EUROPEAN CENTRAL BANK
EUROSYSTEM

Working Paper Series

Ivan Jaccard

Stochastic discounting and the transmission of money supply shocks

No 2174 / August 2018

Abstract

This paper studies the effects of money supply shocks in a general equilibrium model that reproduces a term premium of the magnitude observed in the data. In an environment where financial frictions are the main source of monetary non-neutrality, I find that money supply shocks are less effective at stimulating inflation in recessions than in expansions. In terms of quantitative magnitude, the impact effect on inflation of a money supply shock is about half as large during recessions than during booms. This state dependence is essentially due to the time-variation in stochastic discounting that is needed to match the data.

- *Keywords: Bond premium puzzle, financial frictions, time-varying risk aversion, euro zone economy.*
- *JEL: E31, E44. E58.*

Non-technical summary

In many developed economies, aggregate consumption not only fell abruptly during the Great Recession but also recovered very slowly. In a large class of models used in the finance literature for asset pricing, risk aversion increases when consumption falls below trend for a prolonged period of time. In such models, the historical decline in cumulated consumption growth observed in the euro area after the subprime and sovereign debt crises therefore implies a dramatic increase in household risk aversion.

In the euro zone, some of the most aggressive monetary policy measures introduced by the ECB, such as the two three year long-term refinancing operations, were implemented at the end of 2011 and beginning of 2012, precisely during this period of exceptionally high risk aversion. The main prediction of the mechanism studied in this paper is that the unprecedented levels of risk aversion implied by the dynamics of aggregate consumption should have affected the transmission mechanism of the liquidity injections implemented by the ECB.

In the model economy envisioned in this paper, consumers are reluctant to spend and prefer to save for the future when risk aversion is high. This stronger precautionary saving motive during recessions reduces the inflationary pressures produced by an expansionary money supply shock. In other words, households are less inclined to spend any additional income that they receive when risk aversion is high and this precautionary saving motive reduces the inflationary effect of a liquidity injection.

This model implication is consistent with the lower than expected inflationary pressures observed in the euro area between 2012 and mid-2016, and which occurred in spite of the unprecedented monetary policy measures deployed during this period. This mechanism therefore provides one potential explanation for the missing inflation observed in recent years and the main policy implication of this result is that attitudes towards risk and precautionary saving motives could affect Central Banks' ability to steer inflation.

Whereas the response of inflation to liquidity injections is more muted during recessions, in the model economy studied in this paper, I also find that these policies are more effective at stimulating credit. If the quantity of credit that can be allocated to firms depends on the real stock of money, a more muted response of inflation implies that a greater quantity of credit is available for lending. As a result, this more subdued response of inflation to monetary policy generates larger credit expansions in recessions than in booms. This stronger effect on credit in turn implies that money supply shocks have a greater effect on output during recessions, when consumption is below trend and risk aversion is high.

1 Introduction

Fluctuations in stochastic discounting are necessary to resolve standard asset pricing puzzles and understanding the determinants of this time-variation is a central question in finance (e.g, Cochrane and Hansen 1992, Cochrane 2011). By contrast, stochastic discounting only plays a marginal role in most of the macroeconomic models used to analyze monetary policy transmission. This paper contributes to fill this gap by studying the transmission of money supply shocks in a model in which fluctuations in stochastic discounting are needed to generate a risk premium on long-term bonds of the magnitude observed in the data.

Introducing habit persistence in DSGE models has considerably improved our understanding of monetary policy transmission and habits are a key building block of the class of models used by Central Banks for policy analysis (e.g., Christiano et al. 2005, Smets and Wouters 2007, Christiano et al. 2014). At the same time, generating realistic asset pricing implications within these models has proved particularly challenging and most of these macroeconomic frameworks cannot reproduce key asset pricing facts, such as the risk premium on long-term bonds observed in the data. Given the importance of long-term interest rates for monetary policy, and hence of the term premium, the question is whether this limitation matters for our understanding of monetary policy transmission.

To shed light on this issue, this paper studies the transmission mechanism of money supply shocks in a model with habit persistence that is capable of generating an average term premium on long-term bonds of about 1%. In an environment where stochastic discounting matters, my main finding is that the effectiveness of monetary policy depends on the state of the economy. Whereas positive money supply shocks generate inflationary pressures, I find that the impact effect of a monetary policy shock on inflation is about half as large during recessions than during booms.

In the flexible price economy that is envisioned, inflation is the price of current relative to future consumption and its dynamics is determined by households' intertemporal preferences. When they expect good times ahead, households anticipate a decline in marginal utility and the need to save for the future becomes less pressing. A decline in marginal propensity to save generates inflationary pressures because households become more willing to spend rather than save any additional income that they receive.

State dependence is achieved by introducing endogenous fluctuations in risk aversion that are countercyclical, as the empirical evidence suggests (e.g., Gordon and Saint-Amour 2000, 2004). Habit formation implies that households are unwilling to lower consumption beyond a time-varying subsistence level. When consumption is close to this subsistence level, which is the case during recessions, risk aversion rises and uncertainty about the future has a greater impact on economic choices.

The smaller impact on inflation of monetary policy during recessions follows from the effect of risk aversion on agents' precautionary saving motives. In recessions, the decline in marginal propensity to save induced by a liquidity injection is dampened by a precautionary effect. This precautionary effect stems from the impact of future expected shocks on the valuation and can be explained by the nonlinear relationship between marginal utility and consumption present in models with habits. When consumption is close to the subsistence level, a negative shock that further reduces consumption generates a decline in marginal utility that is particularly large. As a result, the expected volatility of marginal utility increases during recessions when consumption is low and already close to this subsistence level. This effect in turn implies that households are more inclined to build precautionary buffers in recessions. The resulting precautionary saving motive reduces the decline in marginal propensity to save induced by expansionary monetary policy shocks, thereby leading to inflationary pressures that are more subdued in recessions than in booms.

In this environment, the amount of credit that can be allocated to financially constrained firms depends on the real quantity of money available in the economy. After a positive liquidity injection, an increase in inflation reduces the real stock of money balances. The more muted response of inflation in recessions in turn implies that, in real terms, a relatively larger quantity of funds is available for lending. As a result, this more muted response of inflation to monetary policy generates larger credit expansions in recessions than in booms. This larger credit expansion in turn implies that expansionary money supply shocks exert a larger effect on output in a recession than in a boom.

In the euro zone, some of the most aggressive monetary policy measures introduced by the ECB, such as the two three year long-term refinancing operations, were implemented at the end of 2011 and beginning of 2012.[1] As shown in Figure 1, as a result of the double dip recession experienced by the euro area economy, this period was marked by an unprecedented decline in aggregate consumption. In a model in which utility depends on the difference between consumption and a time-varying subsistence level, a large and persistent decline in consumption relative to trend generates an increase in risk aversion. This point is illustrated in Figure 2, which reports a standard measure of risk aversion that depends on the difference between aggregate consumption and a slow moving reference

[1] These two operations provided €489.2 billion to 523 credit institutions and €529.5 billion to 800 credit institutions, respectively (e.g., ECB 2012).

level.[2]

This illustrates that some of the most aggressive monetary policy measures were implemented during a period of exceptionally high risk aversion. One main prediction of the mechanism studied in this paper is that the unprecedented level of risk aversion observed during this period should have affected the transmission of the liquidity injections implemented by the ECB, by attenuating the positive effect of these measures on inflation. This model implication is consistent with the lower than expected inflationary pressures observed in the euro area between 2012 and mid-2016, and which occurred in spite of the unprecedented monetary policy measures deployed at the end of 2011.[3]

Finally, whereas these results rely on the time-variation in risk aversion induced by habits, this mechanism generates a relatively small welfare cost of business cycle fluctuations. Relative to a world without shocks, consumption is only 0.5% higher in the economy subject to business cycle fluctuations. The welfare cost of business cycle fluctuations provides an indirect measure of risk aversion (e.g., Tallarini 2000, van Binsbergen et al. 2012) and the low cost that I obtain confirms that in this environment a moderate degree of curvature is necessary to generate a 1% term premium on long-term bonds.

Literature Estimating the effects of monetary policy shocks in booms and recessions is a challenging task and, at the current juncture, a consensus still has not emerged. The stronger effect of monetary policy on quantities that I obtain with this mechanism is for instance consistent with the empirical findings documented by Peersman and Smets (2001, 2005) who use euro zone data but at variance with the results reported by Tenreyro and Thwaites (2016) who use U.S. data. In contrast, the more muted response of inflation to monetary policy shocks during recessions that I obtain with this model is consistent with the findings of Tenreyro and Thwaites.

The empirical facts documented by Santoro et al. (2014) also suggest that monetary policy has a stronger effect on output during recessions and they rationalize their empirical findings by combining loss aversion with nominal rigidities. Relative to this latter study, the key difference is that in my case the effects of money supply shocks on inflation are

[2] Risk aversion is computed using the following utility function:

$$u_t = \frac{(c_t - x_t)^{1-\sigma}}{1-\sigma}$$

where:

$$\gamma x_{t+1} = m x_t + (1-m) c_t$$

[3] Between 2012 and mid-2016, euro zone inflation remained lower than the forecasts produced by the Eurosystem and by other institutions (e.g., Ciccarelli and Osbat 2017).

about twice larger during booms than during recessions, whereas their mechanism implies a response of inflation that is nearly symmetric. Moreover, the fluctuations in stochastic discounting that I obtain are sufficient to generate a term premium of 1%. Reproducing a term premium of this magnitude is a challenge for DSGE models, especially in models with habits (e.g., Rudebusch and Swanson 2008, 2012).

Using a novel empirical approach, Barnichon and Matthes (2018) find that negative monetary policy shocks have a stronger impact on unemployment than positive ones. The model mechanism that I study generates asymmetries in the transmission of money supply shocks that are consistent with their results. As I show in section 6, negative money supply shocks have stronger real effects than expansionary ones. As in Barnichon and Matthes (2018), the response of inflation to money supply shocks is also asymmetric but in the opposite direction.

Early attempts aimed at replicating asset market facts in models with production have concluded that simply adding habit persistence has little effect on bond prices (e.g., Den Haan 1995) or more generally that models with habits cannot jointly explain financial market and business cycle facts (e.g., Lettau and Uhlig 2000). More recent attempts have shown that the puzzle persists even when slow moving habits are combined with labor market frictions (e.g., Rudebusch and Swanson 2008). Relative to this strand of literature, this paper studies the transmission of money supply shocks in an environment where the introduction of habits in the composite of consumption and leisure helps to overcome these difficulties (e.g., Jaccard 2014). This novel specification helps to increase risk premia in a version of the Jermann (1998) model in which labor supply is endogenously determined. It would be possible to generate the state dependence of inflation to monetary policy shocks in the fixed labor model. Fluctuations in hours worked are however necessary to generate significant monetary non-neutralities. As I show in section 5, without a labor wedge, monetary policy is almost neutral in this flexible price environment.

Studies on the implications of habit formation for the transmission of monetary policy include the work by Fuhrer (2000) and Bouakez et al. (2005). Relative to this literature, I study the higher-order terms in the Taylor expansion to assess whether monetary policy transmission is affected by the state of the economy, using the techniques developed by Adjemian et al. (2014) and Andreasen et al. (2017). Resorting to higher-order approximations allows me to capture the nonlinearity present in models in which utility depends on a time-varying subsistence level.

As in Constantinides (1990), Abel (1990) and Campbell and Cochrane (1999), the time-variation in risk aversion obtained with habit formation is the key source of nonlinearity that affects intertemporal choices. Recent contributions that build on this strand of literature include the work by Bekaert and Engstrom (2017) and Campbell et al. (2015). Relative to these studies, I study how the nonlinearity induced by habit persistence affects the transmission of money supply shocks in a model with endogenous capital accumulation. The introduction of a labor margin also alters households' attitudes towards risk and has a substantial impact on how risk aversion should be measured (e.g., Swanson 2012).

Coibion and Gorodnichenko (2015) have shown that introducing household inflation expectations into New Keynesian models and deviations from the full-information rational expectation assumption reconciles the Phillips curve with the data (see also Coibon et al. 2017). Relative to these studies and to the New Keynesian literature in general (e.g., Woodford 2003, Galí 2015), the main difference is that I study the transmission of money supply shocks and inflation in a model that abstracts from nominal rigidities. As pointed out by Wei (2009), the time-variation in marginal costs induced by price stickiness dampens the effects of technology shocks. This effect acts as a shock absorber and reduces the equity premium generated by standard New Keynesian models. Since supply shocks are a main source of risk in nominal bond pricing (e.g., Piazzesi and Schneider 2007), abstracting from price stickiness makes it easier to generate a term premium of a realistic magnitude. As shown by Dew-Becker (2014), including bond prices in the estimation of a New Keynesian model also decreases the contribution of investment specific technology shocks to business cycle fluctuations.

As in Gomes, Jermann and Schmid (2016), I find that it is possible to obtain non-trivial monetary non-neutralities even when prices are fully flexible (see also De Fiore et al. 2011). Whereas their study emphasizes long-term nominal debt, I focus on the role of credit conditions in transmitting the effects of monetary policy shocks. Relative to Fuerst (1992) or Christiano and Eichenbaum (1992) who rely on a similar approach to generate non-neutralities, the effects of monetary policy on output that I obtain are more persistent. Significant monetary non-neutralities are also obtained in the neoclassical model developed by Cooley and Quadrini (1999). By combining search frictions with limited participation, their model can be used to study the effects of monetary policy on the link between unemployment and inflation.

Following van den Heuvel (2008, 2016), this demand for financing is satisfied by a banking sector that intermediates funds between households and firms in the non-financial corporate sector (see also Goodfriend and McCallum 2007; Gertler and Karadi 2011; Boissay et al. 2016; Quadrini 2016). In Brunnermeier and Koby (2018), the transmission of monetary policy is nonlinear and depends on the tightness of liquidity constraints. Relative to this latter study and to Boccola (2016), I study an economy in which time-varying risk aversion rather than occasionally binding financial constraints is the main source of nonlinearity.

The implications of stochastic discounting are illustrated by studying the effects of money supply shocks in a flexible price model in which the cost channel is the main source of non-neutrality. The cost channel and associated notion that monetary policy could be transmitted through aggregate supply has a long tradition in macroeconomics. If short-term rates affect production costs, changes in nominal rates and credit conditions could affect firms' ability to supply goods and services. The empirical findings reported by Barth and Ramey (2002), Dedola and Lippi (2005), Gaiotti and Secchi (2006), and Ravenna and Walsh (2006) among others, suggest that the cost channel of monetary policy is sufficiently large to have non-negligible monetary policy implications. In the present study, a cost channel of monetary policy is obtained by introducing financial frictions into the analysis.

I motivate the introduction of money demand and money supply shocks by the role played by balance sheet policies in the post-crisis era. The generation of macroeconomic models developed before the crisis generally abstracts from the role of money demand and monetary aggregates are not explicitly modelled. Moreover, the effects of unconventional monetary policy are often studied in the context of cashless economies (e.g., Curdia and Woodford 2009; Woodford 2012).

There is also an influential literature on the effects of government intervention and in particular of asset purchases and credit subsidies but monetary aggregates play no role in these models (e.g., Gertler and Karadi 2011, 2013; De Fiore et al. 2016; Del Negro et. al. 2017). In Piazzesi and Schneider (2017), uncertainty affects inflation by changing investors' demand for money. In their environment, non-standard policy measures can increase the price level and thus counteract the deflationary effect induced by an increase in uncertainty.

