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The financial accelerator and market-based debt instruments: a role for maturities?

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Non-technical summary

Research Question

Although empirical work that is motivated by the financial accelerator approach introduced by Bernanke, Gertler, and Gilchrist (1999) (BGG thereafter) often draws its attention to yields of corporate bonds, in most of the theoretical models with BGG-type frictions the debt instrument is seen as a loan without a market-determined price. From this point of view, it is worthwhile to investigate whether market-based debt can directly be included in the BGG framework instead of non-market-based debt.

Contribution

In this paper, we modifiy the financial accelerator approach by introducing market-based debt instruments, i.e. we allow the debt to have a market-determined price. In addition, we introduce a maturity structure for these corporate bonds. The modified financial accelerator approach is then embedded into a New Keynesian dynamic stochastic general equilibrium model in order to investigate how the modifications change the transmission of shocks.

Results

Our results show that, compared to the standard BGG framework, a dampening of shocks can occur due to the price component in debt instruments. Price changes contribute positively to the finance premium because the ability to service the debt is affected. This result crucially depends on the average maturity of the bond portfolio. The resulting attenuation effect is stronger for longer maturities. As opposed to longer maturities, shorter maturities tend to produce similar quantitative and qualitative dynamics to those obtained by the standard BGG case because the price effect vanishes. Our results show that the BGG approach can be modified by market-based debt. However, the average maturity crucially affects the dynamics.

Nicht-technische Zusammenfassung

Fragestellung

Obwohl der von Bernanke et al. (1999) (folgend BGG genannt) vorgeschlagene Finanzakzelerator-Ansatz allgemein Kredite ohne Marktpreis betrachtet, wird der Ansatz häufig genutzt, um empirische Modellierungen zu motivieren, in denen Renditen von Unternehmensanleihen herangezogen werden. Daher erscheint es angebracht zu untersuchen, unter welchen Bedingungen Kredite mit Marktpreis direkt in den BGG-Ansatz integriert werden können.

Beitrag

Wir modifizieren den ursprünglichen BGG-Ansatz um Kredite, die am Markt gehandelt werden und einen Marktpreis aufweisen (Schuldverschreibungen). Ferner führen wir eine durchschnittliche Laufzeitstruktur in das Modell ein. Das modifizierte BGG-Modell wird dann in ein neukeynesianisches Modell eingebettet, um die Auswirkungen dieser Modifikationen auf makroökonomische und finanzielle Größen in einem gesamtwirtschaftlichen Rahmen zu betrachten.

Ergebnisse

Die Ergebnisse zeigen, dass die aus dem BGG-Ansatz bekannten Verstärkungstendenzen durch die Verwendung von Krediten mit Marktpreis abgemildert werden, d.h. der Akzelerator abgeschwächt wird. Unerwartet schwankende Marktpreise beeinflussen das Nettovermögen und somit den Verschuldungsgrad. Höhere Preise als Folge eines Schocks erhöhen den Verschuldungsgrad und damit die externe Finanzierungsprämie. Dieser Effekt wirkt umso stärker, je länger die Laufzeit des Marktportfolios ist. Kürzere Laufzeiten tendieren dazu, ähnliche Dynamiken zu erzeugen wie der ursprüngliche BGG-Ansatz, da der Preiseffekt an Bedeutung verliert. Unsere Ergebnisse zeigen, dass der BGG-Ansatz unter bestimmten Bedingungen um Marktkredite modifiziert werden kann, wobei Laufzeitstruktureffekte eine bedeutende Rolle spielen.

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The Financial Accelerator and Market-Based Debt Instruments: A Role for Maturities?*

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Abstract

This paper shows how the average maturity of corporate bonds can affect the transmission of shocks if financial frictions prevail. We modify a standard financial accelerator model à la Bernanke, Gertler, and Gilchrist (1999) and allow for market-based debt which has a market-determined price. Our results show that the average maturity of bonds is essential for the transmission of shocks. The dynamics are largely identical to the standard BGG model for shorter maturities, while the model behaves differently for longer maturities. In this case a prolongation channel becomes apparent which attenuates the original amplification mechanism.

Keywords: DSGE Model, Financial Frictions, Maturites, Financial Accelerator, Capital Market

JEL classification: E3, E44, G3

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1 Introduction

The financial accelerator introduced by Bernanke et al. (1999) (hereinafter BGG) has come to be a widely used approach in recent macro-finance models to describe financial frictions between the financial and the non-financial sector (Christiano, Trabandt, and Walentin, 2011; Carrilloa and Poilly, 2013; Christiano, Motto, and Rostagno, 2014). Christiano et al. (2014) have recently argued, with the help of an estimated New Keynesian dynamic stochastic general equilibrium (DNK) model with BGG-type financial frictions, that risk shocks are very important sources of variations in the business cycle. Although empirical work that is motivated by the BGG model draws its attention to yields of corporate bonds (see De Pace and Weber (2013); Mizen and Tsoukas (2012); Gilchrist, Yankov, and Zakrajsek (2009)), in most of the theoretical models with BGG-type frictions the debt instrument is seen as a loan without a market-determined price. The aim of the paper is to incorporate market-based debt into the BGG framework.

Generally, it turns out that corporate bond spreads convey relevant information for future economic activity that is particularly related to financial health (Mody and Taylor, 2004; Gilchrist et al., 2009; Gilchrist and Zakrajsek, 2012). Consequently, the risk premia of financially constrained non-financial firms seems to react more sensitively to shocks than those of more unconstrained firms (Mizen and Tsoukas, 2012). However, recent work can also show that the countercyclical relationship between spreads and economic activity broke down for high-yield bonds during the financial crisis (De Pace and Weber, 2013). From this point of view, it is worthwhile to model bond spreads directly in the BGG framework instead of credit spreads, as is usually done. Market-based debt is generally characterized by market prices. Not only does the trajectory of market prices determine returns, but market prices also affect the repayment capacity if securities are not repaid at par value. How prices of market debt affect the economy when financial frictions prevail is of economic importance because some authors claim that credit spreads, as measured by bond spreads, have a non-trivial role for monetary policy (Cúrdia and Woodford, 2010; Teranishi, 2012).

In this paper, we modifiy the financial accelerator model by introducing market-based debt instruments, i.e. we allow the debt to have a market-determined price. In this regard, bonds' maturity structure plays an important role. We argue that the introduction of security prices in the BGG framework is important because the average maturity of corporate bonds affects the transmission of shocks due to price effects. Our results show that the BGG approach can be modified by market-based debt. However, the average maturity crucially affects the dynamics. Including maturities into a dynamic general equilibrium model is highly important because most contracts last one period in theory but clearly longer in reality. Maturity transformation in banks has been recently investigated by Andreasen, Ferman, and Zabczyk (2013) in a real business cycle model. We propose a different approach by relying on a well-known New Keynesian framework.

The paper is organized as follows. In section 2 we discuss the modification of the BGG approach by including market-based debt instruments. Section 3 provides the dynamic general equilibrium framework in which the financial accelerator is embedded. Before we investigate the dynamics of the models in Section 5, we present the calibration in Section 4. Section 6 concludes.

