# Liquidity Constraints, Risk Premia and the Macroeconomic Effects of Liquidity Shocks

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**Abstract**

We study the macroeconomic effects of liquidity shocks in a dynamic general equilibrium model in which firms and households are subject to liquidity constraints. The supply of liquidity is endogenously determined by a financial sector that allocates the production of liquidity services between the different sectors of the economy. In our environment, the model that generates realistic asset pricing predictions also has a stronger endogenous propagation mechanism. Our results suggest that the exceptional magnitude of the Great Recession can be explained by a negative liquidity shock originating in the financial sector.

- *JEL:* E3, E4, G1.
- *Keywords:* Financial Frictions, Asset Pricing, Bayesian Estimation.

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# 1 Introduction

One of the most important functions of safe financial assets is to facilitate exchanges by serving as collateral in financial transactions. In this respect, high quality financial assets offer liquidity services that are comparable to the ones provided by a standard medium of exchange such as money (e.g., Singh and Stella 2012). An important empirical regularity observed during the Great Recession is that the financial crisis has been accompanied by a shortage of pledgeable assets. The unprecedented size and severity of the credit rating downgrades, which affected nearly one third of securities that were rated AAA (e.g., Benmelech and Dlugosz 2010), and the collapse in securitization issuance by the private sector led to a massive reduction in the quantity of assets that were considered safe (e.g., IMF 2012).[1]

The tightening in bank lending standards observed during the early stages of the financial turmoil (see Figure 1 in Appendix A) illustrates that the shortage of pledgeable assets affected the real economy by reducing the quantity of credit available to households and firms. Moreover, the increase in money market spreads that simultaneously occurred (see Figure 2), and which is one of the main empirical regularities that differentiates this recession from previous ones, suggests that shocks originating in the financial sector must have played a predominant role. To evaluate whether this mechanism could generate a large recession, a stock market crash and an increase in liquidity spreads, this work studies the role of liquidity constraints in a dynamic general equilibrium model in which the provision of liquidity services is undertaken by a financial sector.

In our model economy, the key assumption is that a financial asset is needed to facilitate transactions. The stock of this financial asset, which represents the stock of safe or money-like asset, is owned by a financial sector. The main task of these financial intermediaries is to manage the production of safe assets and to allocate the liquidity services that they provide between the different sectors of the economy. From the perspective of firms and households, liquidity risk stems from the necessity to have access to liquidity services in order to consume the market consumption good and to operate firms in the final good sector. Liquidity services therefore serve to "grease the wheels" of the economy by limiting the impact of transaction frictions on the allocation of resources.

[1] In Europe, the total supply of safe assets has fallen from roughly €5.8 trn in 2006 to €1.6trn in 2012 (e.g., Goldman Sachs 2012).

In this environment, a liquidity crisis can be generated by small transitory shocks to the supply of safe assets produced by the financial sector. By reducing the quantity of pledgeable assets available in the economy, adverse liquidity shocks impair the mechanism of exchange and raise the cost at which households and firms are able to obtain liquidity services from the financial sector. Liquidity spreads rise, stock prices fall, and the liquidity shortage generates a deep recession as well as a persistent decline in consumption.

Our first main result is that the macroeconomic effects of liquidity shocks crucially depend on the model's asset pricing implications. Since our mechanism requires a low elasticity of intertemporal substitution in consumption (EIS) to match the equity premium, the response of consumption is more gradual and more persistent in the model that generates plausible asset pricing predictions. By tying agents' consumption to the quantity of safe assets in circulation, liquidity constraints make consumption smoothing conditional on the availability of liquidity services. As a result, a shock that reduces the quantity of liquidity services has a greater effect on marginal utility and therefore asset prices in an economy in which these two ingredients are combined.

The real effects of liquidity shocks are obtained by introducing a preference specification that strengthens this motive for consumption smoothing while simultaneously reducing the wealth elasticity of labor supply (e.g., Jaccard 2013). Introducing a specification of habits in the composite of consumption and leisure creates the complementarity between consumption and hours needed to generate a contraction in output. With a standard preference specification, by contrast, negative liquidity shocks are expansionary and fail to significantly alter the dynamics of output and equity prices. Moreover, the equity premium generated by the model in this case is implausibly small.

Compared to studies that investigate the real effects of liquidity shocks (e.g., Fuerst 1992, Lucas 1990), the main difference is that, in the model that matches the equity premium, the effects of liquidity shocks on economic activity can be very persistent. The qualitative implications can also substantially differ from the ones arising in a standard cash-in-advance model (e.g., Cooley and Hansen 1995, Hairault and Portier 1995), since in our economy, a positive liquidity shock reduces the cost of obtaining credit lines and generates a persistent increase in output, consumption, employment, and investment. The second main difference is that liquidity shocks generate the co-movement between equity prices and output that has been observed during the crisis. As pointed out by Shi (2012), standard models cannot easily generate this co-movement, or reproduce the lead-lag structure between equity prices and output observed in the data.

As in He and Krishnamurthy (2012), we find that liquidity frictions have a nonlinear impact on risk premia. Compared to their mechanism, an interesting difference is that in our economy the equity premium has an inverted U-shaped relationship with the tightness of the liquidity constraint. For most values of the velocity parameter, a tightening of the liquidity constraint raises the equity premium and increases the volatility of output. When the constraint is already very tight, however, while a further tightening of the velocity parameter raises the volatility of output, the impact on the equity premium can be ambiguous.

Turning to the empirical analysis, we find that liquidity factors have the potential to explain a significant fraction of business cycle fluctuations in the euro area. Following Jermann and Quadrini (2012), we examine the behavior of the estimated shock during the financial turmoil. Our analysis suggests that the exceptional magnitude of the Great Recession can be explained by a negative liquidity shock originating in the financial sector. The shock was transmitted to the other sectors of the economy by triggering a tightening of liquidity conditions faced by households and firms.

# 2 The environment

The economy is composed of a representative household, a financial sector or liquidity service producer, and a final goods-producing sector. The firms produce the final goods using labor and capital, which are both rented from the household sector. The stock of safe or liquid assets is produced by the financial sector and the liquidity services derived from the production of this asset is rented to households and firms. The presence of transaction frictions makes liquidity services necessary to consume the final consumption good and to produce the final output good.

The economy is subject to three sources of exogenous disturbances: shocks to total factor productivity in the final good sector, monetary policy shocks, and liquidity shocks. The specifications of preferences and technology are compatible with balanced growth. The deterministic growth rate at which the economy is growing along the balanced growth path is denoted $\gamma$.

## 2.1 Households

Households derive utility from consuming a market consumption good, $c$, and leisure, $L$. Following Jaccard (2013), we assume that habits are formed over the mix of consumption and leisure, where the reference level or habit stock is denoted, $h$. 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.[2] The modified discount factor and the curvature parameter are denoted[3] $\widehat{\beta}$ and $\sigma$, respectively. The law of motion that governs the accumulation of the habit stock is given as follows:

$$\gamma h_t = m h_{t-1} + (1-m) c_t (\psi + L_t^v), \tag{1}$$

where $m$ captures the rate at which the habit stock depreciates.

As far as the allocation of time is concerned, households divide their time endowment between leisure activities, $L$, and hours worked in the final goods-producing sector, $N$. Normalizing the total time endowment to 1, the allocation of time constraint takes the following form:

$$N_t + L_t = 1 \tag{2}$$

The sequential budget constraint in period $t$ is given as follows:

$$w_t N_t + r_{Kt} k_{t-1} + d_{Tt} = c_t + x_t + r_{St} s_{Ht} \tag{3}$$

where $k$ is the amount of physical capital that is rented to the firm, $r_K$ is the remuneration rate of physical capital, $x$, is the amount of resources invested in physical capital, and $d_T$ is total profits received from the financial and the final good sectors. The wage rate is represented by $w$ and the quantity of liquidity services that households obtain from the liquidity service producer is denoted $s_H$. The cost of borrowing liquidity services is given by the interest rate, $r_S$.

Following Jermann (1998), capital accumulation is determined by households' saving and investment decisions and obeys an intertemporal accumulation equation subject to adjustment costs:

$$\gamma k_t = (1-\delta) k_{t-1} + \left( \frac{\eta_1}{1-\epsilon} \left( \frac{x_t}{k_{t-1}} \right)^{1-\epsilon} + \eta_2 \right) k_{t-1} \tag{4}$$

where the cost of adjusting the capital stock depends on the elasticity parameter,

[2]These parameters are restricted to ensure concavity in $L$ and that both good are always normal goods.