A large body of literature has demonstrated that introducing non-linearities in DSGE models is necessary in order to match asset pricing facts within this class of models (e.g., Jermann 1998; Tallarini 2000; Boldrin, Christiano, and Fisher 2001; Campanale et al. 2010; Gourio 2012, 2013; van Binsbergen et al. 2012; Croce 2014; Swanson 2016; Jaccard 2018). The main innovation is that I study how the nonlinearities introduced in this literature affect the transmission of monetary policy shocks.[4]

In the present study, the model is calibrated using euro zone data to ensure that a realistic term premium can be reproduced. The volatility of inflation and of the short-term

[4]In Amisano and Tristani (2017), the state-dependence of monetary policy is caused by switches in regimes in the variance of shocks.

nominal risk-free rate can be replicated and it is also possible to match average inflation as well as the mean short-term real rate. But one quantitative limitation of the analysis is that I will not try to match the equity premium or the volatility of stock returns.

2 The Environment

The model is composed of a non-financial or corporate sector, a commercial banking sector, a Central Bank, a household sector and a government. A role for external financing is introduced by assuming that firms in the non-financial sector need to pay workers and capital owners in advance of production and have to pledge liquidity to gain access to the rental market for physical capital.

Households

The representative agent owns the economy's stock of capital and derives utility from consuming a consumption good and from cash holdings. All variables are detrended and the deterministic growth rate along which the economy is growing is denoted by γ (e.g., King and Rebelo 1999). The period t budget constraint of the representative agent is given as follows:

$$prof_{Tt} + tr_{Gt} + r_{Kt}k_{t-1} + w_t N_t + \frac{\mu_t m_{t-1}}{1+\pi_t} + i_{Dt}d_t + \frac{b_{t-1}}{1+\pi_t} = c_t + x_t + \gamma m_t + \frac{1}{1+i_{Bt}}\gamma b_t \quad (1)$$

On the revenue side, households receive a capital income from working and renting the economy's capital stock to the corporate sector. The representative agent owns all the sectors of the economy and receives a dividend income paid by the financial and non-financial sectors as well as a transfer from the government.

The total income received from the different sectors of the economy is denoted by $prof_T$ and the lump sum transfer received from the government is denoted by tr_G. Households own the economy's capital stock and rent it to the non-financial corporate sector. The capital stock is denoted by k and r_K is the rental rate of capital. Labor supply is endogenously determined and households divide their total time endowment, which I normalize to 1, between hours worked in the corporate sector and leisure:

$$L_t + N_t = 1 \quad (2)$$

where leisure and hours worked are denoted by L and N, respectively, and where w is the wage rate. The real stock of money balances carried from the previous period is denoted $\frac{\mu m}{1+\pi}$. Households allocate a fraction of their real stock of money balances to the banking sector and keep the remaining fraction at home. The fraction of real money balances that is kept at home is given by the difference between the total stock of money and the amount that households choose to deposit in the banking sector:

$$s_t = \frac{\mu_t m_{t-1}}{1+\pi_t} - d_t \tag{3}$$

The fraction of real money balances allocated to the banking sector takes the form of a within period deposit and the deposit rate at which real money balances are remunerated by banks is denoted by i_D. s represents the fraction of real balances that is kept liquid and that households can access at any time to purchase consumption goods for instance. By contrast, the amount deposited in the banking sector, which is denoted by d, is illiquid in the sense that it cannot be used for transaction purposes within the period.

Relative to a standard New Keynesian model (e.g., Smets and Wouters 2007), a main difference is that as in Lucas (1972) or Bénassy (2005) the exogenous monetary policy disturbance takes the form of a shock to the quantity of money carried from the previous period and does not affect the monetary policy rule directly. Given that the monetary policy shock affects the quantity of real money balances in circulation and hence the balance sheet of the Central Bank, I interpret μ_t as a non-standard monetary policy shock. The non-standard monetary policy shock μ follows an autoregressive process of order one,

$$\log \mu_t = \rho_\mu \log \mu_{t-1} + \varepsilon_{\mu t}$$

where the random disturbance ε_μ is normally distributed with mean zero and standard deviation σ_μ. Households also invest in a short-term risk-free bond issued by the government. The real payoff received by households depends on inflation and is given by the coupon payment deflated by inflation $b/(1+\pi)$.

On the expenditure side, consumption and investment are denoted by c and x, respectively. Real money balances that will be carried into period $t+1$ are denoted γm, whereas γb is the stock of government bonds held by households at the end of the period and that will be carried into the next one. The price at which this short-term risk-free bond is purchased is denoted by $\frac{1}{1+i_{Bt}}$. The rate of return of the nominal risk-free bond i_B is controlled by the Central Bank.

Capital accumulation is subject to adjustment costs, and following Jermann (1998) and Baxter and Crucini (1993) among others, I use the following specification:

$$\gamma k_t = (1-\delta)k_{t-1} + \left(\frac{\theta_1}{1-\epsilon}\left(\frac{x_t}{k_{t-1}}\right)^{1-\epsilon} + \theta_2\right) k_{t-1} \tag{4}$$

where ϵ measures the degree of adjustment cost and can be interpreted as the elasticity of Tobin's Q to changes in the investment to capital ratio. The parameters θ_1 and θ_2 are chosen to ensure that the model with and without adjustment costs have the same deterministic steady state.

Habits are formed over the composite good consisting of the different components of utility (e.g., Jaccard 2014). The composite good not only depends on consumption and leisure but also on the fraction of real money balances that agents use for transaction purposes. This implies the following law of motion for the habit stock, which is denoted by h :

$$\gamma h_t = \tau h_{t-1} + (1-\tau)c_t^{\kappa} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) \tag{5}$$

where τ is a memory parameter that affects the rate at which the habit stock depreciates over time. The weight of consumption in the utility function is denoted by the parameter κ. The objective of the representative agent is to maximize lifetime utility, which is given as follows:

$$\max_{c_t,b_t,s_t,N_t,h_t,k_t,x_t,m_t} E_0 \sum_{t=0}^{\infty} \widehat{\beta}^t \frac{\left(c_t^{\kappa} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) - h_{t-1}\right)^{1-\sigma}}{1-\sigma}$$

subject to constraints (1) to (5). 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 $\widehat{\beta}$, where $\widehat{\beta} = \widetilde{\beta}\gamma^{1-\sigma}$.

The non-financial or corporate sector

The final output good produced by the corporate sector is denoted by y and the production function takes a standard Cobb-Douglas form:

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

where k is the stock of capital that firms rent from the representative agent and where r_K is the rental rate of capital. 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 ε_A is normally distributed with mean zero and standard deviation σ_A. The autoregressive parameter is denoted by ρ_A, where $0 \leq \rho_A \leq 1$.

A cost channel of monetary policy is introduced by assuming that firms need to obtain credit in order to operate. The loan is intratemporal in the sense that it is received at the beginning of the period and needs to be reimbursed with an interest payment before the end of period t. The amount of bank-based financing received at the beginning of the period is denoted by l and i_L is the interest rate that is paid to bankers.

Firms in the non-financial sector produce a composite output good using labor and capital as production inputs. Relative to the neoclassical growth model, the difference is that managers also have to choose the optimal financing structure that maximizes the value of the firm. Profits at time t, which are denoted by $prof_F$, are given as follows:

$$prof_{Ft} = y_t - r_{Kt}k_{t-1} - w_t N_t - i_{Lt} l_t \tag{7}$$

The amount of external financing needed at the beginning of period t is determined by the following liquidity constraint:

$$l_t \geq w_t N_t + r_{Kt}k_{t-1} + \eta k_{t-1} \tag{8}$$

On the left handside, l denotes the within-period loan obtained from the banking sector. Liquidity is firstly needed to pay workers and capital owners in advance, the cost of which is given by $wN + rk$. The second main role of liquidity is to alleviate the information asymmetry problem in the rental market for physical capital. Firms need physical capital to operate their technology. The standard assumption is that firms are able to rent the capital stock from the representative agent at the beginning of the period and can return it before the period ends. Lending relationships are subject to agency problems and it is unlikely that households will agree to lend their entire stock of capital, which represents their total wealth, without asking for some form of guarantee. To address this issue, I assume that firms need to pledge liquidity to secure the transaction. The required amount of liquidity that needs to be pledged is proportional to the economy's capital stock and is determined by the last term ηk, where η is a measure of credit market imperfections. The higher η, the larger the amount of liquidity that needs to be pledged in order to access the rental market for capital. This parameter can therefore be interpreted as a measure of the ease at which contracts can be enforced, which formalizes the notion that a higher amount of liquid wealth needs be to pledged in economies where contracts are more difficult to enforce.[5]

The objective of managers in the corporate sector is to maximize the value of the firm, which is given by the infinite discounted sum of future profits :

$$\max_{N_t, k_{t-1}, l_t} \quad E_0 \sum_{t=0}^{\infty} \widehat{\beta}^t \frac{\lambda_t}{\lambda_0} prof_{Ft}$$

where $\widehat{\beta}^t \lambda_t / \lambda_0$ is the stochastic discount factor of the representative agent who owns firms in the non-financial sector, subject to equations (6), (7) and (8).

The Central Bank

The Central Bank provides money to the private sector and sets the short-term risk-free rate. Any profit or loss made by the Central Bank, which is denoted by tr_{CB}, is directly transferred to the government. The receipts from the Central Bank are denoted by tr_{CB} and this transfer is financed by issuing real money balances. In period t, this implies the following budget constraint:

$$tr_{CBt} = \gamma m_t - \mu_t \frac{m_{t-1}}{1 + \pi_t} \tag{9}$$

Since nowadays Central Banks use the short-term nominal interest rate as their main policy instrument, the Central Bank sets the nominal interest rate by following an interest rule. The nominal interest rate only responds to deviations from the Central Bank inflation's target, which is denoted by π^* :

$$i_{Bt} = \overline{i_B} + \phi_\pi (\pi_t - \pi^*) \tag{10}$$

where $\overline{i_B}$ denotes the steady state level of the nominal interest rate, which is the rate set by the Central Bank when inflation is exactly on target. The parameter ϕ_π measures the sensitivity of the nominal interest rate to deviations from the inflation target.

The commercial banking sector

Following van den Heuvel (2008, 2016), the commercial banking sector intermediates funds between households and the non-financial sector. Banks collect deposits at the beginning of the period, which are then lent to the corporate sector. I simplify the analysis by assuming that the lending and deposit decisions occur within the period.

As in Goodfriend and McCallum (2007), I assume that banks are endowed with a technology that can be used to produce credit using deposits as an input. The production

[5] The sensitivity of the results to this parameter is studied in section 5.

function is given by a linear technology that links the quantity of loans extended to the non-financial sector to the quantity of deposits raised at the beginning of the period:

$$l_t = d_t \tag{11}$$

Each period bankers optimally choose the amount of deposits to collect from households d and the quantity of credit to extend to firms l to maximize profits, which are given as follows:

$$\max_{l_t, d_t} \; prof_{Bt} = i_{Lt} l_t - i_{Dt} d_t - \chi l_t$$

subject to constraint (11). The cost of producing loans, which I denote by the parameter χ, determines the magnitude of the financial intermediation spread.

The government

Since the government does not play any role in this environment, I simplify the analysis by assuming that the lump sum transfer made by the government to the representative agent is financed by issuing a short-term risk free bond and by the receipts from the Central Bank. The transfer made to households is denoted by tr_G. In period t, the budget constraint of the government is given as follows:

$$tr_{Gt} = tr_{CBt} + \frac{1}{1 + i_{BT}} \gamma b_t - \frac{b_{t-1}}{1 + \pi_t}$$

Market clearing condition

The aggregate budget constraint can be derived by combining the budget constraint of the different agents. The representative agent owns the different sectors of the economy and the total income received from the different sectors is given by $prof_{Tt} = prof_{Ft} + prof_{Bt}$. Any loss or profit made by the Central Bank is transferred to the government. Since the government in turns makes a lump sum transfer to the representative agent, the economy's consolidated budget constraint is given as follows:

$$y_t = c_t + x_t \tag{12}$$

Equilibrium definition

A competitive equilibrium in the economy is a sequence of prices:

$$\varpi, q, \lambda, \varphi, w, r_K, i_D, i_L, i_B, \pi$$

where ϖ denotes the Lagrange multipliers associated with the loan-in-advance constraint, q is Tobin's Q, λ is marginal utility, φ is the Lagrange multiplier associated with the law of motion of the habit stock, and quantities:

$$l, y, c, x, d, N, k, h, s, m$$

that satisfy households and firms efficiency conditions as well as the resource constraint (12) for all states, for t=1...∞, and given initial values for the three endogenous state variables k, h and m.

Risk-free nominal rate

Optimality conditions in the household sector imply the following Euler condition that relates the price of purchasing a risk-free nominal government bond to its expected payoff:

$$\frac{1}{1+i_{Bt}} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{1+\pi_{t+1}} \tag{13}$$

where $\frac{1}{1+i_B}$ is the price of the short-term bond, and where $\beta E_t \frac{\lambda_{t+1}}{\lambda_t}$ is the stochastic discount factor used to evaluate future payoffs.[6] The expected payoff from holding a one period risk-free bond that pays a coupon equal to unity depends on expected inflation, *i.e.* $1/(1+\pi)$. The rate of return of the nominal risk-free bond i_B is controlled by the Central Bank and is the standard monetary policy instrument.

The pass-through of non-standard monetary policy shocks to lending rates

The household optimality conditions can be analyzed to gain intuition into how non-standard monetary policy shocks are transmitted to the real economy. Using the fact that $s_t = \frac{\mu_t m_{t-1}}{1+\pi_t} - d_t$, combining the optimality condition with respect to m with the optimal choice of credit in the banking sector yields the following Euler condition:

$$1 = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{1+\pi_{t+1}} \mu_{t+1} (1 + i_{Dt+1}) \tag{14}$$

where $(1+i_D)/(1+\pi)$ is the return, expressed in real terms, from lending the economy's stock of money balances to the banking sector. The non-standard monetary policy shock μ can therefore be interpreted as a risk premium shock in the sense that it drives a wedge between the expected return of the asset and the risk-free nominal rate controlled by the Central Bank, *i.e.* $E(i_D - i_B)$.

[6] To economize on notation, I define $\beta = \widetilde{\beta}\gamma^{-\sigma}$.

To illustrate how a non-standard monetary policy shock affects the spread between bank deposit rates and the risk-free rate, I log-linearize equations (13) and (14) around the deterministic steady state of the model. After a few manipulations, the spread can be expressed as follows:

$$E_t\widehat{i}_{Dt+1} - \widehat{i}_{Bt} = -\frac{1+i_B}{i_B}E_t\widehat{\mu}_{t+1}$$

This expression illustrates that non-standard monetary policy shocks work primarily through their effect on the spread between deposit and policy rates. The final effect on lending rates i_L then depends on the magnitude of the financial intermediation spread. Profit maximization in the banking sector implies the following relation between i_D and i_L :

$$i_{Lt} = i_{Dt} + \chi \tag{15}$$

where χ denotes the fixed cost of producing loans.