2 The Agency Problem

2.1 The Financial Accelerator Approach

We follow Bernanke et al. (1999), who rely on Townsend (1979), and posit a costly state verification problem between financial intermediaries and non-financial firms.[1] Non-financial firms realize idiosyncratic shocks that affect the repayment capacity of their external funds. We assume that non-financial firms acquire physical capital which is exposed to these idiosyncratic shocks. The signals are private to non-financial firms. However, financial intermediaries can get knowledge of the signals by spending resources, i.e. incurring monitoring costs. In cases where the idiosyncratic shock is not sufficient to generate enough returns for the non-financial firm to cover all of its debt, it has to give all remaining assets to the intermediaries, which makes the contract incentive-compatible. Because of asymmetric information in conjunction with monitoring costs, non-financial firms combine net worth with debt to purchase physical capital.

In the BGG setting, funds are intermediated between non-financial firms (entrepreneurs) and financial intermediaries with the help of mutual funds (Christiano et al., 2014; Christiano and Ikeda, 2013). The mutual funds obtain financial resources from households and redistribute them to the entrepreneurs. Each financial contract is immanently risky, but through diversification the risk can be eliminated completely. As a result of diversification, the mutual funds can guarantee their ability to pay the risk-free rate to their creditors while the entrepreneurs have to pay the external finance premium in addition to the risk-free rate to compensate the mutal funds for expenses related to monitoring. The resulting external finance premium varies positively with entrepreneurs' leverage ratio.

Typically, the financial contract is seen as a debt instrument that has a constant price of unity. We modify the BGG setting in this respect, i.e. we allow for a debt instrument with a price that changes over time, i.e. we treat bonds. Thus, the balance sheet constraint of the entrepreneurs becomes

$$Q_t^B B_{m,t+1} = Q_t^K K_{m,t+1} - NW_{m,t+1}, \tag{1}$$

where Q_t^B is the real price of the bond, $B_{m,t+1}$ is the quantity of bonds the m-th entrepreneur demands, Q_t^K is the price of capital, $K_{m,t+1}$ the capital stock each m-th entrepreneur holds and $NW_{m,t+1}$ is the net worth of each m-th entrepreneur. The introduction of the real bond price Q_t^B makes this model different from the standard BGG model, in which Q_t^B is equal to one.

By introducing the bond price and the risky (gross) bond rate Z_{t+1} we modify the condition that determines the threshold $\overline{\omega}_{m,t+1}$ for the productivity process, below which bankruptcies occur, given the value of capital held and given the return on capital $R_{m,t+1}^K$

$$\overline{\omega}_{m,t+1}\left(1 + R_{t+1}^K\right) Q_t^K K_{m,t+1} = Z_{t+1} Q_t^B B_{m,t+1}. \tag{2}$$

In Eqs. (1) and (2) the initial consequences of the introduction of the price become clear. Given the value of capital the entrepreneurs want to purchase, given their real quantity of

[1] An alternative setting which is frequently used sees financial frictions between the financial intermediaries, namely banks, and their creditors (see, for example, Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011). As argued by Christiano et al. (2014), both approaches are closely linked.

bonds, and the contractual bond rate, an increase in bond prices raises the productivity threshold for defaults and lowers entrepreneurial net worth.

Following the standard BGG approach, the entrepreneur's expected earnings can be expressed as the difference between the earnings on the projects given all realizations of the productivity exceeding the threshold value and the costs of the credit raised for the non-default cases

$$\mathcal{E}_{m,t+1} = E_t \left[\left(\int_{\overline{\omega}^j}^{\infty} \overline{\omega}_{m,t+1} dF(\omega) - (1 - F(\overline{\omega}_{m,t+1})) \overline{\omega}_{m,t+1} \right) \left(1 + R^k_{t+1}\right) Q^K_t K_{m,t+1} \right]. \quad (3)$$

The function $F(\overline{\omega}_{m,t+1})$ in Eq. (3) represents the cumulative density function for realizations of $\overline{\omega}_{m,t+1}$. Thus, its value given one specific realization of $\omega_{m,t+1}$ is the probability of default. In the case of a default, i.e. where the productivity variable falls short of the threshold, the entrepreneurs surrender all remaining assets to the financial intermediary.

Similarly to Bernanke et al. (1999) or Christiano et al. (2014), we can rewrite Eq. (3), with the help of the definition $\Gamma^f(\overline{\omega}) = \overline{\omega} \int_{\overline{\omega}}^{\infty} f(\varpi) d\varpi + \int_0^{\overline{\omega}} \varpi f(\varpi) d\varpi$, to obtain the optimization problem. Net earnings are maximized by choosing the optimal value for $\omega^e_{m,t+1}$ and $K_{m,t+1}$ subject to the participation constraint of the intermediaries which states that intermediaries demand a return which is at least identical to the risk-free rate.

$$\begin{aligned} & \max_{\{K_{m,t+1}, \overline{\omega}_{m,t+1}\}} \left(1 - \Gamma^f(\overline{\omega}_{m,t+1})\right) \left(1 + R^k_{t+1}\right) Q^K_t K_{m,t+1} \\ s.t. \quad & \left[\Gamma^f(\overline{\omega}_{m,t+1}) - \mu G(\overline{\omega}_{m,t+1})\right] \left(1 + R^k_{t+1}\right) Q^K_t K_{m,t+1} \\ & = \left(1 + E_t\left(r^B_{t+1}\right)\right) \left(Q^K_t K_{m,t+1} - NW_{m,t+1}\right) \end{aligned} \quad (4)$$

The function $G(\overline{\omega})$ is defined as $\int_0^{\overline{\omega}} \varpi f(\varpi) d\varpi$ and comprises the default events. The expression $\overline{\omega} \int_{\overline{\omega}}^{\infty} f(\varpi) d\varpi$ is equal to $(1 - F(\overline{\omega}_{m,t+1})) \overline{\omega}_{m,t+1}$. Intermediaries act in a market of perfect competition and earn zero profits.

As a result of profit maximization, we obtain the two well-known optimality conditions: the first-order condition of the contract (Eq. (5)) and the budget constraint of the entrepreneurs (Eq. (6))

$$\begin{aligned} 0 \;=\; & \frac{\left(1 + R^k_{t+1}\right)}{\left(1 + E_t\left(r^B_{t+1}\right)\right)} \left(1 - \Gamma^f(\overline{\omega}_{m,t+1}; \sigma_t)\right) + \frac{\Gamma^f_{\varpi}(\overline{\omega}_{m,t+1}; \sigma_t)}{\left(\Gamma^f_{\varpi}(\overline{\omega}_{m,t+1}; \sigma_t) - \mu G_{\varpi}(\overline{\omega}_{m,t+1}; \sigma_t)\right)} \\ & \times \left(\left[\Gamma^f(\overline{\omega}_{m,t+1}; \sigma_t) - \mu G(\overline{\omega}_{m,t+1}; \sigma_t)\right] \frac{\left(1 + R^k_{t+1}\right)}{\left(1 + E_t\left(r^B_{t+1}\right)\right)} - 1 \right) \end{aligned} \quad (5)$$

and

$$\left[\Gamma^f(\overline{\omega}_{m,t+1}; \sigma_t) - \mu G(\overline{\omega}_{m,t+1}; \sigma_t)\right] \frac{\left(1 + R^k_{t+1}\right)}{\left(1 + E_t\left(r^B_{t+1}\right)\right)} \frac{Q^K_t K_{m,t+1}}{NW_{m,t+1}} - \left(\frac{Q^K_t K_{m,t+1}}{NW_{m,t+1}} - 1 \right) = 0. \quad (6)$$

Because of the arguments outlined above, the mutual funds issue a representative bond to the households. The bond that is at the center of the modification is assumed to have a fixed payoff (i_0) every period that is one determinant of the bond return r^B_t. We provide more details in the next subsection.