[3]where $\widehat{\beta} = \beta \gamma^{1-\sigma}$

$\epsilon$. The two adjustment cost parameters $\eta_1$ and $\eta_2$ are calibrated to ensure that the deterministic steady state of the model is not affected by the introduction of adjustment costs (e.g., Baxter and Crucini 1993).

We assume that households face a constraint that creates a demand for liquidity services. Liquidity risk stems from the fact that liquidity services are needed to alleviate a transaction friction, and that these services need to be rented from the financial sector. The liquidity constraint takes the following form:

$$\theta s_{Ht} \geq c_t \tag{5}$$

where $\theta$ is the velocity parameter. Compared to a standard cash-in-advance constraint, the difference is that the supply of $s_H$ will be endogenously determined by the financial sector.

The representative agent optimally chooses consumption, investment, hours worked, the capital stock and the habit stock to maximize expected lifetime utility:

$$Max_{c_t,L_t,x_t,k_t,h_t,s_{Ht}}\ E_0 \left\{ \sum_{t=0}^{\infty} \widehat{\beta}^t \frac{1}{1-\sigma} \left[c_t(\psi + L_t^{\upsilon}) - h_{t-1}\right]^{1-\sigma} \right\},$$

subject to constraints (1) to (5).

## 2.2 The final goods-producing sector

The final output good, $y$, is produced via a Cobb-Douglas production function using capital and labor:

$$y_t = A_t k_{t-1}^{\alpha} N_t^{1-\alpha} \tag{6}$$

where the stochastic total factor productivity level is denoted $A$. The technology shock follows an autoregressive process of order 1 with persistence, $\rho_A$, and standard deviation $std(\varepsilon_A)$. Profits of the final goods-producing firms take the following form:

$$d_{Ft} = A_t k_{t-1}^{\alpha} N_t^{1-\alpha} - w_t N_t - r_{Kt} k_{t-1} - r_{St} s_{Ft} \tag{7}$$

where the quantity of liquidity services rented from the financial sector is denoted, $s_F$. Firms in the final good sector are subject to a transaction friction that is proportional to the sum of their wage plus interest rate bill. This constraint, which captures the idea that liquidity services are needed to finance a share of the firm's current expenditures, takes the following form:

$$\kappa s_{Ft} \geq w_t N_t + r_{Kt} k_{t-1} \tag{8}$$

where $\kappa$ is the velocity parameter.

Managers in the final goods-producing sector maximize the value of the firm which is equal to the present discounted value of all current and future expected cash flows:

$$Max_{k_{t-1}, s_{Ft}, N_t} \ E_0 \sum_{t=0}^{\infty} \widehat{\beta}^t \frac{\lambda_t}{\lambda_0} d_{Ft}$$

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 (6) to (8).

## 2.3 The financial sector

Firms in the financial sector allocate the liquidity services provided by the production of safe financial assets between the household and the final goods-producing sectors. The accumulation of safe assets is financed via retained earnings and dividends in the financial sector are given as follows:

$$d_{Lt} = r_{St} s_{Ft} + r_{St} s_{Ht} + \varrho_t \frac{s_{Tt-1}}{1 + \pi_t} - \gamma s_{Tt} \tag{9}$$

where $s_T$ is the stock of safe assets that the liquidity service producer owns on its balance sheet. The inflation rate is denoted by $\pi$ and $\varrho$ represents the liquidity shock that affects the stock of safe financial asset. As in Lucas (1972), $\varrho$ is modelled as a multiplicative factor whereby the stock of safe assets carried from $t-1$, $\frac{s_{Tt-1}}{1+\pi_t}$, are multiplied by $\varrho_t$, so that liquidity producers start periods $t$ with $\varrho_t \frac{s_{Tt-1}}{1+\pi_t}$. The liquidity shock follows an autoregressive process of order 1 with persistence, $\rho_S$, and standard deviation $std(\varepsilon_S)$.

The main function of the financial sector is to choose how to allocate the liquidity services provided by the stock of safe assets between households and final good producers. This portfolio decision is captured by introducing the following constraint into the optimization problem:

$$\varrho_t \frac{s_{Tt-1}}{1 + \pi_t} = s_{Ht} + s_{Ft} \tag{10}$$

The timing reflects the usual cash-in-advance assumption that only liquidity accumulated in previous periods, i.e. $s_{Tt-1}$ can be distributed to households and firms for current-period transactions.[4] Adjusting the total amount of liquidity services that is distributed, $s_{Ht} + s_{Ft}$, is no longer possible once the total quantity of safe assets available, $\varrho_t \frac{s_{Tt-1}}{1+\pi_t}$, has been determined. A rebalancing of liquidity holdings across the two sectors can however always occur after the total quantity has been chosen, since the allocation of liquidity services between firms and household is determined in period $t$. The allocation of liquidity services is also affected by the inflation rate in period $t$. By eroding the value of the existing stock of safe assets, an increase in the inflation rate for instance lowers the quantity of liquidity services available in the economy in period $t$.

Managers maximize the value of the representative liquidity service producer, which is equal to the present discounted value of all current and future expected cash flows:

$$Max_{s_{Ft}, s_{Ht}, s_{Tt}} \; E_0 \sum_{t=0}^{\infty} \widehat{\beta}^t \frac{\lambda_t}{\lambda_0} d_{Lt}$$

subject to constraints (9) and (10).

## 2.4 Monetary policy

The conduct of monetary policy is captured by an interest rate rule linking the interest rate, $r_S$, to the inflation rate, $\pi$. For simplicity, we abstract from any measure of output gap and $\omega_\pi$, which denotes the sensitivity of the targeted rate to a change in inflation, is the only policy parameter set by the monetary policy authorities. The monetary policy rule is given as follows:

$$r_{St} = \omega_\pi \pi_t + \xi_t$$

The non-sytematic component of monetary policy is denoted $\xi_t$, which is an autoregressive process of order 1 with persistence $\rho_M$ and standard deviation $std(\varepsilon_M)$.

## 2.5 Market equilibrium

A competitive equilibrium in the economy is a sequence of prices $\lambda, \varphi, \mu_F, \mu_H, q, w, r_K, r_S, \pi$ where $q$ is Tobin's Q, $\lambda$ is marginal utility, $\varphi$ is the Lagrange multiplier associated with equation (1), $\mu_F$ and $\mu_H$ are the Lagrange

[4] See Svensson (1985) for a discussion of the importance of timing assumptions in cash-in-advance models.

multipliers associated with the liquidity constraints (8) and (5), and quantities $c, h, x, k, N, s_T, s_H, s_F$ and $y$ that satisfy households and firms efficiency conditions as well as the economy-wide resource constraint:

$$y_t = c_t + x_t + \gamma s_{Tt} - \varrho_t \frac{s_{Tt-1}}{1+\pi_t},$$

for all states, for t=1...∞, and given initial values for the three endogenous state variables, $k, h$ and $s_T$.

# 3 Parameter selection

Compared to a standard real business cycle model, the velocity parameters $\theta$ and $\kappa$ are the new parameters that we introduce. The main obstacle is that data on liquidity services by sectors are needed to accurately calibrate these two key parameters. Given that the European Central Bank publishes the decomposition by sector of $M3$ counterparts since 2003, which is a broad measure of money, we calibrate the model using European data. In principle, the choice of the currency area should only have a minor impact on the calibration. As shown by Smets and Wouters (2005), the main characteristics of the Euro Area business cycles are very similar to the one observed in the United States. To facilitate comparison with the neoclassical growth model, we therefore use parameter values that are considered standard in the literature whenever possible. 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 asset pricing and business cycle statistics of interest.