Pricing of long-term bonds

The stochastic discount factor of the representative agent can be used to derive an asset pricing equation that characterizes the dynamics of risk-free long-term bonds. The price of a perpetual bond with infinite maturity that pays a constant coupon, which is normalized to 1, is given by the following textbook formula:

$$p_{Bt}^{LT} = \beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}\left(1+\varrho p_{Bt+1}^{LT}\right)$$

where ϱ is the rate of decay of the asset. The realized return in period t is defined as follows:

$$r_{Bt}^{LT} = \frac{1+\varrho p_{Bt}^{LT}}{p_{Bt-1}^{LT}}$$

The average yield to maturity of this perpetual bond can be computed by solving the following equation:

$$p_{Bt}^{LT} = \sum_{k=1}^{\infty}\frac{\delta_C^{k-1}}{(1+yield_t)^k}$$

Given the simplifying assumption of an infinite maturity, the yield is given by the inverse of the price of the long-term bond and also depends on the longevity of the asset:

$$yield_t = \frac{1}{p_{Bt}^{LT}} + \varrho - 1$$

Term premium

To compute the corresponding term premium, we first need to derive the price of this long-term bond under the assumption that investors are risk neutral. Denoting the risk neutral price $\widetilde{p}_{Bt}^{LT}$, this price can be obtained by replacing the stochastic discount factor of the agent by the risk-free nominal rate:

$$\widetilde{p}_{Bt}^{LT} = \frac{1}{1+i_{Bt}} E_t \left(1 + \varrho \widetilde{p}_{Bt+1}^{LT}\right)$$

The yield to maturity under risk neutral probabilities $yield_{RNt}$ is then given by the inverse of the risk neutral price:

$$yield_{RNt} = \frac{1}{\widetilde{p}_{Bt}^{LT}} + \varrho - 1$$

Up to a first-order approximation or in the deterministic version of the model, the two definitions for $\widetilde{p}_{Bt}^{LT}$ and p_t^{LT} are equivalent since certainty equivalent holds in these two cases. However, once the model is solved using higher-order approximations, the effect of uncertainty on the valuation drives a wedge between the two concepts, because risk averse investors will require a compensation for holding an asset whose price declines during recessions. In a model in which risk and stochastic discounting both matter, the price of a long-term bond computed under the assumption of risk neutrality is therefore higher than the price obtained using the stochastic discount factor of a risk averse agent. Since risk adjustments reduce asset prices, risk aversion increases the yield of a long-term bond. The average term premium $E(tp_t)$ can then be computed as follows:

$$E(tp_t) = E(yield_t) - E(yield_{RNt})$$

and provides a measure of the effect of risk adjustments on bond yields.

Real risk-free rate

The real risk-free rate can be derived by pricing an inflation index bonds whose coupon is independent of inflation. Using the stochastic discount factor of the agent, the real risk-free rate i_{Rt} is given as follows:

$$\frac{1}{1+i_{Rt}} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}$$

Similarly, long-term real risk-free interest rates can be derived by pricing an inflation-indexed security that is purchased today and that delivers one unit of consumption in k periods:

$$\frac{1}{1+i_{Rt}^{k}} = \beta^{k} E_{t+k} \frac{\lambda_{t+k}}{\lambda_{t}}$$

Inflation and asset pricing

It is easy to show that in this model the dynamics of inflation is determined by the agent's stochastic discount factor. To illustrate this point, I start by substituting the interest rule (10) into the Euler equation that links the Central Bank's policy rate to expected inflation:

$$\frac{1}{1+\overline{i_B}+\phi_{\pi}(\pi_t-\pi^{*})} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}$$

After linearizing this expression around the model's deterministic steady state, I obtain the following expression:

$$\widehat{\pi}_t = \frac{1}{\beta\phi_{\pi}} E_t \widehat{\pi}_{t+1} - \frac{1+\pi^{*}}{\pi^{*}}\frac{1}{\beta\phi_{\pi}}\widehat{sdf}_{t,t+1} \tag{16}$$

which links current and expected inflation to the agent's stochastic discount factor, and where $\widehat{\pi}$ denotes the inflation rate expressed in deviation from the Central Bank's target π^{*}. In period t, the stochastic discount factors is given by the difference between expected and current marginal utility:

$$\widehat{sdf}_{t,t+1} = E_t\widehat{\lambda}_{t+1} - \widehat{\lambda}_t$$

Abstracting from the effects of higher-order terms, an increase in stochastic discounting generates deflationary pressures. Intuitively, a higher discount factor reflects a desire to purchase assets that can be used to transfer wealth across time. An increase in stochastic discounting therefore reduces inflation because it reflects a higher preference for future relative to current consumption. Inflation, which is the price of consumption today, therefore declines when the stochastic discount factor rises. As in a standard New Keynesian model, the Taylor principle applies and indeterminacy is avoided for values of ϕ_{π} that are larger than $1/\beta$ (e.g., Gertler et al. 1999).

Is the loan-in-advance constraint always binding?

In this model, if present, the loan-in-advance constraint is always strictly binding. Optimality in the non-financial sector implies that the Lagrange multiplier associated to the loan-in-advance constraint (8), which is denoted by ϖ, is proportional to the bank lending rate i_L :

$$i_{Lt} = \frac{\varpi_t}{\lambda_t}$$

Given that profit maximization in the banking sector implies that:

$$i_{Lt} = i_{Dt} + \chi$$

and given that the fixed cost of production χ is always strictly positive, the Lagrange multiplier ϖ is always strictly positive as long as $i_{Dt} \geq 0$.

The optimal allocation of real money holdings between transaction services and deposit implies the following optimality condition:

$$i_{Dt} = \frac{1-\kappa}{\kappa}\frac{c_t}{s_t}$$

The case $c < 0$ or $s < 0$ is never observed in this model. The fact that the components of utility are always strictly positive ensures that the case $i_D < 0$ never occurs in equilibrium. A strictly positive deposit rate in turn implies that i_L and thus ϖ are always strictly positive. If present, the loan-in-advance constraint therefore always binds.

3 Parameter selection and results

As illustrated by Figure 3 in the appendix, the spread between bank lending rates for small loans and the 3 month risk-free rate, as measured by the yield on a 3 month French government bond, increased dramatically during the subprime and sovereign debt crisis episodes. The persistent decline that has been observed since the end of 2011 coincides with the introduction of an important structural change in the conduct of non-standard monetary policy. This second phase saw the introduction of two three year long-term refinancing operations that were implemented in December 2011 and February 2012. These two operations provided €489.2 billion to 523 credit institutions and €529.5 billion to 800 credit institutions, respectively (e.g., ECB 2012).[7]

[7]These measures were followed by the introduction of targeted longer-term refinancing operations in June 2014, which led to an injection of €739 billion, and the ECB's Expanded Asset Purchase Programme or quantitative easing which was launched in January 2015.

Relative to the measures implemented before 2012, the key difference is that during this second phase the horizon of the ECB's refinancing operations increased to 3 years. Given the structural changes in non-standard monetary policy observed at the end of 2011, I choose to calibrate the model using pre-2012 data only.[8] The model main parameters are selected by minimizing the distance between a set of empirical moments and their corresponding model counterparts. Since this sample includes the crisis and corresponds to the phase in which less aggressive non-standard measures where implemented, the model is calibrated using both real and non-standard monetary policy shocks as the main sources of exogenous disturbances. For the sake of parsimony, I also assume that the technology shock is the only source of real disturbances. Using the parameter values obtained by estimating the model with pre-2012 data, I then simulate the effects of a non-standard monetary policy shock on the economy.

Deterministic growth rate, capital share and labor supply

This first set of parameters has a limited impact on the model dynamics and is set to values that are considered standard in the literature. The quarterly deterministic growth rate at which the economy is growing along the balanced growth path γ is set to 1.005, which implies an average annual rate of two percent. As shown by Constantinides (1990) and Boldrin, Christiano and Fisher (2001), with habits, the coefficient of relative risk aversion is independent of the habit parameter and mainly depends on the curvature coefficient σ.

When σ is set to 1, this preference specification reduces to the log utility case when the habit parameter τ is set to 1. Utility becomes separable when the habit formation block is switched off by setting τ to 1 and, as I discuss below, in this special case the cost channel is the only source of monetary non-neutrality in this economy. The advantage of setting σ to 1 is therefore that it will allow us to distinguish the cost channel of monetary policy from the non-neutralities arising from the non-separability in the utility function. The effect of the cost channel will be captured by the tightness of the loan-in-advance constraint and the contribution of the non-separability will only depend on the habit formation parameter τ.

The capital share in the production function α is set to 1/3. The first labor supply parameter ψ is calibrated to ensure that in the steady state, agents spend about 20 percent of their time on work related activities, which corresponds to a value for N of 0.2. The curvature parameter υ is chosen to imply a value for the Frisch elasticity of labor supply of about 1, which is a value that is considered standard in the literature (e.g., Hall 2009; Chetty et al. 2011).

[8] Other major changes in the composition of the ECB's executive Board, which include the appointment of a new President, were observed in 2011.

Persistence of non-standard monetary policy shock and McCaulay duration

Available estimates of non-standard monetary policy shocks suggest that exogenous innovation to the Central Bank's balance sheet are typically short-lived (e.g., Boeckx et al. 2017; Gambacorta et al. 2014). This result could be explained by the fact that some of the main non-standard measures introduced before 2011 typically had a short maturity. While these measures were expected to be rolled over, the short maturity of these operations could explain the lack of persistence uncovered in the empirical literature. Given that in the model it is difficult to distinguish the effect of the shock standard deviation σ_μ from that of the persistence parameter ρ_μ, I use this a priori knowledge to fix the persistence parameter to 0.5. This implies that the non-standard monetary policy shock has an initial impact on the economy that completely disappears after 8 quarters.

The rate of decay of the long-term bonds is determined by the parameter ϱ. If ϱ is set to 0, the asset reduces to a one period risk-free security. Setting this parameter to 0.9865 implies a McCaulay duration of about 10 years (e.g., Rudebusch and Swanson 2012).

Matching moment procedure

The remaining 12 parameters are calibrated to match a set of 12 moments that characterize the eurozone business cycle. Since with uncertainty higher-order terms in the Taylor expansion drive a wedge between the deterministic and the stochastic version of the model, it is necessary to simulate the model and find the combination of parameter values that minimizes the distance between the estimated and simulated moments. Table 1 below reports the combination of parameter values that allows the model to replicate the set of moments that are targeted and the comparison between the model and the data is shown in Table 2 in the appendix.

Table 1: Moment Matching Procedure, Structural Parameters

β	κ	η	χ	π^*	ϕ_π	δ	τ	ϵ	σ_A	ρ_A	σ_μ
0.998	0.997	0.02	0.0050	0.006	4.3	0.0035	0.60	2.1	0.007	0.978	0.0285

Relation between structural parameters and model implied first and second-order moments

It is difficult to associate each structural parameter with only one moment as most parameters have a significant impact on the entire system through general equilibrium effects. Some parameters do however have larger effects on a subset of model implications.

This subsection discusses the main channels through which each parameter affects the set of moments reported in Table 2.

As illustrated by the variance decomposition shown in Table 3, technology shocks are the main drivers of business cycle aggregates and account for nearly 90 percent of the variance of output. The technology shock standard deviation parameter σ_A can therefore be associated to the volatility of output and business cycle aggregates in general. The last column of Table 3 illustrates that fluctuations in m are mostly driven by the monetary policy shock, which suggests that the monetary policy shock standard deviation σ_μ can be associated to the standard deviation of the Central Bank's balance sheet.

The magnitude of the intermediation spread $E(i_L - i_D)$ is pinned down by the fixed cost of producing loans χ. The preference parameter κ determines the weight of real money balances used for transaction in the utility function. The volatility of deposits is therefore particularly sensitive to this parameter value. The parameter η measures the quantity of liquid wealth that firms need to pledge in order to borrow the household capital stock. This parameter mainly affects the steady state importance of bank-based financing in the economy and pins down the loan to output ratio $E(l/y)$.

The subjective discount factor β affects the volatility of consumption and investment. Since it affects the extent to which technology shocks are perceived as permanent, the technology shock persistence parameter also modifies the agent's consumption and saving decision. This decision also depends on the value of the habit formation parameter, which measures the elasticity of intertemporal substitution. The capital adjustment cost parameter ϵ has a crucial impact on the volatility of investment and affects the ease at which the economy's storage technology can be used to achieve consumption smoothing. By modifying the consumption and saving decision, β, ρ_A, τ and ϵ have a predominant impact on the volatility of consumption and investment. Since these two parameters also affect agents' propensity to save, they are important determinants of asset prices and can therefore also be associated to the risk-free rate volatility and to the term premium on long-term bonds.

The parameter π^* is the inflation rate that the Central Bank targets and this parameter has a direct effect on the average inflation rate. The inflation coefficient in the interest rule ϕ_π has a first-order impact on the volatility of inflation.

4 Results

As illustrated in Table 2, the main distinguishing feature of this model is its ability to generate a 1% term premium on long-term bonds. In the data, the estimated term premium is taken from Hördahl and Tristani (2014) and corresponds to a safe nominal bond denominated in euros with a 10 year maturity. Generating a term premium of this magnitude is a challenge for standard models (e.g., Rudebusch and Swanson 2008, 2012). Without habits, the predicted term premium declines from 1% to 0.01%. Introducing fluctuations in stochastic discount factors are therefore necessary to generate a plausible term premium. The model slightly overpredicts the volatility of the short-term nominal risk-free rate but the theoretical moment still lies within the 95% confidence interval.

Relative to a real business cycle model (e.g., King and Rebelo 1999), household deposits and the money stock are the main variables that have been introduced. As illustrated by the variance decomposition reported in Table 3, fluctuations in monetary aggregates are mainly driven by the nominal disturbance. This illustrates that it would not be possible to reproduce these two moments without money supply shocks.

In spite of its simplicity, the model is able to also reproduce the dynamics of inflation. The mean and standard deviation predicted by the model are close to their empirical counterparts. It is also possible to generate a positive correlation between inflation and output. As shown below, the correlation predicted by the model lies within the 95% confidence interval for the estimated correlation.

Output Inflation Correlation

Data		Model
Estimated Moment	95% Confidence Interval	Theoretical Moment
0.32	[0.08, 0.52]	0.15

The model is also able to match the mean real risk-free rate. This ability to match financial market facts does not compromise the model's overall ability to match business cycle facts such as the volatilities of output, consumption and investment.

The welfare cost of uncertainty

One advantage of internal habits is that this specification ensures that risk aversion is independent of the habit parameter (e.g., Constantinides 1990; Boldrin, Christiano and Fisher 2001). The introduction of a labor margin also modifies the concept of risk aversion that is relevant for asset pricing applications (e.g., Swanson 2012).

As initially demonstrated by Tallarini (2000), the welfare cost of business cycle fluctuations provides an indirect measure of risk aversion, since it gives a sense of how much agents dislike fluctuations in their consumption basket. An indirect measure of the welfare cost of business cycle fluctuations can be obtained by calculating a risk compensation in terms of consumption equivalent units. Relative to a world without shock, average consumption is only 0.5% higher in the economy subject to business cycle fluctuations. The low premium needed to compensate agents for the uncertainty caused by business cycle fluctuations confirms that a modest degree of curvature is needed to reproduce a 1% term premium in this model.

Non-standard monetary policy shocks

The next step is to simulate the effects of a money supply shock using the calibration for the period that preceded the implementation of the more aggressive measures introduced by the ECB at the end of 2011. Using the parameter values that reproduce the moments shown in Table 2, I simulate the effects of a one standard deviation non-standard monetary policy shock. Figure 4 below shows the response of the shock process μ, the Central bank's balance sheet m, output y, and the price of long-term bonds p_B^{LT} to the positive non-standard monetary policy shock.

In a model with habits and adjustment costs, the model's state space is potentially highly non-linear. This implies that the response of the endogenous variables to shocks can be influenced by the particular point in the state space from which the impulse response is computed. I therefore compute the impulse responses showing the effect of monetary policy on the model's endogenous variables using a second-order approximation. Following Adjemian et al. (2014), the impulse responses are obtained by computing an average response. This methodology takes into account the state of the economy when computing the response of the endogenous variables to a one standard deviation shock and the pruned state-space is obtained by using the techniques developed by Andreasen et al. (2017).

