

# Asset Pricing and the Propagation of Macroeconomic Shocks

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## Abstract

This paper considers the implications of habit formation and financial frictions for the propagation of macroeconomic shocks. In a model that is capable of matching asset pricing moments, a short-lived shock that destroys a small fraction of the economy's stock of pledgeable collateral generates a persistent recession, a stock market crash, and a flight-to-safety effect. This novel mechanism creates a tight link between the asset pricing implications of macroeconomic models and their ability to propagate and amplify the effects of macroeconomic shocks.

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# 1 Introduction.

The subprime financial shock that hit the American economy was transmitted to Europe through the continent's exposure to toxic financial products (e.g., Puri et al. 2011; Ongena et al. 2015). A central feature of this crisis is that a large share of these financial products were considered safe before the shock hit. Many of these products had a high credit rating and were widely used as pledgeable collateral in the years preceding the crisis (e.g., Benmelech and Dlugosz 2010; IMF 2012). The second key feature of the subprime crisis is that the initial shock that triggered the recession was highly transitory. While the European banking sector suffered large write-downs on securities (e.g., ECB 2009, 2010), the vast majority of these losses were uncovered within a few quarters. Yet, the continent's exposure to toxic financial products initiated one of the deepest recession ever recorded.

Three main obstacles need to be overcome in order to study the propagation of a subprime shock in a dynamic general equilibrium model. First, the propagation mechanism of traditional dynamic stochastic general equilibrium (DSGE) models is not sufficiently powerful to generate large and persistent recessions in response to small shocks that have little intrinsic persistence (e.g., Cogley and Nason 1995; Chang et al. 2002). Second, standard macroeconomic frameworks are unable to generate differences in risk premia across asset classes. It is therefore difficult to study the effects of safe asset scarcity in standard general equilibrium frameworks, since most DSGE models cannot explain the difference in risk premia between safe and risky assets observed in the data. Finally, reproducing the co-movement between macroeconomic and financial market variables that is observed during recessions has always proved challenging (e.g., Shi 2015; Biggio 2012).

The present paper addresses these issues by developing a dynamic general equilibrium model that can be used to study the macroeconomic implications of safe asset scarcity. Relative to a real business cycle model (e.g., King, Plosser, and Rebelo 1988; King and Rebelo 1999), the first main departure is the introduction of a financing-in-advance constraint. This financing friction creates a role for financial intermediation, as households need to obtain credit from a banking sector in order to finance consumption expenditures in advance. Bankers' access to short-term funding in turn depends on the stock of safe assets that they can pledge as collateral, the supply of which is endogenously determined by an investment banking sector. In this environment, a subprime shock that destroys a fraction of the economy's safe asset stock reduces the amount of collateralized funding that banks can raise, which in turn induces a contraction in lending. The resulting credit crunch leads to a fall in consumption and triggers a recession.

The choice to focus the analysis on a transmission mechanism that operates from bank lending to retail customers can be motivated by the findings documented by Puri et al. (2011). Using data on consumer loans, they show that the U.S. financial crisis induced a contraction in the supply of retail lending in Germany, the largest eurozone economy, and find evidence of supply side effects as banks exposed to toxic subprime assets rejected substantially more loan applications than non-affected banks. Moreover, as illustrated by Figure 1, bank lending standards for euro area households tightened dramatically during the crisis period. In addition, in the eurozone, this is consumption and not investment that has been growing at a historically slow pace since 2009 (e.g., ECB 2011; Vermeulen 2016).<sup>1</sup>

Other channels such as bank lending to euro area firms played a relevant role during the crisis (e.g., Ongena et al. 2015). But one important specificity of the retail lending channel is that it is considerably more difficult for households to find alternative sources of financing when bank lending dries up. By contrast, the recourse to market-based financing is an important margin of adjustment that the corporate sector can use to alleviate the effects of a credit crunch (e.g., De Fiore and Uhlig 2015).

The second main departure from the neoclassical growth model is the introduction of habits in the composite of consumption and leisure (e.g., Jaccard 2014). This particular preference specification helps to resolve standard asset pricing anomalies and allows us to study the effects of safe asset scarcity in a model that is able to match risk premia. The asset that agents use as a pledgeable asset is safe in the sense that it behaves like an insurance against shocks. Its risk premium over the corresponding risk-free rate is therefore slightly negative, whereas riskier assets such as stocks are compensated by a sizeable equity premium.

My first main finding is that this novel mechanism creates a tight link between the asset pricing implications of macroeconomic models and their ability to propagate and amplify the effects of exogenous shocks. In particular, the model's endogenous propagation mechanism is considerably stronger in the version of the model that is able to generate a 5.5 percent equity premium. Without habits, by contrast, the model-implied equity premium falls to 0.01 percent and the model loses much of its ability to propagate the effects of transitory financial shocks.

The more persistent recession obtained in the version of the model that matches the equity premium is due to the combination of two factors. First, rebuilding the economy's stock of collateral after an adverse financial shock is costly and takes time. Second, with habits, the low intertemporal elasticity of substitution in consumption that is needed to

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<sup>1</sup>In the eurozone, consumption is also by far the largest component of gross domestic product (GDP).

match asset pricing moments creates a strong consumption smoothing motive. In such an environment, agents' main priority after a subprime shock is to rebuild the economy's stock of safe assets, since collateral is needed to access the credit market and finance consumption expenditures. On impact, a larger fall in consumption can be avoided by reallocating resources to the financial sector. But, in a general equilibrium environment, this reallocation of resources comes at the cost of delaying the recovery by crowding out business investment in the real economy. The recession is therefore less painful on impact but lasts much longer.

The second main finding of this study is that this model mechanism can reproduce some key regularities observed during the financial crisis. In particular, a shock that is calibrated to generate cumulated losses of a plausible magnitude within the banking sector generates a deep and persistent recession, a fall in consumption, investment and hours worked, as well as a stock market crash. This mechanism also generates an increase in the price of safe assets that contributes to attenuating the effects of the shock by increasing the value of the economy's stock of pledgeable assets. In this sense, the flight-to-safety effect triggered by adverse financial shocks acts as an endogenous stabilization mechanism (e.g., Gourinchas and Jeanne 2012).

As in Jermann and Quadrini (2012), the interaction between financial frictions and the labor market is crucial for the results of the present study. The financing-in-advance constraint introduces a time-varying wedge into the agent's intratemporal consumption-leisure optimality condition that increases in importance during periods of recession. The model-implied wedge can be constructed using the structure of the model and compared with eurozone data. As illustrated in Figure 2, the fact that this wedge is countercyclical and rose sharply during the financial crisis is consistent with the mechanism under study.

This paper primarily builds on the literature that jointly studies asset pricing and business cycle facts in production economy models (e.g., Jermann 1998; Tallarini 2000; Boldrin, Christiano, and Fisher 2001; Danthine and Donaldson 2002; Campanale, Castro, and Clementi 2010; Gourio 2012; Jaccard 2014; Croce 2014). The difference between the approach followed in this paper and the approaches of these studies is that, as in Gourio (2013), I study financial frictions in a model that can match asset pricing moments.<sup>2</sup>

The present work is related to the literature that uses habit formation to resolve asset pricing puzzles and, as in Constantinides (1990), I specify that habit formation is internal while the resolution proposed by Abel (1990) and Campbell and Cochrane (1999) relies on

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<sup>2</sup>Uhlig (2007), Rudebusch and Swanson (2012), and Swanson (2016) among others study the asset pricing implications of DSGE models augmented with nominal rigidities.

an external specification. Relative to the literature that uses Epstein-Zin-Weil preferences (e.g., Weil 1989, 1990; Epstein and Zin 1989), the main difference is that my mechanism creates a tight link between the model's asset pricing implications and the dynamics of macroeconomic variables. In particular, while the introduction of Epstein-Zin-Weil preferences leads to a separation of quantity and asset price determination (e.g., Tallarini 2000), the model's endogenous propagation mechanism is considerably stronger in the version that is capable of generating realistic asset pricing predictions.

My approach is also inspired by the seminal contribution of Kiyotaki and Moore (1997) who showed how fluctuations in the price and quantity of collateral can affect the transmission of shocks in a model in which agents face collateral constraints. Relative to their mechanism, I consider the case of an agent that needs to obtain a loan in order to finance consumption expenditures. In this respect, my mechanism shares some important similarities with the body of literature on cash-in-advance constraints (e.g., Abel 1985; Svensson 1985; Lucas and Stokey 1987; Cooley and Hansen 1995; Hairault and Portier 1995; Cooley and Quadrini 1999; Alvarez, Atkeson, and Kehoe 2002). At the same time, a key difference is that the amount of borrowing that can be obtained, which in turn affects agents' consumption decisions, depends on the resale value of a pledgeable asset whose supply is endogenously determined.

This work is also related to a recent strand of the literature in which capital quality shocks are a main source of business cycle fluctuations (e.g., Gourio 2012; Gertler and Karadi 2011). Relative to these studies, since my financial shock does not directly affect the production function or the law of motion of physical capital, the main difference is that these shocks originate in a different segment of the economy. The investment banking sector produces safe assets, but does not retain any residual risk on its balance sheet after having sold these assets to credit-constrained agents. In this sense, this sector is meant to capture the role played by the shadow financial sector in providing money-like securities to the real economy (e.g., Singh and Stella 2012; Gennaioli, Shleifer, and Vishny 2013; Moreira and Savov 2016).

As in Kiyotaki and Moore (2012), I augment the neoclassical growth model with financial frictions and study the macroeconomic effects of shocks that propagate to the rest of the economy through financial frictions. Relative to their version of the liquidity shock hypothesis, my mechanism addresses a point recently raised by Shi (2015) and Biggio (2012) in the sense that in my model a negative financial shock generates a persistent recession as well as a large fall in equity prices. By contrast, liquidity shocks generate a negative co-movement between equity prices and output in the baseline version of the Kiyotaki-

Moore model.<sup>3</sup> As shown by Nezafat and Slavik (2015), introducing this mechanism into the neoclassical growth model nevertheless helps to increase the equity premium and raises the volatility of Tobin's  $Q$ .

This work builds on the real business cycle literature (e.g., Kydland and Prescott 1982; Long and Plosser 1983; King, Plosser, and Rebelo 1988; King and Rebelo 1999) and my model reduces to the neoclassical growth model when the financing constraints are not binding. My mechanism introduces an endogenous time-varying wedge into the agent's intratemporal consumption-leisure optimality condition and is, in this respect, also related to the labor wedge literature summarized in Shimer (2009),<sup>4</sup> and whose link with the real business cycle model's endogenous propagation mechanism is discussed in Gourio and Rudanko (2014).

This paper is also related to a more recent work that studies the macroeconomic implications of safe asset shortages. The mechanism through which the financial sector was able to create safe assets at the cost of exposing the system to a panic is described in Caballero (2010). Caballero and Fahri (2015) develop a theory of the macroeconomic effects of safe asset shortages that is motivated by the secular downward trend in equilibrium real interest rates observed for more than two decades. Relative to these studies, the key difference is that I consider the case of Walrasian markets where the price and quantity of safe assets are determined as an equilibrium outcome.

Another recent strand of the literature studies the role played by information about the underlying collateral during the financial crisis. In Gorton and Ordonez (2014), information is costly to produce and the lack of information production during periods of economic booms makes the economy vulnerable to small shocks. While in this model the origin of a crisis remains exogenous, its duration crucially depends on the stock of information produced in the economy. Kurlat (2013) shows how asymmetric information about asset qualities affects the transmission of aggregate shocks. The core mechanism relies on an asymmetric information problem which prevents buyers from distinguishing assets that are useless lemons from high-quality assets. Bigio (2015) studies the interaction between limited enforcement and asymmetric information and shows that increases in capital quality dispersion can reproduce some key regularities that were observed during the Great Recession. Finally, Gorton and Ordonez (2015) endogenize the creation of safe assets and show that whether a credit boom is sustainable very much depends on the characteristic

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<sup>3</sup>Cui and Radde (2016) address this issue by endogenizing asset liquidity using search frictions. In the framework developed by Jermann and Quadrini (2012), a positive co-movement is obtained by introducing capital adjustment costs.

<sup>4</sup>See also Chari et al. (2007).

of the technology shock. In a similar vein, Boissay, Collard, and Smets (2015) provide a mechanism that can explain why credit booms can sometimes end up in a banking crisis.

Relative to this latter strand of the literature, my study focuses on the asset pricing implications of macroeconomic models and I do not attempt to formalize the mechanism that led to the creation and destruction of toxic financial products. Since this process originated in the U.S. housing market (e.g., Jeske et al. 2013; Berger et al. 2015; Justiniano et al. 2016) and since the focus of my paper is the eurozone, the initial subprime shock is treated as an exogenous event.

## 2 The environment.

The economy is composed of four representative sectors: a household sector, a commercial banking sector, a non-financial corporate sector, and an investment banking sector. Households are liquidity constrained and need to obtain a loan from commercial banks in order to finance a fraction of their consumption expenditures in advance. Access to refinancing in the commercial banking sector in turn depends on the quantity of assets that banks can pledge as collateral. Pledgeable assets consist of financial assets that commercial banks purchase from the investment banking sector. In the model, the asset produced by the investment banking sector, which I refer to as the safe asset, takes the form of a zero coupon asset whose only function in the economy is to serve as collateral. Financial shocks are shocks that destroy a fraction of the existing stock of pledgeable assets accumulated by commercial banks. The specifications of preferences and technology are compatible with balanced growth and  $\gamma$  denotes the deterministic growth rate of the economy along the balanced growth path.

### Households

The sequential budget constraint faced by the representative household in period  $t$  is given as follows:

$$\pi_{Tt}e_t + w_{Ft}N_{Ft} + w_{St}N_{St} = c_t + r_{Lt}l_t + p_{Et}(\gamma e_{t+1} - e_t) \quad (1)$$

On the revenue side, the representative agent firstly receives a dividend income  $\pi_T$  from owning firms in the other sectors of the economy, where  $e$  denotes the quantity of stocks held by households. As far as the allocation of time is concerned, the representative agent divides his or her time endowment between leisure activities  $L$ , hours worked in the final goods-producing sector  $N_F$ , and hours worked in the investment banking sector  $N_S$ . The

wage rates paid by firms in the non-financial and investment banking sectors are denoted by  $w_F$  and  $w_S$ , respectively. Normalizing the total time endowment to 1, the allocation of time constraint takes the following form:

$$N_{Ft} + N_{St} + L_t = 1 \quad (2)$$

On the expenditure side of the budget constraint,  $c$  is consumption,  $r_L$  denotes the cost of obtaining credit from the commercial banking sector, and  $l$  is credit. Equity prices are denoted by  $p_E$  and  $e$  denotes equity holding, where the time subscript  $t + 1$  refers to the stock of equity held at the end of period  $t$ .

