

The Effects of Government Bond Purchases on Leverage Constraints of Banks and Non-Financial Firms*

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This paper investigates how government bond purchases affect leverage-constrained banks and non-financial firms by utilizing a stochastic general equilibrium model. My results indicate that government bond purchases not only reduce non-financial firms' borrowing costs, amplified through a reduction in expected defaults, but also lower banks' profit margins. In an economy in which loans priced at par dominate in banks' balance sheets—as a reflection of the euro area's structure—the leverage constraint of non-financial firms is relaxed while that of banks tightens. I show that the leverage constraint in the non-financial sector plays an essential role in transmitting the impulses of government bond purchases to the real economy. In a bank-financed economy, this channel mainly controls the positive impulse on output and inflation following from government bond purchases, although the soundness of the financial sector deteriorates. This paper adds a new perspective to the discussion regarding the efficacy of government bond purchases as a policy tool.

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1. Introduction

Asset purchase programs have been introduced by several central banks over the past few years as additional policy measures designed to support real economic activity. The basic idea behind government bond purchases as a policy tool is to reduce medium- and long-term interest rates for the purpose of positively affecting consumption and investment decisions. The slope of the yield curve, however, is evidently positively related to bank profitability (English, Van den Heuvel, and Zakrajsek 2012; Borio, Gambacorta, and Hofmann 2015). From this point of view, government bond purchases also have the potential to undermine profitability in the banking sector.

In this paper, I shed more light on this relationship and its consequences by investigating the effects of government bond purchases on banks' and non-financial firms' equity when both sectors are leverage constrained. I draw on the structure of a bank-based economy which is similar to that of the euro area. The main contribution of this paper is to show that the success of government bond purchases as a policy tool for stimulating output and inflation depends on how they affect financial health in the non-financial and financial sectors. Leverage constraints in the non-financial sector tend to be relaxed, while they become more binding in the banking sector because bank profits vanish. The focus on two leverage constraints allows me to discuss transmission channels of government bond purchases in which the interplay of the leverage constraints is responsible for the effects on real economic activity. This setting makes it possible to scrutinize why a decline in bank profits can occur and what consequences this has on the economy.

Government bond purchases generate their effects mainly through portfolio rebalancing (e.g., Gagnon et al. 2011; Krishnamurthy and Vissing-Jorgensen 2011). By reducing the supply of bonds available to the market, bond prices rise, while (expected) returns fall, which induces the holders of such assets to invest in other assets. As a direct consequence, term premiums fall (English, Van den Heuvel, and Zakrajsek 2012). Furthermore, shifts in banks' portfolios will reduce the interest on borrowings, and borrowing conditions in the non-financial sector might eventually improve. In general, the pricing of assets is heavily influenced by the balance sheet constraint of financial intermediaries,

such as banks as the main holders of financial assets (e.g., He and Krishnamurthy 2013). The risk-bearing capacity of intermediaries, which is synonymous with their financial soundness, determines a large part of non-financial firms' borrowing costs (Gilchrist and Zakrajsek 2012). Another relevant part of non-financial firms' borrowing costs is related to expected defaults which might ultimately decline following an asset purchase program (Gilchrist and Zakrajsek 2013). Therefore, by influencing long-term interest rates, government bond purchases simultaneously affect the financial health of the non-financial sector and the financial sector.

Bank equity can be stimulated through government bond purchases by rising asset prices (the balance sheet channel as described by Krishnamurthy 2010 and Gertler and Karadi 2011, 2013). A relevant assumption in this regard is that assets are priced mark-to-market, i.e., valued at their current market price, which is why asset prices determine bank equity (Adrian and Shin 2010). Loans are usually priced at par, while bonds are mark-to-market. For loans, the asset price effect on bank equity, i.e., the balance sheet channel, is therefore irrelevant because the face value matters, whereas the balance sheet channel is important for holdings of bonds. Hence, accounting effects might also control the way in which and how strongly government bond purchases affect the economy with lending as the transmission channel because they have an impact on the tightness of intermediaries' balance sheet constraint (Adrian, Moench, and Shin 2010). Moreover, in reality other agents like households also hold government bonds for saving purposes. Changing relative returns might, in turn, also influence consumption decisions rather than investment (e.g., Chen, Cúrdia, and Ferrero 2012).

I draw on a fully specified New Keynesian general equilibrium model which is able to capture these facts. I utilize a framework in which leverage-constrained banks play the most important role in financial intermediation and hold loans priced at par value in addition to corporate bonds and government bonds priced mark-to-market. Furthermore, non-financial firms are subject to an agency problem related to the fact that they can default on their obligations from which a leverage constraint results. Purchases are conducted by an intervention authority which reduces the supply of government bonds available to banks and households. The paper is able to provide results from two different domains: Firstly, it

presents new results on how government bond purchases affect the economy based upon the interplay between a leverage-constrained non-financial sector and leverage-constrained banks. Secondly, it also allows for assessing the strength of their impact on the euro area's economy. Estimating the model helps to find parameter values for the elements controlling not only the propagation channels but also the size of the effects. In this regard, the estimated model is able to match business cycle characteristics in both the real and the financial sectors. Asset price increases can stimulate bank equity, while a decrease in returns on bank assets might place downward pressure on bank equity through a fall in bank profits. The relative importance of these channels is an empirical question and the estimation is able to provide evidence for its importance, as the model allows for both transmission channels.

My results show that outright purchases of government bonds tend to weaken bank net worth through a drop in returns on banks' assets as a consequence of portfolio rebalancing effects in the banking sector, while real economic activity improves. Through my model, I am able to show that lower borrowing conditions for firms alleviate their leverage constraint by raising net worth, for which reason their financial health improves (credit channel). The prevalence of loans priced at par contributes to depressing the financial health of banks by weakening bank equity in the medium run owing to the decline in returns on banks' assets. The resulting deleveraging need in the banking sector basically constrains the credit supply and dampens the expansion in loans. The often-discussed balance sheet channel does not offset the negative effects on bank net worth as a result of the fall in loan rates. Based upon a counterfactual analysis, it turns out that larger financial frictions in the non-financial corporate sector raise the efficiency of bond purchases, because reductions in borrowing costs have stronger effects on that sector's financial soundness. The model allows me to show that the credit channel in a bank-based economy has a quantitative equivalent to the balance sheet channel in a market-based economy in terms of stimulating output.

The remainder of the paper is structured as follows. I start in section 2 with a brief review of the literature. Section 3 provides a description and derivation of the model. Section 4 contains the empirical analysis before dynamics from simulations of the model are presented in section 5. Section 6 concludes.

2. Literature Review

In this section, I review the literature which is closely related to my paper. There are several contributions in the literature which deal with government bond purchases in general equilibrium. One strand focuses on affecting predominantly savings (and consumption) decisions by altering the return on households' assets (Chen, Cúrdia, and Ferrero 2012; Jones and Kulish 2013; Ellison and Tischbirek 2014), in which case the channel is similar to standard monetary policy. Compared with these approaches, I place a stronger emphasis on the banking sector and the impact on capital production. Models like that of Chen, Cúrdia, and Ferrero (2012), for example, cannot be used for the present research question because they do not feature a financial sector which is leverage constrained.¹ In this regard, my approach is closely related to Gertler and Karadi (2013) and Carlstrom, Fuerst, and Paustian (2017). While the banking sector shares elements of Gertler and Karadi (2013), I introduce a second leverage constraint on behalf of the non-financial firms and additionally allow for both loans priced at par and corporate bonds in banks' balance sheet. Carlstrom, Fuerst, and Paustian (2017) also allow for two constraints affecting investment decisions. Regarding the banking sector, their approach and mine also start from an incentive problem for bankers. However, my second constraint is related to firms' net worth, i.e., a leverage constraint arises as it does in the banking sector, while theirs is a "loan-in-advance" constraint which binds the market value of funds to the market value of investment opportunities. Hence, the role of net worth on investment decisions cannot be investigated. A combination of a leverage-constrained banking sector with a leverage-constrained non-financial sector can also be found in Hirakata, Sudo, and Ueda (2011), Sandri and Valencia (2013), Zeng (2013), and Rannenberg (2016).² In contrast to these papers, my focus is on government bond purchases, and my model introduces three assets to banks' balance sheet with an important role

¹Although they allow for constraints in the household sector, there is no role for leverage constraints in the non-financial sector.

²In this respect, the present model is closely related to Rannenberg (2016), who combines a costly state verification problem with an incentive-compatibility constraint in the banking sector.

for portfolio rebalancing. Cúrdia and Woodford (2011) investigate asset purchases and treat several inefficiencies in financial intermediation which are imposed exogenously. In the present model, similar inefficiencies evolve endogenously by giving a role to leverage. The purchases in my model are initially financed by issuing agency debt, whereas this modeling device can also be found in Gertler and Karadi (2011). Since it is assumed that the agency has full credibility, it pays the risk-free rate on its debt. There is also a feedback to taxpayers in the present model. If profits (or losses) are realized, they are redistributed to the fiscal authority, which has to adjust (lump-sum) taxes to keep the government solvent. Hence, I additionally introduce the possibility of feedback effects on taxes, which takes into account elements discussed by Christiano and Ikeda (2013). My paper also shares similarities with Darracq Pariès and Kühn (2016), in which a similar model is used. However, the focus of their paper is on optimal government bond purchases.

3. Model

A standard dynamic New Keynesian (DNK) model following Smets and Wouters (2003) and Christiano, Eichenbaum, and Evans (2005) is extended to include a financial sector with borrowing constraints between all borrowers and lenders in the private sector. In this respect, I assume that there are borrowing constraints between the real sector and the financial market and between the bank and its creditors. While, in the first case, lenders are confronted with a costly state verification problem, as outlined in Bernanke, Gertler, and Gilchrist (1999), the agency problem between the bank and its lenders is modeled as proposed by Gertler and Kiyotaki (2010). This allows me to abstract from default problems in the banking sector.³ The model consists of households, two types of entrepreneur, intermediate goods firms, final goods firms, mutual funds, banks, and a public sector as active agents.

A continuum of households saves, consumes, and supplies labor to the intermediate goods firms. Households receive income from labor and from financial assets to consume a bundle of final goods,

³Such a framework is discussed by Rannenberg (2016) and also utilized in Kühn (2014a).

purchased from final goods firms. The financial wealth of households arises from holdings of government bonds and bank deposits.

I start from Bernanke, Gertler, and Gilchrist (1999) but distinguish between two types of entrepreneur (type A and type B entrepreneurs) in order to introduce a role for different debt instruments. Both entrepreneurs process newly produced physical capital, which is exposed to the individual skills of each entrepreneur and is then rented out to intermediate goods firms. The two types of entrepreneur own different types of capital which are both used complementarily in the production of intermediate goods. Both types of entrepreneur can finance their projects by raising external funds in excess of their net worth. The goods-producing sector is similar to Smets and Wouters (2003). The two types of physical capital are rented out to intermediate goods firms, which combine physical capital with rented labor to produce differentiated intermediate goods. The intermediate goods firms sell their goods in a market of monopolistic competition to final goods producers. Finally, the final goods firms bundle the differentiated goods into a homogeneous final good. The final good can be used for consumption, in capital utilization, as investment goods, or as government expenditures. Banks receive funds from households (short-term debt) and invest in loans, corporate bonds, and government bonds.⁴

3.1 Households

The economy is populated by a continuum of households which are indexed by h with $h \in (0, 1)$. Each h -th household decides on the supply of labor, how much to consume and to save, and on the allocation of its wealth. Households' utility function is given in equation (1),

$$E_0^j \sum_{j=0}^{\infty} \beta^j \left[\ln (C_{h,t+j} - h^C C_{h,t-1+j}) - \kappa \nu_{t+j}^N \frac{(N_{h,t+j})^{1+\varphi}}{1+\varphi} \right], \quad (1)$$

with discount factor β , a scaling parameter κ , the inverse Frisch elasticity φ , and a shock to labor supply ν_t^N , which follows a

⁴A rough sketch of the model can be found in figure 21 in the online appendix, available at <http://www.ijcb.org>.

stationary AR(1) process. The term h^C reflects the internal habits in consumption $C_{h,t}$ with $h^C \in (0, 1)$.

The households supply differentiated labor services ($N_{h,t}$) to the intermediate goods sector. Because of a monopolistically competitive labor market in which labor services are imperfect substitutes, each household has market power to set its nominal wage (W_t). Following Erceg, Henderson, and Levin (2000), I assume, by analogy with Calvo pricing, that the household is not able to renegotiate its nominal wage in each period. Instead, it can only reoptimize with a specific probability $(1 - \gamma^w)$. In periods in which the household cannot renegotiate, it follows an indexation rule $\tilde{W}_t = \tilde{\pi}_{w,t} W_{t-1}$, with

$$\tilde{\pi}_{w,t} = (\pi_{t-1})^{\xi_w} (\pi)^{1-\xi_w} (z_t)^{\xi_z} (z_s)^{1-\xi_z},$$

where ξ_w is the weighting parameter for the past rate of inflation and ξ_z the weighting parameter for the shock to the growth rate of technology z_t . Related to this, z_s is the steady-state growth rate of a non-stationary productivity process. A labor agency is introduced that buys differentiated labor from households and pays the individual wage in order to produce a representative labor aggregate as output

$$N_t = \left[\int_0^1 N_{h,t}^{\frac{1}{\lambda_w}} dh \right]^{\lambda_w}, \quad (2)$$

where λ_w represents the degree of substitution and is the markup of the wage over the household's marginal rate of substitution. By minimizing the costs of producing this aggregator, the labor agency takes the wage rates of each differentiated labor input $W_{h,t}$ as given. From this optimization problem there follows the demand for labor of household h for use in goods production

$$N_{h,t} = N_t \left(\frac{W_{h,t}}{W_t} \right)^{\frac{\lambda_w}{1-\lambda_w}}. \quad (3)$$

By combining equations (2) and (3), one obtains the aggregate wage index

$$W_t = \left[\int_0^1 W_{h,t}^{\frac{1}{1-\lambda_w}} dh \right]^{1-\lambda_w}. \quad (4)$$

With the knowledge of demand for its labor, the household can proceed with determining the optimal wage rate ($W_{h,t}^*$) and the optimal labor supply ($N_{h,t}^*$). Thus, it maximizes

$$\max_{\{W_{h,t}\}} E_t \sum_{s=0}^{\infty} (\beta\gamma_w)^s \left[-\kappa V_{t+s}^N \frac{\left(N_{h,t+s}^*\right)^{1+\varphi}}{1+\varphi} + \lambda_{h,t+s} \frac{\Psi_{t+s}^w (1-\tau^w) W_{h,t}^* N_{h,t+s}^*}{P_{t+s}} \right] \quad (5)$$

by making use of equation (3). Households pay taxes on their labor income with the tax rate τ^w . Marginal utility of consumption is denoted by $\lambda_{h,t}$ and the price level by P_t . Changes in rates of inflation until date s , which are important for indexation, are summarized in Ψ_{t+s}^w in equation (5). Before utility maximization is carried out, the optimal nominal wage emerges from a sub-problem in which the household minimizes its disutility of labor by choosing its nominal wage given the labor demand of firms.⁵

It is assumed that some household members leave the household sector for a random period of time. A specific group of them becomes bank managers, who operate banks, while another group becomes entrepreneurs who conduct investment projects in the real sector.⁶ The remaining household members place deposits (D_t) with banks, and buy risk-free long-term government bonds ($B_t^{gov,H}$) and (short-term) bonds issued by a public agency (B_t^{IA}). On holdings of agency's bonds they receive the risk-free rate i_t , while they obtain the risk-free return $r_t^{B,gov}$ on long-term government bonds which are traded at price $Q_t^{B,gov}$ expressed in real terms.⁷ Deposits earn interest based upon the short-term interest rate r_t^D .

In order to allow for longer-term bonds, I follow Woodford (2001) and assume that only a fraction of the government bonds ($1-\rho^{B,gov}$)

⁵The derivation is presented in the online appendix.

⁶A more detailed description can be found in the online appendix.