On impact, the shock increases the exogenous component of money supply by about 3%. The top right panel of Figure 4 shows that the shock leads to an increase in the stock of money, which jumps by about 6% on impact. The stock of money responds in a hump-shaped manner and its response is more persistent than the shock itself. This difference in the dynamics of μ and m illustrates the importance of distinguishing exogenous from endogenous movements in the Central Bank's balance sheet.

As shown by the bottom left panel, the increase in real activity triggered by the shock remains small in magnitude. The magnitude of the output effect is nevertheless significant and a positive money supply shock generates a maximum increase in output of about 0.3%. Whereas the initial disturbance is short-lived, the response of output is more persistent than the shock itself and reaches a peak increase three quarters after the initial shock hit.

The bottom right panel shows the effect of the shock on the price of a long-term bond. The hump-shaped response of long-term bonds is due to the effect of inflation on the valuation. As shown in Figure 6 below, on impact, an expansion of the Central Bank's balance sheet generates an increase in inflation. Since long-term bonds are nominal assets, on impact, the increase in inflation erodes the value of the outstanding stock of safe debt as well as that of the fixed coupon payment. This negative effect is however compensated by the increase in risk appetite induced by the balance sheet expansion. Relative to its steady state value, the maximum increase in bond prices reaches about 1.4 percent. Although the quantitative impact on output remains modest, non-standard monetary policy shocks therefore have a sizeable effect on the price of long-term nominal bonds.

The upper left panel in Figure 5 shows the response of credit to the non-standard monetary policy shock. As shown by equation (3), the total stock of liquidity is divided between the amount that households choose to keep at home and the share that is deposited in the banking sector. Since the marginal utility from holding cash balances is decreasing, households only absorb a fraction of the increase in liquidity and deposit the remaining fraction in the banking sector. The supply of funds available for financial intermediation therefore rises and this supply effect generates a decline in the deposit rate i_D, which is then passed through to firms via the lending rate i_L.

The top right panel of Figure 5 shows the response of the price of a short-term bond to the non-standard monetary policy shock. Since the behavior of the price of short-term bonds is determined by monetary policy, the initial decline can be explained by the increase in short-term rates induced by the shock. A positive non-standard monetary policy shock raises the supply of money and increases inflation. The increase in short-term rates is therefore due to the response of the Central Bank to the inflationary pressures created by the non-standard monetary policy shock. Relative to the effect of a standard monetary policy shock, the key difference is therefore that an increase in inflation can be obtained despite a tightening of the policy rate controlled by the Central Bank.

The two bottom panels of Figure 5 report the effects of the shock on investment and hours worked. The policy stimulates investment and hours worked and the maximum impact on the two variables reaches about 0.6 and 0.4 percent, respectively.

In Figure 6, as discussed above, the 0.6% increase in inflation that occurs on impact can be explained by the effect of the shock on the agent's stochastic discount factor. A positive money supply shock generates an hump-shaped increase in output. Immediately after the shock hit, agents become more optimistic about the future because they expect that income will rise. Building precautionary buffers is not a priority and the demand for assets that can be used to transfer wealth across times declines. The preference for present relative to future consumption increases, which leads to a decline in the stochastic discount factor. As illustrated in equation (16), up to a first-order approximation, the dynamics of inflation in this model is determined by the stochastic discount factor.

Since the increase in money supply is only transitory, agents realize that these favorable conditions will not last. After the initial period of abundant liquidity and low marginal utility, as the effect of the non-standard monetary policy shock starts to fade away, agents understand that marginal utility will have to rise in the future. This effect raises the demand for assets that can be used to transfer wealth across times and the stochastic discount factor starts to gradually increase. This higher preference for future levels of consumption relative to current levels then generates deflationary pressures, which explains the prolonged period of below trend inflation that occurs after the initial increase observed on impact.

Finally, the remaining panels in Figure 6 show the response of real long-term rates to the monetary policy expansion. The shock generates a gradual reduction in the 10 year long-term rate, which declines by about 12 basis points three quarters after the shock hit. The effect on the shorter end of the yield curve is more pronounced and as shown on the bottom right panel the maximum decline in the 5 year real risk-free rate exceeds 20 basis points.

Limitations

While the model is able to match the stylized facts reported in Table 2, it fails on other dimensions. It is well-known that models with habits generate excessive risk-free rate fluctuations. In this paper, this issue is mitigated by the introduction of slow moving habits and by the fact that I do not try to match the equity premium and only target a 1% term premium.

It is also not possible to account for the dynamics of credit market variables and this model cannot reproduce the high volatility of hours worked observed in the data. Since the model abstracts from unemployment, this framework cannot be used to study the link between different measures of slack and inflation (e.g., Den Haan et al. 2017, Stock and Watson 2018). One interesting direction would be to introduce search and matching frictions into the analysis and study how the model mechanism analyzed in this paper affects the Phillips Curve relationship.

5 The real effects of monetary policy

The real effect of money supply shocks critically depend on the response of inflation. To gain intuition into this result, it is useful to analyze how shocks to μ are transmitted to the real economy. As discussed above, the money supply shock is firstly transmitted through the spread between the deposit rate and risk-free interest rate:

$$1 = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{\mu_{t+1}}{1+\pi_{t+1}} \left(1 + i_{Dt+1}\right)$$

There is also a quantity effect that depends on the real quantity of money available in the economy. This effect can be illustrated by the portfolio decision that governs the allocation of the real stock of money holding between transaction services and deposits:

$$\frac{\mu_t}{1+\pi_t} m_{t-1} = s_t + d_t$$

Since money supply shocks only affect the dynamic system through these two equations, the real effects of a money supply shock critically depend on the response of $\mu_t/(1+\pi_t)$. In response to a positive innovation to μ_t, the stronger the response of inflation, the weaker the effect of the shock on the real economy. To illustrate how the response of inflation affects the transmission of non-standard monetary policy shock, consider the case in which the interest rate rule (10) is replaced by the following monetary policy rule:

$$\gamma m_t = \frac{\mu_t}{1+\pi_t} m_{t-1} \tag{17}$$

If the behavior of standard monetary policy is determined by this particular monetary policy rule, any increase in the exogenous component of money supply can be offset by a proportional increase in inflation. Monetary policy is therefore completely neutral in this case.

Notice that this neutrality result obtained when the interest rate rule is replaced by this monetary policy rule is not general and very much depends on the implicit assumption that the Central Bank is not concerned about inflation stabilization. Adding an inflation target in the monetary policy rule (17) would be sufficient to break the classical dichotomy. As shown by Christiano and Eichenbaum (1992), introducing frictions such as costs of adjusting flow of funds is another way to generate monetary non-neutralities in this model. Relative to their approach, the advantage of the mechanism studied in this paper is that it allows to generate monetary non-neutralities that are more persistent.

The labor wedge

The magnitude of the effect on output depends on the specification of the loan-in-advance constraint and the model reduces to an economy with money in the utility function if the constraint is removed from the analysis. In equation (8), the fact that firms need to pay workers in advance of production, and that this effect is internalized, introduces a wedge in the marginal product of labor:

$$w_t = (1 - \alpha)\frac{y_t}{N_t}\frac{1}{1 + \frac{\varpi_t}{\lambda_t}}$$

where ϖ is the Lagrange multipliers associated to the constraint. To illustrate the quantitative importance of the labor wedge, I also study a version of the model in which liquidity is not required to pay workers in advance of production:

$$l_t \geq r_{Kt}k_{t-1} + \eta k_{t-1} \tag{18}$$

The value of the contract enforcement parameter η is then adjusted to ensure that the average loan to output ratio observed in the data, *i.e.* $E(l/y)$, can be matched. Figure 7 below compares the response of output in the benchmark model in which the loan-in-advance constraint is given by equation (8) to the case in which this constraint abstracts from wage payment, as in equation (18). Clearly, without a labor wedge, the transmission mechanism of non-standard monetary policy shocks becomes considerably weaker. It is still possible to generate a very small increase in output but the peak effect that is obtained in this case stands at about 0.06%, while the maximum increase obtained in the labor wedge model exceeds 0.3%.

The non-neutrality of money with non-separable preferences

In this economy, the link between bank lending rates and factor payments introduced by the loan-in-advance constraint is the main source of monetary non-neutrality. It should however be noted that the introduction of habits in the composite of consumption and leisure is sufficient to break the classical dichotomy. Figure 8 below shows the response of output to a money supply shock in the version of the model in which constraint (8) is removed from the analysis. In this case, the model reduces to an economy with money in the utility function. In this version of the model, given that σ is set to 1, money supply shocks are completely neutral when the habit block is switched off. This corresponds to the log utility case and, without financial frictions, monetary policy shocks have no effect on the economy in the case $\sigma = \tau = 1$ since preferences are separable in this case.

To isolate the effect of preferences on the transmission mechanism, in Figure 8, the black dotted line shows the response of output to a positive monetary policy shock in the case in which setting $\tau < 1$ is the only source of monetary policy non-neutrality. This case corresponds to a model without financial frictions and in which the non-separability due to this particular habit specification is the only source of monetary non-neutrality.

The comparison with the blue line, which shows the cost channel model in the case $\tau < 1$, illustrates that the loan-in-advance constraint is the main source of non-neutrality in this model. The red dotted line is the model without a labor wedge discussed above and shown in Figure 7. The tiny difference between the red dotted and black dashed lines shows that without a labor wedge and without the non-separability due to habits, monetary policy would be close to neutral in a model without nominal rigidities.

The credit multiplier

As shown by Daetz et al. (2017), the effectiveness of non-standard monetary policy measures crucially depends on the willingness of agents to lend to the real economy. The facts that they document suggest that liquidity hoarding could have contributed to decrease the effectiveness of the ECB long-term refinancing operations. In the context of the present study, this effect is captured by the introduction of a portfolio decision between cash that is kept at home for transaction purposes and the amount deposited in the banking sector. The larger the share of liquidity that is allocated to deposits, the larger the real effects of the monetary injection. By contrast, increases in cash holdings s in response to liquidity injections reduce the amount deposited in the banking sector and hence the effect of monetary policy on output.

Figure 9 shows the impulse response of the credit multiplier,

$$cmul_t = \frac{l_t}{\mu_t m_t/(1+\pi_t)}$$

to a positive money supply shock. The credit multiplier declines substantially on impact and the maximum decline exceeds 7 percent, about 3 quarters after the implementation of the shock. This sharp decline illustrates that the real effect of liquidity injections are dampened by cash holdings, which is in line with the mechanism described by Daetz et al. (2017).

The fact that the ECB introduced targeted longer-term refinancing operations (TLTRO) in 2014 seems consistent with the hypothesis that liquidity hoarding could have contributed to reduce the effectiveness of liquidity injections. In spirit, TLTROs were very similar to the funding for lending scheme used by the Bank of England. These programmes were designed to encourage lending to the real economy by providing incentives to lend rather than hoard the funds obtained from the Central Bank.

6 The state dependence of monetary policy transmission

To test for state-dependency, I start by simulating 100,000 different trajectories for output by drawing a corresponding number of realizations for the two exogenous shocks. Since each trajectory depends on the sequence of random shocks, this methodology allows me to generate a distribution of realized values for output that depends on the state of the economy in a given period, say period 100 (see Figure 10). An impulse response that depends on the state of the economy can then be obtained by simulating the effects of a one standard deviation monetary policy shock, starting from each particular value of the distribution obtained for output in period 100.[9]

In the left panel of Figure 11, the red dotted line shows the impulse response of output to a positive non-standard monetary policy shock when the economy is in a boom phase. A boom state corresponds to a value for the log of output that is contained in the 66th percentile of the distribution shown in Figure 10. The red dotted line is then the average of all impulse responses that were calculated for a state of the economy in which output is equal or superior than 66% of all realized observations. Similarly, the blue continuous line shows the average impulse response to a positive one standard deviation shock for the case in which the economy was in a recession. The recession state corresponds to the cases in which output was in the 33rd percentile of the distribution, which in Figure 10 corresponds to values equal or inferior than 33% of all realizations. The right panel of Figure 11 shows the response of inflation in these two different states.

As shown in the right panel of Figure 11, the effects of non-standard monetary policy shocks on inflation are stronger when the economy is in a boom than in a recession. On impact the difference is quantitatively relevant since inflation increases by 0.4% in the recession state compared with an increase on impact that exceeds 1% in the boom state.

In the habit model, the difference in inflation dynamics shown in Figure 11 can be explained by the response of the stochastic discount factor, which reacts less when the economy is in a recession. As illustrated in the left panel of Figure 12, while on impact a positive non-standard monetary policy shock reduces the stochastic discount factor, this effect is stronger during booms than recessions. The stronger decline in stochastic discounting in boom times in turn implies stronger inflationary pressures on impact. This

[9] Following Adjemian et al. (2014) an impulse response is therefore the difference between the series to which a one standard deviation monetary policy shock is added and the initial simulated path. The impulse response analysis shown in this section has greatly benefitted from comments and suggestions from M. Juillard whose help is gratefully acknowledged. Any remaining error is my own responsibility.

result follows from the fact that in this model inflation dynamics is entirely determined by households' intertemporal preferences. A decline in stochastic discounting signals an increase in the preference for present relative to future consumption. Since inflation is the price of present consumption, inflation increases when stochastic discounting declines.

When the economy is in a recession, the fact that agents expect good times ahead after a positive shock lowers their stochastic discount factors. But the key difference is that in those states of the world, agents are particularly concerned about the effects of future shocks because the composite good $c^{\kappa}s^{1-\kappa}(\psi + L^{\upsilon})$ is dangerously close to the habit stock. In this particular region of the state space, the difference is that the need to avoid any further decline in the composite good is particularly pressing. Relative to a boom state, the incentive to build precautionary buffers is thus stronger during periods of recession. This effect explains why a positive shock gives rise to an initial decline in stochastic discounting that is less pronounced when the economy is in a recession. Agents still understand that the shock has a positive effect that is persistent and that marginal utility will continue to decline for several periods. But when the composite good is close to the reference level, the stronger precautionary saving motive in those states of the world affects the valuation of future payoffs. Intuitively, the introduction of habits generates a "cliff effect" because agents in this model need to make sure that the composite good will never fall below the time-varying reference level h. Relative to the boom state, the decline in stochastic discounting is therefore lower during recessions because utility is close to the time-varying reference level in those states of the world. Or in order words, because of this "cliff effect", the preference for present relative to future consumption increases by less during recessions because the incentive to build precautionary buffers is stronger.

In this environment, the amount of credit that can be allocated to financially constrained firms depends on the real quantity of money available in the economy. After a positive liquidity injection, an increase in inflation reduces the real stock of money balances. The more muted response of inflation in recessions in turn implies that, in real terms, a relatively larger quantity of funds is available for lending. As shown in the right panel of Figure 12, the asymmetric effect of money supply shocks on credit is particularly strong. During recessions, a one standard deviation monetary policy shock increases credit by almost 1% on impact and the maximum impact reaches about 1.3% about two quarters after implementation. In boom times, as illustrated by the red dotted line, the effect on credit is considerably smaller. On impact, credit decreases slightly and the maximum effect only reaches about 0.6%.

This more muted response of inflation to monetary policy therefore generates larger credit expansions in recessions than in booms. This larger credit expansion in turn implies that expansionary money supply shocks exert an effect on output that is greater during recessions than during booms.