2.2 Introducing maturities

Since the maturity of bonds is generally longer than one period in reality, we need to deal with an (average) maturity structure. Woodford (2001) proposes a simple way to take account of average maturities that deviate from one period. He assumes that every period a fraction of bonds matures $(1-\rho)$, whereas the remaining fraction ρ is repaid in later periods (we call ρ the maturity parameter in the following).[2] Chen, Cúrdia, and Ferrero (2012) choose a similar approach to account for maturity considerations. In line with both contributions we assume that each entrepreneur issues corporate bonds with a specific maturity every period.[3] Consequently, the right-hand side of Eq. (2) is the aggregate and comprises a continuum of bonds with corresponding prices. We need to modify this equation with the definition $Q_t^B B_{m,t+1} = \sum_{s=0}^{\infty} Q_{t|t-s}^B B_{m,t-s+1}$, where $Q_{t|t-s}^B$ is the price of a bond in period t issued s periods ago, which gives us

$$\overline{\omega}_{m,t+1}\left(1+R_{t+1}^K\right)Q_t^K K_{m,t+1} = Z_{t+1}\sum_{s=0}^{\infty} Q_{t|t-s}^B B_{m,t-s+1}. \tag{7}$$

Furthermore, we assume that every series s of each non-financial firm m defaults to the same extent if the non-financial firm cannot satisfy all its obligations.[4] Under these circumstances it is easy to show that the price of a series depends on the current bond price and the maturity parameter ρ $\left(Q_{t|s} = \rho^s Q_t\right)$ from which it follows that the aggregate quantity of bonds $B_{m,t}$ is the sum of all series weighted by the maturity parameter $(B_t = \sum_{s=0}^{\infty} \rho^s B_{m,t-s})$.[5]

By introducing maturities we are faced with the problem of choosing a proper definition of the bond return because of the economic interpretation related to it. We can fundamentally distinguish between holdings until maturity and period holdings. If bonds have a maturity of more than one period the definition of (expected) returns becomes relevant because it is related to the investment strategy.[6] From investors' perspective the expected return over the entire period is relevant for the first case, while it is the expected period return for the latter. Since holdings until maturity are less relevant for financial intermediaries in reality we take the period perspective.[7] Given that no arbitrage holds, the (nominal) period return r_t^B for a (composite) bond, that carries a coupon, accordingly arises as

[2] This can be thought of as a reinvestment.

[3] For the sake of simplicity, we assume that entrepreneurs issue bonds so that the average maturity remains the same, i.e. their issuance policy is to control the average maturity. Otherwise we need to think about the reasons why entrepreneurs have different issuance policies.

[4] This is a conventional assumption which is usually covered by enforced law. However, specific series can be affected by default in reality while it is not the case in our model.

[5] Derivations can be found in Chen et al. (2012).

[6] Note that the model will be calibrated to reflect quarterly data. If bonds have a maturity of one quarter, a distinction will not be necessary.

[7] Following the International Financial Reporting Standards (IRFS 13) a fair value measurement can be used to determine the book value of financial assets in firm's balance sheet which is close to market prices. This approach can be applied to both assets and liabilities. The US Generally Accepted Accounting Principles (US GAAP) contain similar guidelines.

$$E_t\left(r^B_{t+1}\right) = \frac{E_t\left(\pi_{t+1}\right)\left(\rho E_t\left(Q^B_{t+1}\right) + i_0\right) - Q^B_t}{Q^B_t}. \tag{8}$$

Woodford (2001) assumes that bond prices result from an "exogenously specified deterministic" process. In that case the perfect-foresight solution does not deviate much from the solution for small stochastic changes. Based upon Woodford (2001), Chen et al. (2012) opt for another formulation of the return and draw on the yield-to-maturity. Hence, it is possible to proxy for different maturities by varying the term ρ in Eq. (8) (see Woodford, 2001). Again, ρ^s states that a fraction of the bonds is paid $s+1$ periods after they are issued. For $\rho = 1$ the bonds become consols and for $\rho = 0$ they are one-period bonds.

2.3 Integrating maturities in the BGG framework

In the following we show what changes if we include bonds with a specific (average) maturity into the BGG framework. In order to prevent households from having to bear the costs of defaulting, mutual funds were introduced, which hold a fully diversified portfolio (Christiano et al., 2014). Households transfer their savings consequently to mutual funds which intermediate them to the entrepreneurs. As mentioned, mutual funds hold a portfolio of entrepreneurial bonds and issue risk-free bonds which are bought by households. This leads to the mutual funds' portfolio $\int_0^1 \sum_{s=0}^{\infty} Q^B_{t|t-s} B_{m,t-s+1} dm$, which must be refinanced. An overview of this setting is given in Fig. 1.

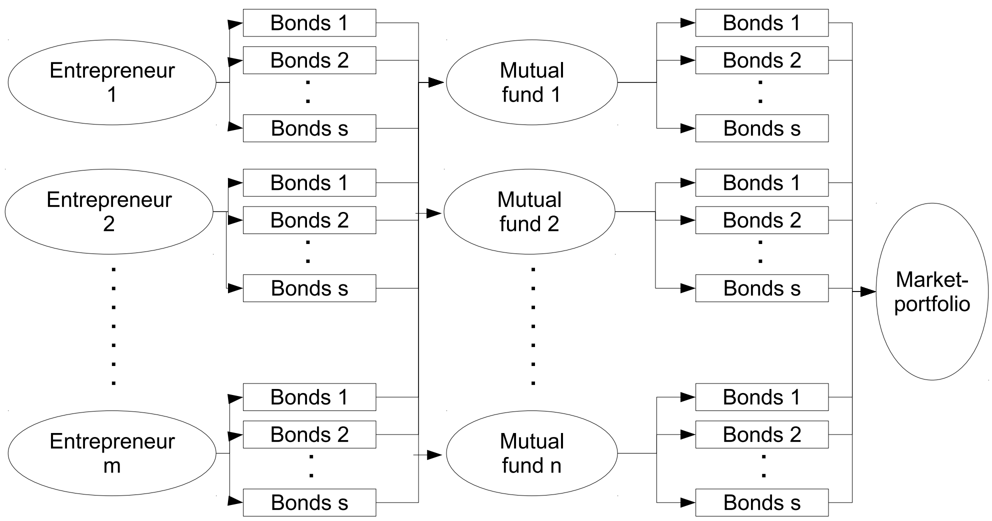

Figure 1: Financial Sector in the modified BGG model

For the sake of simplicity, we assume that financial intermediaries do not conduct term transformation which means that the average maturity of corporate bonds is identical to the average maturity of the bonds financial intermediaries issue.[8] It follows that mutual funds issue bonds every time they plan to buy bonds from entrepreneurs. In order to match