Financial frictions are introduced by assuming that households need to obtain a loan from the commercial banking sector in order to finance part of their consumption expenditures. The relationship between consumption and credit that households obtain from the commercial bank is given by the following financing-in-advance constraint:

$$c_t \leq \xi l_t \quad (3)$$

where  $\xi$  is a velocity parameter that determines the tightness of the constraint.

The representative household derives utility from consuming a market consumption good and leisure. To maximize the model's ability to explain asset pricing facts, I assume that habits are formed over the composite of consumption and leisure, where the reference level or habit stock is denoted by  $h$  (e.g., Jaccard 2014). Net utility is given by the difference between the composite good  $c(\psi + L^v)$  and the reference level,  $h$ . The two labor supply parameters,  $v$  and  $\psi$ , control the Frisch elasticity of labor supply and determine the steady state time allocation.<sup>5</sup> In an infinite horizon model, the subjective discount factor is affected by the growth rate of the economy along the balance growth path (e.g., Kocherlakota 1990) and I denote the modified discount factor by  $\hat{\beta}$ , where  $\hat{\beta} = \tilde{\beta}\gamma^{1-\sigma}$ . The curvature parameter is denoted by  $\sigma$  and the law of motion that governs the accumulation of the habit stock is given as follows:

$$\gamma h_{t+1} = \tau h_t + (1 - \tau)c_t(\psi + L_t^v) \quad (4)$$

where  $0 \leq \tau \leq 1$  is a memory parameter that controls the rate at which the habit stock depreciates. The agent's dynamic optimization problem can be expressed as follows:

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<sup>5</sup>These parameters are restricted to ensure concavity in  $L$  and that both goods are always normal goods.

$$\max_{c_t, l_t, N_{Ft}, N_{St}, e_{t+1}, h_{t+1}} E_0 \left\{ \sum_{t=0}^{\infty} \hat{\beta}^t \frac{1}{1-\sigma} [c_t(\psi + L_t^v) - h_t]^{1-\sigma} \right\}$$

The representative agent optimally chooses consumption, the quantity of credit, the number of hours worked in the two sectors, the number of shares, and controls the evolution of his or her habit stock in order to maximize expected lifetime utility subject to constraints (1) to (4).

### Commercial banks

The commercial banking sector collects deposits from the non-financial corporate sector and decides how much to lend to the household sector. The key assumption is that banks need a collateral in order to secure short-term deposits. The safe financial instrument that bankers use as collateral takes the form of a zero-coupon asset. The accumulation of safe assets is governed by the following law of motion:

$$\gamma s_{t+1} - (1 - \eta_t) s_t = x_t \tag{5}$$

where  $\eta_t$  is a time-varying depreciation rate that modifies the stock of safe assets available at the beginning of period  $t$ . The quantity of new assets purchased from the investment banking sector is denoted by  $x$  where  $s$  denotes the safe asset stock. The subprime shock is modelled as a random disturbance to the depreciation rate (e.g, Ambler and Paquet 1994) of the existing safe asset stock and the stochastic component, which I denote by  $\log z_t$ , has mean zero, and follows an autoregressive process of order one:

$$\log z_t = \rho_Z \log z_{t-1} + \varepsilon_{Zt}$$

The depreciation rate therefore depends on the realized value of the stochastic shock:

$$\eta_t = \log z_t$$

and  $\eta_t$  is constant and equal to zero in the version of the model that abstracts from financial shocks.

Each period, commercial banks choose the quantity of loans to extend to the household sector as well as the quantity of newly-produced safe assets to purchase from the investment banking sector. Short-term deposits are the only source of financing and profits in the banking sector in period  $t$  are given as follows:

$$\pi_{Bt} = r_{Lt}l_t - r_{Dt}d_t - p_{St}x_t \quad (6)$$

where deposits and the cost of funding are denoted by  $d$  and  $r_D$ , respectively.

To keep the analysis tractable, I model the bank production function as a linear technology that links the quantity of loans produced by commercial banks to the quantity of short-term funding that they are able to raise:

$$l_t = d_t \quad (7)$$

For simplicity, I abstract from the role of monitoring in the production function of bank loans (e.g., Goodfriend and McCallum 2007).<sup>6</sup>

The amount of short-term deposits that can be raised is constrained and depends on the quantity of safe assets that bankers can pledge as collateral. This collateral constraint, which provides an upper bound on the quantity of financing that the commercial banking sector is able to raise, is given as follows:

$$d_t \leq \varrho(1 - \eta_t)p_{St}s_t \quad (8)$$

where  $\varrho$  is a parameter that determines the tightness of the collateral constraint. The market value of the stock of safe assets that are available at the beginning of the period is denoted by  $p_{Ss}$  and the amount of short-term financing that banks can raise is affected by the realization of the financial shock. This constraint captures the notion that the secured market is a major source of short-term financing for many financial institutions and that this market played a key role during the crisis. A main factor that exposed the financial system to the subprime shock was the need to guarantee the safety of deposits by pledging collateral. As shown by Gorton and Metrick (2012), this is the combination of secured lending and securitized products that was at the nexus of the crisis.

The refinancing and lending choices in the banking sector take the form of a within-period decision and the timing of events is as follows. The representative bank starts the period with a stock of safe assets that was purchased in period  $t - 1$  and carried over into period  $t$ . At the beginning of period  $t$ , commercial banks receive a deposit  $d$  from the non-financial corporate sector that is used to finance their activity and which is constrained by the amount of pledgeable collateral available at the beginning of the period. Depositors take the stock of pledgeable assets of bankers as collateral and, in exchange, agree to provide

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<sup>6</sup>Another simplifying assumption is that I abstract from bank regulation (e.g., Van den Heuvel 2008; 2016).

short-term financing. Once deposits have been received, banks choose the quantity of loans to extend to the household sector. Before the end of the period, households reimburse their loans to the commercial bank principal plus interest. Banks are then able to reimburse depositors, make the interest payment, get their collateral back and decide on the quantity of newly-produced safe assets to purchase.

Each period, managers in the commercial banking sector choose the optimal quantity of credit to extend to the household sector as well as the quantity of safe financial products to purchase from the investment banking sector in order to maximize the firm's market value, which is equal to the present discounted value of all current and future expected cash flows:

$$\max_{l_t, s_{t+1}} E_0 \sum_{t=0}^{\infty} \hat{\beta}^t \frac{\lambda_t}{\lambda_0} \pi_{Bt}$$

subject to constraints (5) to (8).

### **Firms in the non-financial corporate sector**

Firms in the non-financial sector produce a final output good  $y$  using physical capital  $k$  and labor  $N_F$  as productive inputs. In addition to the production decision, I assume that another main function of the non-financial sector is to determine its investment policy. Investment, which I denote by  $i$ , is financed through retained earnings and determines the stock of financial capital that firms have at their disposal. In parallel to the investment decision, the non-financial sector needs to decide how to optimally allocate its stock of financial capital between the different sectors of the economy. Financial capital, which is denoted by  $a$ , is a composite capital good that can be divided between the amount of physical capital used in the production function  $k$ , funds lent to the investment banking sector  $m$ , and funds deposited in the banking sector  $d$ :

$$a_t = k_t + m_t + d_t \tag{9}$$

The accumulation of financial capital is subject to an adjustment cost and evolves over time according to the following law of motion:

$$\gamma a_{t+1} \leq (1 - \delta) a_t + \left( \frac{\theta_1}{1 - \epsilon} \left( \frac{i_t}{a_t} \right)^{1-\epsilon} + \theta_2 \right) a_t \tag{10}$$

Following Hayashi (1982), Baxter and Crucini (1993), and Jermann (1998), among others, I adopt a specification of adjustment costs that penalizes changes in investment that are

large relative to the existing stock of financial capital.<sup>7</sup> Since an increase in investment needs to be financed by reducing the dividend paid to shareholders, this friction could capture a cost that managers incur when they need to convince shareholders to accept a reduction in dividends in order to finance investment projects. One possible interpretation is that convincing shareholders to finance large investment projects is more costly than financing smaller investment projects, since large projects need to be financed through higher amounts of retained earnings.

Given the capital allocation decision faced by management, profits in the final good sector are given as follows:

$$\pi_{Ft} = y_t + r_{Mt}m_t + r_{Dt}d_t - w_{Ft}N_{Ft} - i_t \quad (11)$$

where  $r_M$  is the rate at which funds lent to the investment banking sector are remunerated, and where the production function for the final output good is given by:

$$y_t = A_t k_t^\alpha N_{Ft}^{1-\alpha} \quad (12)$$

The random technology shock  $A$  follows an autoregressive process of order one,

$$\log A_t = \rho_A \log A_{t-1} + \varepsilon_{At},$$

where the random disturbance  $\varepsilon_A$  is normally distributed. The autoregressive parameter is denoted by  $\rho_A$ , where  $0 \leq \rho_A \leq 1$ . In each period, managers in the final goods-producing sector choose the optimal number of hours worked, investment, the evolution of the stock of financial capital, and how capital is allocated between the different sectors of the economy to maximize the firm's market value, which is equal to the present discounted value of all current and future expected cash flows:

$$\max_{N_{Ft}, i_t, k_t, d_t, m_t, a_{t+1}} E_0 \sum_{t=0}^{\infty} \widehat{\beta}^t \frac{\lambda_t}{\lambda_0} \pi_{Ft}$$

where  $\widehat{\beta}^t \frac{\lambda_t}{\lambda_0}$  is the discount factor of the representative agent who is the owner of the firm, subject to constraints (9) to (12).

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<sup>7</sup>The two adjustment cost parameters,  $\theta_1$  and  $\theta_2$  are chosen to ensure that in the deterministic version of the model, the economies with and without adjustment costs have the same deterministic steady state (e.g., Baxter and Crucini 1993; Jermann 1998).

### The investment banking sector

The investment banking sector is endowed with a production technology that enables firms in this sector to produce a financial asset that commercial banks use as pledgeable collateral. The quantity of new assets is produced via a Cobb-Douglas production function:

$$x_t = m_t^\phi N_{St}^{1-\phi} \quad (13)$$

where  $m$  denotes the amount of short-term funding that the investment banking sector borrows from the non-financial sector. In each period, the investment banking sector chooses the number of hours worked in hiring from the representative agent as well as the quantity of funds that maximizes profits,

$$\max_{m_t, N_{St}} \pi_{St} = p_{St}x_t - w_{St}N_{St} - r_{Mt}m_t$$

subject to constraint (13), and where  $r_M$  represents the cost of borrowing short-term funds from the non-financial sector.

At the beginning of the period, the financial sector receives a loan from the non-financial sector  $m$ , which needs to be reimbursed at the end of period  $t$ . Although firms in this sector only have access to short-term financing, the key is that the technology that they operate allows them to create a long-term zero coupon asset that banks can use as a pledgeable collateral. The output produced by the investment banking sector can be thought of as a financial product that is complex to design. Financial engineers are therefore required to design this product and  $(1 - \phi)$  denotes the labor share in the production function of safe assets.

### Market equilibrium

A competitive equilibrium in the economy is a sequence of prices  $\lambda, \varphi, \mu, \chi, q, w_S, w_F, r_M, r_D, r_L, p_S, p_E$  where  $q$  is Tobin's Q,  $\lambda$  is marginal utility,  $\varphi$  is the Lagrange multiplier associated with equation (4),  $\mu$  and  $\chi$  are the Lagrange multipliers associated with the financing in advance and collateral constraints (3) and (8), respectively, and quantities  $c, l, i, x, k, m, N_F, N_S, a, s, h, e$  and  $y$  that satisfy efficiency conditions of households and firms in the different sectors of the economy as well as the economy-wide resource constraint:

$$y_t = c_t + i_t$$

for all states, for  $t=1\dots\infty$ , and given initial values for the three endogenous state variables,

$a, h$  and  $s$ .

### The financing-in-advance wedge

Relative to the neoclassical growth model, the key difference is that financial frictions introduce a wedge into the agent's consumption-leisure optimality condition. With habits, the first-order condition with respect to consumption is given as follows:

$$\{[c_t(\psi + L_t^v) - h_t]^{-\sigma} + \varphi_t(1 - \tau)\}(\psi + L_t^v) = \lambda_t + \mu_t \quad (14)$$

As in a standard cash-in-advance model, the marginal utility of consumption must exceed the marginal utility of wealth in a model in which consumption expenditures need to be financed in advance. The difference between the two, which is given by the Lagrange multiplier  $\mu$ , determines the value of liquidity services (e.g., Walsh 2003). The consumption-leisure optimality condition can be derived by combining equation (14) with the first-order condition with respect to hours worked in the non-financial sector. With this internal habit specification, the terms capturing the effects of habits cancel out and the only difference relative to the neoclassical growth model is the introduction of a wedge, captured by the term  $\mu/\lambda$ , into the consumption-leisure optimality condition:

$$\psi + L_t^v = \frac{c_t v L_t^{v-1}}{w_{Ft}} \left(1 + \frac{\mu_t}{\lambda_t}\right) \quad (15)$$

This wedge shows how the tightness of the financing-in-advance constraint in equation (3) affects the agent's optimal consumption and leisure choices. Combining optimality conditions in the household and banking sectors, the financing-in-advance wedge can be further decomposed into a first term that captures the cost of funding and a second term that reflects the effect of collateral scarcity:

$$\xi \frac{\mu_t}{\lambda_t} = r_{Dt} + \frac{\chi_t}{\lambda_t} \quad (16)$$

The first term on the right-hand side of equation (16) shows how the funding cost of commercial banks affects the financing-in-advance wedge through  $r_D$ . The ratio between the two Lagrange multipliers  $\chi/\lambda$  can be thought of as a collateral scarcity wedge, which measures the tightness of the collateral constraint (8). This second term therefore shows how collateral scarcity in the banking sector impacts the financing conditions faced by households. This decomposition illustrates the two channels through which the cost of short-term funding and the availability of collateral in the banking sector affect the financing conditions faced by households, which in turn determine the ease by which consumption

expenditures can be financed.