⁷Below, I mean “default free” when I talk about risk-free rates and spreads.

issued during the last period are repaid in this period.⁸ Regarding the definition of the nominal bond rate ($r_t^{B,gov}$), I obtain

$$r_t^{B,gov} = \pi_t \left(\frac{\rho^{B,gov} Q_t^{B,gov} + 1}{Q_{t-1}^{B,gov}} \right) - 1 \quad (6)$$

as the period return.⁹ In addition, holdings of government bonds are related to costs

$$\Theta_t^{gov,H} = \frac{v^{B,gov}}{2} \left(B_{h,t}^{gov,H} - B_h^{gov,H} \right)^2 Q_{h,t}^{B,gov} + \tau^{B,gov} Q_{h,t}^{B,gov} B_{h,t}^{gov,H} \quad (7)$$

with $v^{B,gov}$ and $\tau^{B,gov}$ as scaling parameters and $B_h^{gov,H}$ as the steady-state holdings of government bonds. The cost function in equation (7) captures two ideas. The first part on the right-hand side takes into account arguments from the “preferred-habitat” theory of the term structure (as argued by Gertler and Karadi 2013), while the last part borrows a little from the literature on trading costs (see Harris and Piwowar 2006, for example).¹⁰

Households receive income from dividend payments ($Div_{h,t}$) provided by intermediate goods firms and capital producers, from their

⁸In Woodford (2001) $\rho^{B,gov}$ is interpreted as exponentially decaying coupons. This statement is economically equivalent to the representation here, as the coupon payment is one. Chen, Cúrdia, and Ferrero (2012) also allow for a maturity structure. While they use the yield to maturity in their model, I draw on the period return as done by Woodford (2001) (see page 685 therein).

⁹Consequently, the yield to maturity can be expressed as $r_{ytm,t}^{B,gov} = \pi_t \left(\rho^{B,gov} + \frac{1}{Q_t^{B,gov}} \right) - 1$ by using the relationship between the yield to maturity and the period return, $r_t^{B,gov} = \left(1 + r_{ytm,t}^{B,gov} \right) \frac{Q_t^{B,gov}}{Q_{t-1}^{B,gov}} - 1$. This relationship is derived in section H in the online appendix. The yield to maturity is utilized by Chen, Cúrdia, and Ferrero (2012), for example. More details can be found in the technical appendix of Chen, Cúrdia, and Ferrero (2012). The yield to maturity is effectively used as the observable in the estimation of my model.

¹⁰Harris and Piwowar (2006) propose different functions capturing trading costs which are related to transactions. For municipal bonds in the United States, transaction costs fall with larger transactions and vanish with large trades. However, fixed costs also play a role by looking at equations (1) and (6) in their model. I translate their arguments into the functional form above.

supply of labor, and from investments in financial assets. Following Erceg, Henderson, and Levin (2000), households are assumed to buy state-contingent securities with a lump-sum transfer to equalize income differences among the continuum of households. Households' expenditures are allotted to consumption; to lump-sum taxes; to transfers including payments to capital producers, entrepreneurs, and bank managers, $\Xi_{h,t}$; and to the purchases of financial assets, i.e., public-sector bonds, corporate bonds, and deposits.

The budget constraint in real terms becomes

$$\begin{aligned} & (1 + i_{t-1}) \frac{B_{h,t-1}^{n,IA}}{P_t} + (1 + r_t^{B,gov}) \frac{Q_{t-1}^{B,gov} B_{h,t-1}^{n,gov,H}}{P_t} \\ & + (1 + r_{t-1}^D) \frac{D_{h,t-1}^n}{P_t} + (1 - \tau^w) \frac{W_{h,t}}{P_t} N_{h,t} + \frac{Div_{h,t}}{P_t} + \Xi_{h,t} \\ & \geq (1 + \tau^C) C_{h,t} + T_t + \frac{D_{h,t}^n}{P_t} + \frac{B_{h,t}^{n,IA}}{P_t} + \frac{Q_t^{B,gov} B_{h,t}^{n,gov,H}}{P_t} + \Theta_t^{gov,H}, \end{aligned}$$

where the superscript n denotes nominal terms. Households pay taxes on their labor income and on their consumption expenditures, τ^w and τ^C , respectively.

From the no-arbitrage conditions it follows that each household holds the same amount of assets, which is why I can aggregate easily. All first-order conditions can be found in the online appendix.

3.2 Final Goods Firms

The final good (Y_t) is a composite of the continuum of differentiated intermediate goods purchased from all i monopolistic competitive firms in the intermediate goods market which is populated by perfectly competitive final goods producers

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{1}{\lambda_{p,t}}} di \right]^{\lambda_{p,t}}, \quad (8)$$

where $\lambda_{p,t}$ represents the markup of prices over marginal costs. It follows a stationary stochastic AR(1) process in logs with a non-zero mean.

By taking the prices of the intermediate goods as well as the price of the final good as given, the final goods firm maximizes its profits

by choosing the amount of intermediate goods and the amount of output of final goods. From the optimization problem there follows the demand function for intermediate goods

$$Y_{i,t} = Y_t \left(\frac{P_{i,t}}{P_t} \right)^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}}, \quad (9)$$

where P_{it} is the price of the i -th intermediate good and P_t the price of the final good.

3.3 Intermediate Goods Firms

A continuum of the intermediate goods firms with mass one plan to rent capital ($\tilde{K}_{i,t}$) from the entrepreneurs and homogeneous labor ($\tilde{N}_{i,t}$) from the households for use in production. Intermediate goods arise following a standard production function of the Cobb-Douglas type with constant returns to scale and fixed costs (Ω)

$$Y_{i,t} = A_t \left(\tilde{K}_{i,t} \right)^\alpha \left(Z_t \tilde{N}_{i,t} \right)^{1-\alpha} - Z_t \Omega_i, \quad (10)$$

where the term α is the share of capital in production. The production technology is affected by a (stationary) shock to total factor productivity A_t which follows an AR(1) process in logs and a non-stationary technology shock Z_t , whereas its growth rate follows an AR(1) process in logs, i.e., $\log(z_t) \equiv \log(Z_t/Z_{t-1}) = (1 - \rho_z) \log(z_s) + \rho_z \log(Z_{t-1}/Z_{t-2}) + \epsilon_{z,t}$, with ρ_z as the autoregressive parameter and $\epsilon_{z,t}$ as the iid innovation. I allow for different types of capital in the production process such that the stock of capital is a composite index. I modify the production technology because I later introduce two different debt instruments. For this reason, I will attribute the production of one capital good to one specific debt instrument.¹¹

¹¹Bernanke, Gertler, and Gilchrist (1999) and Fisher (1999) also introduce heterogeneous financially constrained firms and proceed similarly. Unlike them, I do not introduce two complete goods-producing sectors with fixed-input shares and a bundling technology to produce the final good. Instead, I split up the physical stock of capital. This approach allows me in a sense to endogenize the financing decision in terms of the intermediate goods by varying the capital input. Carlstrom, Fuerst, and Paustian (2010) distinguish between two different types of

Firms minimize their real costs by choosing inputs given their production technology. Thus,

$$\min_{\{\tilde{K}_{i,t}^A, \tilde{K}_{i,t}^B, \tilde{N}_{i,t}\}} r_t^{k,A} \tilde{K}_{i,t}^A + r_t^{k,B} \tilde{K}_{i,t}^B + w_t \tilde{N}_{i,t}$$

$$s.t. \quad Y_{i,t} = A_t \left(\tilde{K}_{i,t} \right)^\alpha \left(Z_t \tilde{N}_{i,t} \right)^{1-\alpha} - Z_t \Omega_i \tag{11}$$

$$\text{and } \tilde{K}_{i,t} = \left((\zeta^K)^{\frac{1}{\gamma^K}} \left(\tilde{K}_{i,t}^A \right)^{\frac{\gamma^K-1}{\gamma^K}} + (1 - \zeta^K)^{\frac{1}{\gamma^K}} \left(\tilde{K}_{i,t}^B \right)^{\frac{\gamma^K-1}{\gamma^K}} \right)^{\frac{\gamma^K}{\gamma^K-1}} . \tag{12}$$

The terms $r_t^{k,A}$ and $r_t^{k,B}$ are the costs of capital in real terms and w_t is the real wage. The terms A and B refer to type A and B entrepreneurs and ζ^K is the share of utilized type A entrepreneurs' capital in utilized total capital with γ^K as the elasticity of substitution.¹² The first-order conditions for the minimization problem of each intermediate goods firm are presented in the online appendix. With their help it can be shown that the ratio of type B entrepreneurs' capital to type A entrepreneurs' capital as well as the capital-to-labor ratios are the same across all firms.

Following on Calvo (1983), optimal pricing is only possible with a probability of $1 - \gamma$, whereas the remaining fraction of firms that cannot optimize their price set the price equal to its value in the last period multiplied by the past rate of inflation (π_{t-1}) which is weighted by the steady-state rate of inflation (π). Consequently, the optimization problem for adjusting firms becomes

$$\max_{\{P_{i,t}^*\}} E_t \sum_{j=0}^{\infty} \beta^j \lambda_{t+j} \gamma^j [Y_{i,t} (P_{i,t}^* - mc_{i,t+j} P_{t+j})]$$

labor, while one of the two is subject to credit constraints. The model here is basically very similar to their approach, except that I introduce a third input for production and relate credit constraints to two of the inputs. The idea of having two different types of entrepreneurs is akin to Aksoy and Basso (2014), who introduce two types of entrepreneur in order to have a segmentation for short- and long-term debt.

¹²This approach is akin to the one in Krusell et al. (2000), where unskilled and skilled labor are combined. However, I favor the properties of the CES function to have constant elasticities of substitution between the inputs.

subject to equation (9). The optimal price of the intermediate good is denoted by $P_{i,t}^*$ and $mc_{i,t}$ represents the marginal costs. The first-order conditions can be found in the online appendix.

3.4 Capital Producers

The economy is populated by capital producers that are owned by households and work in a market of perfect competition. By doing so, they combine undepreciated physical capital with investment goods of class e ($e \in [A, B]$) to produce new physical capital of the same class.

$$K_t^e = K_{t-1}^e (1 - \delta^e) + I_t^e \left[1 - \Psi \left(\frac{I_t^e}{I_{t-1}^e} \right) \right] \mu_{I,t} \quad (13)$$

Equation (13) presents the law of motion of capital, where K_t^e is the capital stock, δ^e the rate of depreciation, I_t^e the amount of investment goods, and $\mu_{I,t}$ an investment-specific technology shock which follows a stationary AR(1) process in logs and hits both sectors simultaneously. Adjustment costs for investment are denoted by $\Psi \left(\frac{I_t^e}{I_{t-1}^e} \right)$ and follow

$$\Psi \left(\frac{I_t^e}{I_{t-1}^e} \right) = \frac{1}{2} \left[\exp \left[\sqrt{\Psi''} \left(\frac{I_t^e}{I_{t-1}^e} - 1 \right) \right] + \exp \left[-\sqrt{\Psi''} \left(\frac{I_t^e}{I_{t-1}^e} - 1 \right) \right] - 2 \right], \quad (14)$$

where $\Psi(1) = \Psi'(1) = 0$ and $\Psi''(1) > 0$. Capital producers maximize their profits distributed to households, Div_t^I , by determining the amount of newly produced investment goods

$$\max_{\{I_t^A, I_t^B\}} E_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} Div_{t+j}^I$$

subject to the laws of motion for capital, by taking the prices for capital Q_t^e into account, and to the flow-of-funds constraint $I_t^A + I_t^B = F_t^I$, where F_t^I denotes the funds received from households. The variable $\Lambda_{t,t+j}$ represents the discount factor which is households' pricing kernel $\beta \frac{\lambda_{t+j}}{\lambda_t}$. For convenience, investment goods have the same price as physical capital.

3.5 *Entrepreneurs*

I follow Bernanke, Gertler, and Gilchrist (1999) and assume that the economy is populated by a continuum of entrepreneurs that buy capital from capital producers, transform the capital into new capital exposed to an idiosyncratic processing risk, and rent the capital to intermediate goods producers after observing the shock.

Furthermore, I borrow from Bernanke, Gertler, and Gilchrist (1999) and Fisher (1999) and introduce two borrowing-constrained firms to allow for different debt instruments as in De Fiore and Uhlig (2015). I split the continuum of entrepreneurs, with $m \in [0, 1]$, into two groups $e \in [A, B]$ with $A : m \in [0, \varrho)$ and $B : m \in [\varrho, 1]$. The grouping of new entrepreneurs into the two groups is exposed to a random process with fixed probabilities, whereas the population of each entrepreneurial group remains constant. In line with De Fiore and Uhlig (2011), I assume that type B entrepreneurs will solely rely on bank finance, while type A entrepreneurs issue bonds in the capital market.

Financial intermediaries are faced with a costly state verification problem.¹³ The productivity shock to type e entrepreneurs' skills ω_t^e can only be observed by the intermediaries if they pay a fixed fraction μ^e of the amount that can be recovered in the case of a default, while entrepreneurs always have knowledge about their productivity. As a result, entrepreneurs finance their investment projects with external funds (debt) and internal funds (net worth).

For capital processing, the entrepreneurs' individual skills are of importance and the entrepreneurs decide on the capital utilization ($u_{m,t}^e$). The skills of both type A and B entrepreneurs are subject to idiosyncratic shocks which affect the physical properties of capital. These shocks $\omega_{m,t}^e$ are drawn from a log-normal distribution with unit mean and are independent over time and across entrepreneurs. For the m -th entrepreneur, I obtain the amount of processed capital $\hat{K}_{m,t}^e$:

$$\hat{K}_{m,t}^e = \omega_{m,t}^e K_{m,t}^e. \quad (15)$$

¹³I discuss the optimality of the contract in section G.1 in the online appendix.

Both types of entrepreneur finance the capital purchases with their own net worth ($NW_{m,t}^e$) and external funds ($L_{m,t}^e$),

$$Q_t^e K_{m,t}^e = NW_{m,t}^e + L_{m,t}^e, \tag{16}$$

where Q_t^e is the real price of entrepreneurs' capital. For type A entrepreneurs, this means that they borrow from the capital market by issuing bonds $B_{m,t}$ at real price $Q_t^{B,corp}$, i.e., $L_{m,t}^A = Q_t^{B,corp} B_{m,t}$. Type B entrepreneurs obtain loans ($L_{m,t}^B = L_{m,t}$) from banks.

For the case where the value of the project is exactly equal to the debt service, I can define $\bar{\omega}_{m,t}^e$ as a productivity threshold for which the borrower is just able to satisfy the debt contract. I assume that the contract is signed before the shocks materialize.¹⁴ Since the contract is negotiated based upon the expected capital return, I have to distinguish between ex ante and ex post thresholds. The ex ante threshold is the expected value for $\bar{\omega}_{m,t}^e$ given the contractual (risky) loan rate Z_t^e and the expected return on entrepreneurs' projects

$$E_t \bar{\omega}_{m,t+1}^e = \frac{Z_t^e L_{m,t}^e}{E_t \left[(1 + R_{t+1}^{k,e}) \right] Q_t^e K_{m,t}^e}.$$

After the shock has occurred, the realized (gross) capital return—expressed in nominal terms—emerges as

$$\begin{aligned} & 1 + R_{m,t}^{k,e,\omega} \\ &= \frac{\pi_t \left[(1 - \tau^K) \left(r_{m,t}^{k,e} u_{m,t}^e - \Gamma(u_{m,t}^e) \right) + Q_t^e (1 - \delta^e) \right] + \tau^K \delta^e Q_{t-1}^e}{Q_{t-1}^e} \omega_{m,t}^e \\ &= (1 + R_{m,t}^{k,e}) \omega_{m,t}^e. \end{aligned} \tag{17}$$

The term τ^K is the tax rate on capital income which is identical to both sectors; $u_{m,t}^e$ denotes the capital utilization with related

¹⁴Thus, I follow Benes and Kumhof (2015) slightly and replace the realized capital return with the expected capital return. This timing convention proxies reality more closely, particularly for bank financing, and allows for unexpected defaults in the period of the shocks.

costs captured by the function $\Gamma(u_{m,t}^e)$.¹⁵ If the realized idiosyncratic shock is greater than (or equal to) the ex post threshold, the entrepreneur will be able to repay his debt as contractually agreed and keep the difference as net earnings. A realization of the shock that is below the ex post threshold level results in a default, and the entrepreneur has to liquidate the remaining amount in order to satisfy its lenders.

Similar to Carlstrom, Fuerst, and Paustian (2016) and Dmitriev and Hoddenbagh (2017), entrepreneurs have a long-run perspective and maximize the expected lifetime utility $V_{m,t}^{E,e}$ at the end of period t , i.e., the franchise value,

$$V_{m,t}^{E,e} = \max_{\{K_{m,t}^e, \bar{\omega}_{m,t+1}^e\}} E_t \left[\sum_{i=1}^{\infty} \Lambda_{t,t+i} (1 - p_t^{E,e}) (p_t^{E,e})^{i-1} \Pi_{m,t+i}^{E,e} \right],$$

whereas $p_t^{E,e}$ is the probability that an entrepreneur stays in business and is exposed to an iid shock, and $\Pi_{t+i}^{E,e}$ are the terminal funds available for exiting entrepreneurs at $t + i$ and transferred to households. Terminal funds are simply their net worth at that period in time, i.e., $\Pi_{m,t}^{E,e} = NW_{m,t}^{E,e}$. Net worth, in turn, results from the net payoffs entrepreneurs receive from their projects after taking the profitability of their projects into account,

$$NW_{m,t+1}^{E,e} = E_t (1 - \Theta(\bar{\omega}_{m,t+1}^e; \sigma_t^e)) \left(\frac{1 + R_{t+1}^{k,e}}{\pi_{t+1}} \right) Q_t^e K_{m,t}^e, \quad (18)$$

where $\Theta(\bar{\omega}_{m,t+1}^e; \sigma_t^e)$ reflects the payments to the creditors given the outcome of the project. The standard deviation σ_t^e of the distribution can be time varying, i.e., deviating from its steady-state value σ^e , and obeys a stationary AR(1) process in logs. A time-varying standard deviation gives rise to the possibility of a “financial risk shock,” which increases the range of realizations of the shocks (see, for instance, Christiano, Motto, and Rostagno 2014).