[8] In the absence of large long-lasting stochastic shocks, the yield curve is flat. For this reason, mutual funds have no incentive to exploit term transformation.

the flow of funds, the purchases in the amount $Q^B_{t|k}B_{m,k}$ from the m-th entrepreneur at time k are financed by issuances of the n-th series $Q^{B,mf}_{t|k}B^{mf}_{n,k}$ with the same maturity.[9] With the help of the definition $Q^{B,mf}_t B^{mf}_{n,t} = \sum_{k=0}^{\infty} Q^{B,mf}_{t|k}B^{mf}_{n,k}$ and the corresponding definition for entrepreneurs, we can formulate the participation constraint of the intermediary with respect to the m-th entrepreneur as

$$\begin{aligned} &\left[\begin{array}{c} \left[1-F\left(\overline{\omega}_{m,t+1}\right)\right]\left(1+r_t^{B,risky}\right)Q_t^B B_{m,t+1} \\ +(1-\mu)\int_0^{\overline{\omega}_{m,t+1}}\omega\left(1+R_{t+1}^k\right)Q_t^K K_{m,t+1}dF\left(\omega\right) \end{array}\right]. \\ \geq\ &\left(1+E_t\left(r_{t+1}^B\right)\right)Q_t^{B,mf}B_{n,t+1}^{mf} \end{aligned} \tag{9}$$

Since every individual bond issuance of entrepreneurs is tied to bond issuances of mutual funds, we can replace $Q^B_t B_{m,t}$ in Eq. (9) by $Q^{B,mf}_k B^{mf}_{n,t}$.

The risky bond return, as given in Eq. (2), can be rewritten so that we define the risky bond rate as $E_t\left(r^{B,risky}_{t+1}\right) = E_t\left(\pi_{t+1}\frac{\rho Q^B_{t+1}+i_0}{Q^B_t}\right) - 1$. However, we can easily relate the risky bond rate to the risk-free bond rate by introducing a finance premium $r^{B,risky}_t = r^B_t + fp_t$, thereby obtaining

$$E_t\left(r_{t+1}^{B,risky}\right) = E_t\left(\pi_{t+1}\frac{\rho Q_{t+1}^{B,mf}+i_0}{Q_t^{B,mf}}\right) - 1 + E_t\left(\pi_{t+1}rp_{t+1}\right), \tag{10}$$

where rp_{t+1} is the finance premium in real terms and reflects compensation for risk.

In order to back out the determinants of the compensation for risk, we can re-write Eq. (6) with the help of Eq. (2) and the definition $Z_t = \left(1 + r^{B,risky}_t\right)$ to obtain

$$\left(1+E_t\left(r_{t+1}^{B,risky}\right)\right) = \frac{\left(1+E_t\left(r_{t+1}^B\right)\right)\overline{\omega}_{t+1}}{\Gamma^f(\overline{\omega}_{t+1};\sigma_t)-\mu G(\overline{\omega}_{t+1};\sigma_t)}. \tag{11}$$

As can be seen in Eq. (11) the risky bond rate depends on the risk-free return, the productivity threshold and intermediaries' net earnings after monitoring costs they have to bear as a consequence of entrepreneurs' defaults. With the use of the definitions for the returns and the participation constraint (Eq. (4)) we can solve for the risk compensation to get

$$E_t\left(rp_{t+1}\right) = \frac{\overline{\omega}_{t+1}F\left(\overline{\omega}_{t+1}\right)-(1-\mu)G(\overline{\omega}_{t+1};\sigma_t)}{\Gamma^f(\overline{\omega}_{t+1};\sigma_t)-\mu G(\overline{\omega}_{t+1};\sigma_t)}\left(\frac{\rho E_t\left(Q_{t+1}^{B,mf}\right)+i_0}{Q_t^{B,mf}}\right). \tag{12}$$

What is easy to see is that an increase in the productivity threshold causes the risky bond rate to go up via the risk compensation because it is more difficult for the entrepreneurs to repay their debt contractually and the intermediary requests compensation due to increased monitoring costs. A rise in the current bond price contributes to a fall in the risky bond rate. The reason might be that an increased bond price reflects a fall in the risk-free rate which reduces borrowing costs. However, a rise in expected bond prices stimulates the compensation for risk. The economic interpretation is related to the

[9] This is not a necessary assumption to make the model working because of the diversification. However, we do not want to stress the problem of maturity mismatches.

introduction of market-based debt. The formulation implicitly assumes that the remaining fraction is repaid at expected market price (for reinvestment). In the logic of the model, an increase in the expected bond price raises the value of debt that must be repaid in the future. Given the productivity threshold and the corresponding probability of default, this also means that the investor will lose more money with higher future prices. Hence, the investor wants compensation for this risk. In this case, the reinvestment risk is not negligible and a prolongation risk arises. Consequently, an unexpected rise in bond prices causes entrepreneurial net worth to drop because debt must be repaid at higher market prices. This introduces a new channel how maturity structures matter. It becomes clear that price changes are important determinants in the modification of the BGG approach.

Furthermore, we can get more insight into the relations among the risky and the risk-free bond. By making use of the definition for the risky bond rate, we can also express the finance premium in terms of bond prices

$$E_t\left(rp_{t+1}\right) = \left(\frac{\rho E_t\left(Q^B_{t+1}\right) + i_0}{Q^B_t} - \frac{\rho E_t\left(Q^{B,mf}_{t+1}\right) + i_0}{Q^{B,mf}_t}\right).$$

It should be noted that the prices of both bonds differ due to risk considerations. By combining Eq. (8) with the former, we can state a relationship between the price of corporate bonds and mutual funds' bonds.

$$\frac{1}{Q^B_t} = \left(1 + \frac{\overline{\omega}_{t+1} F\left(\overline{\omega}_{t+1}\right) - (1-\mu) G(\overline{\omega}_{t+1};\sigma_t)}{\Gamma^f(\overline{\omega}_{t+1};\sigma_t) - \mu G(\overline{\omega}_{t+1};\sigma_t)}\right)\left(\frac{\rho E_t\left(Q^{B,mf}_{t+1}\right) + i_0}{\rho E_t\left(Q^B_{t+1}\right) + i_0}\right)\frac{1}{Q^{B,mf}_t}. \tag{13}$$

As becomes clear, the price of the entrepreneurial bond is automatically linked to the mutual funds' bond price and to the riskiness of entrepreneurs. Since mutual funds do not know a priori the riskiness of the entrepreneurs, i.e. the realization of $\omega_{m,t}$, but only have knowledge about its distribution, they would charge every entrepreneurial bond issuance with the same risk premium. However, leverage ratio might differ across entrepreneurs which would basically affect the individual risk premium and would make aggregation more difficult. For this reason, we assume that there is a kind of perfect insurance that equates leverage ratios by transfering net worth across the entrepreneurs before the financial contract is signed.[10] Thus, risk premia do not vary across the continuum of entrepreneurs and, therefore, the price of corporate bonds across entrepreneurs either. It becomes clear that the BGG approach is suitable to introduce traded bonds with the help of several assumptions and the equations from Subsection 2.1 still hold, however, an important role for maturities is introduced.