### Asset returns and risk premia

The safe asset can be used as pledgeable collateral and this particular function affects its valuation. The commercial bank's optimality condition with respect to its choice of safe assets can be used to characterize the evolution of the safe asset price by deriving the following asset pricing formula:

$$p_{St} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} p_{S_{t+1}} (1 - \eta_{t+1}) \left( 1 + \varrho \frac{\chi_{t+1}}{\lambda_{t+1}} \right) \quad (17)$$

where for the sake of economizing on notation, I define  $\beta$  as follows:

$$\beta = \tilde{\beta} \gamma^{-\sigma}$$

This Euler condition illustrates that the intertemporal tradeoff between the loss in utility from purchasing the safe asset in period  $t$  and the expected discounted increase in utility in period  $t + 1$  crucially depends on the collateral scarcity effect, which is captured by the term  $\varrho \chi / \lambda$ . The second key distinguishing feature of the safe asset price is that its value is directly affected by the realization of the financial shock in  $t + 1$ .

A risk-free return, which is denoted by  $r_F$  can be derived by assuming the existence of a one-period risk-free bond that is in zero net supply. I then define the safe asset premium as the unconditional expected excess return of the safe asset with respect to the risk-free return:

$$sp = E(E_t r_{t,t+1}^S - r_t^F)$$

where the risk-free return is determined by the standard intertemporal condition:

$$1 = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} r_{Ft}$$

and where the conditional expected return of the safe asset is given as follows:

$$E_t r_{t,t+1}^S = E_t \frac{p_{S_{t+1}}}{p_{St}} (1 - \eta_{t+1}) \left( 1 + \varrho \frac{\chi_{t+1}}{\lambda_{t+1}} \right)$$

The optimality condition characterizing the evolution of equity holdings can be used to derive a textbook asset pricing formula linking the price of equity in period  $t$  to the expected discounted sum of future dividends:

$$p_{Et} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} (\pi_{Tt+1} + p_{Et+1})$$

The equity premium is then defined as the unconditional expected excess return:

$$ep = E(E_t r_{t,t+1}^E - r_t^F)$$

where  $E_t r_{t,t+1}^E$  is given as follows:

$$E_t r_{t,t+1}^E = E_t \frac{\pi_{Tt+1} + p_{Et+1}}{p_{Et}}$$

These definitions are standard and imply that the equity and safe asset risk premia will be equal to zero in the deterministic version of the model or up to a first-order approximation.<sup>8</sup>

### 3 Parameter selection.

I calibrate the main parameters of the model using pre-crisis data and assume that technology shocks are the only source of shocks in the pre-crisis period. Focusing on the case of technology shocks facilitates comparisons with pertinent examples in the literature. Following Jermann (1998), most of the subsequent literature on asset pricing in production economies assumes that technology shocks are the only driving force. Moreover, to the best of my knowledge, there are no other episodes in the short history of the eurozone economy that could be interpreted as a subprime shock. Starting from this pre-crisis calibration, I will then study the propagation mechanism of a financial shock that is calibrated to match the amount of write-downs on securities suffered by the eurozone banking sector during the crisis period.

The pre-crisis calibration is obtained by using a first set of moment conditions that can be derived from the structure of the model or by exploiting steady state restrictions. A second set of parameter values, for which *a priori* knowledge is weak, is chosen to maximize the model's ability to reproduce a series of empirical facts that characterize the eurozone economy.<sup>9</sup>

#### Curvature parameter, technology parameters and population growth

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<sup>8</sup>As explained in Section 4, the model is solved using higher-order perturbation techniques.

<sup>9</sup>The data source used in this section is described in the data appendix.

The deterministic growth rate of the economy  $\gamma$  is calibrated using data on population growth, which is available on an annual basis since 1960. Between 1960 and 2008, the average rate of population growth for the country group that is currently forming the eurozone is 0.5 percent per year, which implies a quarterly growth rate value of 1.0013.

The capital share parameter in the production function of the final output good  $\alpha$  is set to 0.36, which implies a labor share of about 2/3. As shown by the approximate solutions derived in Constantinides (1990), Jermann (1998), Boldrin, Christiano, and Fisher (1997) and Swanson (2012), with internal habits, long-term risk aversion increases with the curvature coefficient  $\sigma$  but is independent from the habit parameter. I therefore set  $\sigma$  to 1, which is a well-accepted value for this parameter.<sup>10</sup>

### **Frisch elasticity of labor supply and steady state time allocation**

In Jaccard (2014), I show that the curvature parameter  $v$  controls the Frisch elasticity of labor supply. In the real business cycle literature, a Frisch elasticity of at least 3 is usually needed to account for business cycle fluctuations (e.g., King and Rebelo 1999). Recent findings however suggest that the Frisch elasticity could be smaller than what is usually assumed in the macroeconomic literature (e.g., Hall 2009; Chetty et al. 2011). In light of these recent findings, I choose a value for  $v$  that implies an elasticity of 0.7, which is the value estimated by Pistaferri (2003).

The second labor supply parameter is chosen to ensure that in the steady state, agents spend on average about twenty percent of their time on work-related activities. This restriction pins down this parameter value, which can be calculated by combining the first-order conditions with consumption and hours worked in the final good sector:

$$\psi = \left(1 + \frac{\mu}{\lambda}\right) \frac{N_F \frac{c}{y} v L^{v-1}}{1 - \alpha} - L^v$$

### **Financing-in-advance constraint**

The transmission of financial shocks to the real economy crucially depends on the financing-in-advance and collateral constraint parameters  $\xi$  and  $\varrho$ . These parameters are calibrated under the assumption that constraints (3) and (8) are always binding. The validity of this assumption will be verified by means of model simulations by checking that the two Lagrange multipliers  $\mu$  and  $\chi$  are always strictly positive in large samples of simulated data.

Using data on consumption and consumer credit, equation (3) can be used to derive

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<sup>10</sup>Shimer (2009) argues that the microeconomic behavior of the neoclassical growth model becomes unreasonable when  $\sigma$  is larger than 1.

a moment condition in order to estimate the financing-in-advance parameter, where the estimated value is given as follows:

$$\widehat{\xi} = \frac{1}{T} \sum_{t=1}^T \left( \frac{c_t}{l_t} \right)$$

Estimating this parameter using quarterly data for the period from 1997 to the third quarter of 2008, I obtain the following point estimate:

$$\widehat{\xi} = 2.96$$

where the lower and upper limits of the 95% confidence interval for the estimated mean are 2.90 and 3.03, respectively.

By contrast, it is considerably more difficult to estimate the collateral constraint parameter  $\rho$  directly from the data. The secured market has always been opaque and available data on transactions by eurozone banks in the pre-crisis period are not sufficiently detailed to derive a moment condition that could be used to pin down this parameter value.<sup>11</sup> Given this lack of information, this parameter is included in the loss function and the sensitivity of the results to this parameter value is discussed in Sections 5 and 6.

### **Additional long-run restrictions**

Following the practice in the real business cycle literature, the depreciation rate of physical capital  $\delta$  can be pinned down by using data on the investment share of output. As an average over the period from the first quarter of 1995 to the third quarter of 2008, I obtain the following value for the investment-to-output ratio:

$$\frac{1}{T} \sum_{t=1}^T \left( \frac{i_t}{y_t} \right) = 0.225$$

where the lower and upper limits of the 95% confidence interval for the estimated mean are 0.221 and 0.228, respectively. Including this long-run restriction in the loss function will serve to identify the rate of depreciation of capital  $\delta$  using the model-implied investment-to-output ratio  $E(i/y)$ .

### **Moment matching procedure**

Given the lack of information on the remaining model parameters, this second set is chosen to maximize the model's ability to match a set of business cycle and asset pricing

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<sup>11</sup>See for instance the 2015 Euro Money Market Survey.

facts that characterize the eurozone business cycle. The volatility of the macroeconomic aggregates is obtained by computing the volatility of year-over-year growth rates. On the business cycle side, I evaluate the model in terms of its ability to match the volatility of the following macroeconomic aggregates: output  $\sigma_y$ , consumption  $\sigma_c$ , investment  $\sigma_i$ , and total hours worked  $\sigma_{N_T}$ .

Following the literature on the risk-free rate and equity premium puzzles (e.g., Mehra and Prescott 1985; Weil 1989), the mean equity premium  $E(r_E - r_F)$  and the mean risk-free rate  $E(r_F - 1)$  are the first two asset pricing variables that I include in the loss function. Equity returns are computed using the STOXX Broad Total Return Index, while I use the short-term real interbank rate as a proxy for the risk-free rate.<sup>12</sup> Relative to the literature, the new asset pricing moment to match is the safe asset premium. I construct the empirical counterpart for the safe asset premium  $E(r^S - r^F)$  by taking the difference between the average total return on an index of securitized bonds<sup>13</sup> and the average money market rate, which is my proxy for the risk-free rate. Finally, since the quantitative implications of the model critically depend on steady state ratios, the estimated value obtained for the investment share  $E(i/y)$  is included in the set of moments to be matched.

The eight remaining parameters to calibrate are the habit parameter  $\tau$ , the subjective rate of time discount  $\beta$ , the capital adjustment cost parameter  $\epsilon$ , the capital share in the production function of safe assets  $\phi$ , the persistence of the technology shock process  $\rho_A$ , the shock standard deviation  $\sigma_A$ , the depreciation rates of financial capital  $\delta$  and the collateral constraint parameter  $\varrho$ . These parameters are chosen in order to minimize the following loss function  $\ell$ :

$$\ell = [\Psi - f(\Theta)]' F [\Psi - f(\Theta)]$$

where  $\Psi = [\sigma_y, \sigma_c, \sigma_i, \sigma_{N_T}, E(r_E - r_F), E(r_F), E(r^S - r^F), E(i/y)]'$  is the vector of moments to match, and where  $\Theta = [\delta, \varrho, \tau, \beta, \epsilon, \phi, \rho_A, \sigma_A]'$  denotes the vector of model parameters.<sup>14</sup> The distance between the theoretical moments  $f(\Theta)$  and the empirical moments  $\Psi$  is minimized for the following combination of parameter values:

$\delta$	$\varrho$	$\epsilon$	$\phi$	$\tau$	$\beta$	$\rho_A$	$\sigma_A$
0.021	0.37	5.53	0.2	0.33	0.98	0.995	0.0032

<sup>12</sup>The three-month euribor money market rate, which is the rate at which euro area banks offer to lend unsecured funds to each other, is used a proxy for the risk-free rate for the pre-crisis calibration. This rate therefore corresponds to a risk-free return net of any liquidity services. The impact of collateral services on the risk-free return is discussed in Section 7.

<sup>13</sup>See Appendix C for a description of the data.

<sup>14</sup>Since I have as many parameters as moments to match, I use an identity matrix for  $F$ .

## 4 The pre-crisis economy.

The comparison between the model implications and the data is reported in Tables 1, 2 and 3. The data used to estimate the empirical moments are described in the data appendix. As shown in Tables 1 and 2, the model is able to broadly capture the volatility of the four business cycle variables  $\sigma_y$ ,  $\sigma_c$ ,  $\sigma_i$  and  $\sigma_{N_T}$  that are targeted, while being able to match the equity premium  $E(r^E - r^F)$ , the risk-free rate  $E(r^F - 1)$ , as well as the safe asset premium  $E(r^S - r^F)$  observed in the data. The fact that the steady state ratios reported in Table 3 can also be matched confirms that it is possible to reproduce this set of asset pricing and business cycle moments in a model that generates long-run properties that are also in line with the data.

In Table 1, the model's ability to generate variation in hours worked that are sufficiently volatile is firstly due to the fact that hours worked in the eurozone are less volatile than output. The lower volatility of hours observed in eurozone data makes it possible to match this moment by setting the Frisch elasticity to a value that is much lower than what is typically assumed in the literature.<sup>15</sup> Second, the decline in the volatility of hours worked that generally arises in models with high adjustment costs (e.g., Boldrin, Christiano, and Fisher 2001) can be avoided because this preference specification reduces the wealth elasticity of labor supply (e.g., Greenwood et al. 1988; Jaimovich and Rebelo 2009). Third, as will be discussed in Section 6, relative to a standard real business cycle model (e.g., King, Plosser, and Rebelo 1988; King and Rebelo 1999), financial frictions introduce a time-varying wedge into the consumption and labor decision of the representative agent that amplifies and propagates the effects of macroeconomic shocks.

As regards moments that were not directly targeted, a first main limitation is that the model generates fluctuations in labor productivity  $\sigma_w$  that are too smooth, relative to what is observed in the data. At the same time, one advantage of this mechanism is its ability to generate fluctuations in Tobin's Q that are much more volatile than what is typically obtained in frictionless production economy models with Epstein-Zin-Weil preferences (e.g., Tallarini 2000). As noted by Croce (2014), explaining the high volatility of Tobin's Q, which in Table 1 is denoted by  $\sigma_q$ , is a challenge for frictionless production economy models even if long-run risk is introduced into the analysis (e.g., Bansal and Yaron 2004).

It is difficult to find a precise empirical counterpart for the safe asset return. If this particular index is used as a proxy for the safe asset return, the empirical excess return that I obtain is slightly negative, suggesting that this asset was considered as an insurance

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<sup>15</sup>In the U.S., hours worked are generally as volatile as output. Even if a Frisch elasticity of 3 is used, standard real business cycle models fail to generate fluctuations in hours worked of this magnitude.

in the years preceding the crisis. Data on euro-based securitized bonds, which include mortgage-backed or asset-backed securities, are only available for a small sample and the wide confidence interval that I obtain for the estimated mean safe asset premium illustrates that this moment is not precisely estimated. The purpose of comparing this empirical moment with its corresponding theoretical counterpart is more to illustrate that the model is able to generate a significant difference between the different asset categories that have been introduced. In the model, the asset used as collateral is a safe asset because it provides an insurance against shocks. By contrast, the excess return required by investors to hold a risky asset such as equity is about 5.5 percent, as suggested by the data.

As illustrated by Table 2, one weakness of production economy models with habits is their tendency to generate excessive risk-free rate variations. In Jermann (1998) and Boldrin, Christiano, and Fisher (2001) for instance, the different mechanisms that are developed allow modified versions of the neoclassical growth model to match the equity premium as well as the mean risk-free rate. However, the high risk-free rate volatility that is obtained in these two studies, 11.5 percent and 24.6 percent, respectively, is significantly higher than the value observed in the data. In the paper that initially defined the equity premium puzzle, using data since 1889, Mehra and Prescott (1985) find an empirical value for the risk-free rate standard deviation of 5.7 percent. Similarly, Cecchetti, Lam, and Mark (1990) who used data since 1892 find a risk-free rate standard deviation of 5.27 percent.