The franchise value of their firm $V_{m,t}^{E,e}$ can be expressed recursively and the maximization problem of each e -type entrepreneur can be written as

¹⁵The term $\tau^K \delta^e Q_{t-1}^e$ reflects the fact that there is a tax exemption for depreciated capital.

$$\begin{aligned}
 & \max_{\{K_{m,t}^e, \bar{\omega}_{m,t+1}^e\}} \left(1 - p_t^{E,e}\right) NW_{m,t}^{E,e} + E_t \Lambda_{t,t+1} p_t^{E,e} V_{m,t+1}^{E,e} \\
 \text{s.t.} \quad & E_t \left[\Theta(\bar{\omega}_{m,t+1}^e; \sigma_t^e) - \mu^e G(\bar{\omega}_{m,t+1}^e; \sigma_t^e) \right] \left(1 + R_{t+1}^{k,e}\right) Q_t^e K_{m,t}^e \\
 & = (1 + r_t^e) \left(Q_t^e K_{m,t}^e - NW_{m,t}^{E,e} \right), \tag{19}
 \end{aligned}$$

by taking equation (18) into account. The function $G(\bar{\omega}_{m,t+1}^e; \sigma_t^e)$ reflects the expected payoffs for the financial intermediaries given defaults of the entrepreneurs and μ^e denotes the share of assets lost for monitoring purposes.¹⁶ For the loan contract of type B entrepreneurs, the nominal risk-free loan rate r_t^L enters intermediaries' participation constraint with timing t , i.e., $r_t^B = r_t^L$. Similar to government bonds, I allow for long-term corporate bonds with a specific maturity structure, which is again modeled according to Woodford (2001) with maturity parameter $\rho^{B,corp}$, such that the nominal period return on these bonds is defined as

$$r_t^{B,corp} = \pi_t \left(\frac{\rho^{B,corp} Q_t^{B,corp} + 1 - \frac{\Upsilon_t^{B,e}}{Q_{t-1}^{B,corp} B_{t-1}^{corp}}}{Q_{t-1}^{B,corp}} \right) - 1, \tag{20}$$

with $Q_t^{B,corp}$ as the real price of the corporate bond.¹⁷ Since the contract is written before the productivity shock to ω_t^A is realized, i.e., before the capital return is known, the contract has a state-contingent nature. Deviations of the realized capital return from its expected value matter for the debt servicing capacity, i.e., bondholders face ex post losses $(\Upsilon_t^{B,e})$ while all ex ante costs of defaults can be completely diversified. As long as the default is not unexpected, its costs are taken into account in bond pricing. Perfect diversification is related to the assumption that every intermediary is able to hold the market portfolio. Consequently, the alternative to investing in corporate bonds bearing a default risk is to invest

¹⁶The expression $1 - \Theta(\bar{\omega}_{m,t+1}^e; \sigma_t^e)$ is the share of entrepreneurial earnings of non-defaulting entrepreneurs, while $\Theta(\bar{\omega}_{m,t+1}^e; \sigma_t^e) - \mu^e G(\bar{\omega}_{m,t+1}^e; \sigma_t^e)$ represents earnings of financial intermediaries by taking default cases into account.

¹⁷See Kühl (2014b) for the implications of introducing bonds with a maturity into the Bernanke, Gertler, and Gilchrist (1999) (BGG) approach.

in the ex ante risk-free market portfolio. However, unexpected ex post losses on the market portfolio can occur which reduce the effective payoff of corporate bonds. For this reason, the expected nominal bond return $E_t \left(r_{t+1}^{B,corp} \right)$ enters the participation constraint of intermediaries for the type A entrepreneur. Hence, in the participation constraint of the intermediaries (equation (19)) I have for the two sectors $r_t^A = E_t \left(r_{t+1}^{B,corp} \right)$ and $r_t^B = r_t^L$.¹⁸ The derivation of the model and the related first-order conditions are presented in the online appendix.

In each period, entrepreneurs leave the market with a given probability of $1 - p_t^{E,e}$ and are exactly replaced by new entrepreneurs just endowed with households' transfers ($NW_t^{E,e,new} = w_m^e$) to keep the population of entrepreneurs stable. The aggregate law of motion for aggregate entrepreneurial net worth ($NW_t^{E,e}$) becomes

$$NW_t^{E,e} = p_t^{E,e} NW_t^{E,e,old} + NW_t^{E,e,new} \quad (21)$$

with $NW_t^{E,e,old} = (1 - \Theta(\bar{w}_t^e; \sigma_{t-1}^e)) \left(\frac{1+R_t^{k,e}}{\pi_t} \right) Q_{t-1}^e K_{t-1}^e$.

After processing the capital with the help of individual skills, the entrepreneurs decide on capital utilization, which entails costs in the form of

$$\Gamma(u_{m,t}^e) = \frac{r^{k,e}}{\psi^k} (\exp [\psi^k (u_{m,t}^e - 1)] - 1), \quad (22)$$

where $r^{k,e}$ is the steady-state rental costs for capital and ψ^k a scaling parameter.

The aggregate amount of physical capital distributed to the intermediate goods sector, after the second stage is accomplished, is obtained by aggregating over the distribution of the productivity shock and over the continuum of entrepreneurs.

¹⁸From this point of view, the two configurations capture the arguments outlined in Carlstrom, Fuerst, and Paustian (2016) and Dmitriev and Hoddenbagh (2017) regarding the timing of interest rates in intermediaries participation constraint.

$$\begin{aligned} \hat{K}_{t+1} &= \int_0^{\varrho} \int_0^{\infty} u_{m,t} \omega K_{m,t} dF(\omega) f(m) dm \\ &+ \int_{\varrho}^1 \int_0^{\infty} u_{m,t} \omega K_{m,t} dF(\omega) f(m) dm = u_t K_t \end{aligned} \quad (23)$$

Equation (23) shows that shocks to entrepreneurs' skills do not matter for the economy as a whole, because the idiosyncratic risk can be diversified perfectly and the utilization rate is identical across all entrepreneurs.

3.6 Financial Intermediaries

3.6.1 Mutual Funds

Mutual funds are introduced to proxy the capital market. This idea follows Bernanke, Gertler, and Gilchrist (1999) and Christiano, Motto, and Rostagno (2014). The mutual funds serve as intermediaries that channel funds from banks, rent them out by buying bonds from type A entrepreneurs, and operate on zero profits. The main objective is to model the linkage between the issuance of bonds and the financing by banks.

3.6.2 Banking Sector

Since households cannot provide funds to the entrepreneurial sector directly, I introduce a banking sector, which basically follows Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). The economy is populated by a continuum of lending banks n with $n \in [0, 1]$. In addition to loans, which the lending banks can grant to type B entrepreneurs directly, they also buy (corporate) bonds issued by type A entrepreneurs.¹⁹ In addition, each lending bank buys government bonds $(B_{n,t}^{gov,B})$. Hence, each n -th lending bank holds three assets which together constitute bank's total assets $A_{n,t}^B$. Funds are raised

¹⁹Note that they do not buy bonds directly from type A entrepreneurs. More precisely, they buy bonds from mutual funds, which, in turn, hold bonds issued by type A entrepreneurs. For the sake of simplicity, I argue that lending banks buy bonds from entrepreneurs, but, technically, the funds are intermediated by mutual funds.

by issuing debt $D_{n,t}$ combined with net worth $E_{n,t}^I$ which is built up by retaining earnings.²⁰ Thus, the balance sheet constraint becomes

$$A_{n,t}^B = L_{n,t} + Q_t^{B,corp} B_{n,t}^{corp} + Q_t^{B,gov} B_{n,t}^{gov,B} = E_{n,t}^I + D_{n,t}. \quad (24)$$

Since the loan rate r_t^L is negotiated before the shocks are realized such that it becomes non-state contingent, ex post defaults can occur, which must be borne by the lending bank. In the corporate bond market, unexpected losses materialize in the ex post period return $r_t^{B,corp}$ as a result of unexpected changes in the price of the corporate bonds (see again equation (20)).

Looking at funding, the bank borrows from households at the rate r_t^D .²¹ The law of motion for net worth is written in real terms, while financial assets are denominated in nominal terms:

$$\begin{aligned} E_{n,t}^I &= (1 + r_{t-1}^L) L_{n,t-1} \frac{1}{\pi_t} + \left(1 + r_t^{B,corp}\right) Q_{t-1}^{B,corp} B_{n,t-1}^{corp} \frac{1}{\pi_t} \\ &\quad + \left(1 + r_t^{B,gov}\right) Q_{t-1}^{B,gov} B_{n,t-1}^{gov,B} \frac{1}{\pi_t} \\ &\quad - (1 + r_{t-1}^D) \frac{1}{\pi_t} D_{n,t-1} \frac{1}{\pi_t} - \Upsilon_{n,t}^L + \mu_{EI,t}. \end{aligned} \quad (25)$$

The term $\Upsilon_{n,t}^L$ in equation (25) comprises losses from the loan portfolio, while $\mu_{EI,t}$ represents an exogenous shock to bank equity. Lending banks maximize the terminal consumption which is equivalent to maximizing the present value of their net worth, i.e., the value of the bank $V_{n,t}^B$. In this case, the bank managers would choose $L_{n,t}$, $B_{n,t}^{corp}$, $B_{n,t}^{gov,B}$, and $D_{n,t}$ optimally.²²

$$V_{n,t}^B = \max_{\{L_{n,t}, B_{n,t}^{corp}, B_{n,t}^{gov,B}, D_{n,t}\}} E_t \sum_{i=1}^{\infty} \Lambda_{t,t+i} (1 - p^B) (p^B)^{i-1} \Pi_{n,t+i}^B \quad (26)$$

²⁰Bank net worth can also be interpreted as inside equity.

²¹Because of the formulation of the bank, these loans comprise both deposits and bank bonds. From this point of view, the interest rate is an “average” rate on bank’s debt.

²²I discuss the optimality of the contract in section G.2 in the online appendix.

The term $(1 - p^B)$ in equation (26) reflects the probability of the exit from the banking business and $\Pi_{n,t+i}^B$ are the terminal funds available for exiting bankers at time $t+i$, which is simply the volume of their equity at that period in time, i.e., $\Pi_{n,t}^B = E_{n,t}^I$.

An agency problem in the banking sector arises because bank managers can divert a fraction θ^{IC} of the bank’s resources which cannot be recovered because of high enforcement costs. Furthermore, different assets can be diverted to different degrees. Thus, the bank’s incentive constraint becomes

$$V_{n,t}^B \geq \theta^{IC} \left(L_{n,t} + \Delta^{B,corp} Q_t^{B,corp} B_{n,t}^{corp} + \Delta^{B,gov} Q_t^{B,gov} B_{n,t}^{gov,B} \right), \tag{27}$$

where $\Delta^{B,corp}$ and $\Delta^{B,gov}$ denote the specific relative shares which can be diverted related to corporate and government bonds, respectively.²³ Hence, bankers maximize equation (26) subject to equation (27).

Since a fraction of bank managers resign, bank managers continue to operate a lending bank with probability p^B . While the exiting bank managers’ net worth is no longer available, the remaining net worth is a fraction of aggregate net worth

$$E_t^{I,old} = p^B \left(\begin{aligned} & (R_{t-1}^L - R_{t-1}^D) L_{t-1} \frac{1}{\pi_t} \\ & + \left(R_t^{B,corp} - R_{t-1}^D \right) Q_{t-1}^{B,corp} B_{t-1}^{corp} \frac{1}{\pi_t} \\ & + \left(R_t^{B,gov} - R_{t-1}^D \right) Q_{t-1}^{B,gov} B_{t-1}^{gov,B} \frac{1}{\pi_t} \\ & + R_{t-1}^D E_{t-1}^I \frac{1}{\pi_t} - \Upsilon_t^L + \mu_{EI,t} \end{aligned} \right), \tag{28}$$

where I made use of the balance sheet constraint and using gross interest rates, i.e., $R_t^L = 1 + r_t^L$, $R_t^{B,corp} = 1 + r_t^{B,corp}$, $R_t^{B,gov} = 1 + r_t^{B,gov}$, and $R_t^D = 1 + r_t^D$. New bank managers fill the gap created by the exit of old bank managers and enter the market in order to start operating a lending bank. From their households they obtain an endowment with which net worth is built up,

²³Like Rannenberg (2016), I combine a BGG-type problem with a GK-type problem. One advantage of this approach is that I am able to investigate the different frictions separately by abstracting from a risky bank environment. The treatment of risky banks would require either an insurance mechanism or the need to deal with bank runs.

$$E_t^{I,new} = \gamma^B \left(\begin{array}{l} (R_{t-1}^L - R_{t-1}^D) L_{t-1} \frac{1}{\pi_t} \\ + \left(R_t^{B,corp} - R_{t-1}^D \right) Q_{t-1}^{B,corp} B_{t-1}^{corp} \frac{1}{\pi_t} \\ + \left(R_t^{B,gov} - R_{t-1}^D \right) Q_{t-1}^{B,gov} B_{t-1}^{gov,B} \frac{1}{\pi_t} \\ + R_{t-1}^D E_{t-1}^I \frac{1}{\pi_t} \end{array} \right),$$

that is a fraction γ^B of assets. Consequently, aggregate net worth is the sum of both components:

$$E_t^I = E_t^{I,old} + E_t^{I,new}.$$

3.7 Public Sector

3.7.1 Fiscal Authority

To finance government expenditures G_t , the fiscal authority uses internal funds, i.e., from tax revenues (T_t) and profits received from an intervention authority (\mathcal{P}_t^{IA}), and external funds, i.e., from the issuance of long-term government bonds B_t^{gov} in the capital market traded at price $Q_t^{B,gov}$. The budget constraint of the fiscal agent is given in equation (29).

$$G_t + \left(1 + r_t^{B,gov} \right) Q_{t-1}^{B,gov} B_{t-1}^{gov} = \mathcal{P}_t^{IA} + T_t + Q_t^{B,gov} B_t^{gov} \quad (29)$$

Government expenditures follow a stationary AR(1) process in logs around its steady-state value. Tax revenues stem from labor income, capital returns, and consumption taxes. The fiscal agent adjusts the tax rate in order to stabilize the level of real government debt, where the term ξ^{BG} is a positive number which reflects the fact that governments' insolvency is ruled out by conducting a passive fiscal policy (see, for example, Leeper 1991). The tax is consequently adjusted following deviations of last period's government debt from a target, where the target is the steady-state value of government bonds (steady-state price $Q_s^{B,gov}$ times steady-state quantity B_s^{gov}). The tax rule is presented in equation (30).

$$T_t = T \exp(\mu_{T,t}) + \tau^C C_t + \tau^K r_t^{k,A} K_t^A + \tau^K r_t^{k,B} K_t^B + \tau^w w_t N_t + \xi^{BG} \left(Q_{t-1}^{B,gov} B_{t-1}^{gov} - Q_s^{B,gov} B_s^{gov} \right), \quad (30)$$

whereas T denotes lump-sum taxes and $\mu_{T,t}$ is a shock to lump-sum taxes which follows an AR(1) process.

3.7.2 Central Bank

The central bank conducts monetary policy by controlling the policy rate $i_t^{PR} (= i_t = r_t^D)$. For this purpose, it obeys a Taylor rule, the objective of which is to set the policy rate according to

$$(1 + i_t^{PR}) = (1 + i_{t-1}^{PR})^{\rho^{smooth}} (1 + i)^{(1-\rho^{smooth})} \left(\frac{\pi_t}{\pi}\right)^{\phi^\pi (1-\rho^{smooth})} \times \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi^y (1-\rho^{smooth})} \exp(\epsilon_{M,t}), \quad (31)$$

with smoothing parameter ρ^{smooth} . The term ϕ^π is the weight given to deviations of the current period's rate of inflation from its target π and ϕ^y to output growth. Furthermore, the term $\epsilon_{M,t}$ represents an unexpected monetary policy shock.