To minimize the role played by the curvature coefficient, we set $\sigma$ to 1. This implies that the elasticity of intertemporal substitution will be essentially determined by the habit parameter $h$, and will be equal to unity when the habit formation channel is switched off, which corresponds to the case $h = 1$. Labor market data can be used to calibrate $\upsilon$ and $\psi$, the two labor supply parameters. First, according to the European labor force survey, in 2011, about 50% of the euro zone population was active. Second, assuming that active agents work on average 8 hours per day, the representative European agent should spend on average 4 hours per day on work related activities. This implies a fraction of time spent working in the final goods-producing sectors, $N$ of about 0.2. This steady state restriction pins down the first labor supply parameter, $\psi$. Following the business cycle literature, estimates of the Frisch elasticity of labor supply can be used to pin down the remaining labor supply parameters, $\upsilon$. Following Hall (2009), we set $\upsilon$ to 3.5 which implies a Frisch elasticity of about 1.[5] The capital share parameter, $\alpha$, the depreciation rate of capital, $\delta$, and the quarterly trend growth rate, $\gamma$, are set to 0.36, 0.025, and 1.005, respectively. These are all standard values used in the real business cycle literature (e.g., King and Rebelo 1999).

In the cases in which the constraints are not binding, *i.e.* $\mu_{Ht} = 0$ and $\mu_{Ft} = 0$, the safe assets is not needed and the demand from households and firms for liquidity services is zero. Since the supply is endogenously determined, profit maximization in the financial sector ensures that the quantity produced will be zero in this case. The case $c_t < \theta s_{Ht}$ and $\mu_{Ht} = 0$ or $\kappa s_{Ft} > w_t N_t + r_{Kt} k_{t-1}$ and $\mu_{Ft} = 0$ can therefore be ruled out since output and consumption are always positive for plausible range of parameter values.

The subjective discount factor is calibrated to ensure that the Lagrange multipliers associated with the two liquidity constraints (5) and (8) are always strictly positive. Setting $\widehat{\beta}$ to 0.983 ensures that the case $\mu_{Ht} \leq 0$ or $\mu_{Ft} \leq 0$ will be extremely unlikely.[6] The two velocity parameters can be calibrated using data on monetary aggregates as well as the liquidity constraints (5) and (8). First, the decomposition by sector of the counterparts of $M3$, which is the broadest measure of money available for the Euro Area, provides an indicator of the quantity of liquidity services that households and non-financial corporations obtain from the financial sector.[7]

From equation (5), which implies that:

$$\theta = E\left(\frac{c}{s_H}\right)$$

and using the counterpart to $M3$ that corresponds to the household sector as a proxy for $s_H$, as well as data on consumption, we obtain $\theta = 0.275$.

Similarly, together with equation (8), the first-order conditions of the model can be used to derive the following formula for the second velocity parameter:

[5] With this preference specification, the Frisch elasticity of labor supply depends on several additional parameters. The forumula is derived in Jaccard (2013).

[6] This was checked by simulating a sample of 100'000 observations, which corresponds to 25'000 years of data. For the combination of parameter values discussed in section 4 and 5, the case $\mu_{Ht} \leq 0$ or $\mu_{Ft} \leq 0$ were never observed. See Appendix F for an illustration.

[7] See the data appendix for a detailed description of the data used to calibrate the two velocity parameters.

$$\kappa = E\left(\frac{y - s_F r_S}{s_F}\right)$$

Using data on output, the money market rate, and the counterpart of $M3$ corresponding to the non-financial sector as proxies for respectively $y, r_S$ and $s_F$, we obtain $\kappa = 0.54$. Finally, the habit formation parameter, $h$, the capital adjustment costs parameter, $\epsilon$, the monetary policy rule parameter, $\omega_\pi$, and the two shock process parameters, $\rho_S$ and $\sigma_S$, are chosen to maximize the model's ability to reproduce the following features of the data:

*(i) The mean liquidity premium*

The increase in the Libor-OIS spread observed in all the major developed economies is the main empirical fact that distinguishes the Great Recession from other episodes. To maximize the model's ability to generate plausible implications on this key dimension, we firstly include the mean liquidity premium into the set of empirical moments that the model will have to match. Over the period 1999-2013, the observed mean Libor-OIS spread, which we use as a proxy for the liquidity premium, $E(r_S - r_F)$, is 0.25%, and the low observed excess return on the safe asset is the first empirical observation to reproduce.[8]

*(ii) The liquidity premium and the autocorrelation coefficient*

As illustrated by Figure 2, the other important empirical regularity that can be exploited to discipline the calibration is that the increase in the Libor-OIS spread observed at the very beginning of the Great Recession was transitory. This suggests that these shocks have little persistence and this information can be used to calibrate the shock process parameters. To capture this additional feature of the data, the autocorrelation coefficient of the observed liquidity premium, which we denote $\rho(lp_t, lp_{t-1})$ and which is equal to 0.78, is the second empirical fact that we include into the set of moments to match.

*(iii) The equity premium*

In the model, the key difference between $k$ and $s_T$ is that, in contrast to physical capital, the stock of liquid asset represents a safe asset. Safe assets provide liquidity services because they are better store of values than risky assets and this difference in risk premia between the two asset classes needs to be replicated by the model.

[8] We use the OIS rate rather than the interest rate on European government bonds as a proxy for the risk-free rate.

Following Shi (2012) and others, we use the equity premium, $E(r_E - r_F)$, as a proxy for the excess returns on physical capital, which as an average over the period 1999-2007, is approximately equal to 3.5%.

*(iv) The volatility of output*

To ensure that the size of the liquidity shock that will be required to reproduce these asset market facts is consistent with the model's business cycle implications, we also include the volatility of output into the set of moments that the model will have to reproduce. Over the period 1995-2013, the quarterly standard deviation of output, which is denoted $g_y$, is 0.65%.

*(v) The mean inflation rate*

Finally, to maximize the model's ability to explain the actual behaviour of inflation, the mean annualized inflation rate observed over the period 1995-2013, *i.e.* $E(\pi) = 1.96$, is included into the loss function. This restriction will essentially serve to identify the monetary policy rule parameter, $\omega_\pi$.

**Results**

It is possible to minimize the distance between the model implications and the data for the following set of parameter values:

$$\epsilon = 2.26,\ h = 0.7,\ \omega_\pi = 4.2,\ \rho_S = 0.76,\ \sigma_S = 0.0065$$

Table 1 below reports the model's main predictions on the dimensions discussed above and compare them with the data.

TABLE 1: MODEL VS. DATA

| | Data | Model |
|---|---|---|
| $E(r_{St} - r_{Ft})$ | 0.26 | 0.25 |
| $E(r_{Et} - r_{Ft})$ | 3.50 | 3.50 |
| $E(\pi)$ | 1.96 | 1.96 |
| $\rho(lp_t, lp_{t-1})$ | 0.78 | 0.78 |
| $std(g_Y)$ | 0.62 | 0.65 |

# 4 Inspecting the mechanism

The literature has shown that standard liquidity frictions, such as cash-in-advance constraints, are unlikely to significantly alter the dynamics of a basic real business cycle model (e.g., Cooley and Hansen 1989, 1995). By contrast, and as illustrated by the results presented in Table 2 below, a business cycle model in which the supply of liquidity services is endogenously determined, and that is solely driven by liquidity shocks, has the potential to generate significant business cycle fluctuations.

Table 2: Liquidity cycles

| | Std deviation | | | Correlation | | | Autocorrelation | |
|---|---|---|---|---|---|---|---|---|
| | Data | Model | | Data | Model | | Data | Model |
| $\sigma(g_y)$ | 0.62 | 0.65 | $\rho(g_y, g_y)$ | 1 | 1 | $\rho(g_{yt}, g_{yt-1})$ | 0.66 | 0.72 |
| $\sigma(g_c)$ | 0.34 | 0.82 | $\rho(g_y, g_c)$ | 0.60 | 0.99 | $\rho(g_{ct}, g_{ct-1})$ | 0.49 | 0.62 |
| $\sigma(g_x)$ | 2.31 | 3.17 | $\rho(g_y, g_x)$ | 0.77 | 0.77 | $\rho(g_{xt}, g_{xt-1})$ | 0.33 | 0.09 |
| $\sigma(g_N)$ | 0.97 | 0.94 | $\rho(g_y, g_N)$ | 0.82 | 0.97 | $\rho(g_{Nt}, g_{Nt-1})$ | 0.54 | 0.66 |
| $\sigma(g_w)$ | 0.45 | 0.18 | $\rho(g_y, g_w)$ | -0.84 | 0.82 | $\rho(g_{wt}, g_{wt-1})$ | 0.39 | 0.88 |
| $\sigma(g_q)$ | 8.25 | 7.2 | $\rho(g_y, g_q)$ | 0.44 | 0.71 | $\rho(g_{qt}, g_{qt-1})$ | 0.42 | 0.08 |
| $\sigma(g_\pi)$ | 0.28 | 0.57 | $\rho(g_y, g_\pi)$ | 0.41 | -0.27 | $\rho(g_{\pi t}, g_{\pi t-1})$ | 0.31 | 0.99 |

It is possible to match the volatility of output in a model that generates large fluctuations in investment and hours worked and that is able to reproduce the high volatility of equity prices. Compared to a standard real business cycle model, a main difference is that the model driven by liquidity shocks is able to generate the high autocorrelation in output growth observed in the data. As documented in the literature (e.g., Cogley and Nason 1995, Chang, Gomes and Schorfheide 2002), while the neoclassical growth model is able to reproduce the volatility and the co-movement of the main business cycle variables, it is unable to propagate the effect of technology shocks and fails to explain the persistence of quarterly output growth observed at business cycle frequency.