In the present case, the risk-free rate volatility that I obtain in this model is 7.17 percent. Introducing a law of motion for the habit stock that depreciates slowly (e.g., Campbell and Cochrane 1999; Constantinides 2000), as in equation (4), helps to reproduce a high equity premium while at the same time generating risk-free rate fluctuations that are more stable than what is usually obtained in the literature that uses habits to explain asset pricing puzzles (e.g., Cochrane 2005). Using the real interbank rate as a proxy for the risk-free rate gives an empirical value for the risk-free rate standard deviation of 1.35 percent. This illustrates that explaining the low risk-free rate volatility observed in more recent data samples remains a challenge for this class of models.

At the same time, this mechanism allows the model to generate a standard deviation for stock market returns that is close to what is observed in the data.<sup>16</sup> While matching risk premia comes at the cost of generating excessive risk-free rate variations, one advantage of this mechanism over frictionless models augmented with Epstein-Zin-Weil preferences (e.g.,

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<sup>16</sup>To facilitate comparisons with other recent studies, in Table 2 the standard deviation of stock returns and of the safe asset return are expressed in quarterly terms, and not as annualized rates. Since stock returns are close to i.i.d in this model, the annualized standard deviation is approximately equal to the quarterly standard deviation multiplied by two.

Tallarini 2000) is, therefore, that it provides a potential explanation for the high volatility of stock returns and Tobin's Q observed in the data. Moreover, while the model overstates the risk-free rate volatility, this mechanism generates a standard deviation for the safe asset return  $\sigma(r^S)$  that is close to the value observed in the data.

Finally, as illustrated by the correlation coefficients reported in the lower part of Table 1, a real business cycle model augmented with this particular type of financial friction is able to generate the positive co-movement between the different business cycle variables and output observed in the data.

The advantage of solving the model using perturbation methods (e.g., Adjemian et al. 2014) is that this solution method is time efficient. This is particularly important in my case since I need to simulate the model a very large number of times in order to find the minimum of a loss function that contains eight moments. The disadvantage of this solution method is that it requires differentiability and therefore that it cannot handle discontinuities such as occasionally binding constraints for instance. Since occasionally binding constraints can be an issue in models with financial frictions, a sample of 100'000 observations was simulated for the two Lagrange multipliers  $\mu$  and  $\chi$ . The fact that these two Lagrange multipliers were always strictly positive in a sample of 25'000 years of model-generated data suggests that the case of a negative Lagrange multiplier is very unlikely to occur under this calibration. This confirms that solving the model under the assumption that the financing-in-advance and collateral constraints are always binding is a valid strategy.

The theoretical moments reported in Tables 2 and 3 are obtained using a second-order approximation. Pruning techniques become necessary in order to solve this model using a third-order approximation to the policy function (e.g., Andreasen et al. 2013). I checked that the mean equity and safe asset premia reported in Table 2 are robust to an increase in the order of approximation and that they are both countercyclical under the third-order approximation. Using a sample of model-generated data of 100'000 observations, I obtain an equity and safe asset premia of 5.48 percent and -0.03 percent, respectively, and as explained in Jaccard (2014), relative to the second-order approximation, the risk-free rate standard deviation decreases when the order of approximation is increased.<sup>17</sup>

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<sup>17</sup>When the model is solved using a third-order approximation, the time-variation in conditional variance that is obtained in this case decreases the risk-free rate volatility.

## 5 Introducing financial shocks.

Given the pre-crisis calibration and associated implications reported in Tables 1,2 and 3, the next step is to simulate the effect of a subprime shock, which takes the form of an exogenous increase in the depreciation rate of the economy's stock of safe asset. This shock is meant to capture the effects of losses on structured securities suffered by the European banking sector during the crisis period.

A central feature of the subprime crisis is that the losses caused by toxic financial products were concentrated over a short period of time. Losses on structured products were highest for the 2005, 2006 and 2007 vintages and very few losses were recorded on post-crisis vintages (e.g., Fitch 2012). This illustrates that the subprime shock that altered the economy's safe asset stock was very short-lived. It took some time to realize that a fraction of these financial products was impaired but once the shock hit, the adoption of tighter standards brought the origination of toxic products to a halt.

It is difficult to precisely evaluate the fraction of the economy's safe asset stock that was destroyed by the subprime shock. Estimates of potential write-downs on securities are, however, available and can be used to calibrate the size of the subprime shock. In June 2010, the ECB published an estimate of write-downs on securities (e.g., ECB 2010).<sup>18</sup> Cumulated losses on structured products, which included asset-backed securities and residential mortgage-backed securities, were estimated to stand at 140 billion euros.<sup>19</sup> In 2010, cumulated losses on structured products therefore represented about 1.5 percent of annual eurozone GDP.

The next step is to exploit this information in order to assess how the economy reacts to a negative financial shock of a plausible magnitude. Given the structure of the model, the amount that needs to be written down in period  $t$  can be obtained by multiplying the market value of the existing safe asset stock  $p_{SS}$  by the value of the shock in that period. Given the short-lived nature of the subprime shock, I set the shock persistence parameter  $\rho_Z$  to 0.6 to ensure that all new losses caused by the shock in a given quarter will be concentrated over a three-year period. A cumulated loss can then be obtained by summing all asset write-downs recorded in each quarter over this three-year period. Given this value for the persistence parameter, setting the shock standard deviation  $\sigma_Z$  to 0.033 implies a cumulated loss over this three-year period that amounts to about 1.5 percent of annual steady state output, which corresponds to the magnitude estimated by the ECB.

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<sup>18</sup>The methodology used to provide these estimates is described in ECB (2009a).

<sup>19</sup>Since these figures do not include losses suffered by hedge funds, using these numbers to calibrate the size of the subprime shock should provide a lower bound for the effects of this transmission channel.

Figure 3 shows the distribution of new losses caused by a negative financial shock of one standard deviation that is calibrated using these values for the shock persistence and standard deviation parameters. Cumulated losses expressed as a percentage of annual steady state output in period  $t$  are shown in Figure 4. On impact, the shock generates a destruction in the economy's safe asset stock that amounts to about 0.6 percent of GDP. Eight quarters after the shock hit, cumulated losses already represent about 1.48 percent of GDP. This shock calibration therefore implies that about 98 percent of total losses occur over a two-year period .

### **Impulse response analysis**

The continuous line in Figure 5 shows the response of output, consumption, investment and total hours worked to the adverse financial shock that is calibrated to match the dynamics of asset write-downs shown in Figure 3. In the upper left panel of Figure 5, the response of output is compared with the exogenous financial shock, which is represented by the dashed line. The short-lived increase in  $\log(z_t)$  destroys the economy's safe asset stock by raising the rate at which it depreciates. The response of equity prices, the price of the safe asset, bank loans and the safe asset stock are shown in Figure 6. As can be seen from the top left panel of Figure 5, a main distinguishing feature of this mechanism is its ability to generate a decline in output that is considerably more persistent than the shock itself, which is denoted by the dotted line. A negative financial shock also generates a decline in consumption, investment and hours worked, a stock market crash, as well as an increase in the safe asset price. This mechanism therefore provides a potential solution to the co-movement puzzle.

Figures 7 and 8 show the same impulse response in the case of a negative technology shock whose persistence and standard deviation are calibrated to reproduce the pre-crisis stylized facts shown in Tables 1, 2 and 3.

#### *The difference between financial and technology shocks*

As can be seen in Figure 6, a recession caused by an adverse financial shock increases the price of the safe asset. While the existing stock decreases (see bottom right panel of Figure 6), the ensuing safe asset scarcity effect leads to an increase in appetite for safety that raises the demand for newly-produced safe assets. By contrast, the safe asset price (see top right panel of Figure 8) and the quantity invested in safe assets both decline when the recession is caused by a negative technology shock. The central difference between the two types of shocks is therefore that financial shocks trigger a flight-to-safety effect that raises the quantity invested in safe assets.

A negative technology shock leads to a decline in labor demand, which in turn reduces wages. Given that this preference specification almost eliminates the wealth effect on labor supply, the decline in wages leads to a reduction in the number of hours worked. Lower wages generate a reduction in consumption and since agents decide to consume less, the demand for loans and pledgeable assets declines. At the same time, a negative technology shock reduces savings in the corporate non-financial sector, which in turn lowers the quantity of funds that the sector lends to investment bankers. The investment banking sector reacts to this reduction in the availability of short-term funding by reducing output, which lowers the supply of safe assets. A recession caused by a technology shock therefore reduces both the supply and demand for safe assets but the key is that the reduction in demand has a dominating impact on the dynamics of the safe asset price, which leads to the decline in  $p_S$  shown in Figure 8.

A negative technology shock still leads to a tightening of the collateral constraint but the difference relative to the case of an adverse financial shock is that the collateral scarcity effect is more muted. As illustrated by equation (17), the dynamics of the safe asset price depend on the stochastic discount factor, the collateral scarcity wedge, and the financial shock itself. In both cases, the recessionary effect of the shock reduces the composite good,  $c_t(\psi + L_t^v)$ , which with this preference specification lowers the stochastic discount factor. While the decline in the stochastic discount factor has a negative effect on all asset prices, the key is that the collateral scarcity effect, i.e., the increase in  $\chi/\lambda$ , is much larger when the economy is hit by an adverse financial shock since this shock generates a direct reduction in the existing stock of pledgeable assets.<sup>20</sup>

### Sensitivity analysis

To gain a sense of the magnitude of the effects of financial shocks, Figure 9 reports the sensitivity of year-on-year output growth, in deviation from its mean, to the subprime shock calibrated to generate a cumulated loss amounting to 1.5 percent of GDP and compares the dynamics of output growth predicted by the model with the dynamics observed in the data. The solid line with diamond corresponds to the benchmark calibration discussed above that assumes a cumulated loss of 140 billion euros. From the fourth quarter of 2008 to the third quarter of 2009, which corresponds to the peak of the crisis, an average decline in year-on-year output growth of about 3 percent per year is generated by this mechanism, while in the data the average decline in output growth recorded during this period stood at about 6.8 percent. This suggests that this mechanism has the potential to explain a little

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<sup>20</sup>See equation (5).

less than half of the decline in output growth observed at the peak of the financial turmoil. Since the loss estimate that I use to calibrate the size of the subprime shock is subject to considerable uncertainty (e.g., ECB 2009a), the dotted line in Figure 9 shows the response of output growth implied by the model in the case of a cumulated loss amounting to 198 billion euros, which represents about two percent of GDP. This case corresponds to a loss estimate published by the ECB in 2009 (e.g., ECB 2009b) that includes write-downs on securities issued in central, eastern and south-eastern Europe.

Overall, these results suggest that this particular transmission mechanism played an important role during the crisis period. At the same time, it is also clear that this mechanism alone, which focuses on retail lending, cannot fully account for the exceptional fall in output observed during the Great Recession. The results documented by Jermann and Quadrini (2012), and De Fiore and Uhlig (2015) among others suggest that combining the mechanism studied in this article with financial frictions on the production side of the economy could help to increase the magnitude of the recession. In Jaccard (2013), a simplified version of the present mechanism is studied in a model where both households and firms need credit to finance consumption and production. In this simplified version, it can be shown that these two channels are complementary, suggesting that introducing credit constrained firms into the analysis could be an interesting extension.

The effect of financial frictions on the economy critically depends on the tightness of the collateral and financing-in-advance constraints. Since, for the calibration that I am considering, constraints (3) and (8) are always binding, the effect of financial frictions is determined by the interaction between the financing-in-advance and collateral constraint parameters  $\xi \times \varrho$ . In contrast to the financing-in-advance parameter  $\xi$ , which can be estimated directly using data on bank loans and consumption, it is considerably more difficult to derive a moment condition to estimate  $\varrho$ . As explained in Section 3, setting  $\varrho$  to 0.37 maximizes the model's ability to match the data. Given the importance of this parameter for the transmission of financial shocks, the impulse response of output to a negative financial shock for different values of  $\varrho$  is plotted in Figure 10. The continuous line denotes the response of output for the benchmark calibration discussed above. The low financial friction case is obtained by setting  $\varrho$  to 5 and is depicted by the dotted line, whereas the dashed line represents the case  $\varrho = 0.1$ , which corresponds to the high financial friction case. This sensitivity analysis illustrates that the model's ability to generate persistent slumps (e.g., Hall 2016) critically depends on the tightness of the collateral constraint.

## 6 The model's endogenous propagation mechanism.

The model's endogenous propagation mechanism can be better understood by illustrating how the financing-in-advance constraint affects the agent's consumption-leisure optimality condition. The financing-in-advance wedge in equation (15) can be expressed as follows:

$$f_t = w_t \frac{(\psi + L_t^v)}{c_t^v L_t^{v-1}} \quad (18)$$

where  $f_t = 1 + \mu/\lambda$ . Using data on labor productivity, consumption and hours worked, this expression can be used to construct an empirical counterpart for the model-implied wedge.<sup>21</sup> As can be seen in Figure 2, which shows the empirical wedge constructed using equation (18), its negative co-movement with output is quite striking. Since the onset of the financial crisis, the financing-in-advance wedge has been particularly volatile and its negative co-movement with output is even more pronounced.

### The model's asset pricing implications

As illustrated by the left-hand side panel of Figure 11, the parameter that controls the intensity of habit formation has a strong impact on the dynamics of the financing-in-advance wedge. The dotted line shows the response of this wedge to a negative financial shock using the calibration discussed in Sections 4 and 5, while the dashed line shows the same impulse response, but in the case in which habits are completely switched off by setting  $\tau$  equal to 1. The right-hand side panel of Figure 11 shows how the response of output to a negative financial shock changes when habits are switched off. Clearly, for a shock of a given magnitude, the model's endogenous propagation mechanism is considerably more powerful in the version with habits, that matches the equity premium and risk-free rate reported in Table 2.

This comparison illustrates that the model's ability to amplify and propagate the effects of financial shocks critically depends on the model's pre-crisis asset pricing implications. Without habits, the model loses much of its ability to generate large and persistent declines in output in response to negative financial shocks with such little persistence. At the same time, relative to the pre-crisis calibration discussed in Section 4, switching off habits by setting  $\tau$  equal to 1 would lead to a fall in the equity premium from 5.5 percent to 0.01 percent. The propagation mechanism of financial shocks critically depends on the very low value of the elasticity of intertemporal substitution (EIS) induced by the introduction of

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<sup>21</sup>The empirical counterpart for  $f_t$  is constructed by normalizing the time-series using the steady state of the model.

habit formation (e.g., Yogo 2004; Jaccard 2014), but without a sufficiently low EIS the equity premium generated by the model becomes implausibly small.