3.7.3 The Intervention Authority

In order to investigate government bond purchases, I introduce an intervention authority that is assigned to the public sector. It has full credibility and is able to issue riskless short-term debt which is used to finance government bond purchases ($B_t^{IA} = Q_t^{B,gov} B_t^{gov,IA}$).²⁴ Consequently, the intervention authority obtains funds from issuing short-term debt and from returns of holdings from long-term government bonds. Since the returns on long-term government debt and the costs of short-term debt might differ, i.e., $r_t^{B,gov} \neq i_{t-1}$, the intervention authority earns profits or could even suffer losses. These profits \mathcal{P}_t^{IA} are distributed to the fiscal authority. The intervention authority's balance sheet becomes

$$\begin{aligned} \mathcal{P}_t^{IA} + Q_t^{B,gov} B_t^{gov,IA} + (1 + i_{t-1}) B_{t-1}^{IA} \frac{1}{\pi_t} \\ \leq \left(1 + r_t^{B,gov}\right) Q_{t-1}^{B,gov} B_{t-1}^{gov,IA} \frac{1}{\pi_t} + B_t^{IA}. \end{aligned} \quad (32)$$

²⁴Short-term debt could be understood as central bank liquidity. Since there is no explicit role for central bank liquidity in the model, this is a tractable way to model the transaction related to government bond purchases.

The economic relationships are similar to Gertler and Karadi (2011), where the central bank issues short-term debt to finance credit policy. However, by allowing for profits to be distributed to the fiscal authority, I follow Christiano and Ikeda (2013) and introduce a link to taxes. In reality, government bond purchases are mostly conducted by the central bank. The central bank's profits or losses result, *inter alia*, from seigniorage and outright purchases. Thus, potential losses from outright purchases will be offset against profits from seigniorage and the net profit is then distributed to the fiscal authority. In the case of enduring losses, the central bank needs to be recapitalized by the fiscal authority. A discussion of the central bank's solvency together with earning profits from seigniorage, which would require modeling money, is beyond the scope of this paper. I nevertheless allow for a direct distributional effect from purchases to taxes.²⁵ Since there are no government bond purchases in the sample used to estimate the model, the intervention authority plays no role in the estimation.

Government bond purchases are induced into the model as shocks $\epsilon_{IA,t}$ to the stock of government bonds $(B_t^{gov,IA})$ which is held by the intervention authority

$$B_t^{gov,IA} = \rho_{IA} B_{t-1}^{gov,IA} + \sum_{i=0}^N \epsilon_{IA,t-i}, \quad (33)$$

where ρ_{IA} controls how long the intervention authority holds the portfolio of government bonds. The last term on the right-hand side is able to reflect announced purchases for $i > 0$. For $\epsilon_{IA,t-i}$ with $i = 0$, the increase in the stock of government bonds held by the intervention authority is unanticipated, *i.e.*, the purchases come as surprises. Starting from $i = 1$ and going to N , the increase in the stock is anticipated, which means that purchases are anticipated during this period, as they reflect the anticipated change in the stock.²⁶

²⁵In section E.2 in the online appendix, I will show that the introduction of this intervention authority does not change the general conclusions. For this reason, it helps to clarify thinking about government bond purchases.

²⁶This implementation of a government bond purchase program allows me to distinguish explicitly between the purchase path and the maturity profile governed by ρ_{IA} and makes it possible to look at unanticipated and anticipated

3.8 Market Clearing

In the following equation, I present the market clearing condition for the economy:

$$\begin{aligned}
 Y_t = & I_t^A + I_t^B + C_t + G_t + \Gamma_t^A K_{t-1}^A + \Gamma_t^B K_{t-1}^B \\
 & + K_{t-1}^A Q_{t-1}^A \frac{\left(1 + R_t^{k,A}\right) G(\omega_t^A) \mu^{f,A}}{\pi_t} \\
 & + K_{t-1}^B Q_{t-1}^B \frac{\left(1 + R_t^{k,B}\right) G(\omega_t^B) \mu^{f,B}}{\pi_t}. \tag{34}
 \end{aligned}$$

Investment spending by type A and type B entrepreneurs constitutes aggregate investment $I_t^A + I_t^B$. Costs resulting from changes in the utilization rates in both sectors are expressed as $\Gamma_t^A K_{t-1}^A + \Gamma_t^B K_{t-1}^B$. In addition, monitoring type A and B entrepreneurs by the financial intermediaries absorbs resources, which is embodied in the second line of equation (34). The market for physical capital clears by equating capital supply and capital demand $\widehat{K}_t^e = \widetilde{K}_t^e$.

In terms of asset holdings, a continuum of households meets a continuum of lending banks. The market for corporate bonds clears by introducing mutual funds in the intermediation process, which hold the market portfolio, $\int_0^1 B_{n,t}^{corp} dn = B_t^{corp,B} = \int_0^\varrho B_{m,t}^{corp} dm$, where $B_t^{corp,B}$ denotes aggregate holdings of banks. In the market for loans, it is also assumed that each lending bank holds the market portfolio of loans.²⁷ The market clearing condition results as $\int_0^1 L_{n,t} dn = \int_\varrho^1 L_{m,t} dm$. Regarding the asset market for government bonds, the demand for assets resulting from the continuum of households and banks equals the supply of government bonds,

effects. The anticipated purchases can be interpreted as “news shocks.” An AR(2) formulation as done by Gertler and Karadi (2013) or Carlstrom, Fuerst, and Paustian (2017) would, in principle, yield very similar results but does not allow for investigating the factors mentioned.

²⁷For technical reasons, as for corporate bonds, I need an aggregator that guarantees the same payoff per unit of loans.

$\int_0^1 B_{h,t}^{gov,H} dh + \int_0^1 B_{n,t}^{gov,B} dn + B_t^{gov,IA} = B_t^{gov,H} + B_t^{gov,B} + B_t^{gov,IA} = B_t^{gov}$.²⁸ The intervention authority's holdings of long-term government bonds are given by $B_t^{gov,IA}$. In the absence of government bond purchases by the intervention authority, government bonds are held by banks and households. As can be seen by looking at the market clearing condition, the government bond purchases by the intervention authority reduce the supply of government bonds available to banks and households in the first place. Through resulting changes in bond prices and yields, the agents adjust their portfolios, for which reason there follows a reallocation of government debt. Accordingly, the market for the intervention authority's bonds clears, $\int_0^1 B_{h,t}^{IA} dh = B_t^{IA}$. The deposit rate r_t^D is linked to the policy rate.

4. Empirical Analysis

4.1 Data

For the estimation I use quarterly data for the euro area. Limited by data availability, the period of observation starts in the fourth quarter of 1997 and ends in the third quarter of 2013. Since the aim of this paper is to investigate the effects of government bond purchases in the euro area, I decide to stop with the period of observation at the end of 2013. During 2014 there was speculation about a broad quantitative easing in the Economic and Monetary Union (EMU) of the European Union which could have affected asset prices. To reduce the impact of these effects on the estimates, I cut the period of observation in 2013.

For the estimation I make use of seventeen variables. I can split the variables used for the estimation into two groups. The first group consists of seven standard macroeconomic time series: GDP, consumption, investment, the rate of inflation, the real wage, total employment, and the policy rate. GDP, consumption, and investment are in real terms deflated by their own price deflators and are expressed in per capita terms. The rate of inflation is computed as

²⁸Since the market for long-term government bonds is not segmented, the return to holdings of government bonds is equal to households, banks, and the intervention authority.

the quarterly growth in the GDP deflator. The latter is also used to deflate the nominal wage. GDP, consumption, and investment are collected from the European Central Bank (ECB) and originally stem from Eurostat. The nominal wage (per head), total employment, and the policy rate are taken from the fourteenth update of the Area-Wide Model (AWM) database. As proposed by Smets and Wouters (2003), I proxy hours worked by total employment.²⁹

The remaining ten variables belonging to the second group are specific to the model. As the model reflects portfolios of government and corporate bonds, I draw on the redemption yields from indexes as provided by Merrill Lynch comprising all maturities. In order to remove the impact of the European debt crisis on government bond yields, I choose the redemption yield of German government bonds. For corporate bonds, I take the redemption yield of bonds from non-financial corporations with a BBB credit rating, which is Z_t^A in the model. Loan rates Z_t^B stem from the ECB's MFI Interest Rate Statistics combined with the ECB's Retail Interest Rate Statistics.³⁰ Besides the interest rates, I also address time series to the quantities. Regarding loans, corporate bonds, and government bonds, I make use of the ECB's balance sheet items covering data from banks in the EMU. Since government bonds are held by banks and households in the model, I try to identify the effects outside the banking sector by drawing on the ECB's securities statistics for the entire amount outstanding. Bank equity is reflected by capital and reserves as provided by the ECB's balance sheet items. Regarding net worth of entrepreneurs, I follow Christiano, Motto, and Rostagno

²⁹I consequently make use of the transformation in linearized form,

$$\hat{E}_t = \frac{\beta}{1+\beta} \hat{E}_{t+1} + \frac{1}{1+\beta} \hat{E}_{t-1} + \frac{(1-\beta\gamma^E)(1-\gamma^E)}{(1+\beta)\gamma^E} (\hat{N}_t - \hat{E}_t),$$

where \hat{E}_t denotes total employment and \hat{N}_t hours worked, with hats as log deviations from steady state.

³⁰While the ECB's Retail Interest Rate Statistics stop in 2003, the MFI Interest Rate Statistics start in 2003. In a certain sense, the latter replaced the former. I choose the annualized agreed rate for loans to non-financial corporations (new business coverage) including all maturities. The MFI Interest Rate Statistics provide information about all interest rates on euro-denominated deposits from and loans to households and non-financial corporations resident in the euro-area countries. Transactions are conducted by monetary financial institutions (MFIs) located in the euro area, excluding central banks and money market funds.

(2014) and proxy net worth by stock price indexes. However, I link stock price indexes to the present value of the entrepreneurs instead of linking them to net worth. In the model I have two distinct entrepreneurs. For the aggregate net present value, as the sum of the net present values in both sectors, I take the broad EuroStoxx index. By assuming that market-based debt plays a more important role for very large firms, I proxy the net present value of entrepreneurs in the A sector by the EuroStoxx50 index. Stock prices are taken from the ECB's financial markets statistics. The quantities including the stock price indexes are deflated by the GDP deflator and expressed in per capita terms. Except for the interest rates, the rate of inflation, and total employment, I compute the logarithmic first difference for all variables. Finally, I remove the sample mean from all time series.³¹

I introduce four measurement errors. Two are related to entrepreneurial net worth and are inspired by Christiano, Motto, and Rostagno (2014). In addition, I include measurement errors for the yields on government bonds and the growth of the stock for long-term government bonds in banks' balance sheets. The justification for the latter is related to the fact that there might be other agents in the real world which hold government bonds but have no counterpart in the model.

4.2 *Priors and Calibrated Parameters*

The parameters of the models are estimated with the help of Bayesian techniques as described in An and Schorfheide (2007). The calibrated parameters are given in table 1, and I only present the non-standard parameters in this section. Regarding the business failure rates $F(\bar{\omega}^e)$, I take an average value of bankruptcy rates in the euro area of 0.008.³² The standard deviations of the idiosyncratic productivity shock in the entrepreneurial sector, σ^e , are also calibrated to be identical in both sectors. The value of 0.26 is close to the number used in Christiano, Motto, and Rostagno (2010). The same

³¹This approach is based on Christiano, Motto, and Rostagno (2014, p. 42), who argue that individual detrending prevents “counterfactual implications of the model for the low frequencies from distorting inference in the higher business cycle frequencies.”

³²The data derive from various publications by Creditreform.

Table 1. Calibration of Parameters

Description	Symbol	Value
Discount Factor	β	0.999
Steady-State Labor Input in Goods' Production	N_s	1
Inverse Frisch Elasticity	ϕ	2.5
Depreciation Rate—Type A and Type B Entrepreneurs	δ^A, δ^B	0.025
Steady-State Rate of Inflation, Annualized	π_s	1.8%
Steady-State Growth Rate, Annualized	z_s	1.5%
Share of Government Expenditures on Steady-State Output	G/Y	0.2
Steady-State Indebtedness of Government Relative to Steady-State Output	$Q^{B,gov} B^{gov} / Y$	0.8
Business Failure Rates in Steady State	$F(\omega_s^A), F(\omega_s^B)$	0.008
Standard Deviation of Idiosyncratic Productivity Parameters	σ_s^A, σ_s^B	0.26
Survival Rates of Entrepreneurs	p^{EA}, p^{EB}	0.978
Leverage Ratio	ϕ^{IE}	8
Tax Rate on Capital	τ^K	0.28
Tax Rate on Consumption	τ^C	0.2
Tax Rate on Labor	τ^w	0.45

reference is taken to calibrate the survival rates of entrepreneurs, $p^{E,e}$, which is assumed to be identical in both sectors. Although it seems to be straightforward, the leverage ratio in the banking sector, ϕ^{IE} , is trickier to calibrate. Historical averages from the ECB's balance sheet items indicate a value close to 16. However, the balance sheets of the banks in my model feature just three assets. I experiment with different values and it turns out that, as an outcome of the estimation, data would prefer a number of eight, which I consequently choose. In almost the same manner, it is not straightforward to calibrate the share of government bonds held by banks. Measured against total assets, the share of government bonds (general government) in banks' balance sheets is 0.06, while its share relative to the sum of loans, corporate bonds, and government bonds (total assets

in the model) is 0.24. I decide to set the share at 0.13, which is in the middle between both values. Regarding the fiscal sector, I need to calibrate the ratios of government expenditures and of government bonds to output. Based upon empirical averages, I set the former to 0.2, while the latter takes the value of 0.8.

The prior distributions for the model parameters can be found in the left-hand-side columns in table 2 while those of the shock processes, i.e., the autoregressive parameters and the standard deviations of the shocks, are shown in table 3.

Since I modified the production function, I am interested in estimating the two new parameters. These are the parameters which control the degree of substitution between the two types of capital, γ^K , and the weight ζ^K in the capital bundler. The latter is easier to choose, as it also controls the share of loans relative to corporate bonds. For this reason, I take a value of 0.1 as a mean which reflects that fact that loans dominate in the euro area. The standard deviation of 0.05 for the normal distribution allows a wider range for ζ^K . Since the mean for the degree of substitution controls how much capital financed by loans can be replaced by capital financed by corporate bonds, I take a conservative value of 3 and a standard deviation of 1, which states that the degree of substitution is neither complete nor absolutely imperfect. As a prior distribution I choose the gamma distribution.

Regarding the parameters controlling the response of taxes on changes in government debt, ξ^{BG} , I take a rather small value of 0.1 as a mean, which just guarantees that fiscal policy is passive. Fairly standard priors are used for monitoring costs in both sectors μ^e . The means become 0.2 with standard deviations of 0.05.

For the costs of deviating from the desired level of government bonds holdings in the government bond sector, $v^{B, gov}$, I choose a value of 0.5 as a mean with a standard deviation of 0.25 under the normal distribution. In the banking sector, I decide to estimate the survival rate of bankers p^B in contrast to the strategy applied to the entrepreneurs.³³ Given that I expect a rather high parameter for the survival rate, I nevertheless set the mean to 0.9 with a standard deviation of 0.05, so that I allow for a broader range of values but

³³In the entrepreneurial sector it is difficult to identify all of the related parameters, which is why I do not estimate the survival rates in this sector.