A precautionary saving effect

As shown by Kimball (1990), the magnitude of the precautionary saving motive is determined by the convexity of marginal utility of consumption. The impulse response analysis shown in Figure 13 illustrates this point by showing the response of inflation and output in the boom and recession states in the model without habit formation, which is obtained by setting τ to 1. With this preference specification, the model reduces to the log utility case when τ is set to 1 and the state-dependence of monetary policy almost completely disappears. This confirms that the degree of state dependence increases with the intensity of habits and hence with the degree of convexity of marginal utility.

While habits play a crucial role, it is important to emphasize that in a model with endogenous capital accumulation the degree of adjustment costs plays an equally important role. In a version of the model with habits but without adjustment costs, I also find that the state dependence of monetary policy transmission almost completely disappears. At the same time, the version of the model with habits but without adjustment costs generates a term premium on long-term bonds that is implausibly small. As demonstrated by Jermann (1998), it is the combination of habits and adjustment costs that helps to generate more realistic asset pricing implications in this class of models.

To check that the state-dependence that I obtain is due to the convexity of marginal utility, I also simulated the effects of monetary policy shocks in booms and recessions in a linear version of the model. Figure 14 is obtained by simulating the model augmented with habits and adjustment costs using the calibration described in Table 1 but the impulse response analysis is performed using a first-order approximation to the policy function. Without higher-order terms in the Taylor expansion, it is no longer possible to generate any state dependence since the impact of the convexity of marginal utility on precautionary saving behaviors cannot be captured in this case.

Are the effects of money supply shocks asymmetric?

The empirical facts documented by Barnichon and Matthes (2018) suggest that contractionary monetary policy shocks have a stronger effect on unemployment than expansionary ones. As shown in Figure 15, in this economy, monetary policy shocks also generate effects that are asymmetric. The red dotted line shows the effect of a contractionary monetary policy shock on hours worked. The negative shock leads to a gradual decline in hours worked and the maximum decline reaches nearly 0.6% about two quarters after the shock hit. The effect of a positive monetary policy shock on hours worked is depicted by the blue continuous line. The maximum increase in hours worked reaches 0.48% compared to a decline of about 0.6% in response to a contractionary shock.

In line with the findings documented by Barnichon and Matthes, the response of inflation is also asymmetric but in the opposite direction. Inflation reacts less after a contractionary monetary policy shock when hours worked react more and vice-versa. The stronger response of inflation in response to an expansionary monetary policy shock can be explained by the above-mentioned precautionary saving motive. In good times, risk aversion declines and expansionary monetary policy shocks are particularly effective at stimulating inflation. In this environment, a strong inflation response reduces the real increase in credit available for lending, which attenuates the real effect of monetary policy.

7 Conclusion

This paper shows that introducing realistic fluctuations in stochastic discounting in a standard macroeconomic model can significantly alter the transmission mechanism of monetary policy shocks. One main implication of this result is that attitudes towards risk and precautionary saving motives could affect Central Banks' ability to steer inflation. Higher-order terms in the Taylor expansion could therefore play a more important role in the transmission of monetary policy shocks than previously thought.

Since habit formation is a key building block of most of the macroeconomic models used for policy analysis, studying the implications of time-varying risk aversion for monetary policy transmission is a natural starting point. In the future, it would be interesting to investigate how other mechanisms used in the asset pricing literature to generate realistic fluctuations in stochastic discounting, such as long-run risk (e.g., Bansal and Yaron 2004) or learning (e.g., Adam et al. 2017) for instance, or other preference specifications (e.g., Weil 1989, 1990; Epstein and Zin 1989; Campanale et al. 2010), could affect the link between money and inflation.

8 References

Abel, A. (1990). "Asset Prices under Habit Formation and Catching Up with the Joneses", *American Economic Review*, vol. 80(2), p. 38-42.

Adam, K. & A. Marcet & J. Beutel (2017). "Stock Price Booms and Expected Capital Gains". *American Economic Review*, 107 (8), p. 2352-2408.

Adjemian, S. & Bastani, H. & Juillard, M. & Mihoubi, F. & Perendia, G. & Ratto, M. & Villemot, S., (2014). "Dynare: Reference Manual, Version 4," Dynare Working Papers 1.

Amisano, G. & Tristani, O. (2017). "Monetary Policy and Long-term Interest Rates", mimeo Federal Reserve Board.

Andreasen, M. & Fernández-Villaverde, J. & Rubio-Ramírez, J. (2017). "The Pruned State-Space System for Non-Linear DSGE Models: Theory and Empirical Applications", *The Review of Economic Studies,* forthcoming.

Auerbach, A., and Y. Gorodnichenko (2012). "Measuring the Output Responses to Fiscal Policy." *American Economic Journal: Economic Policy*, 4 (2), p. 1-27.

Bansal R. & Yaron, A. (2004). "Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles", *Journal of Finance*, vol. 59(4), p. 1481-1509.

Barnichon, R. & Matthes, C. (2018). "Functional Approximations of Impulse Responses (FAIR)", *Journal of Monetary Economics*, forthcoming.

Barth, M. & Ramey, V. (2002). "The Cost Channel of Monetary Transmission", NBER Chapters, in: *NBER Macroeconomics Annual*, vol. 16, p. 199-256.

Baxter, M. & Crucini, M., (1993). "Explaining Saving-Investment Correlations", *American Economic Review*, vol. 83(3), p. 416-36.

Bekaert, G. and E. Engstrom (2017). "Asset Return Dynamics under Habits and Bad Environment–Good Environment Fundamentals", *Journal of Political Economy,* 125:3, p. 713-760.

Benassy, J. (2008). "The Macroeconomics of Imperfect Competition and Nonclearing Markets: A Dynamic General Equilibrium Approach", MIT Press.

Boccola, L. (2016). "The Pass-Through of Sovereign Risk", *Journal of Political Economy*, 124 (4), August 2016, p. 879-926.

Boeckx, J. & Dossche, M. & Peersman, G. (2017). "Effectiveness and Transmission of the ECB's Balance Sheet Policies", *International Journal of Central Banking,* Feb. issue, p. 297-333.

Boissay, F. & Collard, F. & Smets, F. (2016). "Booms and Banking Crises", *Journal of Political Economy*, vol. 124(2), p. 489-538.

Boldrin, M. & Christiano, L. & Fisher, J. (2001). "Habit Persistence, Asset Returns, and the Business Cycle", *American Economic Review*, vol. 91(1), p. 149-166.

Bouakez, H. & E. Cardia & F. Ruge-Murcia (2005). "Habit formation and the persistence of monetary shocks", *Journal of Monetary Economics*, vol. 52(6), p. 1073-1088.

Brunnermeier, M. & Koby, Y. (2018). "The Reversal Interest Rate: The Effective Lower Bound of Monetary Policy". mimeo Princeton University.

Campbell, J. & Cochrane, J. (1999). "By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior", *The Journal of Political Economy*, vol. 107, Issue 2, p. 205-251.

Campbell J. & C. Pflueger C. & L. Viceira (2015). "Monetary Policy Drivers of Bond and Equity Risks", mimeo UBC.

Campanale, C. & Castro, R. & Clementi, G. (2010). "Asset Pricing in a Production Economy with Chew-Dekel Preferences." *Review of Economic Dynamics*, vol. 13(2), p. 379-402.

Chetty, R. & Guren, A. & Manoli, D. & Weber, A. (2011). "Are Micro and Macro Labor Supply Elasticities Consistent? A Review of Evidence on the Intensive and Extensive Margins." *American Economic Review*, 101(3), p. 471-75.

Christiano, L. & M. Eichenbaum (1992). "Liquidity Effects and the Monetary Transmission Mechanism", *American Economic Review*, 82(2), p. 346-353.

Christiano L., & M. Eichenbaum & C. Evans (2005). "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy* vol. 113, no. 1, p. 1-45.

Christiano, L., & R. Motto & M. Rostagno (2014). "Risk Shocks." *American Economic Review*, 104 (1): 27-65.

Ciccarelli, M. & C. Osbat (2017). "Low Inflation in the Euro Area: Causes and Consequences", Occasional Paper Series 181, European Central Bank.

Clarida, R., M. Gertler & J. Gali (1999). "The Science of Monetary Policy: A New Keynesian Perspective," *Journal of Economic Literature*, vol. 37(4), p. 1661-1707.

Cochrane, J. (2011). "Presidential Address: Discount Rates", *Journal of Finance*, vol. 66(4), p. 1047-1108, 08.

Cochrane, J. & Hansen, L. (1992). "Asset Pricing Explorations for Macroeconomics", NBER Chapters, in: *NBER Macroeconomics Annual*, Volume 7, p. 115-182.

Coibion, O. & Y. Gorodnichenko (2015). "Is the Phillips Curve Alive and Well after All? Inflation Expectations and the Missing Disinflation." *American Economic Journal: Macroeconomics*, 7 (1): 197-232.

Coibion, O. & Y. Gorodnichenko & R. Kamdar (2017). "The Formation of Expectations, Inflation and the Phillips Curve", NBER Working Paper no. 23304.

Constantinides, G. (1990). “Habit Formation: A Resolution of the Equity Premium Puzzle”, *Journal of Political Economy*, vol. 98, no. 3, p. 519–543.

Cooley, T. & V. Quadrini (1999). "A Neoclassical Model of the Phillips Curve Relation", *Journal of Monetary Economics,* vol. 44, iss. 2, p. 165-193.

Croce, M. (2014). "Long-Run Productivity Risk: A New Hope for Production-based Asset Pricing?", *Journal of Monetary Economics*, Vol. 66, p. 13–31.

Daetz, L. & M. Subrahmanyam & D. Tang & S. Wang (2017). "Did ECB Liquidity Injections Help the Real Economy?", http://dx.doi.org/10.2139/ssrn.2915800.

Cúrdia, V. & Woodford, M. (2011). "The Central-bank Balance Sheet as an Instrument of Monetary Policy", *Journal of Monetary Economics*, vol. 58(1), p. 54-79.

Dedola, L. & Lippi, F. (2005). "The Monetary Transmission Mechanism: Evidence from the Industries of five OECD countries", vol. 49, Issue 6, p. 1543-1569.

De Fiore, F. & P. Teles & O. Tristani (2011). "Monetary Policy and the Financing of Firms", *American Economic Journal: Macroeconomics*, vol. 3(4), p. 112-142.

De Fiore, F. & Teles, P. & Tristani, O. & Correia, I. (2016). "Credit Subsidies", ECB Working Paper Series 1877.

Del Negro, M. & Eggertsson, G. & Ferrero, A. & Kiyotaki, N. (2017). "The Great Escape? A Quantitative Evaluation of the Fed's Liquidity Facilities", *American Economic Review*, vol. 107(3), p. 824-857.

Den Haan, W., (1995). "The Term Structure of Interest Rates in Real and Monetary Economies," *Journal of Economic Dynamics and Control*, vol. 19(5-7), p. 909-940.

Den Haan, W., P. Rendahl, M. Riegler (2017). "Unemployment (Fears) and Deflationary Spirals", *Journal of the European Economic Association,* forthcoming.

Dew-Becker, I. (2014). "Bond Pricing with a Time-Varying Price of Risk in an Estimated Medium-Scale Bayesian DSGE Model". *Journal of Money, Credit and Banking*, vol. 46(5), p. 837-888.

ECB (2012). "Impact of the Two three-year Longer-term Refinancing Operations", ECB Monthly Bulletin March 2012.

Epstein, L. & Zin, S., (1989). "Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: A Theoretical Framework." *Econometrica*, vol. 57(4), p. 937-69.

Fuerst, T. (1992). "Liquidity, Loanable Funds, and Real Activity", *Journal of Monetary Economics*, vol. 29(1), p. 3-24.

Fuhrer, J. (2000). "Habit Formation in Consumption and Its Implications for Monetary-Policy Models", *American Economic Review*, 90(3), p. 367-390.

Gaiotti, E., & Secchi, A. (2006) "Is There a Cost Channel of Monetary Policy Transmission? An Investigation into the Pricing Behavior of 2,000 Firms", *Journal of Money, Credit and Banking*, vol. 38, no. 8, 2006, p. 2013–2037.

Galí, J. (2015). "Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework and Its Applications", Princeton University Press, 2nd edition.

Gambacorta, L. & Hofmann, B. & Peersman, G. (2014). "The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-Country Analysis", *Journal of Money, Credit and Banking*, vol. 46(4), p. 615-642, 06.

Gertler, M. & Karadi, P. (2011). "A Model of Unconventional Monetary Policy", *Journal of Monetary Economics*, vol. 58(1), p. 17-34.

Gertler, M. & Karadi, P. (2013). "QE 1 vs. 2 vs. 3. . . : A Framework for Analyzing Large-Scale Asset Purchases as a Monetary Policy Tool", *International Journal of Central Banking*, vol. 9(1), p. 5-53.

Gomes, J., Jermann, U. and Schmid, L.. (2016). "Sticky Leverage", *American Economic Review*, 106(12), p. 3800-3828.

Goodfriend, M. & McCallum, B., (2007). "Banking and Interest Rates in Monetary Policy Analysis: A Quantitative Exploration", *Journal of Monetary Economics*, vol. 54(5), p. 1480-1507.

Gordon, S. and P. St-Amour. (2000). "A Preference Regime Model of Bull and Bear Markets". *American Economic Review*, 90 (4), p. 1019-1033.

Gordon, S. and P. St-Amour. (2004). "Asset Returns and State-Dependent Risk Preferences". *Journal of Business & Economic Statistics,* vol. 22, No. 3, p. 241-252.

Gourio, F. (2012). "Disaster Risk and Business Cycles", *American Economic Review*, vol. 102(6), p. 2734-66.

Gourio, F. (2013). "Credit Risk and Disaster Risk", *American Economic Journal: Macroeconomics*, vol. 5(3), p. 1-34.

Hall, R. (2009). "Reconciling Cyclical Movements in the Marginal Value of Time and the Marginal Product of Labor", *Journal of Political Economy*, vol. 117(2), p. 281-323.

Hördahl, P. & O. Tristani (2014). "Inflation Risk Premia in the Euro Area and the United States," *International Journal of Central Banking*, International Journal of Central Banking, vol. 10(3), p. 1-47.

Jaccard, I. (2014). "Asset Returns and Labor Supply in a Production Economy", *Journal of Money, Credit and Banking*, Volume 46, Issue 5, p. 889–919.

Jaccard, I. (2018). "Asset Pricing and the Propagation of Macroeconomic Shocks", *Journal of the European Economic Association*, vol. 16, iss. 2, p. 436–486.

Jermann, U. (1998). "Asset Pricing in Production Economies", *Journal of Monetary Economics*, vol. 41(2), p. 257-275.

Jermann, U. & Quadrini, V. (2012). "Macroeconomic Effects of Financial Shocks", *American Economic Review*, vol. 102(1), p. 238-271.

Kimball, M. (1990). "Precautionary Saving in the Small and in the Large", *Econometrica*, vol. 58(1), p. 53-73.

King, R. & Rebelo, S. (1999). "Resuscitating Real Business Cycles." *Handbook of Macroeconomics*, in: John B. Taylor & Michael Woodford (ed.), edition 1, volume 1, chapter 14, p. 927-1007.

Kocherlakota, N. (1990). "On the 'Discount' Factor in Growth Economies." *Journal of Monetary Economics*, vol. 25(1), p. 43-47.

LeRoy, S. & R. Porter (1981). "The Present-Value Relation: Tests Based on Implied Variance Bounds." *Econometrica*, vol. 49, no. 3, 1981, p. 555–574.

M. Lettau & H. Uhlig (2000). "Can Habit Formation be Reconciled with Business Cycle Facts?", *Review of Economic Dynamics*, vol. 3(1), p. 79-99.

Lucas, R. (1972). "Expectations and the Neutrality of Money", *Journal of Economic Theory*, vol. 4(2), p. 103-124, April.