*The case of technology shocks*

The propagation mechanism depends on the model’s asset pricing implications but does not depend on the source of the shock. Interacting financial frictions with habit formation also propagates and amplifies the effects of technology shocks. This point is illustrated by the dotted line in Figure 12, which shows how a change in the habit formation parameter affects the model-implied relationship between the equity premium on the  $x$  axis and the output volatility on the  $y$  axis. The positive slope demonstrates that in this model output volatility and the equity premium in the pre-crisis economy both increase as the intensity of habits rises. Relative to the dotted line, the dashed line shows how this relationship changes when the adjustment cost parameter is set to a higher value. The downward shift obtained when adjustment costs are set to a higher value illustrates that adjustment costs decrease the volatility of output.<sup>22</sup> By contrast, and as initially demonstrated by Jermann (1998), the model’s ability to reproduce a realistic equity premium depends on the combination of high habit intensity and high adjustment costs.

As illustrated by Figure 13, tighter financial frictions, as measured by a decline in the collateral constraint parameter  $\varrho$ , makes it more difficult to generate a high equity premium in this model. This implication is due to the wedge between the marginal utility of consumption and the marginal utility of wealth that the financing-in-advance constraint introduces into the agent’s optimality conditions (see equation 16). In response to a negative technology shock, the increase in the financing-in-advance wedge generated by this mechanism amplifies the decline in consumption and reduces the increase in the marginal utility of wealth that normally occurs in recessions. Intuitively, the collateral scarcity effect induced by a negative shock reduces agents’ incentives to cut investment to smooth consumption during a recession, because cutting investment also leads to a reduction in the economy’s stock of financial capital. Since accumulating financial capital is needed to finance safe asset production, the reduction in investment is less pronounced in models in which financial frictions create a wedge between the marginal utility of wealth and the marginal utility of consumption. The increase in the financing-in-advance wedge triggered by a negative shock can thus be interpreted as a tax on consumption that reduces the desire to consume and increases the desire to save during a recession.

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<sup>22</sup>In models with endogenous labor supply decisions, adjustment costs increase the wealth effect on labor supply. This effect is attenuated by the introduction of habits in the composite of consumption and leisure (e.g., Jaccard 2014).

## Output persistence

The role of habits in strengthening the model's endogenous propagation mechanism can be better understood by analyzing how the habit parameter affects the response of investment and hours worked. In Figures 14 and 15, the continuous lines denote the response of investment and total hours worked to a negative financial shock in the benchmark model that generates a 5.5 percent equity premium in the pre-crisis economy. In these two figures, the dotted lines show what happens to the response of investment and hours worked, respectively, when habits are switched off by setting  $\tau$  equal to 1.

### *The adjustment with log utility*

As illustrated in Figure 14, the response of investment to a negative financial shock is the first key difference between the two cases. Without habits, investment hardly reacts and while the stock of financial capital  $a$  remains quasi-constant, its composition is affected by the shock. The need to rebuild the stock of safe asset to restore access to credit leads to a reallocation of resources towards the investment banking sector. In terms of the resource constraint of the non-financial sector:

$$a_t = k_t + m_t + d_t$$

Since  $a$  remains almost unchanged by the shock, the increase in  $m$  is compensated by a reduction in the quantity of funds that are allocated to the commercial banking sector and the production of the final output good, that is, by a decline in  $k$  and  $d$ .

As illustrated by the response of hours worked in the two cases, which is shown in Figure 15, the labor market also plays a key role in amplifying the response of financial shocks. In the case without habits, agents react to an adverse financial shock by increasing their total number of hours worked, whereas labor effort declines in the version of the model that generates a realistic equity premium. In the log utility case, agents therefore use the labor margin to absorb the effects of the shock. Relative to the dynamics obtained in the habit model, the countercyclical response of hours reduces the fall in output and leads to a faster rebuilding of the safe asset stock when agents have an EIS equal to unity.

### *The adjustment with habits in the composite good*

Since the first main effect of an adverse financial shock is to tighten borrowing conditions, a reduction in the stock of pledgeable collateral inevitably leads to a fall in consumption. Given that this preference specification reduces the wealth elasticity of labor supply, the first main difference relative to the log utility case is that agents are no longer willing to increase labor effort when consumption declines. To maintain their living standards,

agents choose to accommodate the fall in consumption by taking more leisure time. This reduced willingness to use the labor margin to attenuate the effects of the shock in turn leads to a more severe decline in output (see Figure 11, right-hand side panel).

The lower EIS in consumption induced by this preference specification (e.g., Jaccard 2014) implies that the consumption smoothing motive is stronger in the habit model. Since, with this specification agents are also more reluctant to use the labor margin to smooth consumption, the only way to avoid a more abrupt adjustment in consumption is therefore to decrease investment. As illustrated in Figure 14, this joint effect leads to a decline in investment that is much stronger in the model with habits.

Relative to the log utility case, the reduction in investment considerably delays the recovery by reducing the amount of resources allocated to the production of the final output good. Since restoring access to credit can only be achieved by rebuilding the safe asset stock, optimizing agents respond to the negative financial shock by reallocating capital towards the investment banking sector, as in the log utility case. Under habits, the key difference is that the shock not only affects the composition of financial capital but also reduces its level, since investment falls sharply. In this case, the composition effect is therefore exacerbated by this level effect, which reduces the total amount of financial capital that can be allocated to the different sectors of the economy. The delayed recovery in output in turn exacerbates the scarcity of safe assets by reducing the amount of resources available to rebuild the economy's safe asset stock. In the model with habits, this general equilibrium effect generates a decline in the safe asset stock that is considerably more persistent than in the log utility case.

*Financial frictions as a tax on labor supply and consumption*

As initially demonstrated by Greenwood et al. (1988) (see also Jaimovich and Rebelo 2009), using preferences that eliminate the wealth effect on labor supply helps to propagate the effects of shocks. While my preference specification also reduces the wealth elasticity of labor supply, the key difference relative to these studies is that in my case the dynamics of consumption and hours is also significantly affected by the fluctuations in the financing-in-advance wedge induced by this mechanism. To gain intuition into how the financing-in-advance wedge interacts with this preference specification, equations (1L) and (2L) below show the log-linearized consumption and hours worked optimality conditions:

$$\widehat{c}_t = \omega_N \widehat{N}_{Tt} + \omega_h \widehat{h}_t - \omega_\varphi \widehat{\varphi}_t - \omega_\lambda \widehat{\lambda}_t - \omega_{\mu/\lambda} \widehat{\mu/\lambda}_t \quad (1L)$$

$$\xi_c \widehat{c}_t - \xi_N \widehat{N}_{Tt} + \xi_h \widehat{h}_t - \xi_\varphi \widehat{\varphi}_t = \widehat{w}_t + \widehat{\lambda}_t \quad (2L)$$

where the deterministic steady state of the model is the point around which equations (1L) and (2L) are linearized.

Variables with a hat are expressed in deviations from steady state. Relative to equations (1L) and (2L) in Jaccard (2014),  $\widehat{\mu/\lambda}_t$  is the new term that captures the effect of the financing-in-advance wedge on the consumption optimality condition and I denote this new linearization parameter by  $\omega_{\mu/\lambda}$ :

$$\omega_{\mu/\lambda} = \frac{\left(1 - \frac{1-\tau}{\gamma-\tau}\right) \left(1 - \beta \frac{1-\tau}{1-\tau\beta}\right)}{\sigma} \frac{\mu/\lambda}{1 + \mu/\lambda}$$

where  $\mu/\lambda$  denotes the steady state value of the financing-in-advance wedge, and where for the sake of economy with respect to notation, I have defined the modified subjective discount rate of time preference as follows:

$$\beta = \widetilde{\beta} \gamma^{-\sigma}$$

As in King and Rebelo (1999), the Frisch labor supply equation can be derived by substitution in equation (2L) using equation (1L).<sup>23</sup> The new term, the elasticity of labor supply with respect to the financing-in-advance wedge, can be expressed as follows:

$$\frac{\partial \widehat{N}_{Tt}}{\partial \widehat{\mu/\lambda}_t} = \frac{\left(\frac{\Gamma\Omega}{\sigma} - 1\right) \frac{\mu/\lambda}{1 + \mu/\lambda}}{\left(1 - \frac{\sigma}{\Gamma\Omega}\right) \left(1 - \frac{\Gamma\Omega}{\sigma}\right) \frac{\nu L^\nu}{\psi + L^\nu} \frac{N_T}{1 - N_T} - \left\{(\nu - 1) - \frac{\nu L^\nu}{\psi + L^\nu} \frac{\sigma}{\Gamma\Omega}\right\} \frac{N_T}{1 - N_T}}$$

where:

$$\Gamma = 1 - \frac{(1 - \tau)}{(\gamma - \tau)}, \quad \Omega = 1 - \beta \frac{(1 - \tau)}{(1 - \tau\beta)}$$

Since the curvature parameter  $\sigma$  has been set to 1, my specification of habits reduces to the log utility case when habits are switched off by setting  $\tau$  equal to 1. In this particular case, while the financing-in-advance wedge has a direct effect on the consumption optimality condition, movements in  $\widehat{\mu/\lambda}_t$  have no direct effect on the Frisch labor supply equation since this preference specification becomes separable in this case. Therefore, without habits, and

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<sup>23</sup>Relative to the formula derived in Jaccard (2014), the Frisch elasticity of labor supply remains unchanged and the wealth elasticity of labor supply is always positive for any value of the habit parameter where  $0 \leq \tau \leq 1$ , and this elasticity declines as the intensity of habits increases.

in the case where  $\sigma = 1$ , as can be seen from the above formula,  $\partial \widehat{N}_{Tt} / \partial \widehat{\mu} / \lambda_t = 0$  when  $\tau = 1$ . In other words, the financing-in-advance wedge has no direct impact on the Frisch labor supply equation when this specification reduces to the log utility case. Figure 16 shows the sensitivity of this elasticity with respect to the habit parameter  $\tau$ . This elasticity is equal to zero when  $\tau = 1$ , as noted above, and becomes negative as the intensity of habits increases.

Relative to the log utility case, habits in the composite of consumption and leisure therefore create an additional channel through which changes in the financing-in-advance wedge interact with labor supply. An increase in the collateral scarcity wedge, which in turn raises the financing-in-advance wedge, creates a tax that reduces agents' incentive to work. This demonstrates that the reduction in the wealth elasticity of labor supply that is obtained with this preference specification is not the only channel through which this propagation mechanism operates. When combined with habits in the composite good, financial frictions reinforce the complementarity between consumption and hours by acting as a tax that simultaneously affects both margins at the same time.

### **Why not increase curvature?**

As shown by Weil (1989) in the context of an endowment economy, increasing the curvature coefficient does not provide a solution to the risk-free rate puzzle. In a production economy, increasing the curvature coefficient  $\sigma$  reduces the subjective discount factor, making it impossible to simultaneously match the low mean risk-free rate and high equity premium observed in the data (e.g., Jaccard 2014).

In models with balanced growth, another strategy to increase curvature consists of raising  $\sigma$ , while adjusting the subjective discount factor  $\tilde{\beta}$  to ensure that the modified discount factor  $\beta = \tilde{\beta}\gamma^{-\sigma}$  remains constant. In the context of my model, I find that increasing curvature using this strategy does not provide a solution to the equity premium and risk-free rate puzzles either.<sup>24</sup> Moreover, the results that I obtain in this case suggest that the magnitude of the increase in curvature that would be needed to significantly increase the equity premium would generate implausible attitudes towards risk. Following the approach proposed by Cho et al. (2015), I illustrate this point by comparing the effect of uncertainty on consumption and welfare in the model with habits to the case in which I use the curvature coefficient  $\sigma$  to increase the equity premium.

Total welfare in the economy can be computed recursively by expressing  $V$  as follows:

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<sup>24</sup>The parameter space for which the Blanchard-Kahn conditions are satisfied also becomes smaller when the curvature coefficient is increased.

$$V_t = \frac{1}{1 - \sigma} [c_t(\psi + L_t^v) - h_t]^{1-\sigma} + \widehat{\beta} E_t V_{t+1}$$

Following Cho et al. (2015), the effect of uncertainty is studied by comparing average consumption and welfare in the stochastic economy with the deterministic version of the model, where the deterministic version corresponds to the case in which the standard deviation of the technology shock has been set to zero. In the model generating the implications documented in Tables 1 to 3, I find that, relative to a deterministic world, consumption is 6.8 percent higher and welfare is 1.1 percent lower in the economy subject to exogenous technology shocks. Relative to a world without risk, agents therefore need to be compensated by a higher average consumption level in an economy that is subject to business cycle fluctuations, and uncertainty reduces welfare in the habit model.

When I use the curvature coefficient  $\sigma$  rather than the habit parameter  $m$  to increase the equity premium, I find that setting the curvature parameter to 80 allows the model to generate an equity premium of about 2.6 percent. In the habit model that matches the equity premium, the increase in mean consumption that is needed to make agents indifferent between the deterministic and the stochastic economy is about 7 percent. By contrast, the required increase in mean consumption exceeds 60 percent in the model with very high curvature that generates a 2.6 percent equity premium.<sup>25</sup> Moreover, with very high curvature the increase in mean consumption needed to compensate agents for business cycle fluctuations is so large that uncertainty becomes welfare improving; an implication that is difficult to reconcile with the well-accepted notion that business cycle fluctuations are costly (e.g., Lucas 2003; Alvarez and Jermann 2004; Barro 2009).<sup>26</sup> This example confirms that, with standard preferences, setting the curvature parameter  $\sigma$  to very high values generates implausible attitudes towards risk, a point that was initially made by Mehra and Prescott (1985).

## 7 Additional implications.

There is a body of literature suggesting that stock price movements reflect changes in expectations about the future and that changes in expectations could be an important source

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<sup>25</sup>In the very high curvature case where  $\sigma = 80$ , the model implications are computed using a third-order approximation, pruning techniques, and a sample of 200'000 model-generated observations (e.g., Adjemian et al. 2014). In the case where  $m = 0.33$  and  $\sigma = 1$ , the second and third-order approximations generate results that are very similar.

<sup>26</sup>A similar result is obtained in the case of models with low risk aversion (e.g., Cho et al. 2015). Models with standard preferences and low risk aversion cannot generate realistic asset pricing predictions.

of business cycle fluctuations (e.g., Beaudry and Portier 2006; Barsky and Sims 2011). According to Schmitt-Grohé and Uribe (2012), about half of the variance of the growth rates of output, consumption, investment, and hours is attributable to anticipated disturbances. While expected shocks are found to play an important role, as documented by Christiano et al. (2010), reproducing a stock price boom in response to positive news about the future can be a challenge in standard versions of the neoclassical growth model. A positive news about the future decreases future marginal utility of wealth, as agents become more optimistic. Since the risk-free rate dynamics are driven by the difference between current and expected marginal utility, the risk-free rate increases whenever expected marginal utility falls below current marginal utility. This increase in the risk-free rate in anticipation of a positive technology shock contributes to the decline in stock prices that typically occurs in standard versions of the neoclassical growth model.