**Lead-lag structure and the liquidity risk premium**

A main distinguishing feature of the recent crisis is that the recession was preceded by a large drop in stock market value. As shown by Shi (2012), the response of equity prices to liquidity shocks generated by standard business cycle models is usually difficult to reconcile with this key empirical observation.

As shown by Table 3, which reports the lead-lag correlation between equity prices and output over the entire sample, the fact that stock prices are a leading indicator of output is also a more general business cycle characteristic. An interesting implication of the liquidity cycle model is that it is able to generate the co-movement between equity prices and output observed during the Great Recession. In addition, as illustrated by the comparison between the model and the data shown in Table 3, it is also able to reproduce the fact that equity prices are a leading indicator of the cycle.

TABLE 3: LEAD-LAG STRUCTURE

| | Data | | Model | |
|---|---|---|---|---|
| $k$ | $\rho(g_{yt-k}, g_{qt})$ | $\rho(g_{yt+k}, g_{qt})$ | $\rho(g_{yt-k}, g_{qt})$ | $\rho(g_{yt+k}, g_{qt})$ |
| 1 | 0.18 | 0.64 | 0.29 | 0.54 |
| 2 | -0.03 | 0.43 | 0.26 | 0.43 |
| 3 | -0.13 | 0.30 | 0.24 | 0.35 |
| 4 | -0.13 | 0.30 | 0.22 | 0.29 |

The increase in liquidity spreads from about 0.10% at the end of 2007 to 1.6% in 2008 is one of the main specificities of the Great recession. Figure 3 shows the effect of a negative liquidity shock on the liquidity premium, $r_{St} - r_{Ft}$, and on the money market rate, $r_S$, in the model calibrated to reproduce the set of moments described in section 3. This mechanism is able to capture the increase in the liquidity spread observed during the crisis. The magnitude of the increase and the low persistence of the negative shock on the liquidity spread can also be reproduced.

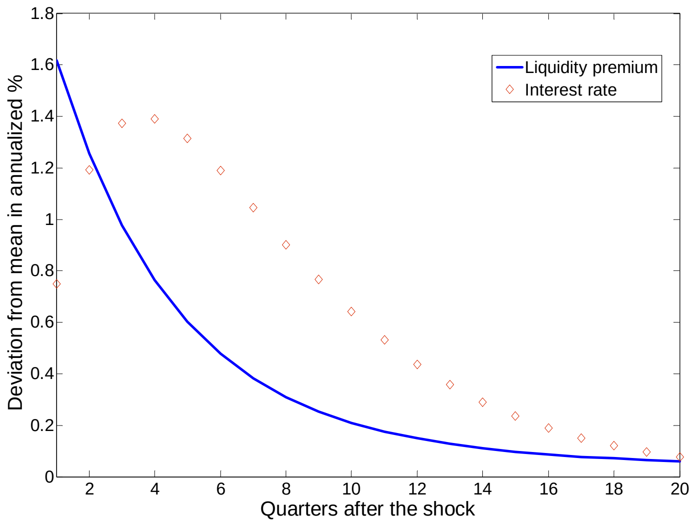


FIG. 3. Liquidity premium and interest rate, negative liquidity shock

**Impulse response analysis**

The response of the main macroeconomic and business cycle variables to a negative liquidity shock, which is depicted by the red diamonds, is shown in Figure 4 below. While the rise in liquidity spreads generated by negative shocks are short-lived, their effects on macroeconomic quantities are considerably more persistent. The hump-shaped response of output that is driven by the response of hours worked allows the model to generate the high degree of autocorrelation in output growth observed in the data. Moreover, the abrupt fall in equity prices generated by this mechanism allows the liquidity shock model to replicate the high volatility of equity prices together with the lead-lag structure between equity prices and output observed in the data.

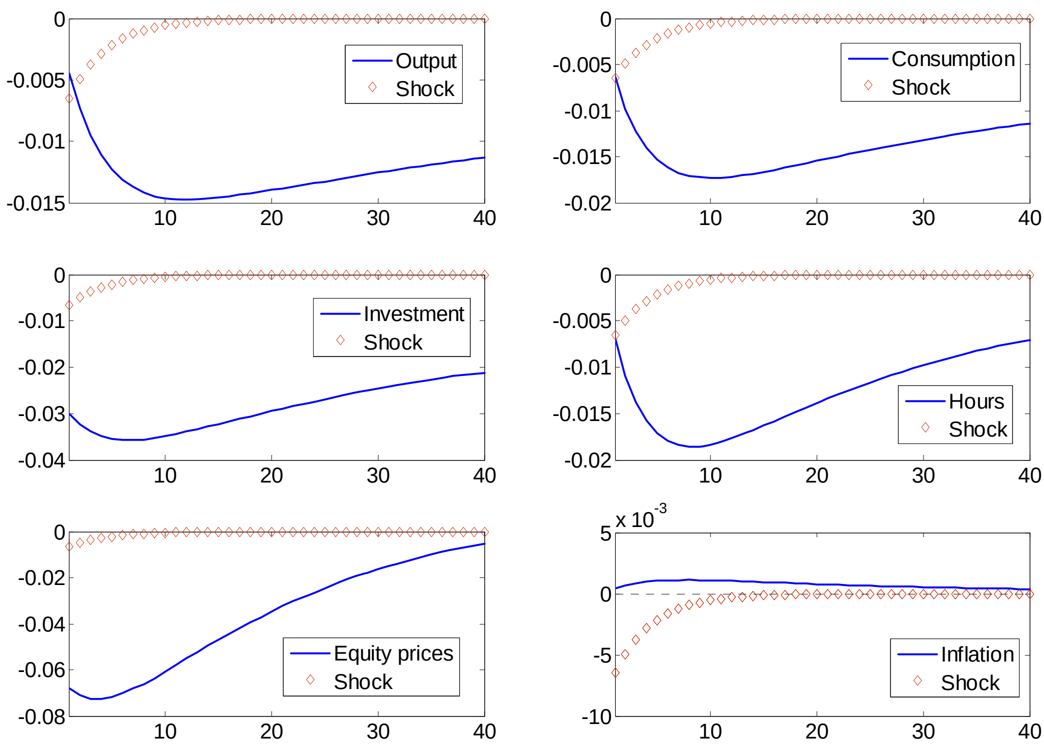


FIG. 4. Negative liquidity shock. y axis: percentage deviation from steady state. x axis: quarters after the shock.

The predicted behaviour of inflation is also consistent with the strong inflationary pressures that were observed at the very beginning of the Great Recession. The inflation rate increases from 1.9% in the third quarter of 2007 to 3.84% in the third quarter of 2008, which also corresponds to a period of heightened tensions in the liquidity market. The fact that the Great Recession started with an unusual increase in the inflation rate is therefore consistent with the liquidity shock hypothesis.[9]

**The propagation mechanism**

The comparison between the shocks (red diamonds) and the response of the endogenous variables (blue continuous line) shown in Figure 4 illustrates that the model's internal propagation mechanism is able to amplify and propagate the effects of small exogenous disturbances that have little intrinsic persistence.