Peersman, G. & Smets, F. (2001). "Are the Effects of Monetary Policy in the Euro Area Greater in Recessions than in Booms?". Working Paper Series 0052, European Central Bank.

Peersman, G. and Smets, F. (2005), The Industry Effects of Monetary Policy in the Euro Area". *The Economic Journal*, 115, p. 319–342.

Piazzesi, M. & Schneider, M. (2007). "Equilibrium Yield Curves". *NBER Macroeconomics Annual* 2006, in Daron Acemoglu, Kenneth Rogoff, and Michael Woodford, p. 389-442.

Piazzesi, M. & Schneider, M. (2017). "Payments, Credit and Asset Prices" mimeo Stanford University.

Quadrini, V. (2014). "Bank Liabilities Channel". *Journal of Monetary Economics,* Vol. 89, p. 25-44.

Ravenna, F. & C. Walsh (2006). "Optimal Monetary Policy with the Cost Channel", *Journal of Monetary Economics*, vol. 53(2), p. 199-216.

Rudebusch, G. & Swanson, E. (2008). "Examining the Bond Premium Puzzle with a DSGE Model". *Journal of Monetary Economics*, vol. 55, p. 111-126.

Rudebusch, G. & Swanson, E. (2012). "The Bond Premium in a DSGE Model with Long-Run Real and Nominal Risks", *American Economic Journal: Macroeconomics*, vol. 4(1), p. 105-43.

Santoro, E. & Petrella, I. & Pfajfar, D. & Gaffeo, E. (2014). "Loss Aversion and the Asymmetric Transmission of Monetary Policy," *Journal of Monetary Economics*, vol. 68(C), p. 19-36.

Shiller, R. (1981). "Do Stock Prices Move Too Much to be Justified by Subsequent Changes in Dividends?," *American Economic Review*, vol. 71(3), p. 421-436, June.

Smets, F. & R. Wouters. (2007). "Shocks and Frictions in U.S. Business Cycles: A Bayesian DSGE Approach", *American Economic Review*, vol. 97(3), p. 586-606.

Stock, J. & M. Watson (2018). "Slack and Cyclically Sensitive Inflation", Paper presented at the 2018 ECB Forum on Central Banking, Sintra, Portugal.

Swanson, E. (2016). "Risk Aversion and the Labor Margin in Dynamic Equilibium Models", *American Economic Review* 102, p. 1663-1691.

Swanson, E. (2016). "A Macroeconomic Model of Equities and Real, Nominal, and Defaultable Debt", Mimeo, University of California Irvine.

Tallarini, T. (2000). "Risk-Sensitive Real Business Cycles", *Journal of Monetary Economics*, vol. 45(3), p. 507-532.

Tenreyro, S. and G. Thwaites (2016). "Pushing on a String: US Monetary Policy Is Less Powerful in Recessions." *American Economic Journal: Macroeconomics*, 8(4), p. 43-74.

van Binsbergen, J. & Fernández-Villaverde, J. & Koijen, R. & Rubio-Ramírez, J. (2012). "The Term Structure of Interest Rates in a DSGE model with Recursive Preferences", *Journal of Monetary Economics*, vol. 59(7), p. 634-648.

Van den Heuvel, S. (2008). "The Welfare Cost of Bank Capital Requirements", *Journal of Monetary Economics*, vol. 55(2), p. 298-320.

Van den Heuvel, S. (2016). "The Welfare Cost of Bank Liquidity and Capital Requirements", mimeo, Federal Reserve Board.

Wei, C. (2009). "A quartet of asset pricing Models in Nominal and Real Economies". *Journal of Economic Dynamics and Control*, vol. 33(1), p. 154-165.

Weil, P. (1989). "The Equity Premium Puzzle and the Risk-free Rate Puzzle." *Journal of Monetary Economics*, vol. 24(3), p. 401-421.

Weil, P. (1990). "Nonexpected Utility in Macroeconomics." *The Quarterly Journal of Economics*, vol. 105(1), p. 29-42.

Woodford, M. (2003). "Interest Rate and Prices: Foundations of a Theory of Monetary Policy", Princeton University Press.

Woodford, M. (2012). "Methods of Policy Accommodation at the Interest-rate Lower Bound," Proceedings - Economic Policy Symposium - Jackson Hole, Federal Reserve Bank of Kansas City, p. 185-288.

9 Appendix

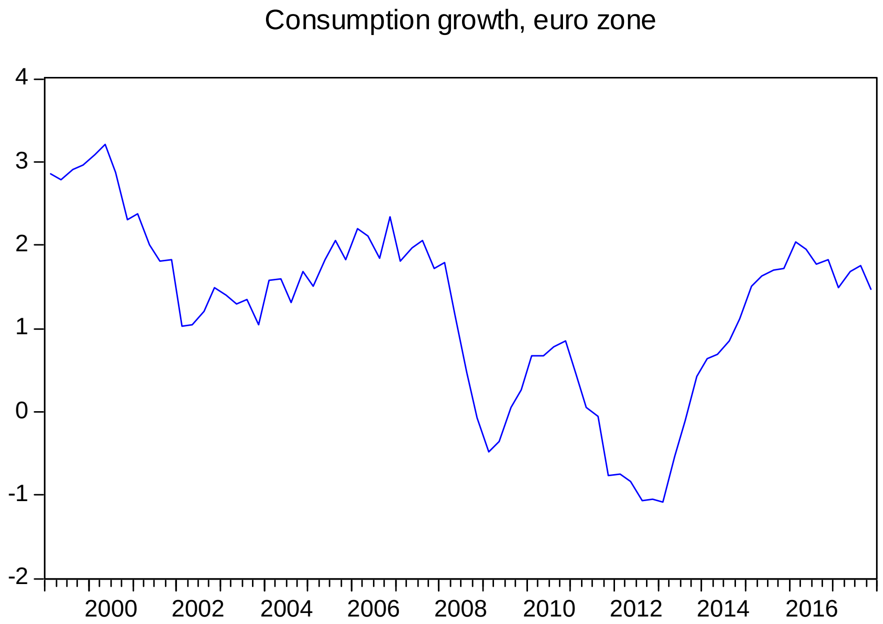


Fig. 1. Year-over-year consumption growth rate, quarterly data. Source: Statistical Office of the European Communities. Final consumption expenditures, euro area 19.

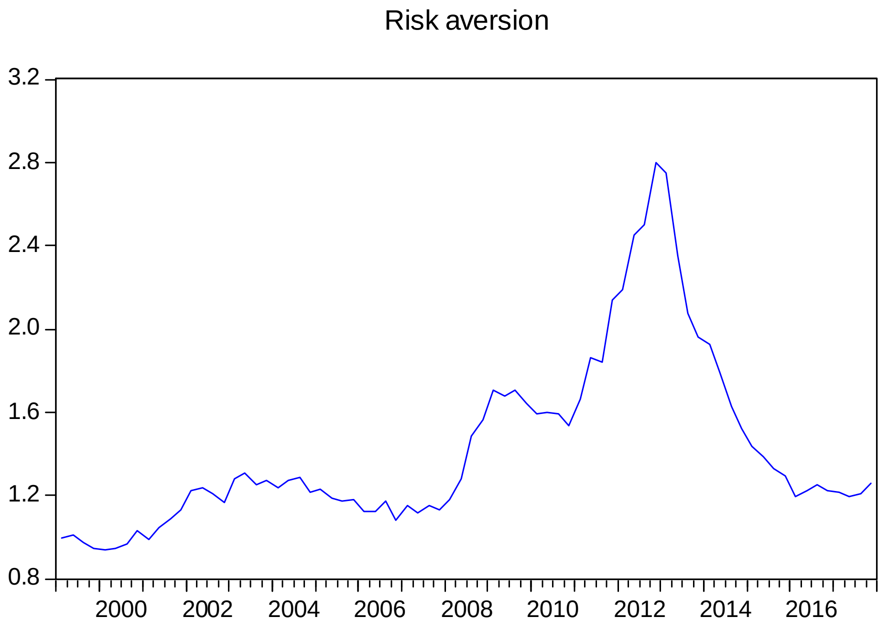


Fig. 2. Risk aversion. $Ra_t = \sigma \frac{c_t}{c_t - x_t}$, where $\gamma x_{t+1} = m x_t + (1-m) c_t$. Calibration: $m = 0.8$, $\gamma = 1.005$, $\sigma = 1$. Normalization: 1999q1=1.

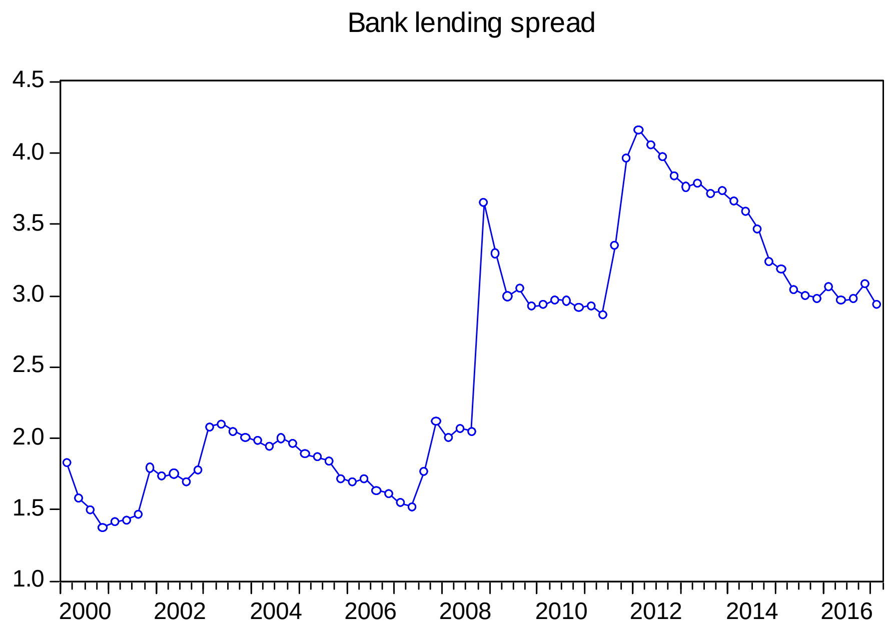


Fig. 3. Bank lending spread. Short-term lending rate minus risk-free rate.

Table 2: Model vs. Data

	Data		Model
	95% confidence interval	Estimated empirical moments	Theoretical moments
$\sigma(g_y)$	[1.71, 2.43]	2.00	2.05
$\sigma(g_c)$	[0.79, 1.13]	0.93	0.94
$\sigma(g_x)$	[4.93, 7.01]	5.79	5.65
$\sigma(g_m)$	[9.89, 14.82]	11.9	11.9
$\sigma(g_d)$	[1.85, 2.72]	2.20	2.43
$\sigma(\pi)$	[0.79, 1.07]	0.91	0.99
$\sigma(i_B)$	[3.61, 4.48]	4.0	4.33
$E(i_R)$	[1.16, 3.0]	2.08	2.04
$E(tp)$	[0.98, 1.32]	1.15	1.0
$E(\pi)$	[1.90, 2.61]	2.26	2.26
$E(i_L - i_D)$	[1.86, 2.18]	2.02	2.02
$E(l/y)$	[1.54, 1.77]	1.66	1.66

Note: g_y, g_c, g_x, g_m, g_d denote the growth rate of output, consumption, investment, money and deposits expressed in year-over-year growth rate, where for output the growth rate is computed as $(y_t/y_{t-4}) - 1) * 100$. σ_π is the annualized inflation rate, $\sigma(i_B)$ is the standard deviation of the short-term risk-free rate in annualized terms, $E(i_R)$ is the mean real risk-free rate, and $E(tp)$ is the term-premium on a long-term bond with a 10 year duration. $E(\pi), E(i_L - i_D)$ and $E(l/y)$ denote the average value of annualized inflation, the investment to output ratio, the intermediation spread and the economy's loan to output ratio.

Table 3: Variance Decomposition

	y	x	c	d	π	i_B	m
Technology	87.7	95.9	62.1	30.0	77.3	77.3	7.0
Monetary	12.3	4.1	37.9	70.0	22.7	22.7	93.0

Table 3: y, x, c, d, π, i_B and m denote output, investment, consumption, deposits, inflation, the policy rate and the Central Bank's balance sheet.

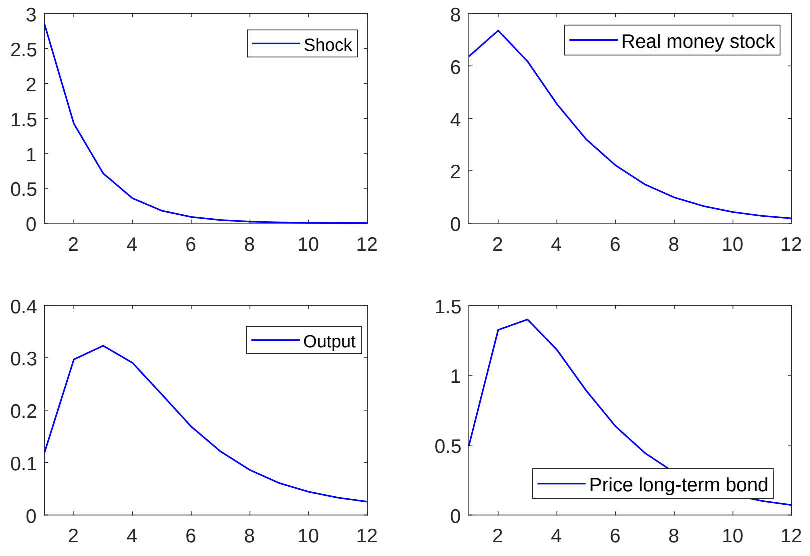


Figure 4. Response in logs to a one standard deviation innovation to μ_t. y axis: percentage deviation from steady state. x axis: quarters after the shock.

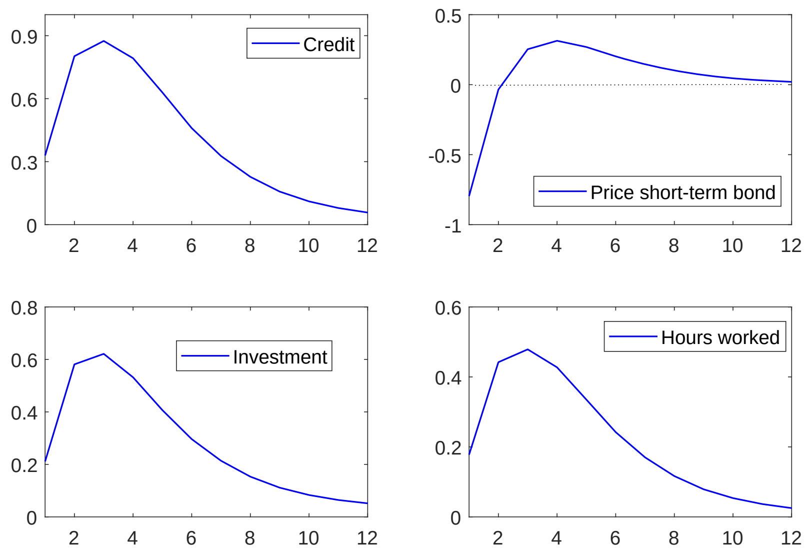


Figure 5. Response in logs to a one standard deviation innovation to μ_t. y axis: percentage deviation from steady state. x axis: quarters after the shock.