In this model, the response of equity prices to a positive technology shock that will materialize four quarters after the announcement is shown in Figure 17.<sup>27</sup> As illustrated in Figure 18, the positive response of dividends to an anticipated technology shock is the main driver of the positive response of equity prices. The second main effect comes from the risk-free rate dynamics. As discussed in Section 6, the marginal utility of wealth becomes less volatile when the degree of financial friction increases. Relative to the case without financial frictions, this effect helps to contain the increase in the risk-free rate that occurs when agents expect good times ahead. While the risk-free rate still rises in response to an anticipated technology shock, this effect is more muted and the increase in dividends allows the model to generate an increase in stock prices in response to positive news about the future (see also Croce 2014; Ai, Croce and Li 2014). The bubble-like response of equity prices also illustrates that this type of non-standard dynamics can be obtained in environments where agents have rational expectations.

### Money-like premium

Following most of the asset pricing literature,  $E(r^F - 1)$  in Table 2 is computed using the standard risk-free rate definition:

$$1 = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} r_{Ft} \quad (19)$$

where the one-period risk-free return is denoted by  $r_F$ .

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<sup>27</sup>To the best of my knowledge, there is no empirical evidence on the effects of an anticipated subprime shock. In the model, a negative anticipated financial shock that is expected to hit the economy one year after the announcement generates a fall in equity prices.

As shown by a recent literature that studies how money-like convenience services affect the valuation of assets that are used as pledgeable collateral (e.g., Greenwood and Vayanos 2010; Krishnamurty and Vissing-Jorgensen 2011, 2012; Venkateswaran and Wright 2013; Caballero and Fahri 2014), the average rate of return on high quality government bonds is typically lower than the return at which two very safe institutions lend funds in the unsecured market to each other. In the context of this model, this observation can be rationalized by deriving the pricing equation of a risk-free one-period bond that provides collateral services. To illustrate how money-like services affect the risk-free rate, equation (20) derives the price of a one-period risk-free bond under the assumption that the holder of a risk-free security can pledge it as collateral:

$$\tilde{p}_{Bt} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left( 1 + \varrho \frac{\chi_{t+1}}{\lambda_{t+1}} \right) \quad (20)$$

In the context of this model, the textbook risk-free definition shown in equation (19) corresponds to the case of a risk-free transaction that does not involve the exchange of any asset that the buyer can use as pledgeable collateral. The difference between these two returns therefore captures the risk adjustment due to the liquidity services provided by pledgeable assets. The difference between these two returns, which I refer to as the money-like premium, can be defined as follows:

$$mp = E(r_t^F - E_t r_{t,t+1}^{ML})$$

where the expected return on the money-like asset is given by the following expression:

$$E_t r_{t+1}^{ML} = \left( 1 + \varrho \frac{\chi_{t+1}}{\lambda_{t+1}} \right) \frac{1}{\tilde{p}_{Bt}}$$

One possible way to test this model implication is to compare the difference between a return on an unsecured transaction in the money market between two very safe institutions with the return obtained from holding a money-like asset, such as a government bond.<sup>28</sup> Given the limited data availability for aggregate eurozone data, I use the Treasury bill (T-bill) rate on a 13-week French government bond as the money-like risk-free return. As in Section 3, the three-month Euribor money market rate, which is the rate at which euro area banks offer to lend unsecured funds to each other, is used as a proxy for  $r^F$  since in the model  $r^F$  corresponds to a risk-free return net of any liquidity services.

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<sup>28</sup>To avoid the issue of default risk, as in Section 3, the empirical counterpart is computed using pre-crisis data only.

As illustrated in Table 4, the empirical value for the average money-like premium that I obtain is 0.37 percent, suggesting that investors require a lower compensation to hold money-like assets. Even though this moment was not directly targeted, the model calibrated to match pre-crisis data is still able to generate a value for the money-like premium that falls within the 95 percent confidence interval estimated in the data. As in the data, the return required by investors to hold an asset that can be pledged as collateral is on average lower than the return at which short-term unsecured borrowing is undertaken. One possible interpretation of this positive spread is therefore that collateral services are remunerated in equilibrium and that investors require a lower expected return for holding money-like assets.

Figure 19 shows the response to a recessionary financial shock of the price of a risk-free one-period bond whose value has been adjusted for collateral services, as shown in equation (20).<sup>29</sup> As is the case for the safe asset price, the price of a one-period risk-free bond that can be used as collateral increases in response to a negative financial shock, an implication that is consistent with the flight-to-safety effect documented in the literature.

### **The predictability of consumption growth**

Since the seminal contribution of Hall (1978), intertemporal models of consumption and savings have been evaluated in terms of their ability to reproduce the dynamics of consumption growth observed in the data. The facts shown in Table 5, which reports the autocorrelation coefficient of quarterly consumption growth in the pre-and post-crisis samples, suggest that the dynamics of consumption has been significantly affected by the crisis. Consumption growth exhibits a low coefficient of autocorrelation in the pre-crisis sample and this coefficient increases dramatically in the post-crisis sample.

As demonstrated by the lower panel of Table 5, the model in which technology shocks are the only driving force generates fluctuations in consumption growth that are only weakly serially correlated, as suggested by pre-crisis data. The low autocorrelation coefficient obtained in the case of technology shocks is consistent with the view that technology shocks are the main drivers of business cycle fluctuations during normal times. As shown in Table 5, another important difference between financial and technology shocks is that the autocorrelation of consumption growth increases when financial shocks become the dominant source of business cycle fluctuations. Interpreted in the context of this model, the higher autocorrelation of consumption growth observed in the post-crisis sample could therefore indicate that financial shocks have been an important driver of business cycle

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<sup>29</sup>The standard deviation and persistence of the financial shock are set to 0.033 and 0.6, as discussed in Section 5.

fluctuations during the crisis period.

## 8 Conclusion.

In comparison to the vast body of literature on the financial accelerator initiated by the seminal contribution of Bernanke, Gertler, and Gilchrist (1999), the quantitative implications of models in which constraints affecting consumption decisions are the main source of friction remain largely unexplored. This article addresses this question by studying the case of an economy in which safe financial instruments have a role in facilitating access to credit. In a model that is capable of matching asset pricing moments, I find that a short-lived shock that destroys a fraction of the economy's safe asset stock can generate a large and persistent recession. Overall, my findings suggest that the asset pricing implications of DSGE models may be more important for our understanding of macroeconomic fluctuations than commonly thought.

This study puts the spotlight on one particular transmission mechanism and abstracts from many other potentially important channels. In this respect, one main limitation of my analysis is that the model abstracts from the housing sector. As shown by Puri et al. (2011), while the available empirical evidence demonstrates that the effect on consumer loans was important and significant, the quantitative magnitude of the mechanism under study was more important for mortgage loans. Introducing a housing market into the analysis to quantify the relevance of this channel would therefore be a natural extension.<sup>30</sup> In contrast to what was observed in Spain, house prices in Germany; the largest eurozone economy, remained stable during the crisis period. Yet, this more resilient housing market did not prevent Germany from experiencing a very large decline in GDP in 2008 and 2009. This suggests that future work on this topic should not only focus on house prices and the mortgage loan market, but also on the heterogeneity observed across euro area economies.

It is also important to emphasize that the present paper studies the 2008-2009 recession and abstracts from the European sovereign debt crisis. The sovereign debt crisis was specific to the eurozone economy, since other major advanced economies such as the United States or the United Kingdom did not experience a recession during this period. This second episode shares some important similarities with the subprime crisis in the sense that the sovereign debt of most eurozone economies was perceived to be very safe before the crisis hit.<sup>31</sup> Understanding the potential links between these two episodes could thus constitute

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<sup>30</sup>See Piazzesi and Schneider (2016) for a recent literature review.

<sup>31</sup>The volume of outstanding euro area government bonds classified as AAA shrank significantly during

another interesting direction for future work on this topic.

Finally, while the model is successful at reproducing risk premia and at generating the high volatility of stock return and of Tobin's Q observed in the data, this success comes at the cost of generating excessive risk-free rate fluctuations. Additional limitations include the fact that the velocity parameter in the financing-in-advance constraint is held constant, whereas the data suggest that introducing time-variation would be more realistic. Introducing a richer characterization of the banking sector would also be needed to match the fluctuations in the loan-to-deposit ratio observed in the data and abstracting from the potential role of debt securities issuance by the government (e.g., Holmstrom and Tirole 1998) is another limitation of the analysis.

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the crisis period, from around two-thirds to only around one-third of all euro area central government bonds in 2014 (e.g., ECB 2014).

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## 10 Appendix A.

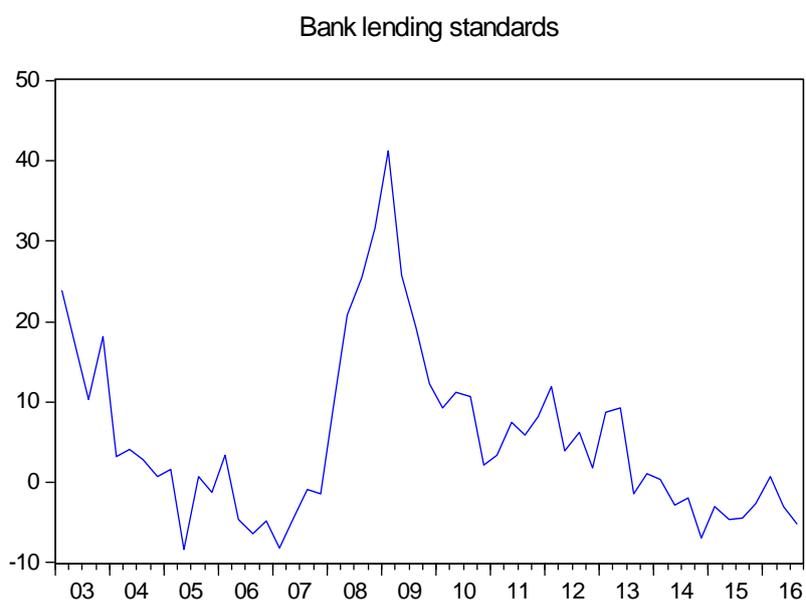


FIGURE 1. Bank lending standards. Banks' credit standards as applied to the approval of loans to households for consumer credit and other lending.

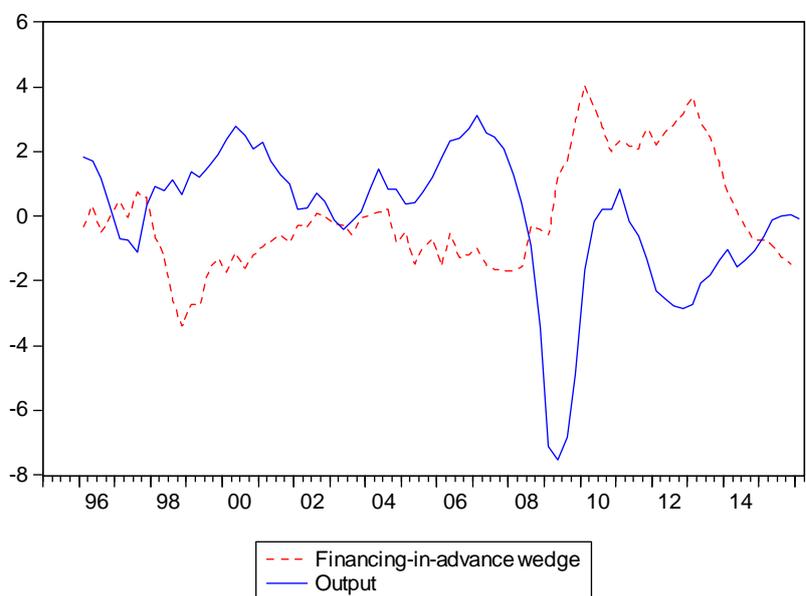


FIGURE 2. Model-implied financing-in-advance (FIA) wedge (dotted line) and output (continuous line). Y/Y growth rates in deviation from mean 1995Q1-2016Q1.

TABLE 1. Business cycle moments

	Data		Model
	95% confidence interval	Estimated empirical moments	Theoretical moments
$\sigma_y$	[0.90, 1.33]	1.07	1.07
$\sigma_c$	[0.52, 0.77]	0.62	0.60
$\sigma_i$	[2.71, 4.02]	3.23	3.10
$\sigma_{N_T}$	[0.58, 0.86]	0.69	0.64
$\sigma_w$	[0.55, 0.82]	0.66	0.50
$\sigma_q$	[13.1, 21.0]	16.1	16.9
$\rho(c, y)$	[0.60, 0.85]	0.75	0.98
$\rho(i, y)$	[0.69, 0.89]	0.81	0.99
$\rho(N_T, y)$	[0.55, 0.83]	0.71	0.96
$\rho(w, y)$	[0.74, 0.91]	0.84	0.94
$\rho(q, y)$	[-0.09, 0.53]	0.25	0.93

Notes: In Table 1, both the theoretical moments and the data are expressed in year-over-year growth rates.  $\sigma_y, \sigma_c, \sigma_i, \sigma_{N_T}, \sigma_w$  and  $\sigma_q$  denote the standard deviations of output, consumption, investment, total hours worked, productivity and Tobin's Q, respectively.  $\rho(c, y), \rho(i, y), \rho(N_T, y), \rho(w, y), \rho(q, y)$  denote the correlation with output of consumption, investment total hours worked, productivity, and Tobin's Q, respectively.

TABLE 2. Asset Pricing Moments

	Data, annualized returns in %		Model, annualized returns in %	
	95% confidence	Estimated empirical		Theoretical
	interval	moments		moments
$E(r^F - 1)$	[1.23, 2.57]	1.9		1.9
$E(r^E - r^F)$	[-3.1, 14.1]	5.50		5.50
$E(r^S - r^F)$	[-2.50, 2.42]	-0.04		-0.03
$\sigma(r^F)$	[1.14, 1.65]	1.35		7.17

	Data, quarterly returns in %		Model, quarterly returns in %	
	95% confidence	Estimated empirical		Theoretical
	interval	moments		moments
$\sigma(r_E)$	[7.04, 9.53]	8.1		7.74
$\sigma(r_S)$	[1.27, 2.16]	1.6		1.79

Notes:  $E(r^F)$  is the unconditional mean risk-free return,  $E(r^E - r^F)$  is the equity premium,  $E(r^S - r^F)$  is the safe asset premium.  $\sigma(r^F)$ ,  $\sigma(r_E)$  and  $\sigma(r_S)$  denote the standard deviation of the risk-free rate, equity returns and the safe asset return, respectively.