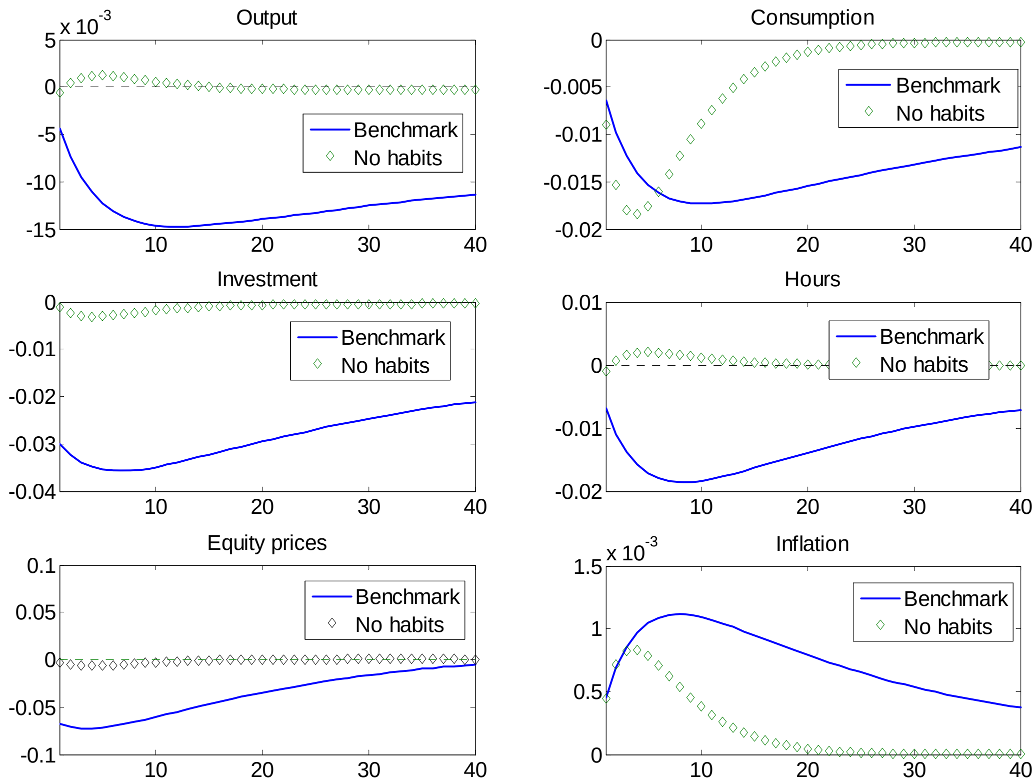


FIG. 5. Negative liquidity shock. y axis: percentage deviation from steady state. x axis: quarters after the shock. Benchmark model vs. case $h = 1$.

[9] The remarks made by Mr. Trichet during his introductory statement on September 4th 2008 illustrates this point: "With regard to price developments, annual HICP inflation has remained considerably above the level consistent with price stability since last autumn, standing at 3.8% in August according to Eurostat's flash estimate, after 4.0% in June and July 2008".

To identify the role played by the preference specification, Figure 5 compares the impulse responses generated by the benchmark model (blue continuous line) with the case in which the habit formation channel is switched off by setting $m$ to 1 (green diamonds).

With this preference specification, the elasticity of intertemporal substitution in consumption can be approximated by the following formula (e.g., Jaccard 2013):

$$EIS = \frac{\left(1 - \frac{1-m}{\gamma - m}\right)\left(1 - \gamma\widehat{\beta}\frac{1-m}{1-m\gamma\widehat{\beta}}\right)}{\sigma}$$

Compared to the log utility case that is obtained when $m$ and $\sigma$ are set to 1, the first main effect of habit formation is therefore to reduce the EIS. As can be seen by comparing the response of consumption in the two cases, consumption is considerably more volatile in the model without habits, which corresponds to a case in which the EIS is approximately equal to 1. Without a mechanism that lowers the EIS, agents choose to absorb the effects of a negative liquidity shock by reducing consumption and much of the adjustment occurs within the first ten quarters. Moreover, since in the log utility case consumption smoothing is not a priority, the reduction in investment that is needed to contain the fall in consumption is considerably smaller than in the model with habits.

As can be seen by comparing the response of hours worked, the labor market implications of the two models are also very different. In both cases, the increase in interest rate induced by the negative liquidity shock reduces the firm's demand for labor, which is determined by the following optimality condition:

$$w_t = \frac{(1-\alpha)}{1 + \frac{1}{\kappa} r_{St}} \frac{y_t}{N_t}$$

In the model without habits, the decline in wages, which through the substitution effect reduces the incentive to work, is quickly offset by the negative wealth effect generated by the increase in marginal utility. The positive response of hours worked that is observed immediately after the shock illustrates that the increase in labor supply induced by the wealth effect has a dominating effect on the dynamics of labor market variables. As illustrated by the response of output, which is mostly positive, adverse liquidity shocks fail to generate a recession when a standard specification of utility is used. Without a different propagation mechanism, the effects of liquidity shocks are therefore very similar to the ones arising in standard cash-in-advance models (e.g., Cooley and Hansen 1995, Hairault and Portier 1995).

The fall in hours worked that is obtained in the model with habits is essentially due to the reduction in the wealth elasticity of labor supply that this preference specification generates (e.g., Jaccard 2013). Intuitively, in response to a negative liquidity shock, consumption smoothing of the composite good is achieved by reducing leisure to mitigate the effects of the fall in consumption on agents' standards of living. By creating a strong aversion to periods of low consumption and high labor effort, this utility specification increases the complementarity between consumption and hours worked that is needed to explain the contractionary effects of negative liquidity shocks. In the logarithmic utility case, by contrast, agents work harder when wages are low and therefore choose to take less leisure during periods of reduced consumption, which is a situation that agents in the habit model are willing to avoid.

The introduction of habit formation allows the model to generate the large decline in equity prices that was observed during the Great Recession. Equity prices are considerably more volatile than output, which is a feature of the data that the model with a standard utility specification cannot replicate. Finally, without habits, the equity premium generated by the model is implausibly small (e.g., Mehra and Prescott 1985).

**Was the Great Recession caused by a technology shock?**

Figure 6 shows the response of the liquidity spread, $r_{St} - r_{Ft}$, and of the money market rate, $r_{St}$, to a negative technology shock, that is calibrated using standard parameter values used in the literature.[10] While technology shocks can reproduce the co-movement between the main macroeconomic and financial variables observed during the crisis, as shown by the blue continuous line, negative technology shocks fail to generate the increase in liquidity spreads that differentiates this recession from previous ones. The quantitative effect of technology shocks on the liquidity spread is also small, which suggests that these shocks are unlikely to be the main factor that initially triggered the Great Recession.

**Liquidity constraints, output volatility and the equity premium**

The strength of the propagation mechanism crucially depends on the velocity parameter, $\theta$. Figure 7 below illustrates this point by showing the sensitivity of the equity premium and of the standard deviation of output to changes in this parameter value.

[10] where we use $\rho_A = 0.979$ and $\sigma_A = 0.0072$.

As shown by the right panel, a tightening of liquidity constraints unambiguously increases the volatility of output, which illustrates that liquidity frictions are the main channel through which these shocks are transmitted to the real economy. The effects on consumption are greater when the liquidity constraint is tighter, which mechanically implies that larger fluctuations in hours worked are needed to stabilize the composite good. This complementarity between consumption and hours worked induced by our mechanism therefore generates a positive relationship between the tightness of the liquidity constraint and output volatility.