Table 2. Model Priors and Estimated Posteriors (parameters)

	Prior Distribution				Posterior Distribution			
	Prior Density	Domain	Mean	SD	Mode	Mean	5 Percent	95 Percent
ρ_π	Beta	$[0, 1]$	0.8	0.15	0.781	0.776	0.739	0.814
ϕ_π	Gamma	\mathbb{R}^+	1.7	0.1	1.680	1.691	1.550	1.824
ϕ_y	Gamma	\mathbb{R}^+	0.1	0.05	0.190	0.186	0.083	0.278
γ	Beta	$[0, 1]$	0.7	0.05	0.776	0.779	0.726	0.827
γ_w	Beta	$[0, 1]$	0.7	0.05	0.701	0.706	0.637	0.776
λ_p	Beta	$(1, 2)$	1.2	0.1	1.632	1.634	1.519	1.751
λ_w	Beta	$[0, 1]$	1.2	0.1	1.163	1.195	1.063	1.316
ξ	Beta	$[0, 1]$	0.5	0.15	0.087	0.101	0.033	0.171
ξ_w	Beta	$[0, 1]$	0.5	0.15	0.116	0.142	0.048	0.232
ξ_z	Beta	$[0, 1]$	0.5	0.15	0.654	0.653	0.498	0.805
h^C	Beta	$[0, 1]$	0.7	0.15	0.652	0.649	0.570	0.723
Ψ''	Gamma	\mathbb{R}^+	4	1.5	4.220	4.367	2.756	5.958
ψ^k	Gamma	\mathbb{R}^+	5	2	3.143	4.087	1.379	6.778
α	Beta	$[0, 1]$	0.3	0.15	0.346	0.345	0.293	0.396
γ^K	Gamma	\mathbb{R}^+	3	1	3.570	4.023	2.078	5.827

(continued)

Table 2. (Continued)

	Prior Distribution			Posterior Distribution				
	Prior Density	Domain	Mean	SD	Mode	Mean	5 Percent	95 Percent
ζ^K	Normal	\mathbb{R}	0.1	0.05	0.026	0.029	0.006	0.050
ξ^{BG}	Gamma	\mathbb{R}^+	0.1	0.05	0.243	0.286	0.143	0.415
γ^E	Beta	$[0, 1)$	0.5	0.15	0.617	0.625	0.570	0.682
μ^A	Beta	$[0, 1)$	0.2	0.05	0.065	0.065	0.040	0.091
μ^B	Beta	$[0, 1)$	0.2	0.05	0.082	0.081	0.053	0.108
$v^{B, gov}$	Normal	\mathbb{R}	0.5	0.25	0.162	0.207	0.062	0.358
p^B	Beta	$[0, 1)$	0.9	0.05	0.972	0.955	0.927	0.983
ρ^B	Beta	$[0, 1)$	0.95	0.025	0.927	0.919	0.871	0.968
$\rho^{B, gov}$	Beta	$[0, 1)$	0.95	0.025	0.884	0.878	0.838	0.920
$r^{B, gov}$	Beta	$[0, 1)$	0.01	0.0025	0.013	0.014	0.012	0.016
r^B	Beta	$[0, 1)$	0.01	0.0025	0.010	0.010	0.008	0.012

Table 3. Model Priors and Estimated Posteriors (shocks)

	Prior Distribution			Posterior Distribution				
	Prior Density	Domain	Mean	SD	Mode	Mean	5 Percent	95 Percent
<i>Autoregressive Parameters of Shocks</i>								
ρ_A	Beta	[0, 1)	0.75	0.15	0.946	0.930	0.891	0.971
ρ_N	Beta	[0, 1)	0.75	0.15	0.991	0.988	0.978	0.998
ρ_G	Beta	[0, 1)	0.75	0.15	0.898	0.890	0.816	0.963
ρ_z	Beta	[0, 1)	0.75	0.15	0.234	0.247	0.111	0.377
ρ_{σ^A}	Beta	[0, 1)	0.75	0.15	0.769	0.754	0.650	0.863
ρ_{σ^B}	Beta	[0, 1)	0.75	0.15	0.908	0.904	0.878	0.932
ρ_{λ_p}	Beta	[0, 1)	0.75	0.15	0.136	0.146	0.062	0.227
ρ_I	Beta	[0, 1)	0.75	0.15	0.358	0.374	0.228	0.525
Transitory Technology Shock								
Labor Supply Shock								
Gov. Spending Shock								
Persistent Technology Shock								
Riskiness Shock, Sector A								
Riskiness Shock, Sector B								
Price Markup Shock								
Marginal Effic. of Invest. Shock								
<i>Standard Deviations of Shocks</i>								
ϵ_M	Invg.	\mathbb{R}^+	0.002	0.01	0.001	0.001	0.0010	0.0014
ϵ_G	Invg.	\mathbb{R}^+	0.005	0.01	0.016	0.016	0.014	0.019
ϵ_A	Invg.	\mathbb{R}^+	0.005	0.01	0.003	0.004	0.003	0.004
ϵ_z	Invg.	\mathbb{R}^+	0.005	0.01	0.004	0.004	0.003	0.005
ϵ_{λ_p}	Invg.	\mathbb{R}^+	0.002	0.01	0.009	0.009	0.007	0.012
ϵ_N	Invg.	\mathbb{R}^+	0.01	0.01	0.024	0.026	0.020	0.032
ϵ_{σ^A}	Invg.	\mathbb{R}^+	0.005	0.01	0.125	0.132	0.104	0.158
ϵ_{σ^B}	Invg.	\mathbb{R}^+	0.005	0.01	0.076	0.079	0.064	0.094
ϵ_{EI}	Invg.	\mathbb{R}^+	0.005	0.01	0.012	0.013	0.007	0.018
$\epsilon_{p^{E,A}}$	Invg.	\mathbb{R}^+	0.005	0.01	0.046	0.048	0.041	0.054
$\epsilon_{p^{E,B}}$	Invg.	\mathbb{R}^+	0.005	0.01	0.006	0.006	0.005	0.007
$\epsilon_{\mu,I}$	Invg.	\mathbb{R}^+	0.005	0.01	0.011	0.012	0.010	0.014
ϵ_T	Invg.	\mathbb{R}^+	0.005	0.01	0.043	0.045	0.036	0.053
Monetary Policy Shock								
Gov. Expenditures Shock								
Transitory Technology Shock								
Persistent Technology Shock								
Price Markup Shock								
Labor Supply Shock								
Risk Shock, Sector A								
Risk Shock, Sector B								
Bank Equity Shock								
Wealth Shock, Sector A								
Wealth Shock, Sector B								
Marginal Effic. of Invest. Shock								
Shock to Taxes								

(continued)

Table 3. (Continued)

	Prior Distribution				Posterior Distribution			
	Prior Density	Domain	Mean	SD	Mode	Mean	5 Percent	95 Percent
<i>Standard Deviations of Measurement Errors</i>								
Net Worth, Aggregate	Uniform	(0, 10)	5	2.8868	0.125	0.127	0.108	0.143
Net Worth, Sector A	Uniform	(0, 10)	5	2.8868	0.134	0.137	0.117	0.157
Yields on Long-Term Gov. Bonds	Uniform	(0, 10)	5	2.8868	1.009	1.043	0.875	1.200
Growth of Long-Term Bond in Banks' Balance Sheet	Uniform	(0, 10)	5	2.8868	0.031	0.033	0.028	0.038

do not deviate too much from values in the literature used for the calibration. Although I know the empirical average maturities (durations) of government and corporate bonds, I nevertheless decide to estimate them in the model. The reason for this is that the model assumption about the implementation of maturities does not exactly match real-world features, i.e., the duration of banks' government bond portfolio can be different from the duration of government bonds outstanding. For this reason, I let the data speak to identify them. I opt for priors with means of 0.95 and standard deviations of 0.025 under the beta distribution. Furthermore, I estimate the steady-state rates for government bonds and the default-free rate for corporate bonds, $r^{B,gov}$ and r^B , respectively. The reason for this is that the default-free corporate bond rate also controls frictions in the type A sector and the banking sector. In the latter case, it helps to pin down the diversion share related to corporate bonds $\Delta^{B,corp}$. The same argument is applied to the steady-state rate for government bonds, as it is related to portfolio costs in the household sector τ^{gov} and to the diversion share related to corporate bonds $\Delta^{B,gov}$ in the banking sector. For both cases, I choose a mean of 0.01 implying annualized interest rates of 4 percent. The standard deviations become 0.0025.

4.3 Posteriors

The mode and the mean together with the 90 percent highest posterior density (HPD) intervals for the model parameters can be found on the right-hand side in table 2 and for the shock processes in table 3. Most of the estimates for the standard parameters are in line with earlier findings in the literature. As known for the euro area, price stickiness exceeds wage stickiness, i.e., γ is 0.776 at its mode while it is 0.701 for γ_w . Accordingly, the markup for prices with a mode of 1.632 is larger than the markup of 1.163 for wages. Furthermore, the largest weight in both indexation rules, for prices and wages, is assigned to steady-state inflation. It is important to note that wages are more tied to current technology growth than to its steady-state rate. Compared to the literature, investment adjustment costs are rather low in the model (a mode of 4.22). The reason for this might be related to the introduction of the banking sector, which

introduces frictions into capital production on its own.³⁴ While the share of capital in production is broadly consistent with the well-known figure in the literature (a mode of 0.346), I am more interested in the estimates for the parameters introduced through the modification of the production functions. Compared with my prior for the degree of substitution, the mode and the mean are slightly above this number (3.57 and 4.023, respectively), which indicates that loans and corporate bonds are not completely imperfect substitutes. However, the share of capital financed by corporate bonds is quite small, with a figure of 0.026 at the mode. The rather small share of corporate bonds can be explained by the fact that the loan sector is related to book-value accounting, while the corporate bond sector refers to mark-to-market accounting in banks balance sheets. Since ζ^K controls the share from loans to corporate bonds in banks' balance sheets, one can see the clear dominance of loans priced at par. Regarding lending to the non-financial sector, the balance sheet channel does not seem to play an important role in the euro area. The mode for the survival rate of bankers, at a figure of 0.972, is close to values used in the literature for calibration.

The monitoring costs in both non-financial sectors are very close to each other. Consistent with De Fiore and Uhlig (2011), for instance, monitoring of corporate bonds seems to be less costly than monitoring of bank loans by looking at the modes. The estimates for monitoring costs in the loan sector are, with a value of around 0.065, closer to the calibrated values in Bernanke, Gertler, and Gilchrist (1999) than to more recent estimates for the United States (see Christiano, Motto, and Rostagno 2014). The reason for this might be that the European economies are more bank financed with strong customer relationships, which might reduce monitoring costs.

Regarding the effectiveness of government bond purchases, the degree of frictions in the banking sector and the household sector is of importance. Through the estimate for the steady-state government bond yield, the trading cost parameter in the household sector becomes τ^{gov} 0.0034. The estimate for the steady-state default-free

³⁴Since it is beyond the scope of this paper to discuss this relationship, I take the results as granted.

corporate bond rate is 3.92 percent annualized, which translates into an asset-specific diversion share of $1.0477 \times 0.0938 = 0.0983$ ($\Delta^{B,corp} \times \theta^{IC}$). Following from the mode for the steady-state government bond yield of 5.08 percent annualized, the asset-specific diversion share related to government bonds becomes $6.8477 \times 0.0938 = 0.6422$ ($\Delta^{B,gov} \times \theta^{IC}$), which shows that frictions related to government bonds are larger than those related to loans or corporate bonds. Furthermore, the estimate for the portfolio deviation costs in the household sector $v^{B,gov}$ of 0.162 at the mode shows that limits to arbitrage also exist in the household sector regarding the pricing of government bonds. The parameters representing the maturity structure are 0.884 (a duration of roughly two years) for government bonds and 0.927 (a duration of roughly three years) for corporate bonds.³⁵

4.4 *Matching Business Cycle Properties*

Before I inspect the dynamics resulting from government bond purchases in the next section, I simulate the model at the mode and compute the related theoretical moments of selected variables. I then compare them with their empirical counterparts in order to evaluate the performance of the estimated model in matching central business cycle facts. Both measures are presented in table 4. Based upon the estimated standard deviations for the shocks and the remaining model parameters, the model is able to capture the fluctuations in most of the variables. The standard deviations of output, investment, and consumption are nearly met exactly, whereas the standard deviation of bank loans is hit perfectly. The volatility of growth in the value of net worth implied by the model is for both variables clearly smaller than in the data. The reason for this is that the value of entrepreneurial net worth is measured by stock market indexes as done by Christiano, Motto, and Rostagno (2014), where I consequently added measurement errors to the observation equation. Overall, the estimated model is quite good at capturing the volatility of macroeconomic and financial variables.

³⁵As mentioned, a reason why these values fall short of the average duration from the market portfolio might be related to the fact that the estimates could capture further features not reflected in the model.

Table 4. Moments Comparison: Model-Implied Deviations vs. Data

		Model	Data
Output Growth, Quarterly Growth	$dGDP$	0.006	0.0066
Investment, Quarterly Growth	dI	0.0144	0.0141
Consumption, Quarterly Growth	dC	0.0048	0.0042
Rate of Inflation, Annualized, Percentage Points	π	1.1581	0.9035
Loan Rate, Annualized, Percentage Points	Z^B	1.1557	0.934
Corporate Bond Rate, Percentage Points	Z^A	1.5695	1.2906
Policy Rate, Percentage Points	i	1.2825	1.4561
Real Wage, Quarterly Growth	dw	0.0038	0.0022
Bank Loans, Quarterly Growth	dL	0.0074	0.0074
Value of Net Worth in Sector A, Quarterly Growth	$dV^{E,A}$	0.0634	0.1174
Value of Net Worth, Quarterly Growth	dV^E	0.0327	0.1158
Bank Holdings of Corporate Bonds, Quarterly Growth	$dQ^{B,corp} B^{corp}$	0.0431	0.0443
Bank Holdings of Government Bonds, Quarterly Growth	$dQ^{B,gov} B^{gov,B}$	0.02	0.0365
Stock of Government Bonds Outstanding, Quarterly Growth	$dQ^{B,gov} B^{gov}$	0.0224	0.0118
Government Bond Yield, Yield to Maturity, Percentage Points	$r^{B,gov}$	1.644	1.259
Growth of Bank Equity, Quarterly Spread between Corporate Bond Rate and Policy Rate, Annualized, Basis Points	dE^I $Z^A - 1 - i$	0.0158 101.44	0.0129 91.34
Spread between Loans Rate and Policy Rate, Annualized, Basis Points	$Z^B - 1 - i$	73.24	61.1

Notes: The table compares the standard deviations of selected observables based upon the simulation of the model at the mode with empirical counterparts. Quarterly growth rates are denoted by d .

Table 5. Moments Comparison: Model-Implied Correlations with Quarterly GDP Growth vs. Data

		Model	Data
Rate of Inflation, Annualized	π	0.0055	0.0122
Investment Growth, Quarterly	dI	0.7295	0.8827
Consumption Growth, Quarterly	dC	0.5563	0.6766
Government Bond Yield, Yield to Maturity	$r^{B, gov}$	0.0235	0.3504
Growth of Bank Equity, Quarterly	dE^I	0.0735	0.3976
Leverage Ratio Banking Sector	ϕ^{IE}	-0.1482	-0.1555

Notes: The table compares the correlations of selected variables to quarterly output growth based upon the simulation of the model at the mode with empirical counterparts. The empirical series for bank leverage is obtained by dividing total assets by bank capital. Data are taken from the ECB's balance sheet items (BSI). The series is linearly detrended. Quarterly growth rates are denoted by d .

Table 5 reports the correlations of selected variables to quarterly output growth, whereas I focus here on the most relevant variables for the sake of brevity. The correlations (relative to quarterly output growth) generated by the model are also rather close to their empirical counterparts. Although the model-implied correlations of government bond yields and bank equity to quarterly output growth are smaller, they have the same sign. As argued by Adrian, Colla, and Shin (2013), the role of capturing the cyclicalities of bank leverage is important for building a macro model with an important banking sector. I draw on a linearly detrended series for bank leverage which is obtained by dividing total assets by bank capital. Both time series are taken from ECB's balance sheet items. The correlation of bank leverage with quarterly growth of per capita GDP, which enters as an observable in the estimation, implied by the estimated model comes very close to its empirical counterpart.³⁶ This moment comparison shows that the model is able to capture dynamics not only in the real economy but also on the financial side. Hence, the structure of

³⁶A more detailed discussion about the correlation between bank leverage and GDP is provided in section F of the online appendix.

the model together with the estimation makes it possible to evaluate quantitatively and qualitatively the effects of government bond purchases in the euro area.

5. Results

In this section, I will discuss the effects of government bond purchases conducted by a public agency, which I have called the “intervention authority,” in order to investigate how the purchases affect leverage-constrained financial and non-financial sectors along with the consequences for the real economy.

5.1 *Effects of Government Bond Purchases on Macroeconomy and Financial Health*

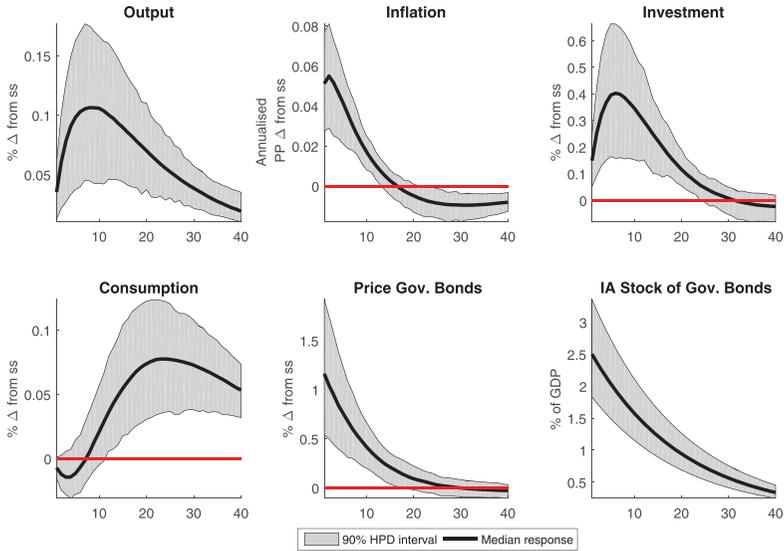
5.1.1 *Baseline Effects from One-Off Program*

First, I present the effects of unexpected purchases conducted in one period, where the stock of bonds held by the intervention authority dissipates over time, i.e., i in equation (33) is set to zero. In figures 1 and 2, the solid black lines represent the effects of government bond purchases amounting to 2.5 percent of GDP. The responses are the medians and are surrounded by their 90 percent highest posterior density intervals (gray areas).³⁷ Figure 1 shows the responses of output, inflation, investment, consumption, the price of government bonds, and the trajectory for the stock of public intermediated government bonds. Figure 2 presents the responses of the net worth of banks, the (aggregate) net worth of entrepreneurs together with the corresponding leverage ratios and spreads; it also depicts lending to entrepreneurs.