TABLE 3. Steady state ratios

	Data		Model
	95% confidence	Estimated empirical	Theoretical
	interval	moments	moments
$E(i/y)$	[0.221, 0.229]	0.225	0.222
$E(c/l)$	[2.90, 3.03]	2.96	2.96

Notes:  $E(i/y)$  is the average investment share of output, and  $E(c/l)$  is the average consumption to loan ratio.

TABLE 4. Money-like premium

	Data, annualized returns in %		Model, annualized returns in %
	95% confidence interval	Estimated empirical moments	Theoretical moments
$E(r^F - r^{ML})$	[0.18, 0.55]	0.37	0.23

Note:  $E(r^F - r^{ML})$  is the money-like premium.

TABLE 5. Autocorrelation consumption growth

Data			
Pre-crisis sample 1995q1-2008q3		Post-crisis sample 2008q4-2012q4	
$\rho(\Delta c_t, \Delta c_{t-1})$	95% conf. interval	$\rho(\Delta c_t, \Delta c_{t-1})$	95% conf. interval
0.09	[-0.18, 0.35]	0.43	[-0.07, 0.75]
Model			
Technology shocks		Financial shocks	
$\rho(\Delta c_t, \Delta c_{t-1})$		$\rho(\Delta c_t, \Delta c_{t-1})$	
0.08		0.17	

## 11 Appendix B.

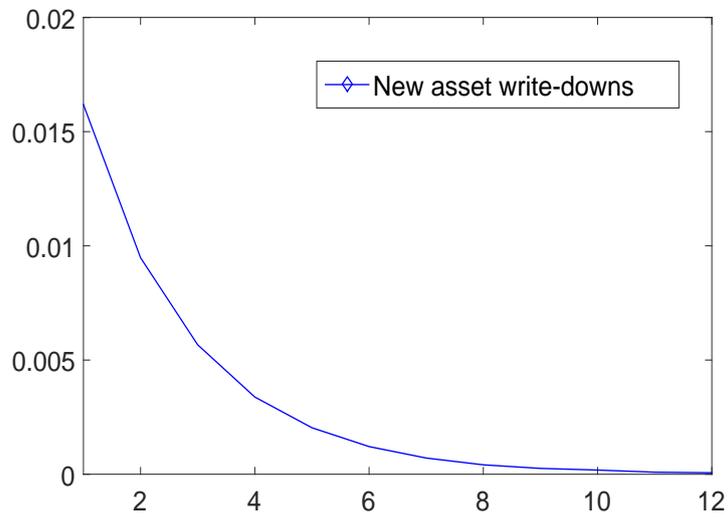


FIGURE 3. New asset write-downs in period  $t$ . y axis:  $\eta_t p_{St} s_t$ . x axis: quarters after the shock.

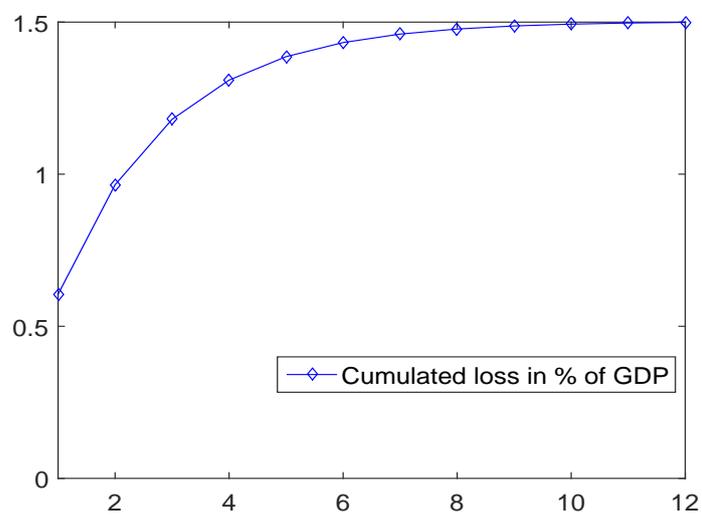


FIGURE 4. Cumulated losses in period  $t$  expressed in percentage of annual steady state GDP. y axis:  $\sum_{k=1}^t \eta_k p_k s_k$ . x axis: quarters after the shock.

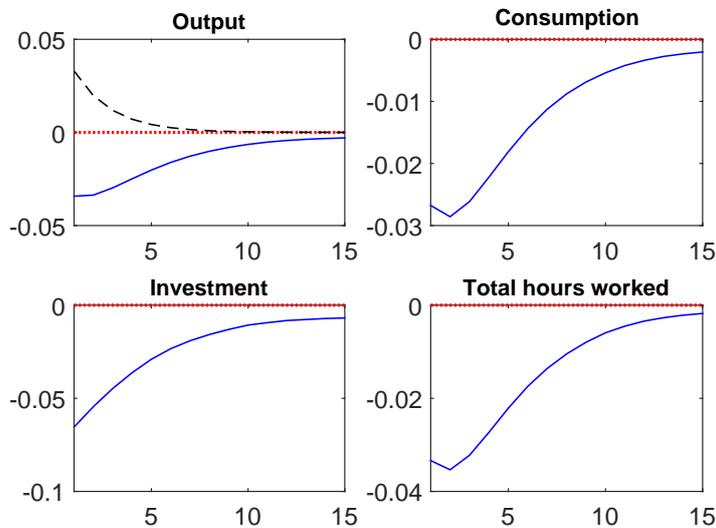


FIGURE 5. In each panel, the continuous line denotes the impulse response of output, consumption, investment and total hours worked to an adverse financial shock with a persistence parameter  $\rho_Z$  set to 0.6 and standard deviation  $\sigma_Z$  of 0.033. The dotted line in the upper left panel shows denotes the exogenous shock  $\log(z_t)$ . y axis: log-deviation from steady state. x axis: quarters after the shock.

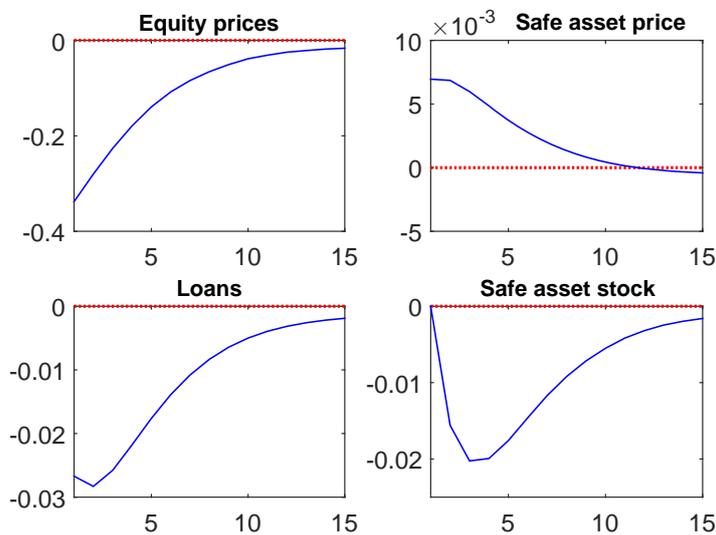


FIGURE 6. Impulse response of equity prices, the safe asset price, bank loans, and the safe asset stock to an adverse financial shock with a persistence parameter  $\rho_Z$  set to 0.6 and standard deviation  $\sigma_Z$  of 0.033. y axis: log-deviation from steady state. x axis: quarters after the shock.

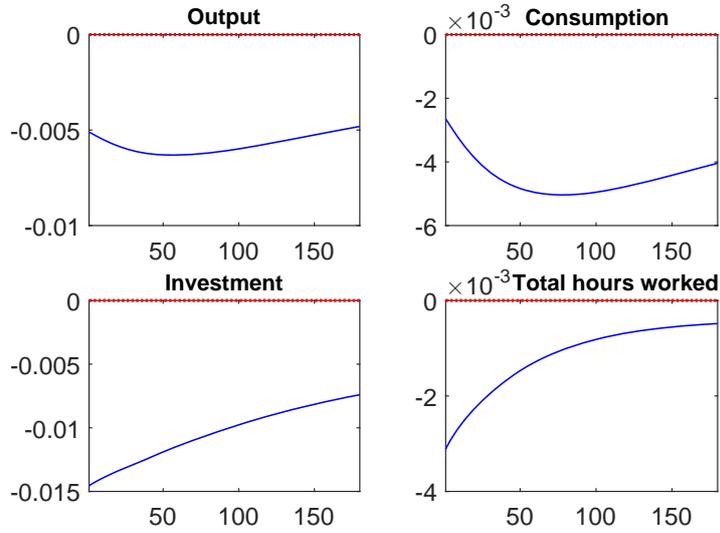


FIGURE 7. Impulse response of output, consumption, investment and total hours worked to a negative technology shock. y axis: log-deviation from steady state. x axis: quarters after the shock.

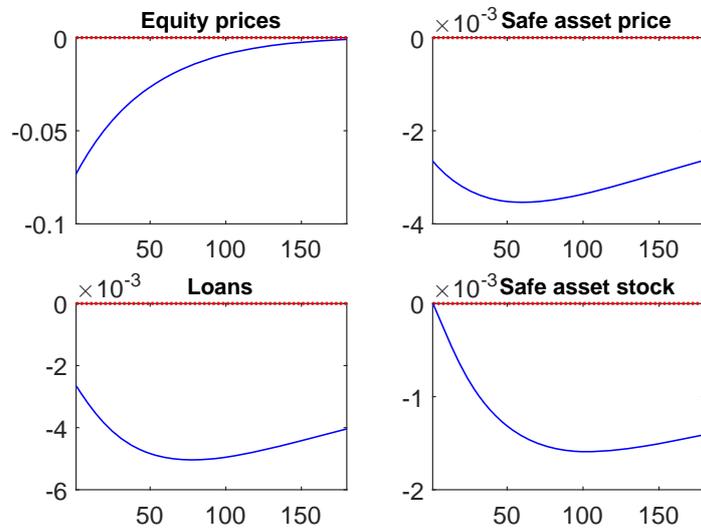


FIGURE 8. Impulse response of equity prices, the safe asset price, bank loans and the safe asset stock to a negative technology shock. y axis: log-deviation from steady state. x axis: quarters after the shock.

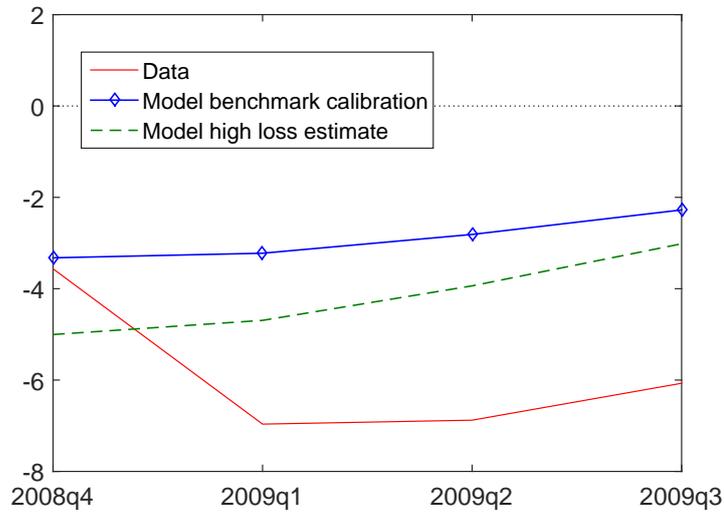


FIGURE 9. Impulse response of year-over-year output growth to a negative financial shock. The full line with diamonds shows the response of output in the case of a cumulated loss of 140 billion euros. The dotted line shows the case of a cumulated loss of 198 billion euros. Model vs. data. y axis: year-over-year output growth in deviation from mean. x axis: quarters after the shock.

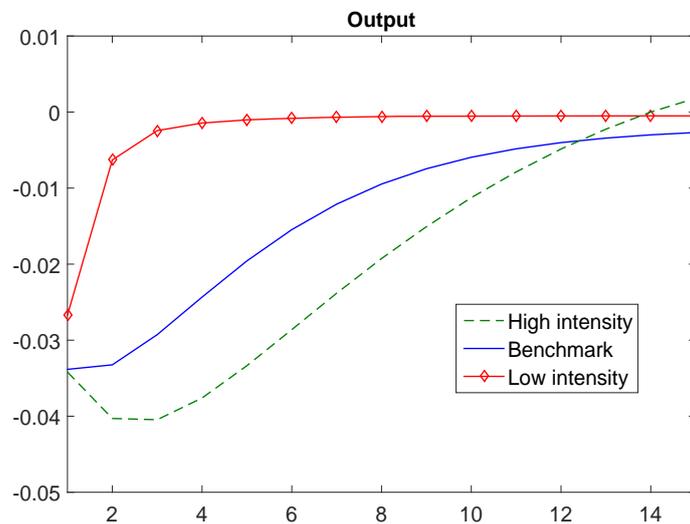


FIGURE 10. Impulse response of output to a negative financial shock for different values of  $\rho$ . y axis: log-deviation from steady state. x axis: quarters after the shock.

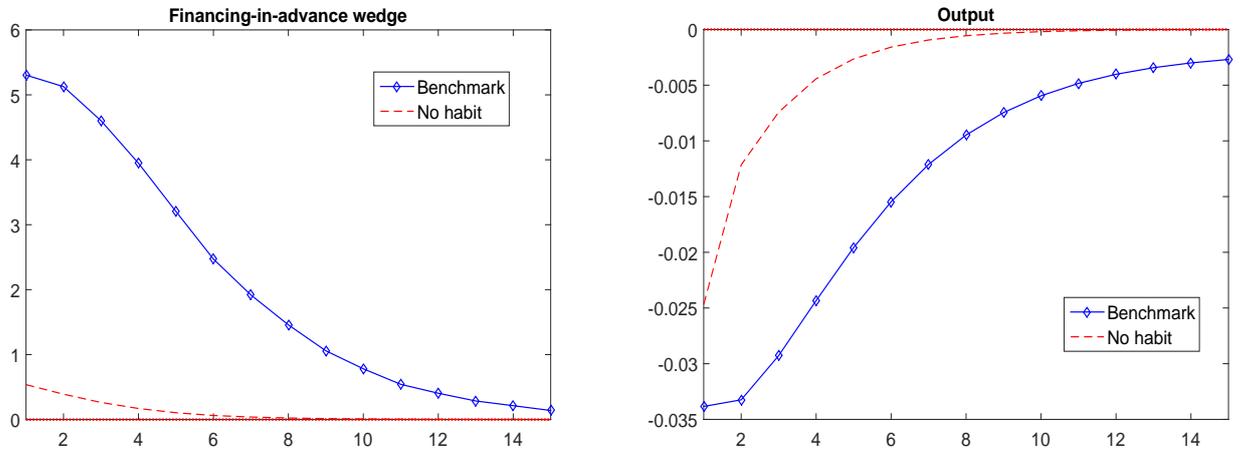


FIGURE 11. Impulse response of the financing-in-advance wedge  $\mu/\lambda$  and output to a negative financial shock. Benchmark model vs. model without habits. x axis: quarters after the shock. y axis: log deviation from steady state.