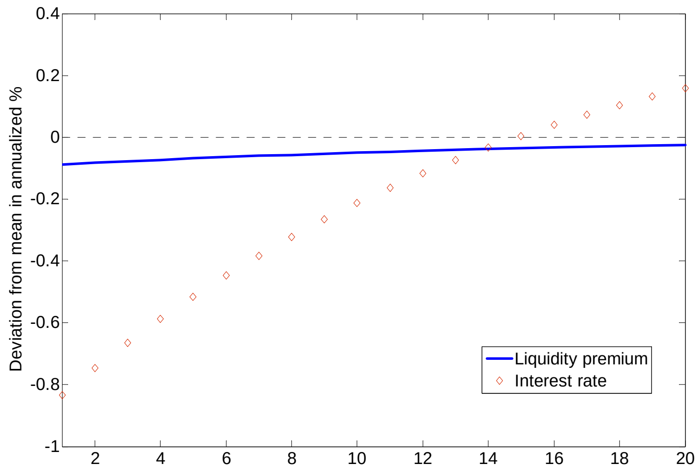


FIG. 6. Liquidity premium and interest rate, negative technology shock

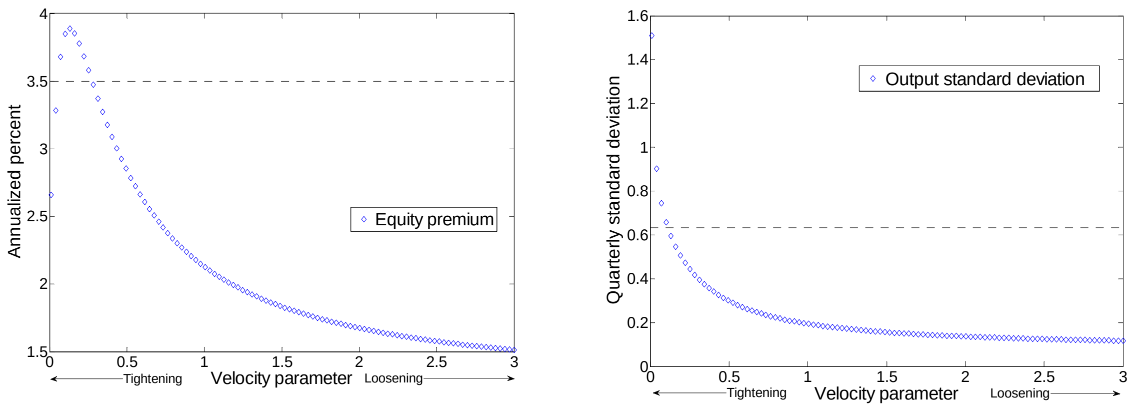


FIG. 7. Sensitivity of the equity premium and output standard deviation to $\theta$

The inverted U-shaped relationship shown in the left panel illustrates that the increase in output volatility that is obtained when the constraint becomes tighter does not necessarily lead to an increase in risk premia. The main reason is that the effects of liquidity shocks on the money market rate, $r_S$, can vary with the degree of tightness of the liquidity constraint.

When the liquidity constraint is relatively loose, it is easier to smooth consumption and small changes in the quantity of liquidity services are sufficient to achieve consumption smoothing. The demand for liquidity services remains stable, and as a result, positive liquidity shocks that shift the supply of safe assets to the right reduce the interest rate that households have to pay to obtain liquidity services. Over the business cycle, the negative correlation between the money market rate and output generated by liquidity shocks creates an additional source of risk, since it implies that the cost of obtaining credit lines will be higher during periods of recession. For most values of the velocity parameter, a tigthening of the liquidity constraint, which increases the quantity of safe asset that will be produced in the steady state, amplifies the procyclical fluctuations in interest rate induced by liquidity shocks. This unfavorable cyclical property of the interest rate, which exacerbates liquidity risk, has to be compensated by a higher risk premium. This explains the negative relationship between $E(r_E - r_F)$ and $\theta$ that is obtained for most values of the velocity parameter.

As shown in Figure 7, when the liquidity constraint is very tight, the relationship between the velocity parameter and the equity premium changes. In this case, consumption smoothing is more difficult to achieve and these larger fluctuations in consumption generate larger variations in the demand for liquidity services. In response to a positive liquidity shock, the reduction in interest rate is attenuated by the rise in the demand for liquidity services. By reducing the procyclicality of the interest rate, these larger fluctuations in the demand for liquidity services that arise when the constraint is very tight lowers the risk premium that investors require to hold the risky asset.

# 5 Estimation

The previous section has shown that liquidity shocks have the potential to explain a non-negligible fraction of business cycle fluctuations, as well as the co-movement between the main macroeconomic and financial variables observed during the crisis. The objective of this section is to further assess the plausibility of the liquidity shock hypothesis by estimating the relative contribution of each of the three shocks that we have introduced to the observed dynamics of business cycle variables in the euro area.

The liquidity, monetary policy and the technology shocks are estimated with Bayesian techniques using output, the short term money market rate, and the price level as observable variables. A full description of the data that is used is provided in the data appendix. To avoid complications stemming from non-stationarity, first differences rather than levels are used for output and for the price level[11]. To enhance the robustness of the empirical analysis, we do not attempt to estimate any structural parameters and keep them at the calibrated values discussed in the previous section. The standard deviations and the persistence of the three exogenous processes are the only parameters that are estimated. This is to avoid problems related to the lack of identification of structural parameters, which commonly arises in this class of models (e.g., Canova and Sala 2009).

**Choice of the priors**

Following Smets and Wouters (2003), we assume that the standard errors of the innovations follow an inverse gamma distribution and that the persistence of the AR(1) processes is beta distributed. For all four shocks, the standard errors of the innovation have a prior mean of 0.007 and a standard deviation of 0.05. The persistence of the AR(1) processes have a prior mean of 0.7 and a standard deviation of 0.15.

Table 4: Prior and Posterior Distribution

| | Prior distribution | | | Posterior mode | | Posterior mean | | |
|---|---|---|---|---|---|---|---|---|
| | Distr. | Mean | St. dev. | Mode | St. dev. | Mean | Low | High |
| $std(\varepsilon_A)$ | Inv G. | 0.007 | 0.05 | 0.0054 | 0.0004 | 0.0055 | 0.0048 | 0.0063 |
| $std(\varepsilon_S)$ | Inv G. | 0.007 | 0.05 | 0.0041 | 0.0003 | 0.0043 | 0.0036 | 0.0048 |
| $std(\varepsilon_M)$ | Inv G. | 0.007 | 0.05 | 0.0112 | 0.0009 | 0.0114 | 0.0099 | 0.0130 |
| $\rho_A$ | Beta | 0.7 | 0.15 | 0.967 | 0.018 | 0.96 | 0.93 | 0.99 |
| $\rho_S$ | Beta | 0.7 | 0.15 | 0.608 | 0.093 | 0.61 | 0.46 | 0.76 |
| $\rho_M$ | Beta | 0.7 | 0.15 | 0.454 | 0.095 | 0.46 | 0.31 | 0.62 |

Table 4: See Adjemian et al. (2012) for a detailed overview of the computation algorithm that is used for the estimation.

[11] This choice is based on a unit root test performed on the level of the 3 variables used for the estimation.

**Posterior estimates of the parameters and variance decomposition**

Table 4 reports the posterior mode of the parameters, their posterior mean, and the 95 percent confidence interval for the estimated mean. The estimated posterior distribution is shown in appendix C. The low shock standard deviation and the low persistence of the estimated liquidity shock indicates that, over the period under consideration, the magnitude of these shocks remains fairly small. In spite of their low volatility and low persistence, as illustrated by the variance decomposition shown in Table 5, liquidity shocks remain a key driver of business cycle fluctuations even when they are competing with the real business cycle model's technology shock. Interestingly, this mechanism also creates a non-negligible source of monetary non-neutrality, since monetary policy shocks explain more than 10 percent of output fluctuations.

TABLE 5: VARIANCE DECOMPOSITION

| | Technology | Liquidity | Monetary policy |
|---|---|---|---|
| Output | 46.9 | 39.4 | 13.7 |
| Consumption | 13.7 | 64.1 | 22.2 |
| Investment | 8.5 | 72.5 | 19.0 |
| Hours | 15.8 | 61.9 | 22.3 |
| Equity prices | 7.9 | 73.0 | 19.1 |
| Inflation | 10.7 | 29.7 | 59.6 |
| Wages | 93.5 | 5.2 | 1.3 |
| Money market | 22.4 | 62.6 | 15.0 |

Table 5 Variance decomposition, quarterly data, 1995-2013

**Liquidity factors during the Great Recession**

Figure 8 below shows the technology, liquidity, and monetary policy shocks that have been estimated using the procedure described above. The empirical analysis suggests that the Great Recession was caused by a combination of negative liquidity and technology shocks. The second key information revealed by this analysis is that, while liquidity factors have been a major cause of the financial turmoil, as can bee seen by the positive innovation observed at the end of 2008, they have also contributed to the recovery. Given that the positive innovation coincides with the introduction of