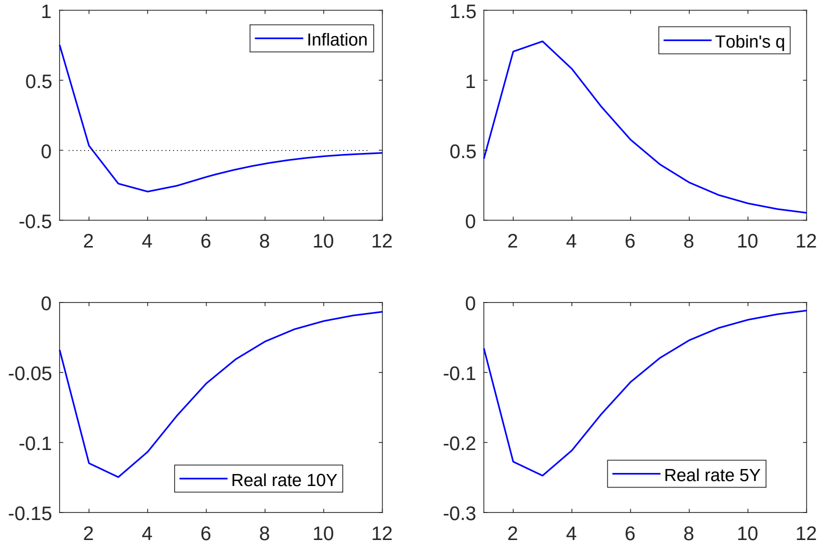


Figure 6. Response in annualized percent to a one standard deviation innovation to μ_t. y axis: deviation from steady state in annualized percent. x axis: quarters after the shock.

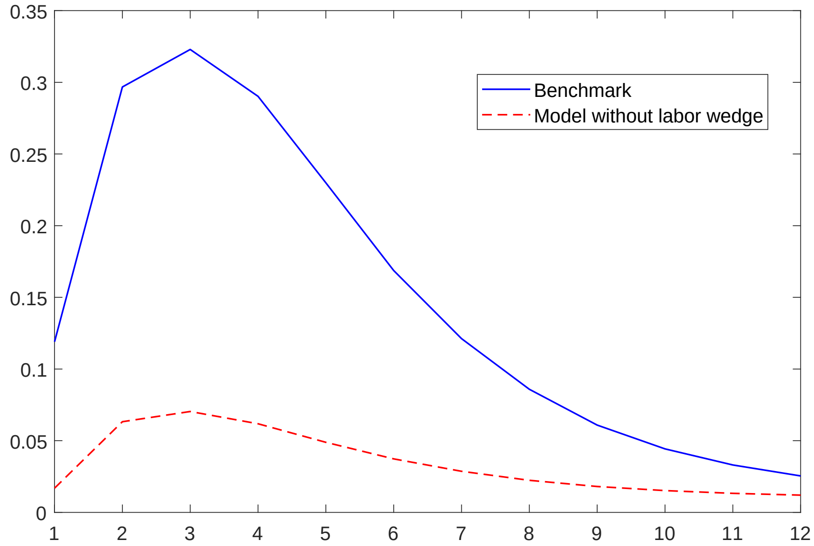


Figure 7. Response of output to a positive shock, benchmark model vs. model without labor wedge. y axis: percentage deviation from steady state. x axis: quarters after the shock.

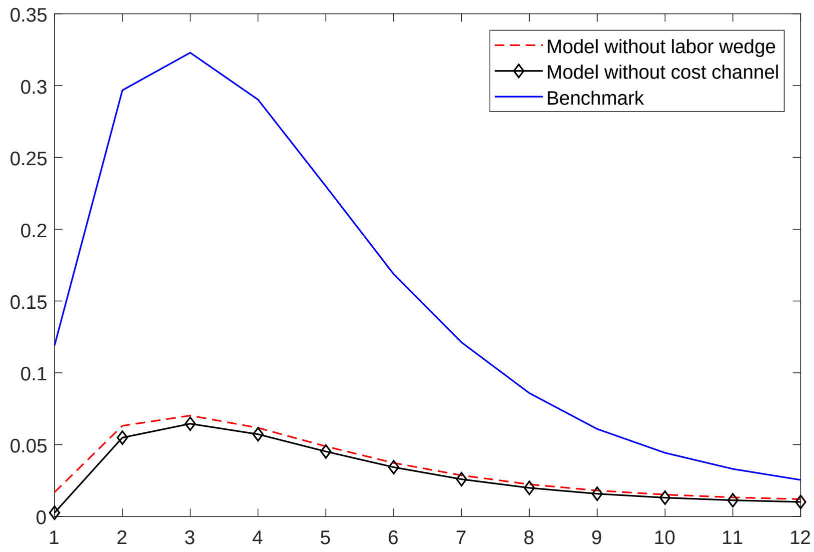


Figure 8. Response of output to a positive shock, benchmark model, model with cost channel but without labor wedge and model without a cost channel. y axis: percentage deviation from steady state. x axis: quarters after the shock.

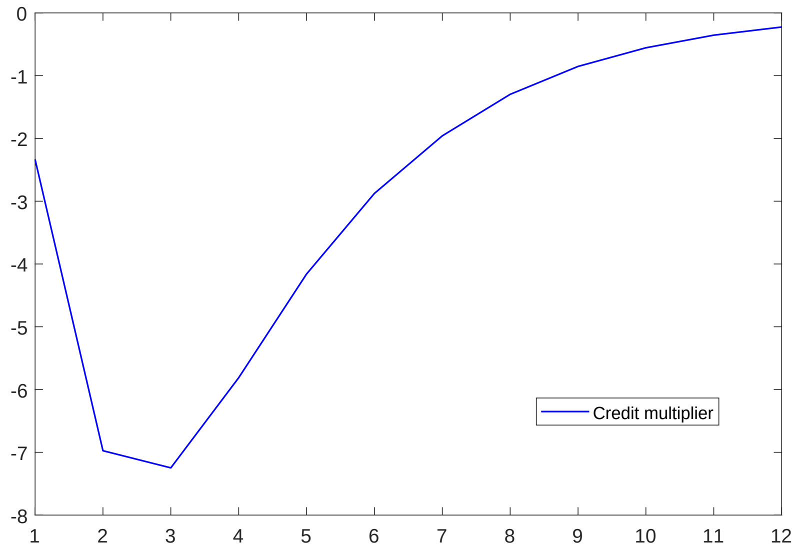


Figure 9. Response of the credit share $l_t/(\mu_t m_{t-1}/(1+\pi_t))$ to a positive shock. y axis: percentage deviations from steady state. x axis: quarters after the shock.

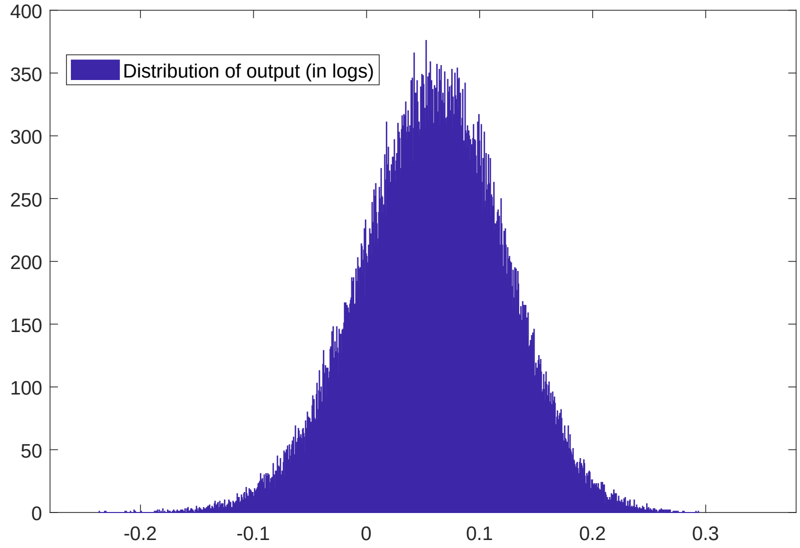
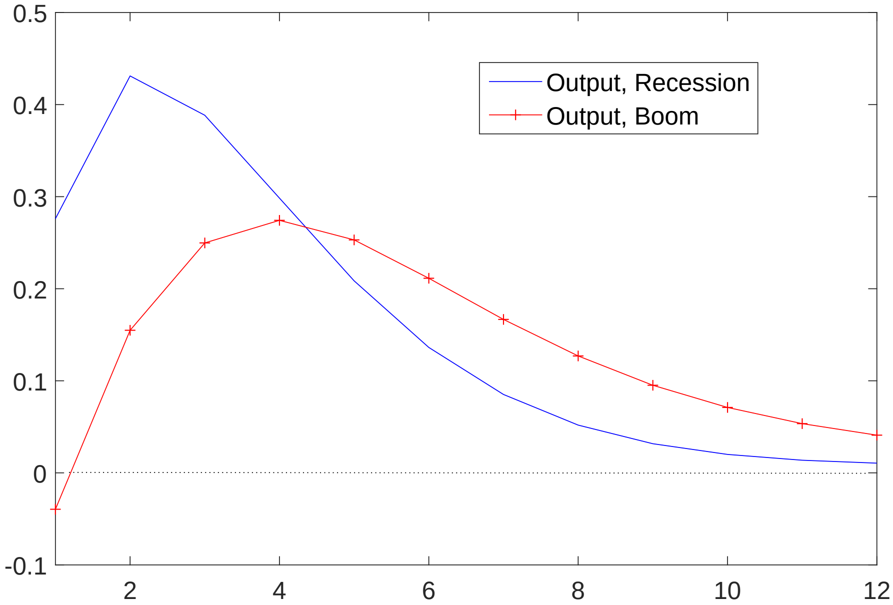


Figure 10. Simulated distribution of the log of output in period 100, for 100'000 simulated trajectories.



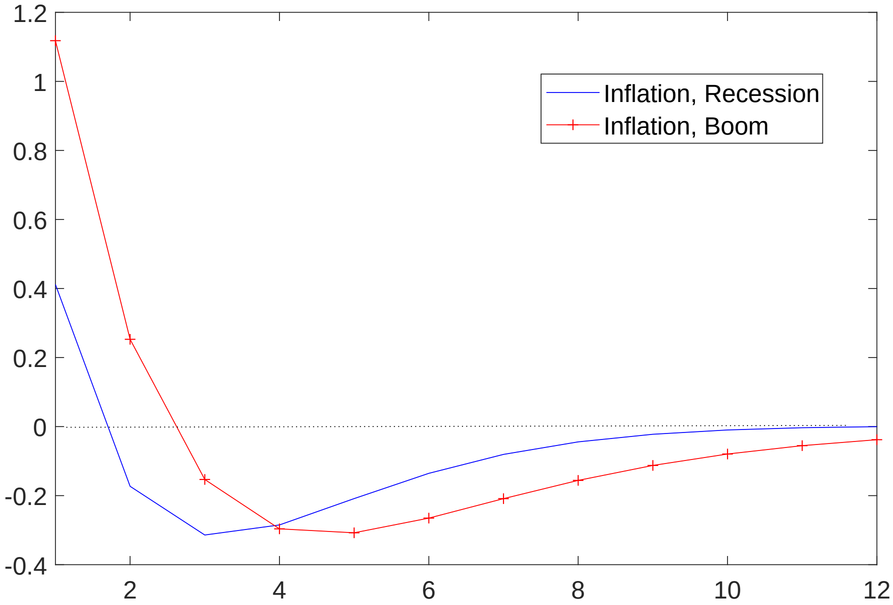


Figure 11. Impulse response of output and inflation in the boom and recession states. y axis: percentage deviation from steady state. x axis: quarters after the shock.

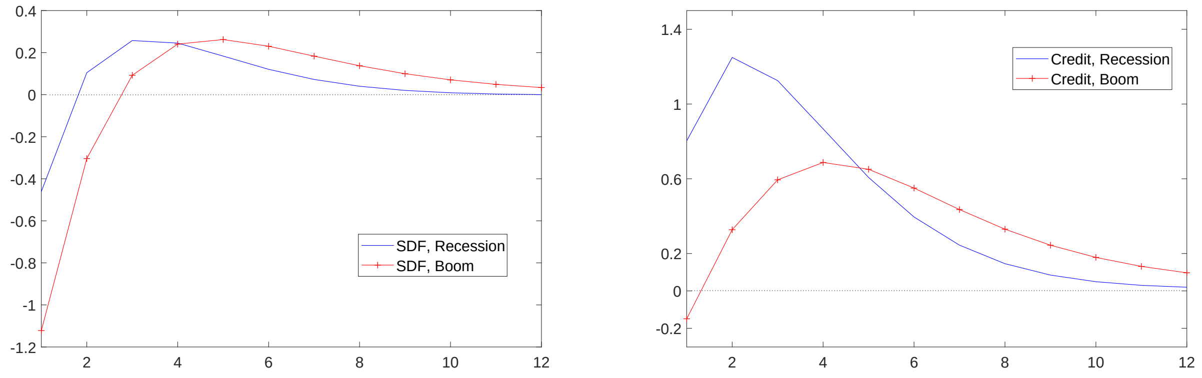


Figure 12. Impulse response of the stochastic discount factor and credit in the boom and recession states. y axis: percentage deviation from steady state. x axis: quarters after the shock.

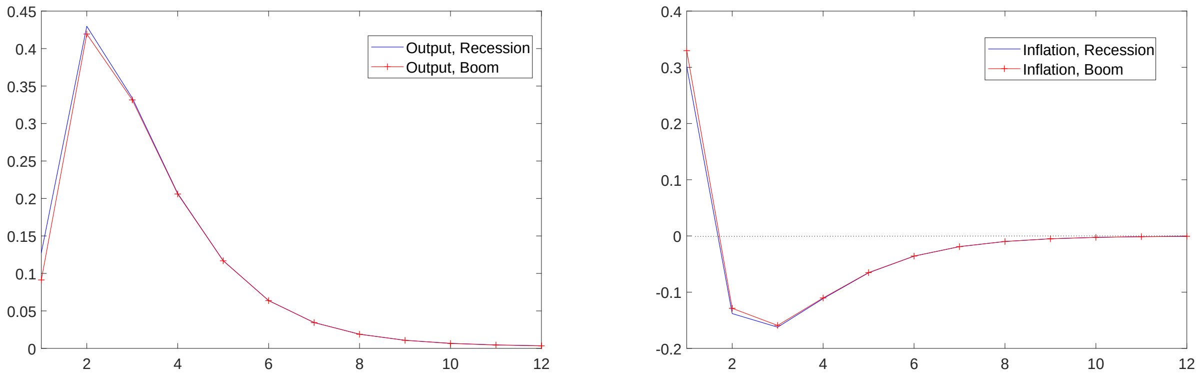


Figure 13. Impulse response output and inflation in the model without habits ($\tau = 1$). y axis: percentage deviation from steady state. x axis: quarters after the shock.

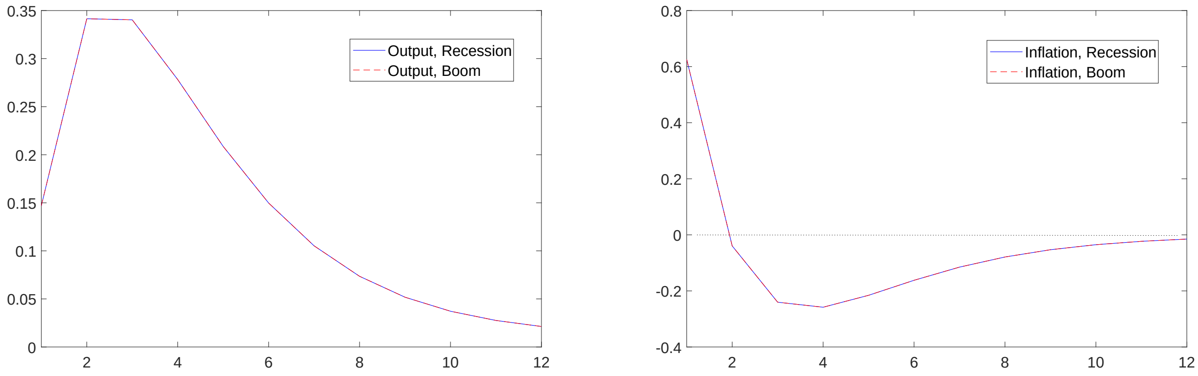


Figure 14. Impulse response output and inflation in the benchmark model when the model is solved using a first-order approximation. y axis: percentage deviation from steady state. x axis: quarters after the shock.