The model is able to distinguish between different spreads. The (external) finance premium for the non-financial sector, defined as $\left(1 + E_t \left(R_{t+1}^{k,e}\right)\right) / (1 + r_t^e)$, measures the costs related to the indebtedness of entrepreneurs. It captures the difference between the return on capital and the costs of external finance, i.e., for

³⁷Impulse responses are obtained by simulating the model at its posterior distribution to get an insight into the uncertainty from the estimation. This approach is akin to that of Chen, Cúrdia, and Ferrero (2012).

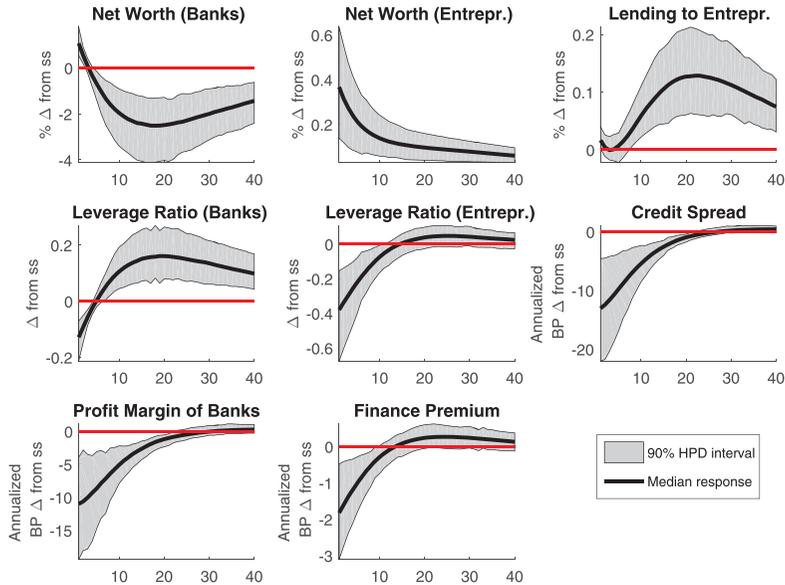
Figure 1. Effects of Government Bond Purchases (1)



Notes: The figure presents the effects of government bond purchases which are induced as “purchase shocks” as presented in equation (33) with $N = 0$. The black solid lines represent the median from a purchase shock amounting to 2.5 percent of gross domestic product (GDP). The gray areas show the 90 percent highest posterior density intervals.

issuing corporate bonds in the capital market in the case of entrepreneur A and bank borrowing for entrepreneur B. This spread is related to expected defaults in the non-financial sector. Furthermore, the bank profit margin reflects financial conditions of banks. It is defined as $(1 + r_t^e) / (1 + r_t^D)$ and is the respective spread between the returns on assets and banks’ costs for external funds. This spread is heavily influenced by the leverage constraint in the banking sector. From this point of view, it resembles the “excess bond premium” from Gilchrist and Zakrajsek (2012). I label this spread “profit margin” because it simply dominates the profit situation in the banking sector from investing in assets. Both spreads together, the finance premium and the profit margin, constitute what I call the “credit spread,” which reflects the overall costs of financial intermediation, $(1 + E_t (R_{t+1}^{k,e})) / (1 + r_t^D)$. Accordingly, the credit spread

Figure 2. Effects of Government Bond Purchases (2)



Notes: The figure presents the effects of government bond purchases which are induced as “purchase shocks” as presented in equation (33) with $N = 0$. The black solid lines represent the median from a purchase shock amounting to 2.5 percent of gross domestic product (GDP). The gray areas show the 90 percent highest posterior density intervals.

comprises financing conditions of entrepreneurs and of banks. The aggregate credit spread is weighted by sector-specific capital. The splitting of the spreads is a clear advantage of this model setup, as it shows how government bond purchases affect financial frictions in the real and the banking sectors differently.

Outright purchases of government bonds conducted by the intervention authority reduce the supply of bonds available to banks and households. As a consequence, bond prices increase, which stimulates banks’ net worth (balance sheet channel). Since bank leverage falls as a consequence, financial frictions in the banking sector are alleviated, as households are willing to provide more funds, and banks raise their credit supply. An increase in credit supply has two consequences: banks demand more corporate bonds, causing the price

of corporate bonds to increase on impact and reinforcing the initial stimulus to banks' net worth. This is very similar to the effects described in Gertler and Karadi (2013). The other outcome is that banks increase their supply of loans. As a result, banks' profit margins in both sectors fall, making investment in capital more attractive. The higher demand for capital increases its price, which reduces entrepreneurs' leverage ratio by boosting the value of entrepreneurs' total assets. The finance premium of entrepreneurs falls as a result, which is the channel discussed by Gilchrist and Zakrajsek (2013). Thus, aggregate investment is boosted on impact, which results in an increase in output and consumption. Government bond purchases eventually improve the financial health of the non-financial sector.

As a consequence of introducing loans priced at par, the balance sheet channel of boosting bank equity by raising asset prices plays a minor role. Hence, lower profit margins in the banking sector translate into lower bank profits, which contracts banks' net worth. Thus, the drop in bank equity resulting from the reduction in lending rates drives banks' leverage ratio upwards in the medium run. Consequently, borrowing constraints are intensified in the banking sector while lending activity generally expands. However, lending volumes react sluggishly because the improvement in the non-financial sector's financial soundness through the improvement in entrepreneurial net worth on impact is sufficient to finance the additional investment activities. In the medium run, the provision of loans increases while lending rates are recovering but remain below their steady-state value. Regarding credit supply, two offsetting forces prevail, obviously stemming from a price (movement on the supply curve) and a quantity effect (movement of the curve). In general equilibrium, lower lending rates coincide with a stronger credit supply, indicating that the credit market clears through the price effect resulting from an increase in credit demand.

However, asset purchases only stabilize banks' balance sheets in the initial period of the policy implementation. This result is consistent with empirical evidence. In the Bank Lending Survey conducted by the European Central Bank, banks were asked in October 2015, April 2016, and October 2016 to evaluate the effects of the Eurosystem's asset purchase program (APP) on specific items. In the first-mentioned survey, a slight majority reported an improvement in bank profits against the backdrop of the APP, while the

assessment has turned negative since April 2016, driven by a drop in the net interest margin, what my model also predicts. At the same time, banks reported an increase in bank leverage and an expansion of total assets driven by granting loans to enterprises.³⁸

The estimation of the model allows me to draw quantitative conclusions from the policy experiment. Following from the surprise program amounting to a stock of 2.5 percent of GDP, output increases to 0.1 percent measured in terms of steady state. The additional effect on annualized rate inflation peaks at 0.06 percent. The drop in bank net worth amounts to 4 percent deviations from steady state, while net worth increases by 0.4 percent on impact. The 90 percent HPD intervals show that the response of the economy to government bond purchases is exposed to a high degree of uncertainty regarding the quantitative effects based upon the posterior distribution. Thus, small changes in parameters might have a larger effect on the outcomes. This issue will be discussed in section 5.2 by looking at relevant parameters.³⁹

By having leverage-constrained non-financial firms and banks in conjunction with pricing loans at par in banks' balance sheets, government bond purchases affect the financial health of both sectors in opposite directions. They alleviate borrowing constraints for non-financial firms, but falling profit margins, as a reflection of portfolio rebalancing effects, undermine the health of the banking sector in the medium run.⁴⁰ Nevertheless, the net effect is positive in this model based upon the estimated parameters for the euro area.⁴¹

³⁸See European Central Bank (2016a, 2016b), section 3.2 "The Impact of the ECB's Expanded Asset Purchase Program."

³⁹Chen, Cúrdia, and Ferrero (2012), for instance, sample from both the prior and the posterior distributions, and ambiguous results occur for the former. The sensitivity analysis which follows in section 5.2 allows for an economic interpretation by using different values for specific parameters. Standard parameters in New Keynesian models do not affect the general conclusions, as shown in section E.1 in the online appendix.

⁴⁰Following from portfolio rebalancing, both households and banks reduce their holdings of government bonds; see figure 14 in the online appendix.

⁴¹The results are discussed by abstaining from the zero lower bound environment, although government bond purchases are usually introduced when the policy rate reaches its lower bound. Section D.4 compares the zero lower bound scenario with the benchmark scenario. As can be seen, the response of consumption now contributes to the differences between the two cases. Since the lower

5.1.2 *The Effects of a Pre-announced Program*

In the previous section, I started to investigate government bond purchases by assuming that the purchases come as a policy surprise (one-off program) in order to highlight the essential channels. In reality, however, central banks announce the future path of government bond purchases. The aim of this section is to explore how the announcement of a program affects the responses of an economy with two leverage constraints. Consequently, I assume that the intervention agency announces the purchases taking place for a specified period starting with the announcement. Thus, there is a policy surprise in the period of the announcement combined with forward guidance on the path of purchases. I present three different scenarios in figures 3 and 4. The benchmark scenario—denoted by solid black lines—is the previous case, in which purchases are conducted as a surprise. In addition, I present results for purchases which are announced four quarters (blue dashed lines) and eight quarters (red dashed lines with dots) in advance and are distributed equally over the respective period.⁴² All programs reach the same maximum stock of 2.5 percent of output.

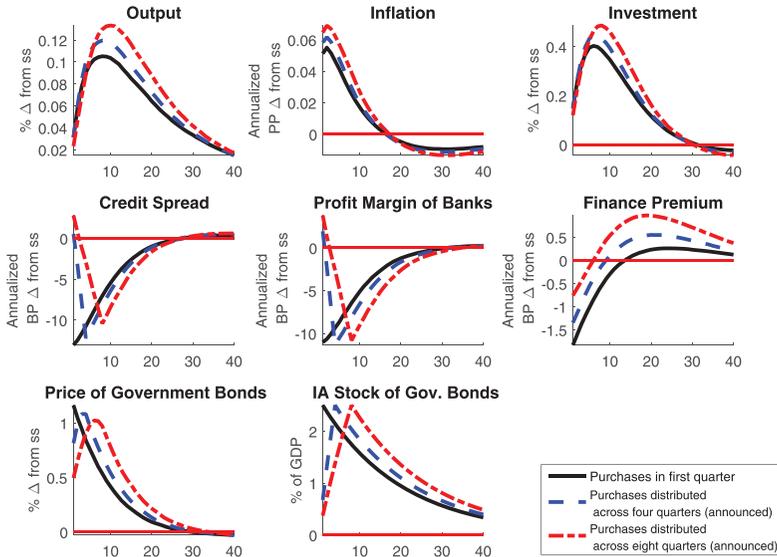
Similarly to the one-off program, the government bond purchases ultimately improve borrowing conditions of non-financial firms, which boosts output via investment. Hence, the macroeconomy does not show qualitatively different effects in the face of these programs compared to the one-off program.⁴³ However, anticipation effects do have an impact on the financial side of the economy. Output peaks at roughly 0.13 percentage points in the second anticipation case on a higher level than in the benchmark case. With the prospect of lower borrowing rates, agents raise their demand for external funds following the announcement of the measures. As a result, the excess demand for credit slightly increases the borrowing

bound has negligible effects on the main channels stressed in the main text, I have delegated the lower-bound case to the online appendix.

⁴²For the first case, N in equation (33) is consequently set to 7, while it is 11 in the second case. The different colors of the lines in these and other figures can be seen in the online version available at <http://www.ijcb.org>.

⁴³It should be noted that the hump-shaped behavior of the real economy is mainly independent of the shape of the program, i.e., the path of portfolio holdings, and therefore comes from the transmission process in which, of course, the parameterization also matters.

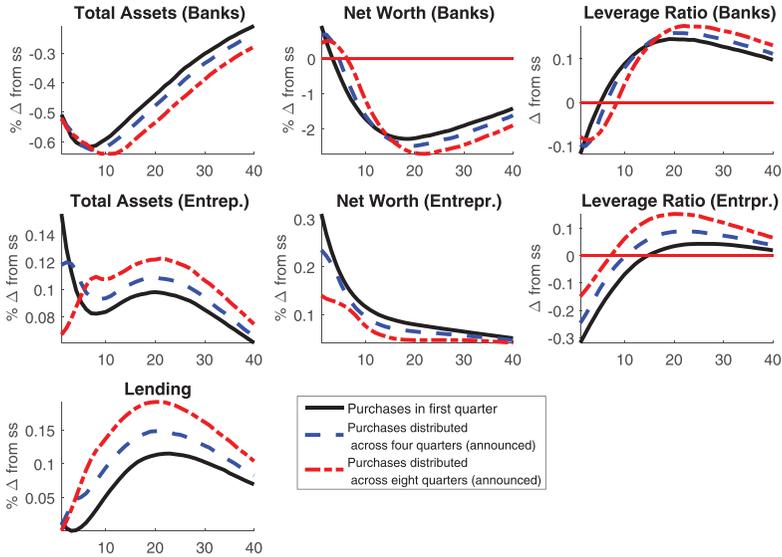
Figure 3. Comparison of Responses to a One-Period Government Bond Purchase Program (Black Solid Lines) and Previously Announced Programs Distributed over One Year (Blue Dashed Lines) and Two Years (Red Dashed Lines with Dots) (1)



Notes: The figure presents the effects of government bond purchases which are induced as “purchase shocks” as presented in equation (33). The purchases are scaled to achieve a maximal stock of 2.5 percent of GDP in each case. The responses are median responses from the estimated model.

rates of the real sector. However, higher profit margins for banks improve their profits, which stimulates the buildup of bank net worth. This is in contrast to the surprise program. The buildup of bank net worth accelerates until the period in which the purchases are conducted. The surprise program raises net worth on impact as a result of the balance sheet channel before net worth starts to shrink again. The improvement in bank net worth peaks at a slightly higher level for the announced programs. While the reduction in banks’ government bond portfolio contracts total assets, lending activity to the non-financial sector is bolstered in the announcement cases, which underscores that a higher credit demand supports the effects. Nevertheless, the trajectory of entrepreneurial leverage shifts upwards.

Figure 4. Comparison of Responses to a One-Period Government Bond Purchase Program (Black Solid Lines) and Previously Announced Programs Distributed over One Year (Blue Dashed Lines) and Two Years (Red Dashed Lines with Dots) (2)



Notes: The figure presents the effects of government bond purchases which are induced as “purchase shocks” as presented in equation (33). The purchases are scaled to achieve a maximal stock of 2.5 percent of GDP in each case. The responses are median responses from the estimated model.

The reason for this is related to a lower trajectory for entrepreneurial net worth, while total assets of entrepreneurs expand by more. This means that firm leverage still drops on impact but exceeds its steady-state level in the medium run, whereas the strength depends upon the duration of the program. Across all cases, i.e., the one-off program or the announced programs, net worth of banks deteriorates in the medium run while net worth of entrepreneurs is above steady state. For the program which is distributed across eight quarters, entrepreneurial leverage rises more strongly in the medium run. The expansion in total assets, however, drives this development and coincides with the expansion in loans.