In order to evaluate the effects of maturities in the dynamic general equilibrium context, we embed the BGG framework into a New Keynesian dynamic stochastic general equilibrium (DSGE) model in the fashion of Smets and Wouters (2003) or Christiano,

[10]This insurance can be seen similarly as the insurance mechanism introduced by Erceg, Henderson, and Levin (2000) with respect to the labor market which equates differences in labor income ex post. However, it is not required that a formal agency preserves the transfers of resources. One can imagine that entrepreneurs with higher leverage ratios might be acquired by entrepreneurs with lower leverage ratios. Market forces would then equate leverage ratios.

Eichenbaum, and Evans (2005) similar to Christiano et al. (2014).

3 Financial frictions in a New Keynesian model

We introduce a standard BGG approach into a standard DNK model à la Smets and Wouters (2003) that is modified to allow for market-based debt which has a price. Hence, there are intermediate goods producers that produce differentiated goods to be sold in a market with monopolistic competition. Through Calvo pricing we introduce stickiness in prices. Non-optimizing firms follow a price indexation as a mixture of steady-state inflation and past inflation. The intermediate goods are bundled following a Dixit-Stiglitz aggregation technology to become final goods. Intermediate goods are produced with the help of capital and labor. Following Erceg et al. (2000) nominal wages are also sticky. The stock of capital can only be adjusted by paying adjustment costs; however, the utilization of capital is allowed to vary, which is associated with costs. After physical capital is produced, it is handed over to entrepreneurs.

3.1 Households

There exists a continuum of households where every l-th household, with $l \in (0,1)$, decides on its consumption ($C_{l,t}$), its labor supply ($N_{l,t}$), and the allocation of its wealth derived from a utility maximization problem. The preferences of the households can be characterized by

$$E_0 \sum_{j=0}^{\infty} \beta^j \left[\frac{(C_{l,t+j} - hC_{t-1})^{1-\sigma}}{1-\sigma} - \kappa \frac{(N_{l,t+j})^{1+\varphi}}{1+\varphi} \right]. \tag{14}$$

In Eq. (14) the parameter β is the discount factor, σ controls the elasticity of intertemporal substitution, and φ reflects the inverse Frisch elasticity. Since households show external habit formation, the parameter h is the habit parameter. The term κ is for scaling purposes. The household can invest in two financial assets: government bonds B_t^G and bonds issued by mutal funds B_t^{mf}. Regarding the former, households earn the risk-free rate while they receive the risk-free bond return for holdings of the latter. Government bonds are in zero net supply. Since households are the owners of intermediate goods firms, the monopolistic profits are paid out as dividends (D_t). Every household has to pay lump-sum taxes (T_t). Besides the returns stemming from their wealth, households receive income from their labor supply.

Concerning the labor supply we follow Erceg et al. (2000) and assume that households supply their differentiated labor to a labor union which demands differentiated labor from all households and bundle this heterogenous labor supply to produce a homogenous labor composite (Eq. (15)).

$$N_t = \left[\int_0^1 N_{l,t}^{\frac{\theta^\omega - 1}{\theta^\omega}} dl \right]^{\frac{\theta^\omega}{\theta^\omega - 1}}. \tag{15}$$

Intermediate goods producers demand the homogenous labor bundle for use in production. Because of monopolistic power in the labor market, households can set wages. In Eq.

(15) the term θ^w controls the substitution among differentiated labor. The labor union minimizes the costs for producing the labor bundle by taking the individual wage rates as given. Following this optimization problem, the demand for each individual unit of labor results as

$$N_{l,t} = N_t \left(\frac{W_{l,t}}{W_t}\right)^{-\theta^w}. \tag{16}$$

By combining Eqs. (15) and (16) we can obtain the aggregate wage index W_t

$$W_t = \left[\int_0^1 W_{l,t}^{1-\theta^w} dl\right]^{\frac{1}{1-\theta^w}}, \tag{17}$$

which is the price intermediate goods firms have to pay for a unit of the labor composite.

Similarly to Calvo pricing in goods markets, households cannot reoptimize their wage every period. Reoptimization is only possible with a probability of $1-\gamma^w$ which they take into account in their optimization problem. Thus, households maximize labor income by choosing the optimal wage rate and by taking the disutility of labor and the demand for their labor as given.

$$\max_{\{W_{l,t}\}} E_t \sum_{s=0}^{\infty} (\beta\gamma^w)^s \left[\lambda_{l,t+s} \frac{\Psi_{t+s}^w}{P_{t+s}} W_{l,t}^* N_{l,t+s}^* - \kappa \frac{\left(N_{l,t+s}^*\right)^{1+\varphi}}{1+\varphi}\right] \tag{18}$$

In Eq. (18) the variable $\lambda_{l,t}$ is the marginal utility of consumption, and the wage indexation is embedded in Ψ_t^w. In cases where households cannot reset their wages, they follow a simple indexation rule that is $\tilde{w}_t = \pi_{t-1}^{\xi^w} \pi^{1-\xi^w} w_{t-1}$, where π is the steady-state rate of inflation.

Since wages and labor supply can fundamentally differ across all households, we assume that a state-contingent insurance exists that equates income across households. Payments from this insurance and transfers to entrepreneurs are denoted by $\Upsilon_{l,t}$. Taking all arguments together, the budget constraint becomes

$$\begin{aligned} P_t Q_t^{B,mf} B_{l,t}^{mf} + P_t B_{l,t}^G + P_t C_{l,t} = \;& P_{t-1}\left(1+i_{t-1+j}\right) B_{l,t-1+j}^G + P_t T_{l,t} + P_t \Upsilon_{l,t} \\ & + P_{t-1}\left(1+r_{t+j}^B\right) Q_{l,t-1+j}^{B,mf} B_{l,t-1+j}^{mf} + P_t D_{l,t} + W_{l,t} N_{l,t} \end{aligned} \tag{19}$$

where the variable P_t denotes the price level. Since households also hold a risk-free bond (with zero net supply) with return i_t, which is the risk-free rate, the no-arbitrage condition $E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\left(r_{t+1}^B - i_t\right)\right] = 0$ results by linking both Euler equations.