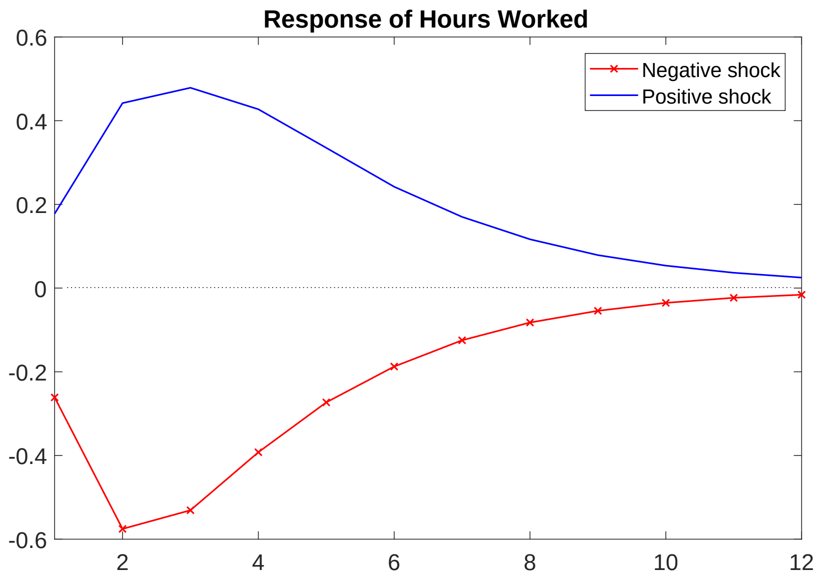


Figure 15. Impulse response of hours worked to an expansionary and contractionary monetary policy shock. y axis: percentage deviation from steady state. x axis: quarters after the shock.

10 Data Appendix

Data appendix to section 3

Variables	Description	Source
Output, y	GDP	Stat. Office of the EC
	EA 19, mio of chained 2010 Euros	1995q1-2011q4
Consumption, c	Final consumption expenditures	Stat. Office of the EC
	EA 19, mio of chained 2010 Euros	1995q1-2011q4
Investment, x	Gross capital formation	Stat. Office of the EC
	EA 19, mio of chained 2010 Euros	1995q1-2011q4
Deposits, d	Total deposits of Euro area Households	ECB
	Amount outstanding	1997q3-2011q4
Central bank's balance sheet, m	Eurosystem balance sheet	ECB
	Bio of euros	1997q3-2011q4
Inflation, π	Harmonized index of consumer prices	ECB
	2015=100, EA 11-19	1990q1-2011q4
Risk-free rate, i_B	French 13 weeks T-bill rate	IFS
	percent per annum	1970q1-2011q4
Real risk-free rate, i_R	French 13 weeks T-bill rate	IFS and INSEE
	minus French CPI inflation	1970q1-2011q4
Lending rate, i_L	Loans to Non-financial corporations	ECB
	Amounts $\leq$1mio, maturity less than a year	2000q1-2011q4
Deposit rate, i_D	Deposits households and NPISH 's	ECB
	Maturity less than a year	2000q1-2011q4

11 Technical Appendix[10]

11.1 The competitive equilibrium

Households

$$\max_{c_t,s_t,b_t,N_t,m_t,x_t,h_t} E_0 \sum_{t=0}^{\infty} \widehat{\beta}^t \frac{\left(c_t^{\kappa} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) - h_{t-1}\right)^{1-\sigma}}{1-\sigma}$$

where:

$$\widehat{\beta} = \widetilde{\beta}\gamma^{1-\sigma}$$

and where to economize on notation, I define:

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

such that:

$$\frac{\mu_t m_{t-1}}{1+\pi_t} = s_t + d_t$$

$$prof_{Tt} + tr_{Gt} + r_{Kt}k_{t-1} + w_t N_t + \frac{\mu_t m_{t-1}}{1+\pi_t} + i_{Dt}d_t + \frac{b_{t-1}}{1+\pi_t} = c_t + x_t + \gamma m_t + \frac{1}{1+i_{Bt}}\gamma b_t$$

$$\gamma k_t = (1-\delta)k_{t-1} + \left(\frac{\theta_1}{1-\epsilon}\left(\frac{x_t}{k_{t-1}}\right)^{1-\epsilon} + \theta_2\right)k_{t-1}$$

$$\gamma h_t = \tau h_{t-1} + (1-\tau)c_t^{\kappa} s_t^{1-\kappa}(\psi + L_t^{\upsilon})$$

First-order conditions:

c_t :

$$\left\{\left[c_t^{\kappa} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) - h_{t-1}\right]^{-\sigma} + (1-\tau)\varphi_t\right\}\kappa c_t^{\kappa-1} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) = \lambda_t$$

N_t :

[10] This section has benefited from comments and suggestions from P. Lieberknecht. Any remaining error is my own responsibility.

$$\left\{\left[c_t^{\kappa}s_t^{1-\kappa}(\psi+L_t^{\upsilon})-h_{t-1}\right]^{-\sigma}+(1-\tau)\varphi_t\right\}c_t^{\kappa}s_t^{1-\kappa}\upsilon L_t^{\upsilon-1}=w_t\lambda_t$$

s_t :

$$\left\{\left(c_t^{\kappa}s_t^{1-\kappa}(\psi+L_t^{\upsilon})-h_{t-1}\right)^{-\sigma}+(1-\tau)\varphi_t\right\}(1-\kappa)c_t^{\kappa}s_t^{-\kappa}(\psi+L_t^{\upsilon})=\lambda_t i_{Dt}$$

m_t :

$$\lambda_t=\beta E_t\lambda_{t+1}\frac{\mu_{t+1}}{1+\pi_{t+1}}+\beta E_t\lambda_{t+1}\frac{\mu_{t+1}i_{Dt+1}}{1+\pi_{t+1}}$$

b_t :

$$\frac{1}{1+i_{Bt}}=\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}$$

k_t :

$$\lambda_t q_t=\beta E_t\lambda_{t+1}q_{t+1}\left[(1-\delta_K)+\frac{\theta_1}{1-\epsilon}\left(\frac{x_{t+1}}{k_t}\right)^{1-\epsilon}+\theta_2-\theta_1\left(\frac{x_{t+1}}{k_t}\right)^{1-\epsilon}\right]+\beta E_t\lambda_{t+1}r_{Kt+1}$$

φ_t :

$$\tau h_{t-1}+(1-\tau)c_t^{\kappa}s_t^{1-\kappa}(\psi+L_t^{\upsilon})-\gamma h_t=0$$

x_t :

$$\varphi_t=\tau\beta E_t\varphi_{t+1}-\beta E_t\left[c_{t+1}^{\kappa}s_{t+1}^{1-\kappa}(\psi+L_{t+1}^{\upsilon})-h_t\right]^{-\sigma}$$

i_t :

$$1=q_t\theta_1\left(\frac{x_t}{k_{t-1}}\right)^{-\epsilon}$$

λ_t :

$$prof_{Tt}+w_tN_t+i_{Dt}\left(\frac{\mu_t m_{t-1}}{1+\pi_t}-s_t\right)+r_{Kt}k_{t-1}-c_t-x_t-\left(\gamma m_t-\frac{\mu_t m_{t-1}}{1+\pi_t}\right)=0$$

The bank

$$\max_{d_t, l_t} \pi_{Ft} = i_{Lt} l_t - i_{Dt} d_t - \chi l_t$$

such that:

$$l_t = d_t$$

First-order condition:
d_t :

$$i_{Lt} = i_{Dt} + \chi$$

The firm

$$\max_{k_{t-1}, N_t, l_t} prof_{Ft} = A_t k_{t-1}^{\alpha} N_t^{1-\alpha} - w_t N_t - r_{Kt} k_{t-1} - i_{Lt} l_t$$

such that:

$$l_t \geq w_t N_t + r_{Kt} k_{t-1} + \eta k_{t-1}$$

First-order conditions:
N_t :

$$w_t = (1-\alpha) \frac{y_t}{N_t} \frac{1}{1 + \frac{\varpi_t}{\lambda_t}}$$

k_t :

$$\alpha \frac{y_t}{k_{t-1}} = \left(1 + \frac{\varpi_t}{\lambda_t}\right) r_{Kt} + \frac{\varpi_t}{\lambda_t} \eta$$

l_t :

$$i_{Lt} = \frac{\varpi_t}{\lambda_t}$$

ϖ_t :

$$l_t = w_t N_t + r_{Kt} k_{t-1} + \eta k_{t-1}$$

The central bank

$$tr_{CBt} = \gamma m_t - \frac{m_{t-1}}{1+\pi_t}$$

$$i_{Bt} = \overline{i_B} + \phi_\pi(\pi_t - \pi^*)$$

The government

$$tr_{Gt} = tr_{CBt} + \frac{1}{1+i_{Bt}}\gamma b_t - \frac{b_{t-1}}{1+\pi_t}$$

Market clearing condition

$$A_t k_{t-1}^{\alpha} N_t^{1-\alpha} = c_t + x_t$$

11.2 Deterministic steady state analysis

Interest rate:

$$i_D = i_B = \frac{1+\pi}{\beta} - 1$$

$$i_L = \frac{\varpi}{\lambda} = i_D + \chi$$

Inflation:

$$\pi = \pi^*$$

Capital to output ratio:

$$\frac{k}{y} = \frac{\beta\alpha}{(1-\beta(1-\delta_K))\left(1+\frac{\varpi}{\lambda}\right) + \beta\frac{\varpi}{\lambda}\eta}$$

where

$$\theta_1 = \left(\frac{x}{k}\right)^{\epsilon}$$

$$\theta_2 = -\frac{\epsilon}{1-\epsilon}\left(\frac{x}{k}\right)$$

So that adjustment costs have no effect on the deterministic steady state of the model. Output

$$y = A\left(\frac{k}{y}\right)^{\frac{\alpha}{1-\alpha}} N$$

Consumption:

$$\frac{c}{y} = 1 - \frac{x}{y}$$

and where:

$$\frac{x}{k} = \gamma - (1 - \delta_K)$$

Transaction services:

$$s = \frac{1-\kappa}{\kappa}\frac{c}{i_D}$$

Credit:

$$l = y\frac{1}{1+\frac{\varpi}{\lambda}} + \frac{1}{1+\frac{\varpi}{\lambda}}\eta k$$

Labor supply parameter ψ for a given value of N.

$$\psi = \frac{\left(1+\frac{\varpi}{\lambda}\right) N\upsilon L^{\upsilon-1}\frac{c}{y}}{(1-\alpha)\kappa} - L^{\upsilon}$$

11.3 The dynamic system

Controls: c, N, L, x, s, l, d, y

States: k, h, m

Co-states: $\lambda, \varphi, \pi, q, i_L, i_D, i_B, \varpi$.

Exogenous: A, μ

$$\left\{\left[c_t^{\kappa} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) - h_{t-1}\right]^{-\sigma} + (1-\tau)\varphi_t\right\} \kappa c_t^{\kappa-1} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) = \lambda_t$$

$$\left\{\left[c_t^{\kappa} s_t^{1-\kappa}(\psi + L_t^{\upsilon}) - h_{t-1}\right]^{-\sigma} + (1-\tau)\varphi_t\right\} c_t^{\kappa} s_t^{1-\kappa} \upsilon L_t^{\upsilon-1} = (1-\alpha)\frac{y_t}{N_t}\frac{1}{1+\frac{\varpi_t}{\lambda_t}}\lambda_t$$

$$c_t(1-\kappa) = \kappa i_{Dt} s_t$$

$$\lambda_t = \beta E_t \lambda_{t+1} \mu_{t+1} \frac{1 + i_{Dt+1}}{1 + \pi_{t+1}}$$

$$\frac{1}{1 + i_{Bt}} \lambda_t = \beta E_t \frac{\lambda_{t+1}}{1 + \pi_{t+1}}$$

$$1 = q_t \theta_1 \left(\frac{x_t}{k_{t-1}} \right)^{-\epsilon}$$

$$\lambda_t q_t = \beta E_t \lambda_{t+1} q_{t+1} \left((1 - \delta_K) + \frac{\theta_1}{1-\epsilon} \left(\frac{x_{t+1}}{k_t} \right)^{1-\epsilon} + \theta_2 - \theta_1 \left(\frac{x_{t+1}}{k_t} \right)^{1-\epsilon} \right) + \beta E_t \lambda_{t+1} \left(\frac{\alpha \frac{y_{t+1}}{k_t} - \frac{\varpi_{t+1}}{\lambda_{t+1}} \eta}{1 + \frac{\varpi_{t+1}}{\lambda_{t+1}}} \right)$$

$$\varphi_t = \tau \beta E_t \varphi_{t+1} - \beta E_t \left[c_{t+1}^{\kappa} s_{t+1}^{1-\kappa} (\psi + L_{t+1}^{\upsilon}) - h_t \right]^{-\sigma}$$

$$i_{Bt} = \overline{i_B} + \phi_\pi (\pi - \pi^*)$$

$$y_t = c_t + x_t$$

$$l_t = y_t \frac{1}{1 + \frac{\varpi_t}{\lambda_t}} + \frac{1}{1 + \frac{\varpi_t}{\lambda_t}} \eta k_{t-1}$$

$$l_t = d_t$$

$$i_{Lt} = i_{Dt} + \frac{\chi_t}{\lambda_t}$$

$$\frac{\mu_t m_{t-1}}{1 + \pi_t} = s_t + d_t$$

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

$$i_{Lt} = \frac{\varpi_t}{\lambda_t}$$

$$(1-\delta)k_{t-1} + \left(\frac{\theta_1}{1-\epsilon} \left(\frac{x_t}{k_{t-1}} \right)^{1-\epsilon} + \theta_2 \right) k_{t-1} - \gamma k_t = 0$$

$$\tau h_{t-1} + (1-\tau) c_t^{\kappa} s_t^{1-\kappa} (\psi + L_t^{\upsilon}) - \gamma h_t = 0$$

$$1 = L_t + N_t$$

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

$$\log(\mu_t) = \rho_\mu \log(\mu_{t-1}) + \varepsilon_{\mu t}$$

Acknowledgements

The views expressed in this article are my own and do not represent the views of the ECB or the Eurosystem. The impulse response analysis performed in Section 6 has benefited from comments and suggestions from M. Juillard. This draft has benefited from comments and suggestions from seminar participants at University of Glasgow, the 2018 Zeuthen Worskhop and from G. Bekaert, M. Ehrmann, N. Kyotaki, G. Primiceri, P. Lieberknecht and W. den Haan. Any remaining errors are my own responsibility.

Ivan Jaccard

European Central Bank, Frankfurt am Main, Germany; email: ivan.jaccard@ecb.europa.eu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

PDF ISBN 978-92-899-3279-0 ISSN 1725-2806 doi:10.2866/81461 QB-AR-18-054-EN-N