Table 6. Present-Value Gains in Output Following One-Off and Announced Programs

In %	One Year	Ten Years
Purchases in Current Quarter	0.00	1.36
Distributed across Four Quarters, Announced	1.07	1.42
Distributed across Eight Quarters, Announced	1.62	1.46

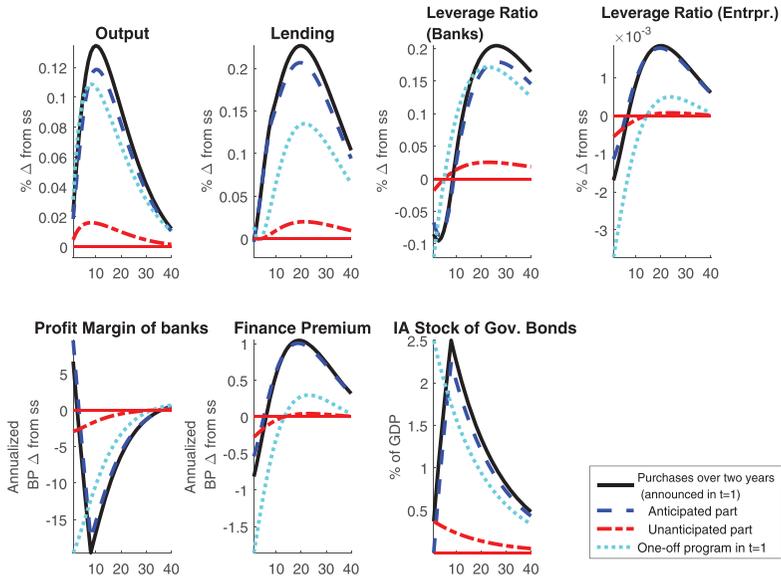
Notes: The table shows the present-value gains in output over a specified period for government bond purchases. The gains in output are expressed as percentage deviations from steady state and are weighted with the time-preference rate. The present-value gain is defined as $gain = \sum_{k=1}^K \beta^k (X_{t+k-1} - X_s) / \sum_{k=1}^K \beta^k (Z_{t+k-1}) \cdot 100$, with X as output and Z the stock of government bonds held by the central bank.

Regarding the quantitative responses of the economy, output rises by more for the announced programs than for the one-off program. However, the balance sheet of the intervention authority has different time profiles in all cases. For the announced programs, the purchased stock is obviously held for longer. In order to allow for a fair comparison, I look at output multipliers for evaluating the effectiveness of the government bond purchases. Table 6 reports the (discounted) gain in output as the discounted sum of output deviations from steady state relative to the discounted sum of the stock of government bonds held by the agency. The present-value gains are calculated over two different horizons: one year and ten years.⁴⁴

A comparison of the present-value gains in table 6 clearly shows that there is an anticipation effect. For a horizon of ten years, present-value gains in output amount to roughly 1.46 percent of the (discounted) stock of government bonds held by the intervention authority over the same period in the case where purchases are announced eight quarters in advance. For the surprise case, the respective output gain is 1.36 percent. It turns out that in the

⁴⁴This is measured as $gain = \sum_{k=1}^K \beta^k (X_{t+k-1} - X_s) / \sum_{k=1}^K \beta^k (Z_{t+k-1}) \cdot 100$, with X as output and Z the stock of government bond purchases held by the central bank with β as the time-preference rate. This measure is based on the present-value multiplier, as it is used to assess the effectiveness of fiscal policies (see, for instance, Mountford and Uhlig 2009).

Figure 5. Decomposition of an Announced Purchase Program with Purchases Distributed over Two Years (Black Lines) into Anticipated (Blue Dashed Lines) and Unanticipated (Red Dashed Lines with Dots) Components and Comparison with a One-Off Program (Turquoise Dotted Lines)



Notes: The figure presents the effects of government bond purchases which are induced as “purchase shocks” as presented in equation (33). The purchase programs (announced and one-off program) are scaled to achieve a maximal stock of 2.5 percent of GDP in each case. The responses are median responses from the estimated model.

short run (a horizon of one year) and medium run (ten years) the announcement of a program produces stronger output effects.

The main difference between the pre-announced programs and the surprise program can therefore be seen in expectational effects. Against the backdrop of the results discussed above, the anticipation effect causes outright purchases to be more successful compared to the one-off program. Figure 5 allows me to gain insight into these expectational effects, as I decompose the announced program with purchases over two years (solid black lines) into its expected (blue

dashed lines) and its unexpected (red dashed lines with dots) components. Furthermore, I again present the responses from the unexpected one-off program (turquoise dotted lines). The last one is qualitatively identical to the unexpected component in the announced program because I assume that the unwinding path of the portfolio is anticipated. It turns out that the expected part is responsible for the initial increase in banks' profit margin. The same is true of the increase in entrepreneurial leverage over the medium run. Both the unexpected and the expected parts have the same impact qualitatively on bank leverage.⁴⁵

5.2 *What Drives the Effects of Government Bond Purchases?*

Having discussed the effects of government bond purchases based upon an estimated model of the euro area, I shed more light on the driving forces in this section. From this point of view, this subsection serves as a sensitivity analysis. I take the estimated model as a point of departure and run several counterfactual experiments by simulating the model at its mode. My focus is on the parameters related to the financial sphere.⁴⁶

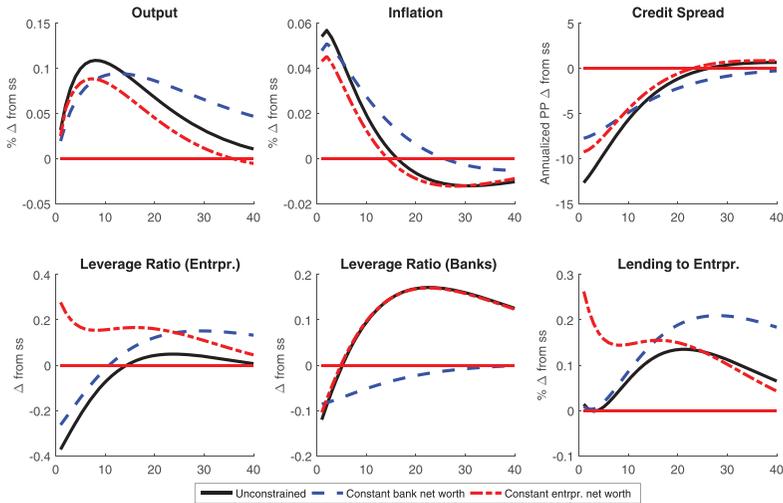
5.2.1 *Role for the Evolution of Sector-Specific Net Worth*

In the presence of two leverage constraints, government bond purchases conducted by the intervention authority tend to relax the borrowing constraint in the corporate sector and make the corresponding constraint in the banking sector more binding. This is a reflection of changes in net worth. To identify the importance of changes in equity in both sectors, I consider cases in which net worth in one sector remains unchanged. The results are presented in figure 6. The black solid lines reflect the benchmark case, while the blue dashed lines show the responses of the economy when bank

⁴⁵Section D.3 in the online appendix tries to disentangle stock from flow effects regarding the anticipation of the program. The role of the information content agents have regarding the purchases is discussed in Darracq Pariès and Kühn (2016).

⁴⁶Variations in standard parameters do not have many effects on the financial sector, as can be seen in section E.1 in the online appendix.

Figure 6. Effects of Government Bond Purchases where Bank Net Worth and Entrepreneurial Net Worth Are Kept Constant



Notes: The figure presents the effects of government bond purchases which are induced as “purchase shocks” as presented in equation (33) by keeping bank net worth (blue dashed lines) and by keeping entrepreneurial net worth (red dashed lines with dots) constant. These cases are contrasted with the unconstrained benchmark case (black solid lines). The purchases are scaled to achieve a maximal stock of 2.5 percent of GDP in every case. The responses are based upon the simulation of the model at its mode.

net worth is kept constant and the red dashed lines with dots show what happens when firms’ net worth remains unchanged.⁴⁷

For the case without constraints on the paths of net worth, banks’ leverage ratio first drops and then recovers before overshooting its steady-state level. Since bank net worth is the main driver, banks’ leverage ratio is obviously prevented from exceeding its steady-state value if bank net worth does not change. Without an effect on bank net worth, output rises by less on impact compared to the unconstrained case because the improvement in banks’ financial health

⁴⁷News shocks to net worth are introduced to keep net worth constant in the respective case.

is less elaborated. However, the missing strong rise in banks' leverage in the medium run causes output to remain above the baseline longer, i.e., the initiated boom lasts longer, which is also translated into a more persistent rise in the rate of inflation. Although credit spreads fall by less, which is related to an upward shift in the trajectory of firms' leverage ratio, lending activity is stronger than in the benchmark case. The weaker response of output in the medium run for the unconstrained case is related to the fact that banks need to bring their leverage ratio down.

The case where the net worth of entrepreneurs is kept constant has nearly no effect on the leverage of banks. In contrast, the response of firms' leverage ratio is reversed. Firms' leverage rises on impact, which is reflected in a less elaborated drop in the credit spread. Output improves by less and is therefore on a lower trajectory, which also means that it falls below the baseline in the medium run, causing a drop in the trajectory for the rate of inflation. Lending activity accelerates because firms need to finance a larger fraction of their investment projects with external funds, as the improvement in their net worth is missing. This is eventually the reason why firms' leverage rises.

These results show that the response of bank leverage mainly controls the shape of the output response, while firms' leverage affects the level of the improvements in output. Thus, my results underline the fact that the financial health of both the banking and the non-financial sector is important for government bond purchases to be effective.

5.2.2 The Role of Financial Frictions in the Non-financial Sector

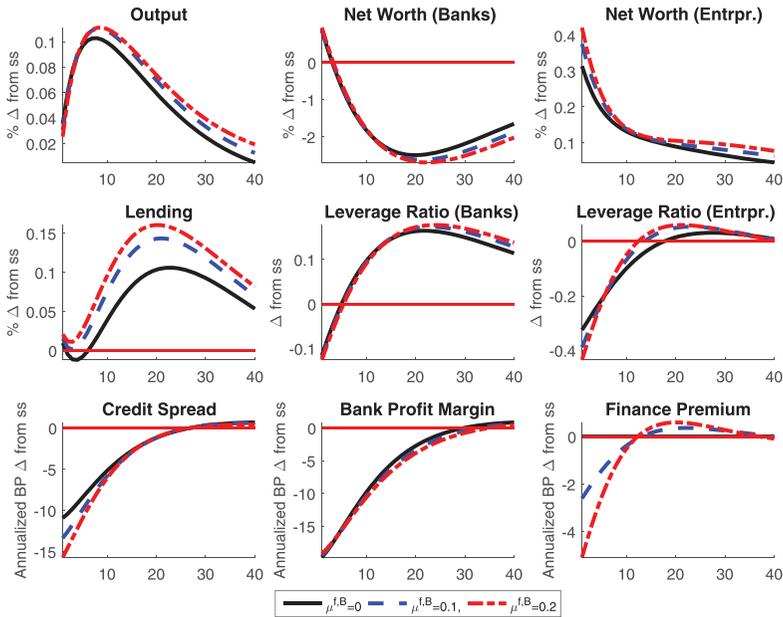
While it is well known that the degree of limits to arbitrage controls the effectiveness of government bond purchases, I provided evidence in the previous section that the financial health of the non-financial sector also plays an important role in this regard. This section has the objective of taking a closer look at the role played by the severity of the leverage constraint in the non-financial sector. In the model, financial frictions in the non-financial sector are driven by monitoring costs, as they determine the costs of expected defaults. The

notion of credit risk is related to expected defaults. Consequently, costs of expected defaults rise if more resources are lost given the probability of default. Hence, higher monitoring costs make defaults more costly, with the result that the finance premium will react more sensitively to changes in the financial health of non-financial firms. Accordingly, a larger role for a leverage constraint arises if monitoring costs are high. For this reason, I treat changes in monitoring costs as a reflection of different degrees of financial frictions in the non-financial sector.

In figure 7, I present the responses of output, bank net worth, entrepreneurial net worth, lending, bank leverage, firm leverage, the (aggregate) credit spread, the overall bank profit margin (covering returns on loans and bonds), and the (aggregate) finance premium on a purchase program conducted in one period for three cases. In the first case (black solid lines) the monitoring costs in the loan sector are set to zero, which deactivates financial frictions in this sector. For the two other cases, financial frictions in the loan sector (sector B) are activated and set at two different levels ($\mu^{f,B} = 0.1$, blue dashed lines; $\mu^{f,B} = 0.2$, red dashed lines with dots). It turns out that the higher the financial constraints for non-financial firms are, the more effective government bond purchases are in supporting output.

As can be seen in figure 7, the finance premium reacts more sensitively than banks' profit margin to changes in monitoring costs in relative terms. Higher frictions in the credit market for entrepreneurial loans make the finance premium fall more sharply given a drop in entrepreneurial leverage, because the costs of expected defaults decline more strongly. This makes asset purchases more effective if financial frictions in the non-financial sector are quite large. Entrepreneurial leverage drops by more with higher financial frictions, which results from a stronger increase in entrepreneurial net worth on impact. Higher net worth coincides with a stronger increase in bank borrowing. Since bank profit margin behaves rather similarly across the cases, the trajectory of bank net worth is almost unaffected by higher monitoring costs. Thus, the stronger rise in lending results from a stronger price effect through credit demand. For the "no frictions" case, the accelerating mechanism is not present, with the result that the decrease in banks' profit margin dominates. The

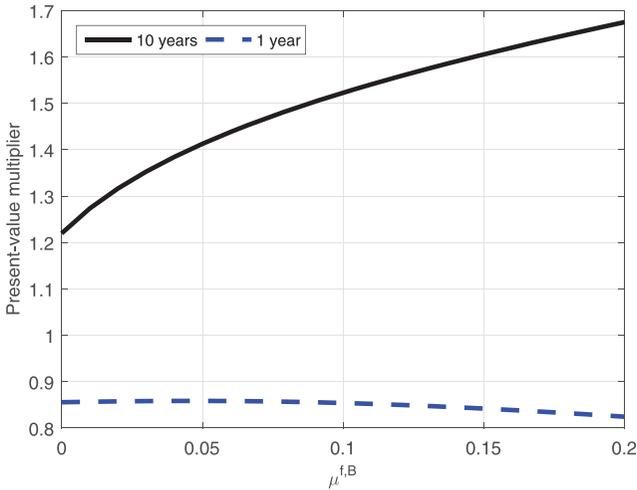
Figure 7. Comparison of Responses to Pure Bond Purchase Shocks for Different Degrees of Financial Friction in the Entrepreneurial Sector B



Notes: The figure presents the effects of government bond purchases which are induced as “purchase shocks” as presented in equation (33) with $N = 0$ (black solid lines) for different values of the monitoring costs in the entrepreneurial sector B (μ^B in equation (19)). The responses are based upon the simulation of the model at its mode.

stimulus to output is mainly driven by the fall in the loan rate, which is completely unrelated to credit risk.

Figure 8 summarizes the impact of frictions (x-axis) on output by looking at the present-value multipliers (y-axis) for a one-year and ten-year horizon, as blue dashed and black solid lines, respectively. While the short-run effect on output tends to be independent of monitoring costs, the output multiplier clearly increases as monitoring costs rise. Thus, government bond purchases stimulate the economy, particularly if the non-financial sector is exposed to strong binding leverage constraints.

Figure 8. Impact of Financial Frictions in the Loan Sector

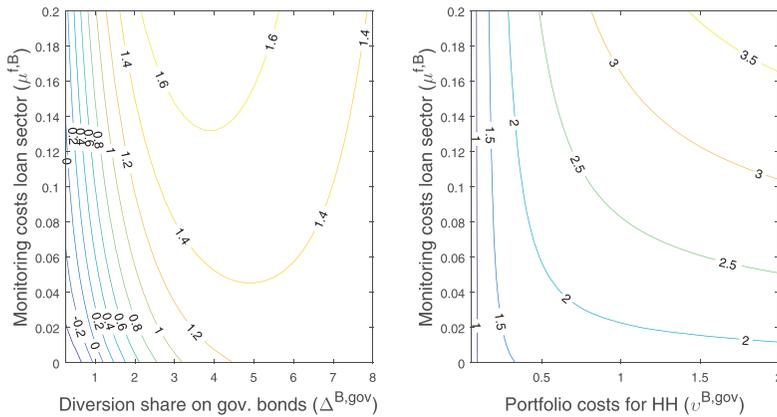
Notes: The figure shows the present-value gains in output following government bond purchases, which are conducted entirely in one period, by varying monitoring costs for the loan sector. The gains in output are expressed in percentage deviations from the steady state and are weighted with the time-preference rate. The present value is defined as $gain = \sum_{k=1}^K \beta^k (X_{t+k-1} - X_s) / \sum_{k=1}^K \beta^k (Z_{t+k-1}) \cdot 100$, with X as output and Z the stock of government bonds held by the central bank.

5.3 *The Role of Market Segmentation in Conjunction with Financial Frictions*

As is known from Andrés, Lopez-Salido, and Nelson (2004), for example, limits to arbitrage are crucial for obtaining non-trivial effects of outright purchases. Portfolio adjustment costs for households and the diversion share related to government bonds in the banking sector, $v^{B,gov}$ and $\Delta^{B,gov}$, respectively, produce limits to arbitrage in the present model. Government bond purchases become more efficient in boosting output if frictions prevail in both sectors.⁴⁸ I provided evidence in the previous section that the severity of financial frictions in the non-financial sector is also highly relevant

⁴⁸This issue is shown for the present model in section D.2 in the online appendix.