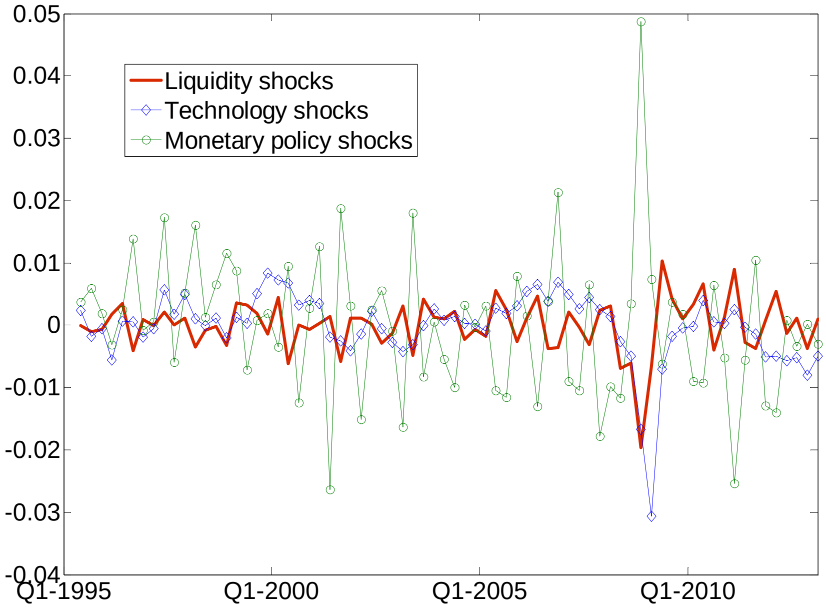


FIG. 8. Estimated technology, liquidity, and monetary policy shocks (innovation).

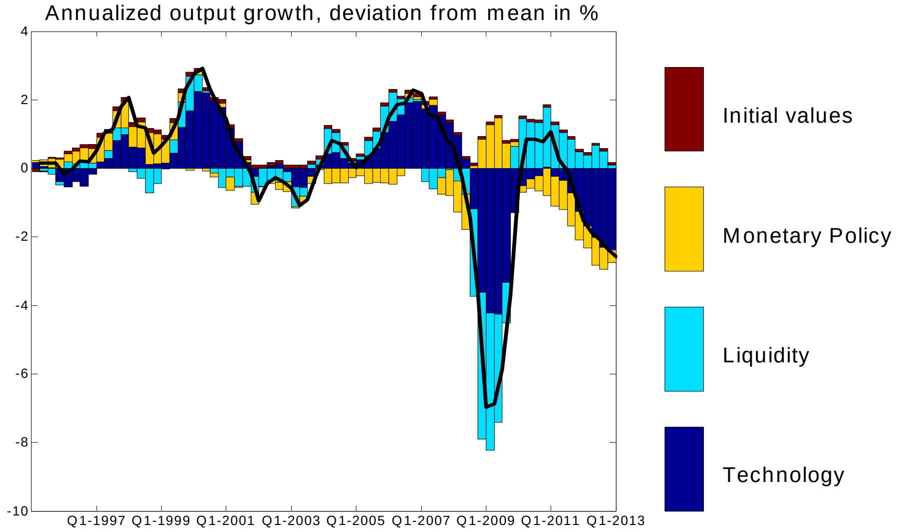


FIG. 9. Historical decomposition of output growth

more aggressive measures aimed at enhancing the supply of credit by the banking sector, a possible explanation is that the non-standard measures introduced by the ECB in October 2008 have helped to restore liquidity.[12] A more detailed model would however be needed to evaluate the effectiveness of the ECB's non-standard monetary policy measures.

During the period that corresponds to the intensification of the crisis, the effects of the negative liquidity shock are partially compensated by a large innovation in the monetary policy rule. One possible interpretation is that the series of interest rate cut implemented by the ECB during this period contributed to attenuate the effects of the liquidity shortage.[13] The small negative innovation detected in 2011 could correspond to the short-lived increase in policy rates observed during this period.

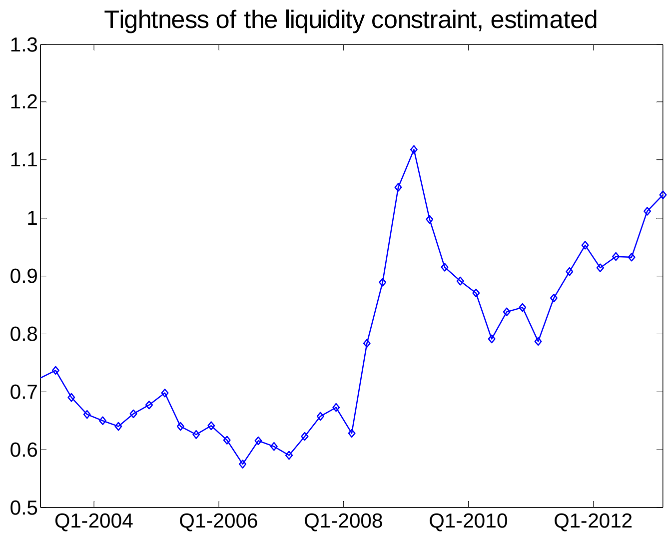


FIG. 10. Value of the Lagrange multiplier associated with the liquidity constraint.

Figure 9 shows the historical decomposition of annualized output growth, expressed in deviation from its mean, over the period 1995 to 2013. This chart confirms that

[12]In October 2008, the ECB reacted to the intensification of the crisis by directly taking up an intermediation role for the provision of liquidity to individual banks, normally played by the money market, by switching from variable tenders to fixed rate tenders with full allotment of the liquidity demanded by counterparts (see ECB Monthly Bulletin article "The ECB's non-standard measures-impact and phasing out", July 2011).

[13]Between October 2008 and May 2009, the ECB lowered the interest rate on its main refinancing operations by 325 basis points.

liquidity shocks played a particularly important role during the Great Recession period. While technology shocks remain an important source of business cycle fluctuations, our analysis therefore suggests that the unusual magnitude of the recession can be explained by a negative liquidity shock originating in the financial sector.

Finally, as illustrated by Figure 10, the behaviour of the Lagrange multiplier associated with the liquidity constraints confirms that liquidity conditions faced by households and firms were exceptionally tight during the financial turmoil period. The shock originating in the financial sector was transmitted to the real economy through the liquidity constraints, and by impairing the mechanism of exchange, the liquidity crisis created by the shortage of pledgeable assets forced firms and households to abruptly adjust consumption and production.

# 6 Conclusion

Early attempts to study the role played by liquidity constraints in dynamic general equilibrium models concluded that standard frictions, such as cash-in-advance constraints, were unlikely to significantly alter the dynamics of a basic real business cycle model. Without nominal rigidities, liquidity shocks do not contribute much to the fluctuations in real variables and positive liquidity shocks are contractionary (Cooley and Hansen, 1989 and 1995). By contrast, in our environment in which the supply of liquidity is endogenously determined, liquidity frictions have a major impact on the model dynamics and our analysis suggests that liquidity shocks played a prominent role during the Great Recession.

One main finding is that the propagation mechanism of liquidity shocks crucially depends on the model's asset pricing implications. The model that generates realistic asset pricing predictions was not only able to reproduce the rise in liquidity spreads but also the persistent decline in output observed during the Great Recession. Without a mechanism that brings the model's asset pricing implications into closer conformity with the data, by contrast, the model's endogenous propagation mechanism is weaker and liquidity shocks cannot be a plausible source of macroeconomic fluctuations.

