t-1}^{1-\eta_y}\right]^{\frac{1}{1-\eta_y}}. \tag{53}$$

B.2 The equivalence of Rotemberg and Calvo

Upon linearizing Eq. (50), we arrive at the following:

$$\widehat{\Pi}_t = \beta_s \mathrm{E}_t \left[\widehat{\Pi}_{t+1}\right] - \frac{\eta_y - 1}{\Pi^2 \phi_p} \cdot \widehat{X}_t. \tag{54}$$

The first-order Taylor expansions of Eqs. (52) and (53) yield the following results:

$$\widehat{P}_t^\star = (1 - \beta\tilde{\phi}_p)(\widehat{P}_t - \widehat{X}_t) + \beta\tilde{\phi}_p \mathrm{E}_t \widehat{P}_{t+1}^\star;$$
$$\widehat{\Pi}_t = (1 - \tilde{\phi}_p)(\widehat{P}_t^\star - \widehat{P}_{t-1}).$$

Upon combining these two equations, we have the inflation equation:

$$\widehat{\Pi}_t = \beta_s \mathrm{E}_t \left[\widehat{\Pi}_{t+1}\right] - \frac{(1 - \tilde{\phi}_p)(1 - \beta\tilde{\phi}_p)}{\tilde{\phi}_p} \cdot \widehat{X}_t. \tag{55}$$

By comparing the inflation equations derived from Rotemberg's and Calvo's price-setting mechanisms, specifically Eqs. (54) and (55), we can solve for the parameter value that translates a Calvo price-setting duration into an equivalent Rotemberg price adjustment cost parameter:

$$\phi_p = \frac{\tilde{\phi}_p(\eta_y - 1)}{(1 - \tilde{\phi}_p)(1 - \beta\tilde{\phi}_p)\Pi^2}. \tag{56}$$

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