Figure 9. Impact of Financial Frictions in the Loan Sector and the Role for Market Segmentation



Notes: The figure shows the present-value gains in output following government bond purchases, which are conducted entirely in one period, in relation to variations in different frictions. The gains in output are expressed in percentage deviations from the steady state and are weighted with the time-preference rate. The present value is defined as $gain = \sum_{k=1}^K \beta^k (X_{t+k-1} - X_s) / \sum_{k=1}^K \beta^k (Z_{t+k-1}) \cdot 100$, with X as output and Z the stock of government bonds held by the central bank.

in achieving non-trivial effects on output following government bond purchases. This section aims to shed light on the interplay between the three main parameters which control the impact of government bond purchases.

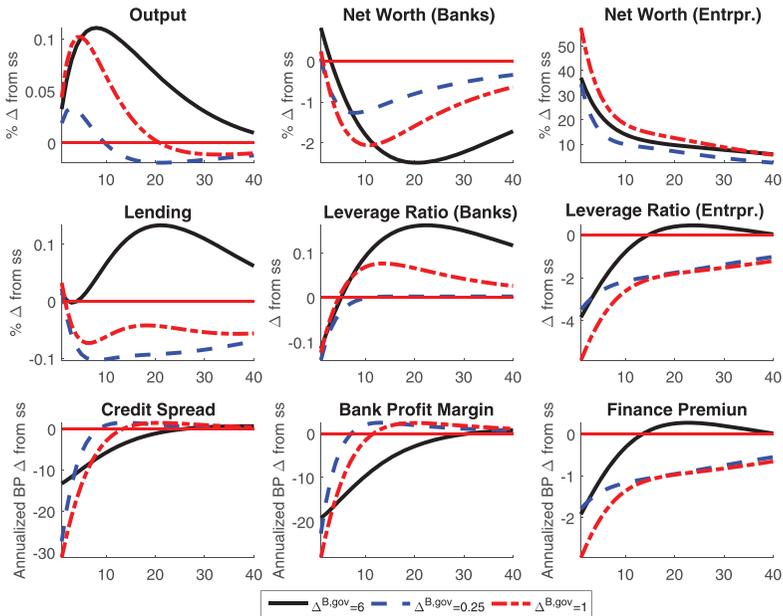
Regarding the effectiveness of government bond purchases, the interplay between financial frictions in the non-financial sector and the factors determining the pricing of government bonds plays an essential role. Figure 9 depicts the present-value gains in output for a horizon of ten years in relation to the monitoring costs in the loan sector (always on the y-axis). On the left-hand side, the diversion share related to government bonds is altered (x-axis), while it is the portfolio costs parameter for households on the right-hand side (x-axis) that is varied. It turns out that monitoring costs, the diversion share, and portfolio costs for households control the effectiveness of government bond purchases together. For low diversion shares on government bonds and low portfolio costs, the output response is

nearly independent from financial frictions in the non-financial sector. The reason for this is that, in these cases, government bond purchases have small effects, as arbitrage quickly removes differences in (expected) returns. Consequently, financial frictions in the non-financial firms sector only start to play a role for intensified limits to arbitrage, and higher monitoring costs tend to raise output gains. However, output gains start to fall at some point for a given level of financial frictions in the non-financial sector by increasing the diversion share related to government bonds. Since very high levels of limits to arbitrage produce strong portfolio rebalancing effects, the negative effect on equity in the medium run starts to slightly offset the improvement in non-financial firms' borrowing conditions.

In figure 10, I present the impulse responses following government bond purchases for output, bank net worth, entrepreneurial net worth, lending volumes, bank leverage, firm leverage, the credit spread, bank profit margin, and the finance premium depending on the frictions in the banking sector by varying the asset-specific diversion share related to government bonds. As is known from figure 9, low levels of $\Delta^{B.gov}$ result in modest improvements in output. This is the case, although for low diversion shares, the credit spread decreases by more on impact through a drop in bank profit margin as a reflection of the initial increase in credit supply and a drop in the finance premium as a result of lower entrepreneurial leverage. However, the credit spread recovers faster to its steady-state value before it exceeds its steady state against the backdrop of lower limits to arbitrage. Consequently, lending volumes contract, and this contraction is accompanied by a smaller drop in bank net worth. For low diversion shares directed to government bonds, the price effects in general equilibrium do not last long enough to stimulate credit volumes in the medium run. Bank leverage does not overshoot its steady state as in the case of higher diversion shares.

Figure 11 shows the related responses of output and the financial variables for different portfolio costs directed to government bond holdings of households. Again, all other parameters remain at their modes. Similar to the previous case, more intensive frictions lead to stronger initial drops in the bank profit margin as a response to government bond purchases. As opposed to low diversion shares related to government bonds, bank leverage drops by less on impact but exceeds its steady-state value faster. Stronger portfolio costs

Figure 10. Impact of Financial Frictions in the Loan Sector: Impulse Responses for Different Asset-Specific Diversion Shares

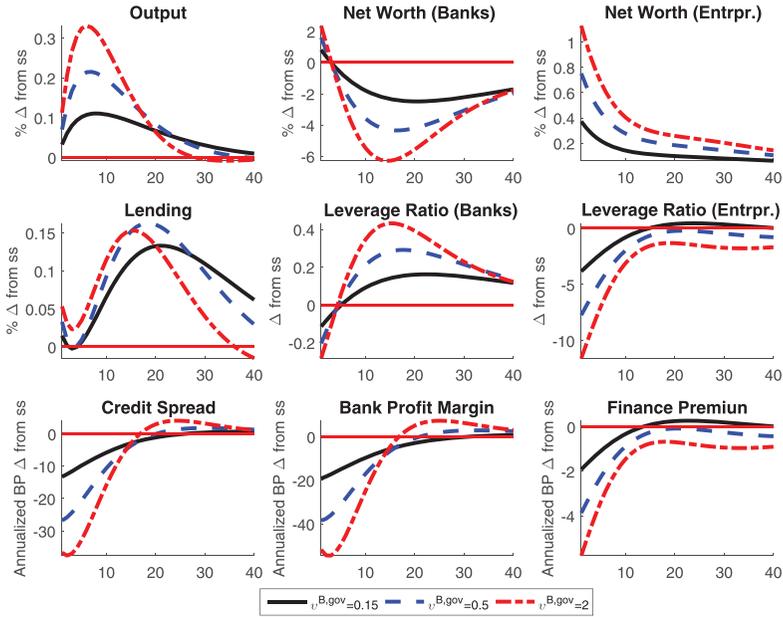


Notes: The figure shows the impulse response function following purchases of government bonds. For the first case (black solid lines), the parameter $\Delta^{B.gov}$ controlling the asset-specific diversion share directed to government bonds is set to 6 (close to benchmark case), for the second case (blue dashed lines) it is 0.25, and for the third case (red dashed lines with dots) it is 1. The responses are based upon the simulation of the model at its mode.

raise bank leverage by more in the medium run, although output increases by more. This shows that the price effect via lending rates clearly dominates lending, although the health of the banking sector deteriorates. This coincides with a strong improvement in the financial soundness of the non-financial sector.

As long as households contribute to limits to arbitrage in a significant way, the effectiveness of government bond purchases in terms of having sizable effects on output will be driven by leverage constraints in the banking sector and also, to a large extent, by leverage constraints in the non-financial sector. While the first result is

Figure 11. Impact of Financial Frictions in the Loan Sector: Impulse Responses for Different Portfolio Costs



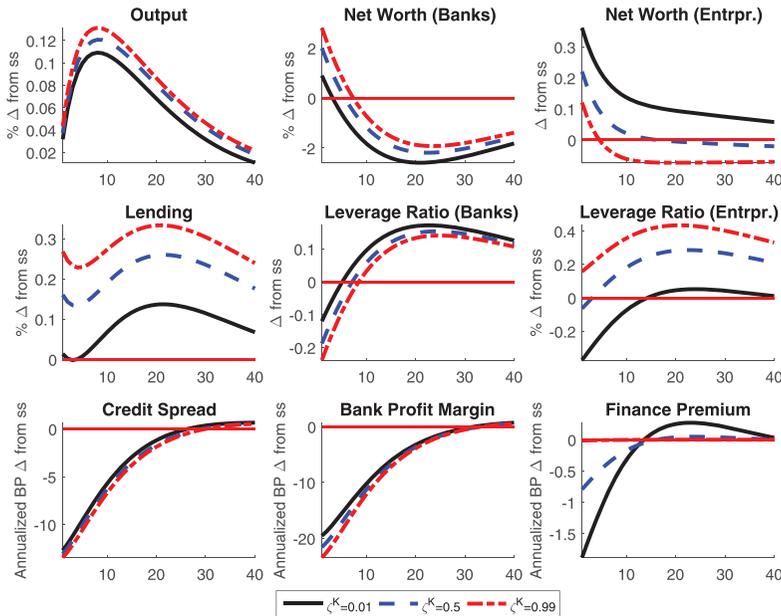
Notes: The figure shows the impulse response function following purchases of government bonds. For the first case (black solid lines), the parameter $v^{B,gov}$ controlling portfolio costs directed to households' holdings of government bonds is set to 0.15 (close to benchmark case), for the second case (blue dashed lines) it is 0.5, and for the third case (red dashed lines with dots) it is 2. The responses are based upon the simulation of the model at its mode.

known from the literature, the second outcome can be derived from my model in which loans priced at par dominate in banks' balance sheets. Variations in frictions in the banking sector affect the relative importance of the price effect, so that loans can contract, and this quantity effect even dominates for aggregate dynamics. For higher portfolio costs, it is again the price effect via lower loan rates that dominates.

5.3.1 Bank-Based vs. Market-Based Economy

An essential feature of the model, which is backed by the estimation, is that loans priced at par dominate in banks' balance sheets.

Figure 12. Dependence of Effects of Government Bond Purchases on the Share of Corporate Bonds in Banks' Balance Sheets



Notes: The figure shows the impulse response function following purchases of government bonds. For the first case (black solid lines), the parameter ζ^K controlling the share of corporate bonds is set to 0.01, for the second case (blue dashed lines) it is 0.5, and for the third case (red dashed lines with dots) it is 0.99. For all cases, the monitoring costs in the A sector are set to 0 and the parameter ρ^B controlling the maturity of the corporate bond portfolio is set to 1. The responses are based upon the simulation of the model at its mode.

In this case, financial frictions in the loan sector have a major impact on the effectiveness of government bond purchases in achieving output gains. To show how the results change if corporate bonds start to dominate in banks' balance sheets, I increase the share of capital financed by corporate bonds, ζ^K as given in equation (11). In figure 12, I present the variables' responses to the purchase shock for three different cases. The first case (solid black lines) reflects an economy in which the balance sheet effect has virtually no meaning. Given the same maturity structure and monitoring costs, cases 2 (blue dashed lines) and 3 (red dashed lines with dots) comprise

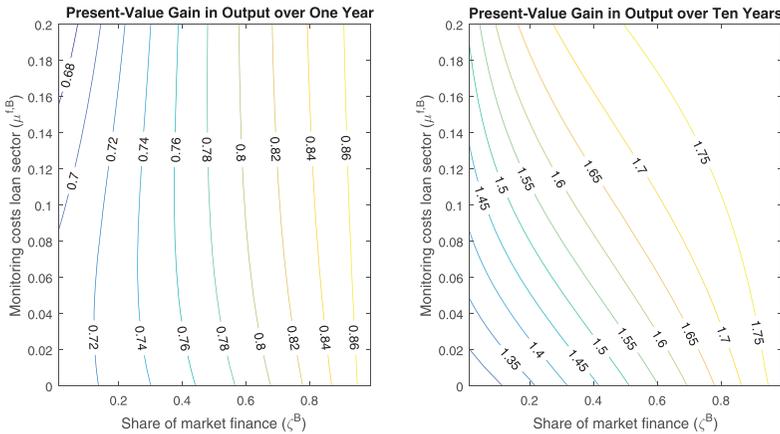
situations with a higher share of corporate bonds in banks' balance sheets. For the third case, loans play nearly no role. In all cases, the corporate bond is a consol and monitoring costs are set to zero in the corporate bond sector.⁴⁹ The share of government bonds in banks' balance sheets remains unchanged.

If corporate bonds start to dominate in banks' balance sheets, the balance sheet channel plays a dominating role. Similar to Gertler and Karadi (2013), purchases of government bonds stimulate banks' net worth, amplified through an increase in the price of corporate bonds, which together lower the leverage ratio and relax financial frictions in the banking sector. Output increases by more with higher shares of corporate bonds in banks' balance sheets following government bond purchases. In the third case, the response of the finance premium does not react as a reflection of no monitoring costs and a dominance of corporate bonds in banks' balance sheet. Here, the positive impact on bank equity is the strongest. Lending activity is more pronounced than in the case where loans dominate in banks' balance sheets as a reflection of the missing effect on the finance premium.

Financial frictions in the loan sector and the balance sheet effects of asset price changes interact. In figure 13, I present the present-value gain in output over one year (left-hand side) and ten years (right-hand side) by varying monitoring costs in the loan sector (vertical axis) and the share of market finance (horizontal axis). For longer horizons, the present-value output gain rises clearly, with higher monitoring costs and changes in the market structure starting from low levels of monitoring costs and a low share of market finance. However, the present-value gains in output become less sensitive to changes in monitoring costs for shorter horizons, as the balance sheet channel clearly dominates the short-run effects. For higher levels of monitoring costs and lower shares of market finance, the effects of government bond purchases on output are equivalent to larger shares of corporate bonds in banks' balance sheet and low monitoring costs. The largest output gains occur for large shares of market finance and high levels of monitoring costs.

⁴⁹This is very similar to the benchmark case in Gertler and Karadi (2013).

Figure 13. Present-Value Gains in Output by Varying the Share of Corporate Bonds and the Financial Frictions in the Entrepreneurial Sector B for Different Horizons



Notes: The figure shows present-value gains in output for government bond purchases which are induced as “purchase shocks” as presented in equation (33) with $N = 0$ for combinations of the parameter which controls the share of corporate bonds ζ^K (x-axis) and monitoring costs in the entrepreneurial sector B (y-axis). The gains in output are measured as deviations weighted with the time-preference rate and expressed in units of purchases in period 1 per units of steady-state output. The present-value gain is defined as $gain = \sum_{k=1}^K \beta^k (X_{t+k-1} - X_s) / \sum_{k=1}^K \beta^k (Z_{t+k-1}) \cdot 100$, with X as output and Z the stock of government bonds held by the central bank.

This again shows that the alleviation of financial frictions in the non-financial sector is an important channel for realizing output effects compared to stabilizing asset prices. In the short run, the balance sheet channel plays a more important role, with rising shares of market finance irrespective of whether frictions in the loan market exist. An increase in the present-value multipliers for large shares of market finance and for larger monitoring costs shows that the credit channel can be a substitute for the balance sheet channel in terms of output gains following government bond purchases. Government bond purchases in an economy with a low level of market finance, while having large frictions in the loan sector, achieves effects similar to those in an economy with a large share of market finance and a low level of frictions in the loan sector. However, output gains

react more sensitively to the increase in market finance than to an intensification of frictions in the loan sector.

As can be seen, the success of government bond purchases in stimulating output depends heavily on the severity of the leverage constraint in the non-financial sector. This credit channel can even be so strong that it is able to compensate for a missing balance sheet channel.

6. Conclusion

In response to a low-inflation environment and a slow economic recovery, central banks around the globe started with asset purchases as an additional policy tool to boost economic activity and rates of inflation. In these programs, purchases of government bonds play the most important role. Reducing the interest rates of medium- and long-term maturities is the main objective of this policy. This paper investigates what effects a reduction in returns on long-term government bonds has on the soundness of non-financial firms and banks in a New Keynesian DSGE model which is estimated with euro-area data. Both sectors are leverage constrained, and government bond purchases improve the financial health of the non-financial sector, while this is only true in the short run for the banking sector as a result from the balance sheet channel. In the medium run, banks' profitability deteriorates and undermines the financial health of the banking sector. Nevertheless, positive effects on output and the rate of inflation remain, predominantly as a result of the reduction in non-financial firms' borrowing conditions, and are amplified by a related reduction in firms' credit risk. With regard to the latter, this paper is able to highlight the channel as discussed by Gilchrist and Zakrajsek (2013). I can show that the larger the financial frictions in the non-financial sector are, the more important this channel becomes. My results provide evidence for fears that the soundness of the banking sector is affected negatively by government bond purchases. However, these effects do not dominate as long as the non-financial sector is sufficiently balance sheet constrained despite the fact that assets priced at par dominate in banks' balance sheets.

In the model, I induce the purchases of government bonds as shocks but do not formulate a specific policy rule as in Jones and Kulish (2013). The aim was to shed light on the transmission of

government bond purchases through the financial sector against the backdrop of two-sided financial frictions and in an environment where loans priced at par dominate in banks' balance sheets. Optimal policy considerations are considered in Darracq Pariès and Kühl (2016), for example.

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