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# 8 Appendix A

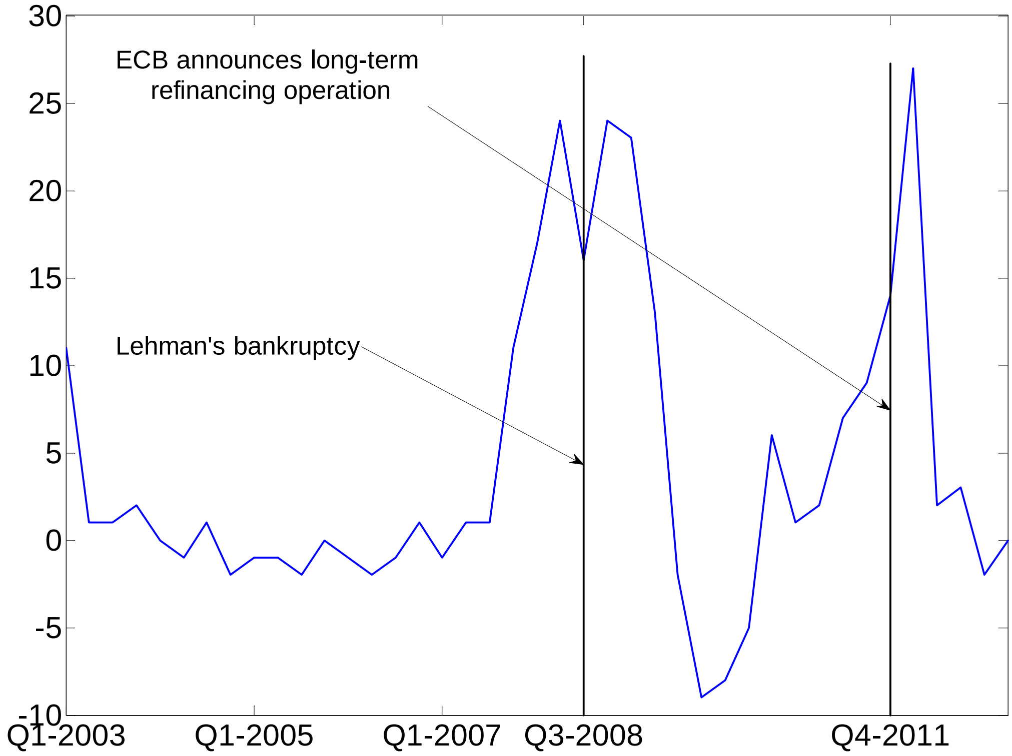



FIG. 1. Euro area bank lending survey. Response to the question: "Over the past three months, how have your bank liquidity position affected your bank's credit standards as applied to the approval of loans or credit lines to enterprises?". A positive net percentage balance indicates that a larger proportion of banks have tightened credit standards (net tightening).

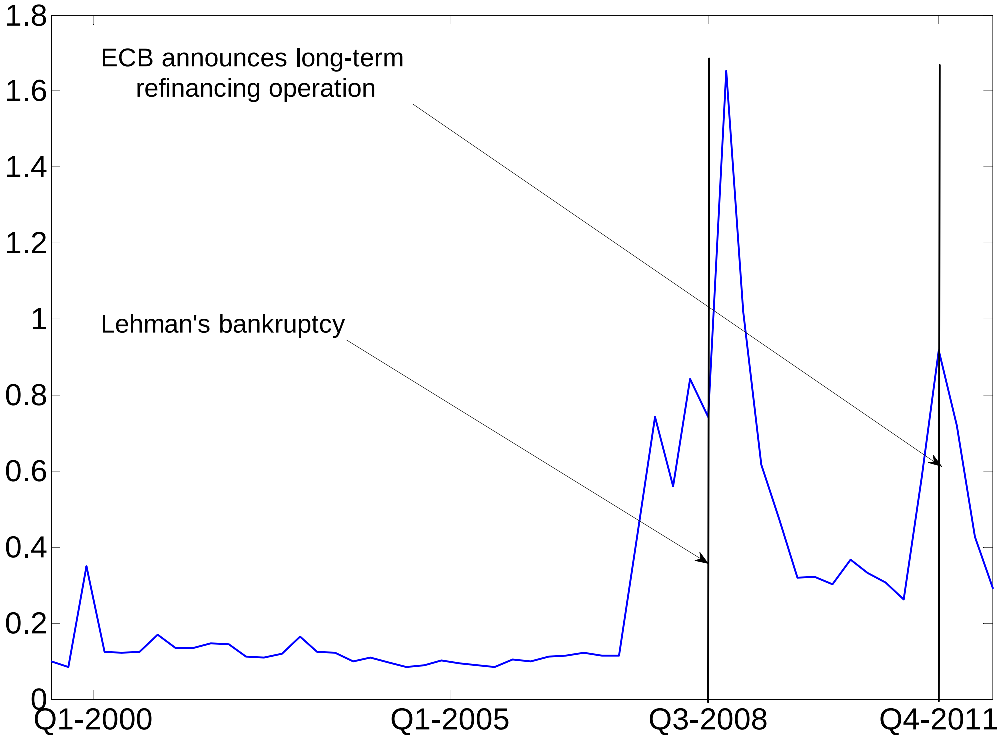
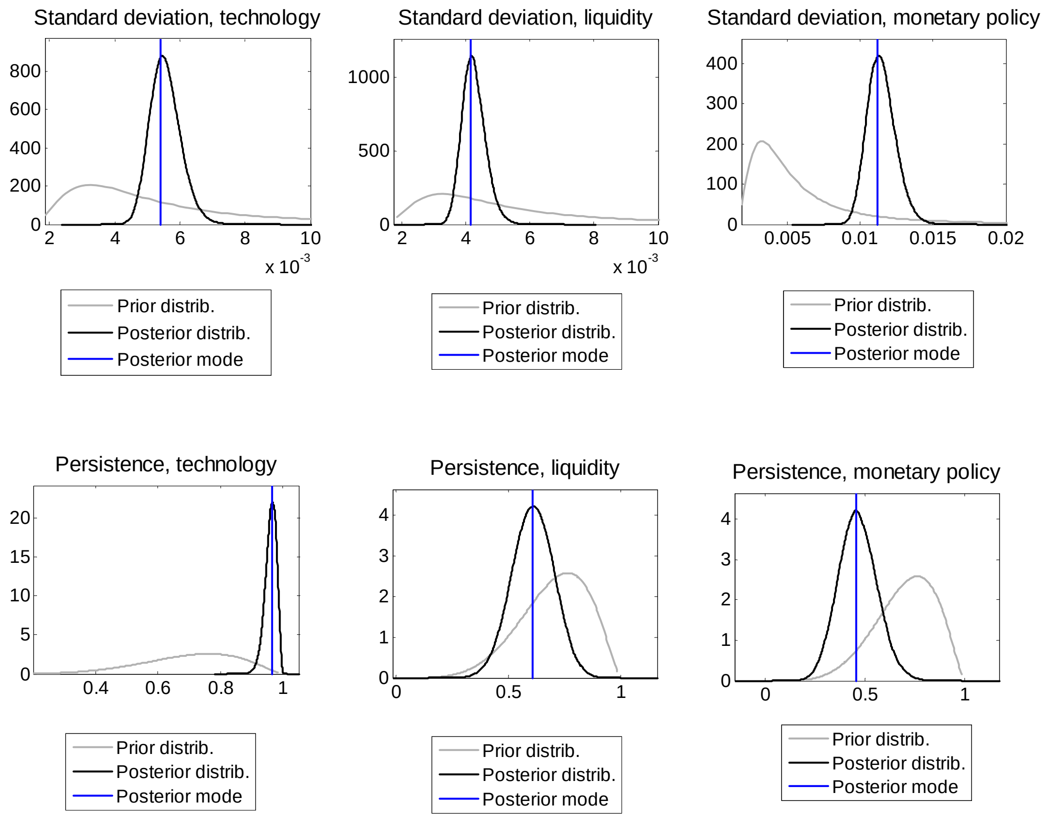



FIG. 2. Liquidity spread: Money market rate-risk-free rate (Libor-OIS spread).

# 9 Appendix B: Data description

| Variable | Description | Source |
|---|---|---|
| Output | Gross domestic product | Stat. Office of the EC |
| Consumption | Final consumption expenditures | Stat. Office of the EC |
| Investment | Gross capital formation | Stat. Office of the EC |
| Hours worked | Hours worked, excl. constr. (2000-2013) | Stat. Office of the EC |
| Wages | Real unit labor cost | Stat. Office of the EC |
| Equity prices | Euro stoxx 50 price index | ECB, Table 4.8 |
| Inflation | HICP inflation | ECB, Table 5.1 |
| Money market rate | Euribor 3 months | ECB, Table 4.6 |
| Equity returns | STOXX Broad Total Return Index | STOXX limited |
| Risk-free rate | EONIA Overnight Indexed Swaps (OIS) | Reuters |
| Liquidity services, households | M3 counterparts: households | ECB, Table 2.3.3 |
| Liquidity services, firms | M3 counterparts: nonfinancial corporations | ECB, Table 2.3.3 |

# 10 Appendix C: Estimated posterior distribution



# 11 Appendix D: Observable variables vs. data