3.2 Final goods firms

In a continuum of intermediate goods producing fims each i-th firm produces the i-th differentiated good. All intermediate goods firms operate in a market with monopolistic competition. The final goods sector is characterized by a representitive producer, due to perfect competition, who purchases the intermediate goods and combines them with the help of a bundling technology (Dixit-Stiglitz aggregator) to obtain the final good (Y_t)

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}, \tag{20}$$

where the parameter θ reflects the market power and determines the price markup. The final goods producing firm maximizes profits by taking the prices of the intermediate goods as well as the price of the final goods as given and by choosing the amount of both intermediate goods they demand and the amount of final goods they supply. As a result the demand function for intermediate goods results as

$$Y_{i,t} = Y_t \left(\frac{P_{i,t}}{P_t} \right)^{-\theta}, \tag{21}$$

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

Each i-th intermediate good is produced with the help of a standard Cobb-Douglas production function with constant returns to scale and fixed costs Ω

$$Y_{i,t} = A_t K_{i,t}^{\alpha} N_{i,t}^{1-\alpha} - \Omega_i, \tag{22}$$

where the term α is the share of capital in production and A_t represents the technology. In order to produce a unit of the intermediate good, the firms need physical capital ($K_{i,t}$), they rent from the entrepreneurs, and homogeneous labor ($N_{i,t}$). In a first step, intermediate goods firms minimize their costs by choosing the inputs given their production technology. Since intermediate goods firms have market power, they are able to set the price optimally. However, frictions prevail, which means that setting optimal prices can only be realized with a probability of $1-\gamma$. In cases where intermediate goods firms cannot choose the optimal price, they adjust prices following an indexation rule ($\bar{\pi}_t$) which is a weighted average of last period's inflation (π_{t-1}) and the steady-state rate of inflation (π)

$$\bar{\pi}_t = \pi_{t-1}^{\xi} \pi^{1-\xi}$$

As a result of the Calvo price frictions, intermediate goods firms maximize their profits by choosing the optimal price $P_{i,t}^*$ given the demand for their goods and given their marginal costs by taking the probability of non-optimization into account

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

where mc_t denotes marginal costs.

3.4 Capital producers

The economy is populated by capital producers which are owned by households and work in a market of perfect competition, which is why all capital producers are identical. After production has taken place in period t capital producers purchase undepreciated physical capital $(1-\delta)\,K_t$ from entrepreneurs at price Q_t^K in order to combine it with newly produced investment goods (I_t) to obtain the new stock of physical capital $(\bar{K}_{t+1})$ for use in the next period. Because of attrition, a fraction of the stock of physical capital depreciates at a constant rate δ every period. The installation of new physical capital by using investment goods entails costs $\Psi\left(\frac{I_t}{I_{t-1}}\right)$. The functional form of the cost function is given by $\Psi\left(\frac{I_t}{I_{t-1}}\right) = \frac{v^I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2$ that satisfies the conditions $\Psi(1) = \Psi'(1) = 0$ and $\Psi'' > 0$. The resulting law of motion for capital is presented in Eq. (23).

$$\bar{K}_{t+1} = K_t\,(1-\delta) + I_t\left[1-\Psi\left(\frac{I_t}{I_{t-1}}\right)\right] \tag{23}$$

After capital producers have constructed the new stock of physical capital, they sell it to the entrepreneurs at price Q_t^K at the end of period t. Capital producers maximize their profits by choosing the amount of newly produced investment goods. For convenience, investment goods have the same price as physical capital.

$$\max_{\{I_t\}} E_t \sum_{j=0}^{\infty} \beta^j Q_{t+j}^K \left[K_{t+j}\,(1-\delta) + I_{t+j}\left[1-\Psi\left(\frac{I_{t+j}}{I_{t-1+j}}\right)\right] - K_{t+1+j}\right]$$

3.5 Entrepreneurs

The economy is populated by a continuum of entrepreneurs. Each m-th entrepreneur with $m \in (0,1)$ buys a specific amount of physical capital from capital producers and rents it out to intermediate goods producers. After having purchased the amount of physical capital at the end of period t and before renting it out during the period $t+1$, entrepreneurs process the stock of capital they now own at the beginning of period $t+1$ and subsequently choose its utilization rate in the following. Entrepreneurial skills are subject to random shocks, which are independently distributed across entrepreneurs and periods following a log normal distribution with a mean of unity. These shocks affect entrepreneurs' individual productivity $\omega_{m,t+1}$ which determines the effective stock of capital the m-th entrepreneur can work with

$$\widetilde{K}_{m,t+1} = \omega_{m,t+1}\bar{K}_{m,t+1}. \tag{24}$$

Before this capital is supplied to intermediate goods producers, entrepreneurs can vary the capital utilization rate u_{t+1} so that the utilized stock of capital for the m-th entrepreneur becomes

$$\widehat{K}_{m,t+1} = u_{m,t+1}\widetilde{K}_{m,t+1}. \tag{25}$$

Variations in the capital utilization rate are linked to costs Γ, which take the form

$$\Gamma(u_{m,t}) = \frac{r^k}{\psi^k}\left(\exp\left[\psi^k\,(u_{m,t}-1)\right]-1\right). \tag{26}$$

In Eq. (26) the term r^k represents the rental costs of capital (in the steady state) and ψ^k is a scaling parameter. After the utilization rate has been chosen, entrepreneurs rent the capital to intermediate goods producers and receive the rental rate on capital r_t^k per units of utilized capital. As already explained above, after production has occurred, entrepreneurs sell the undepreciated capital back at price Q_{t+1}^K. Hence, the return on capital for each m-th entrepreneur results as

$$\begin{aligned} 1+R_{m,t+1}^{k,\omega} &= E_t\left[\pi_{t+1}\frac{\left(\,\left[r_{m,t+1}^k u_{m,t+1}-\Gamma(u_{m,t+1})\right]+Q_{t+1}^K(1-\delta)\,\right)}{Q_t^K}\omega_{m,t+1}\right] \\ &= (1+R_{m,t+1}^k)\omega_{m,t+1}. \end{aligned} \tag{27}$$

Because of asymmetric information between the entrepreneurs and their creditors (see Subsection 2.1), the entrepreneurs cannot solely rely on external finance and buy physical capital (at price Q_t^K) with a combination of own resources (net worth $NW_{m,t}$) and external funds. External funds can be obtained by issuing corporate bonds ($B_{m,t}$) at bond price Q_t^B. Loosely speaking, net worth results as an outcome of entrepreneurial activity. The sale of physical capital back to capital producers after intermediate goods producers give rented capital back to entrepreneurs, together with corresponding rental income, generate earnings. From these earnings entrepreneurs satisfy their liabilities stemming from the issuance of external debt. The remainder constitutes net worth. Thus, external finance is determined by the desired purchases of physical capital and existing net worth.

$$Q_t^B B_{t+1} = Q_t^K K_{t+1} - NW_{t+1}$$

The decision problem of entrepreneurs consists of two problems that can be understood as undertaken in two branches. While entrepreneurial profits are maximized by choosing the threshold productivity and the amount of effective capital in the first branch, utilized capital is found by minimizing utilization costs by choosing the amount of capital. While the second problem is straightforward, the first one is already explained in Subsection 2.1. The law of motion for net worth is the only missing equation. In order to prevent entrepreneurs from accumulating net worth indefinitely, which would obviate the need to raise external finance, we follow Bernanke et al. (1999) and assume that entrepreneurs exit with a specific probability of γ. The total number of entrepreneurs remains constant because new entrepreneurs enter who receive a transfer from their households to start business which is a fraction ξ of total assets. Again, the same insurance mechanism that equates leverage ratios across entrepreneurs also controls the average maturity of old and new entrepreneurs by redistributing resources. Consequently, aggregate entrepreneurial net worth evolves from net earnings (for all non-default cases), i.e. the difference between returns on entrepreneurial projects and the costs for external finance plus the transfer from households.

$$NW_{t+1}^e = \gamma \;\frac{1}{\pi_t}\left[\left(1-\Gamma^f\left(\omega_{t+1}\right)\right)\left(1+R_t^k\right)Q_{t-1}^K K_t\right] + \xi Q_{t-1}^K K_t.$$