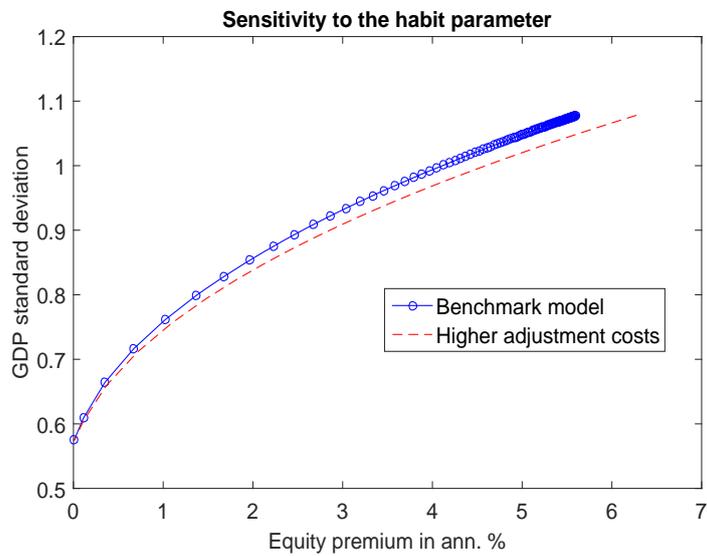


FIGURE 12. Impact of habits and adjustment costs on the equilibrium relationship between output standard deviation and the equity premium. Technology shocks.

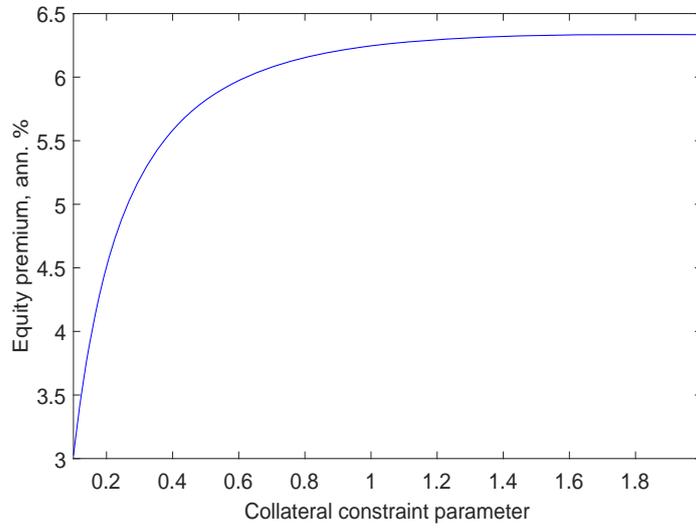


FIGURE 13. Relationship between the equity premium (y axis) and  $\varrho$  (x axis). Technology shocks.

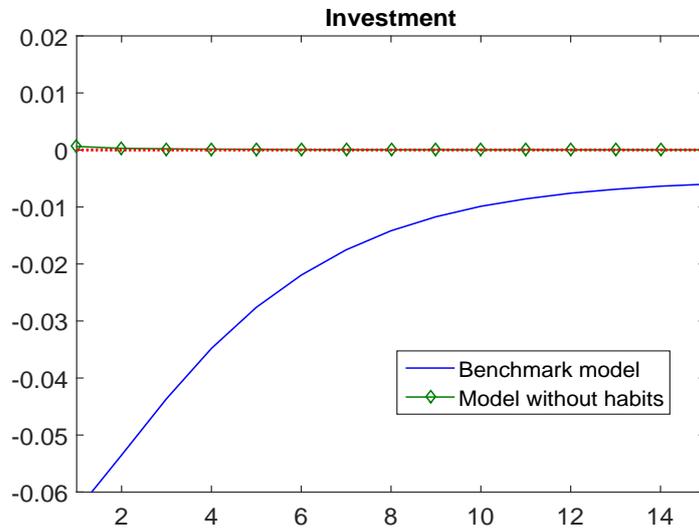


FIGURE 14. Impulse response of investment to a negative financial shock. Benchmark model vs. no habit case. y axis: log deviation from steady state. x axis: quarters after the shock.

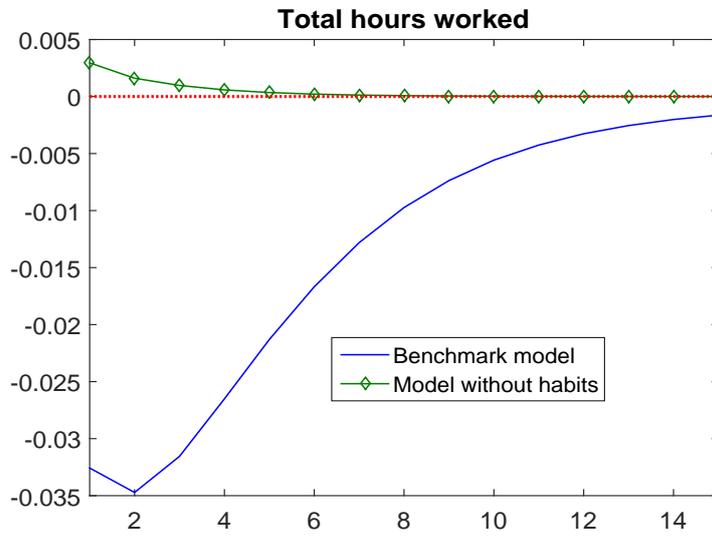


FIGURE 15. Impulse response of total hours worked to a negative financial shock. Benchmark model vs. no habit case. y axis: log deviation from steady state. x axis: quarters after the shock.

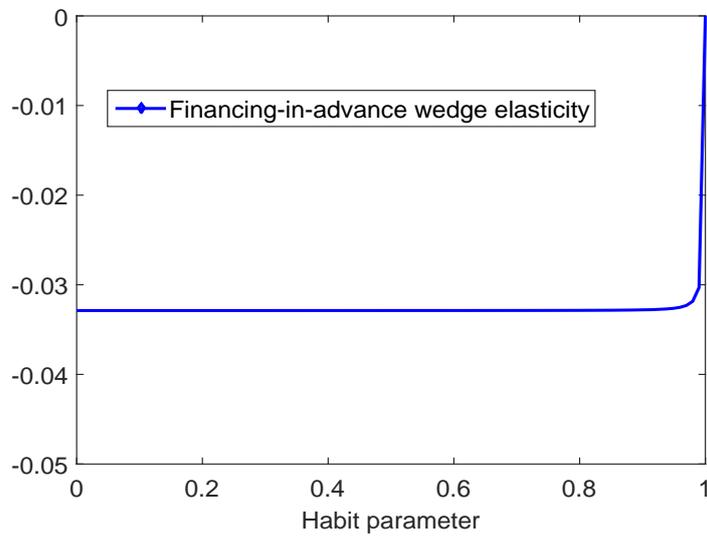


FIGURE 16. Sensitivity of the elasticity of labor supply to the financing-in-advance wedge to changes in  $\tau$  from 1 to 0.

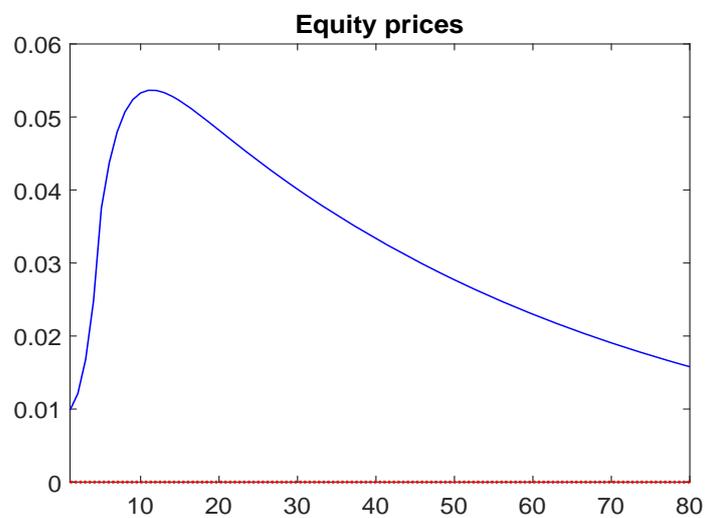


FIGURE 17. Response of equity prices to an anticipated technology shock that materializes four quarters after the announcement. x axis: quarters after the shock. y axis: log deviation from steady state.

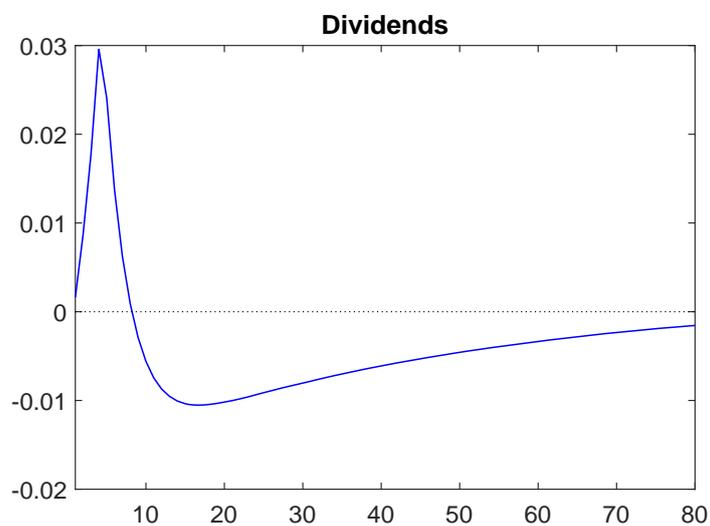


FIGURE 18. Response of dividends to an anticipated technology shock that will hit four quarters after the announcement. x axis: quarters after the shock. y axis: log deviation from steady state.

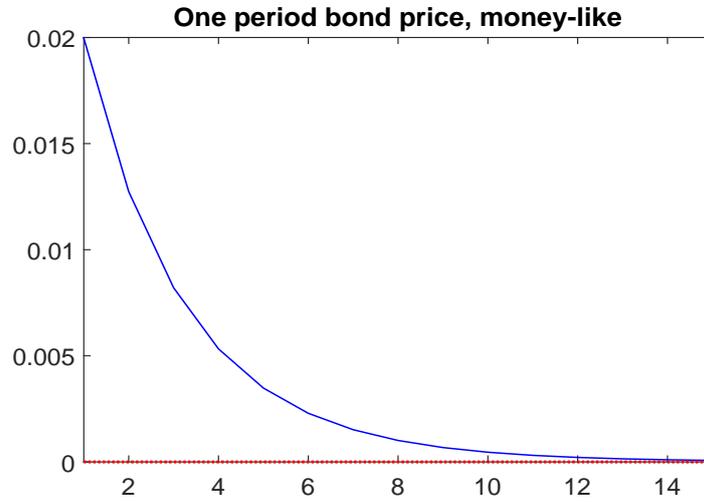


FIGURE 19. Response of the price of a one-period risk-free bond adjusted for money-like services to a negative financial shock. x axis: quarters after the shock. y axis: log deviation from steady state.

## 12 Appendix C.

### Data appendix to Section 3

Variables	Description	Source
Deterministic growth rate, $\gamma$	Euro area 19 population	Stat. Office of the EC 1960-2008
Consumption, $c$	Final consumption expenditures EA 19, bio of €	Stat. Office of the EC 1995q1-2008q3
Loans, $l$	Consumer credit MFI loans to households, bio of €	ECB Table 2.4.2 1997q3-2008q3

Variables	Description	Source
Output, $y$	GDP	Stat. Office of the EC
	EA 19, mio of chained 2010 Euros	1995q1-2008q3
Consumption, $c$	Final consumption expenditures	Stat. Office of the EC
	EA 19, mio of chained 2010 Euros	1995q1-2008q3
Investment, $i$	Gross capital formation	Stat. Office of the EC
	EA 19, mio of chained 2010 Euros	1995q1-2008q3
Hours worked, $N_T$	Hours worked total economy	ECB
	ECB, Table 5.3.1, EA 19	1995q1-2008q3
Wages, $w$	Labor productivity	ECB
	ECB Table 5.1.4, EA 19	1995q1-2008q3
Tobin's Q, $q$	Price to book ratio, MSCI Europe Index	Bloomberg 1998q4-2008q3
Nominal money market rate	Euro area Interbank rate: 3-Month Maturity	ECB 1994q1-2008q3
Real money market rate, $r^F$	Real Euro area Interbank rate: 3-Month Maturity	ECB 1994q1-2008q3
Equity total return index, $r^E$	Euro stoxx total return index growth rate, broad index	STOXX Limited 1987q1-2008q3
Safe asset return, $r^S$	Markit iboxx total return bond index growth rate, securitized <sup>32</sup>	Markit 2001q2-2008q3
Money-like return, $r^{ML}$	French 13 weeks T-bill rate percent per annum	IFS 1970q1-2008q3
<b>Constructed series</b>		
Equity premium, $E(r^E - r^F)$	$\frac{1}{T} \sum_{t=0}^T (r_t^E - r_t^F)$	1994q1-2008q3
Safe asset premium, $E(r^S - r^F)$	$\frac{1}{T} \sum_{t=0}^T (r_t^S - r_t^F)$	2001q2-2008q3
Money-like return, $E(r^F - r^{ML})$	$\frac{1}{T} \sum_{t=0}^T (r_t^F - r_t^{ML})$	1994q4-2008q3

<sup>32</sup>Secured against specific assets or receivables (ABS), mortgages (MBS) or cash flows from a whole business segment (Whole Business Securitizations) in each case via a special purpose vehicle.