3.6 Monetary policy

The central bank follows a Taylor rule for setting the policy rate i_t. In doing so, the central bank reacts to deviations of the rate of inflation from a target rate, with a weight of ϕ^{π}, and to the growth rate in output, with a weight of ϕ^{y}. Furthermore, the central bank conducts interest rate smoothing with the autoregressive parameter ρ^{smooth}. The term ν_t^M reflects an unexpected monetary policy shock.

$$(1+i_t) = (1+i_{t-1})^{\rho^{smooth}} (1+i)^{\left(1-\rho^{smooth}\right)} \left(\frac{\pi_t}{\pi}\right)^{\phi^{\pi}\left(1-\rho^{smooth}\right)} \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi^{y}\left(1-\rho^{smooth}\right)} \nu_t^M. \tag{28}$$

3.7 Market clearing

Markets clear by equating the corresponding demand and supply. In the resource constraint, goods supply meets goods demand. Besides investment goods, consumption, and government expenditure (which make up a fixed percentage of output), capital utilization and monitoring costs also accumulate resources. Thus, the resource constraint of the economy becomes

$$Y_t \quad = \quad I_t + C_t + G_t + K_t \, \Gamma_t + K_t \, Q_{t-1}^K \, \frac{\left(1+R_t^k\right) \, G(\omega_t) \, \mu^f}{\pi_t}. \tag{29}$$

4 Calibration

As usual, we calibrate our model on a quarterly frequency. The parameters for the calibration predominantly stem from Smets and Wouters (2007) and Christiano et al. (2014). The latter have recently estimated a model with BGG-type frictions for US data. Obviously, our model then reflects the structure of the USA. All calibrated parameters can be found in Table 1.

For the curvature of the utility function with respect to consumption we set a value of 1.4. Similarly, the inverse Frisch elasticity becomes 1.9. Both values are from Smets and Wouters (2007). The parameter for habit formation in consumption is equal to 0.7 (Smets and Wouters, 2007; Christiano et al., 2014). The Calvo parameters for prices and wages are set at 0.74 and 0.81, respectively, which are the estimated values in Christiano et al. (2014). The weights on lagged inflation in the indexation rules for prices and wages are taken from the same source and become 0.1 and 0.51, respectively, in our model. We also allow for a steady-state rate of inflation that is set to 2.4 per cent annually, which reflects the US experience. The parameter in the cost function for variations in capital utilization becomes 2.54 (Christiano et al., 2014) and the corresponding parameter for investment adjustment costs is 5.5 (Smets and Wouters, 2007). The discount factor is set at 0.9987 based on Christiano et al. (2014), what induces the nominal risk-free rate to be 2.92 per cent and the real risk-free rate to be 0.52 per cent on an annual basis. The depreciation rate of capital is calibrated to the conventional value of 0.025. Labor is set at 0.33.

Regarding the parameters in the Taylor rule, we set the responsiveness to inflation to 2.4 and to output growth to 0.36. The smoothing parameter becomes 0.85. Our parameters for the BGG part corresponds to the estimated values of Christiano et al. (2014). The share of resources lost for monitoring purposes takes the conventional value of 0.21. Similarly, the variance of the idiosyncratic productivity process becomes 0.26.

Table 1: Calibration of Parameters

Description	Symbol	Value
Discount Factor	β	0.9987
Inverse of Frisch Elasticity of Goods' Production Labor	φ	1.9
Curvature on Utility of Consumption	σ	1.4
Habit Formation	h^C	0.7
Calvo Wages	γ^w	0.81
Wage Elasticity in Labor Aggregator	θ^w	6
Share of Lagged Inflation in Indexation Rule for Wages	ξ^w	0.51
Steady State Labor Input in Goods' Production	N	0.33
Capital Share in Intermediate Goods' Production	α	0.4
Depreciation Rate of Capital	δ	0.025
Price Elasticity in Final Goods' Production	θ	6.5
Calvo Prices	γ	0.74
Investment Adjustment Costs	υ	5.5
Capital Utilization Adjustment Costs	ψ	2.54
Share of Lagged Inflation in Indexation Rule for Prices	ξ	0.1
Taylor Rule - Interest Smoothing	ρ_i	0.85
Taylor Rule - Inflation	ϕ_π	2.4
Taylor Rule - Output Growth	ϕ_y	0.36
Steady-State Rate of Inflation, Annualized	π_s	2.4
Share of Realized Profits Lost in Case of Default Due to Monitoring	μ^f	0.21
Variance of Idiosyncratic Productivity Parameter	σ	0.26
Business Failure Rate in Steady State	$F(\omega)$	0.0056
Survival Probability of Entrepreneurs	γ^f	0.985

The business failure rate becomes 0.0056 and the survival probability of the entrepreneurs 0.985.

5 Analyzing the dynamics

5.1 General evaluation of the modified BGG model

In this subsection we discuss the overall performance of the BGG model modified by market-based debt. We contrast its overall dynamic with those of the standard BGG model and the standard New Keynesian model (standard NK).[11] The underlying two shocks are standard in DNK models (monetary policy shock and productivity shock). In the following figures the modified BGG model is given by the bold black lines, the standard BGG model by the blue dashed lines, and the standard NK model by the red lines with dots. For the modification of the BGG model we set the maturity parameter ρ to 1, which means that the bond is a consol, similar to the formulation in Woodford (2001).

The dynamics resulting from a monetary policy shock for output, consumption, investments, inflation, hours worked, real wages, entrepreneurial net worth, the finance premium, and the bond price can be found in Fig. 2. Following the two first-order conditions related to the BGG approach, the finance premium is defined as $\left(1+R^k_{t+1}\right)/\left(1+E_t\left(r^B_{t+1}\right)\right)$. As can be seen, the qualitative dynamics regarding the macroeconomic variables are mostly similar across the three models. However, qualitative differences emerge through the modification of the standard BGG model with respect to net worth and the finance

[11]In the standard NK model all financial frictions are switched off.

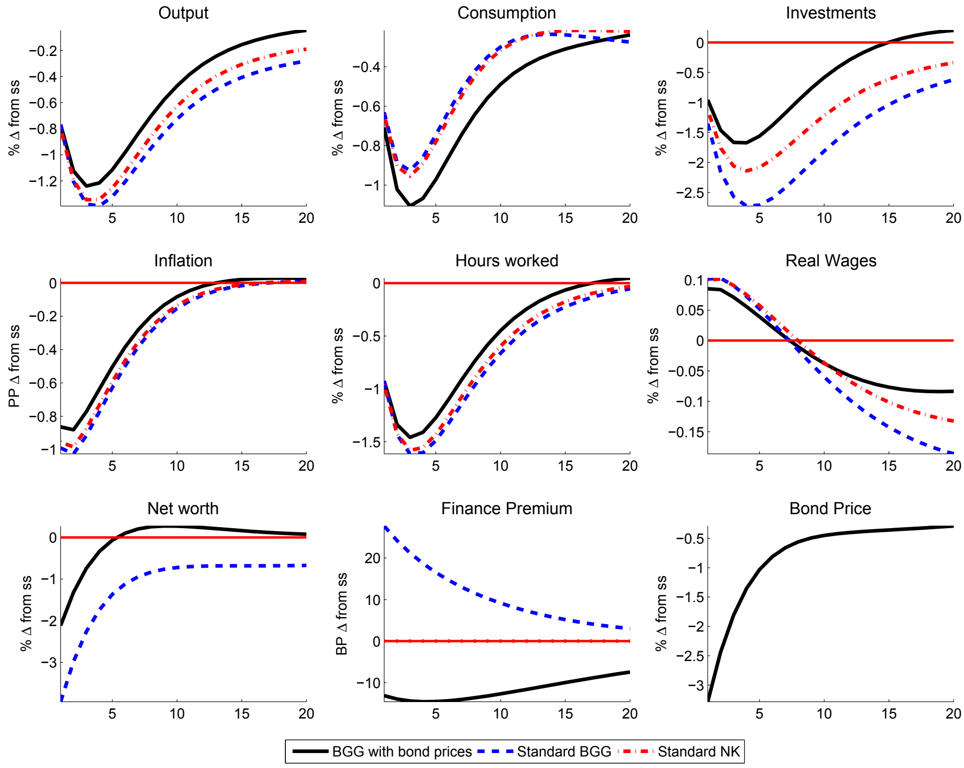

Figure 2: Comparison of Models - Monetary Policy Shock

premium. The introduction of market-based debt with a long maturity structure attenuates the responses of investments and output compared to the standard BGG and the standard NK model. This development is mostly due to the different behavior of the aforementioned two variables. Concretely, the responses of bond prices are the driving force behind and mainly responsible for the differences. By introducing maturities, it is assumed that debt is repaid at the end of every period at the prevailing market price. Since the price drops following the monetary policy shock, it is easier for the entrepreneur to service a given quantity of bonds. Because of this effect net worth shrinks less compared to the standard BGG case. As a result, the leverage ratio decreases which reduces the external finance premium. This is in clear contrast to the standard BGG model in which the finance premium rises. The attenuation of the drop in investments, following the monetary policy shock, stems from the improvement in this part of entrepreneurs' financing conditions. In the case of a very long maturitiy structure, the amplification mechanism of shocks with respect to output and investments, introduced with the help of financial frictions, is even reversed through our modifications. However, consumption decreases by more in the modified model because inflation falls by less which implies a higher trajectory for the risk-free rate.

For the productivity shock, the dynamics of which are shown in Fig. 3, the situation is quite similar. After the productivity shock, the demand for physical capital rises and, as a consequence, its price, which increases entrepreneurs' net worth. Nevertheless, the finance premium slightly increases because of the Fisherian effect (see Christiano, Motto,

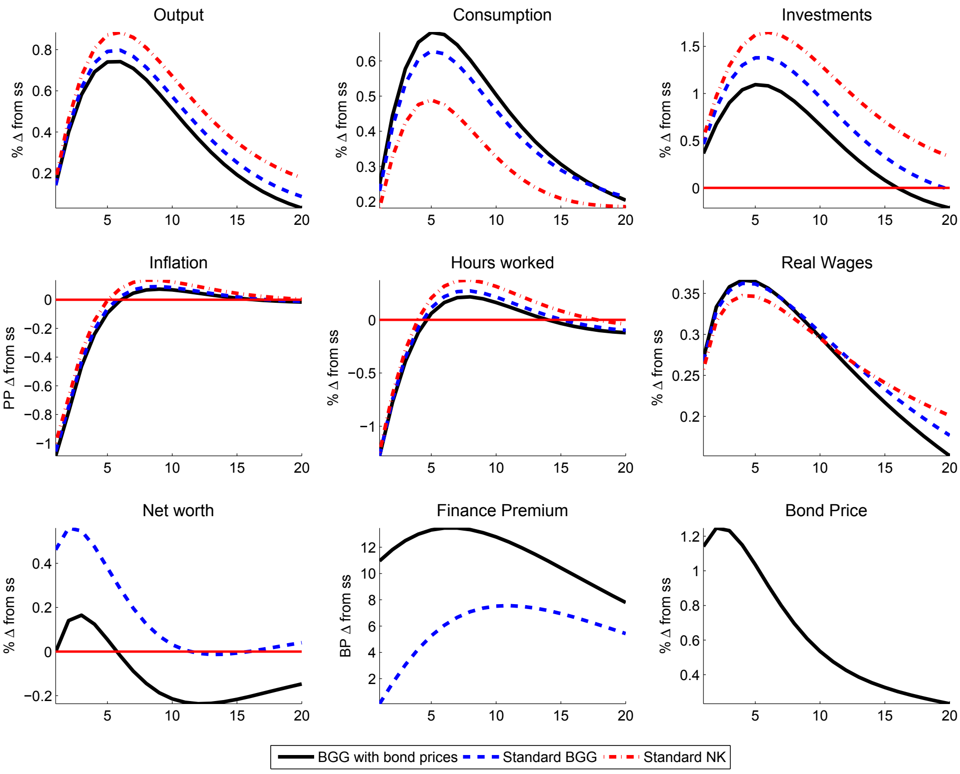

Figure 3: Comparison of Models - Productivity Shock

and Rostagno (2010)). The Fisherian effect stems from the fact that financial contracts are written in nominal terms so that real net worth is also affected by the rate of inflation. As Christiano et al. (2010) show for a transitory productivity shock, which is identical to our productivity shock, the Fisherian effect is mainly responsible for the attenuation of the responses compared to the standard NK model by introducing financial frictions. In the modified model, bond prices also increase which induce the entrepreneurs to have an unexpected higher debt service in the next period with a given quantity of bonds. This effect additionally dampens the increase in net worth in the modified model. The resulting rise in the leverage ratio stimulates the upward pressure in the finance premium and dampens the improvement in investments compared to the standard BGG model. Thus, the introduction of market-based debt with a long maturity structure reinforces the attenuation effects on investments and output resulting from the standard BGG model in the case of the productivity shock.

Summing up the results, the introduction of market-based debt into the standard BGG model attenuates its accelerating mechanism. Changes in bond prices affect net worth which feed back into entrepreneurs' leverage ratio and consequently into the finance premium. In the next section, we discuss the impact of maturities on the dynamics.

5.2 Consequences of different maturities

Fig. 4 shows the effects on output, investments, inflation, the finance premium, the bond price, and net worth following an unexpected monetary policy shock (first column), a productivity shock (second column), and a shock on the riskiness of entrepreneurs (last column). The last shock is typical to understand stress in the financial sector (Christiano et al., 2014). For all three shocks we compare the dynamics of the modified BGG model for three different average maturities. In the first case, the bold black line represents a consol, i.e. $\rho = 1$. The second case comes close to the average maturity in the USA and is given by the dashed red line. The avarage maturity in the USA from 2000 until the emergence of the financial crisis for bonds of non-financial corporations is slightly more than 6 years.[12] This value can be achieved by setting ρ to value of 0.97, which corresponds to an average maturity of slightly less than 6 years.[13] The cyan-colored line with dots reflects an average maturity structure of one period (one quarter), i.e. $\rho = 0$. In addition, we provide the dynamics of the standard BGG model as a benchmark, which is given by the blue dashed dotted lines.

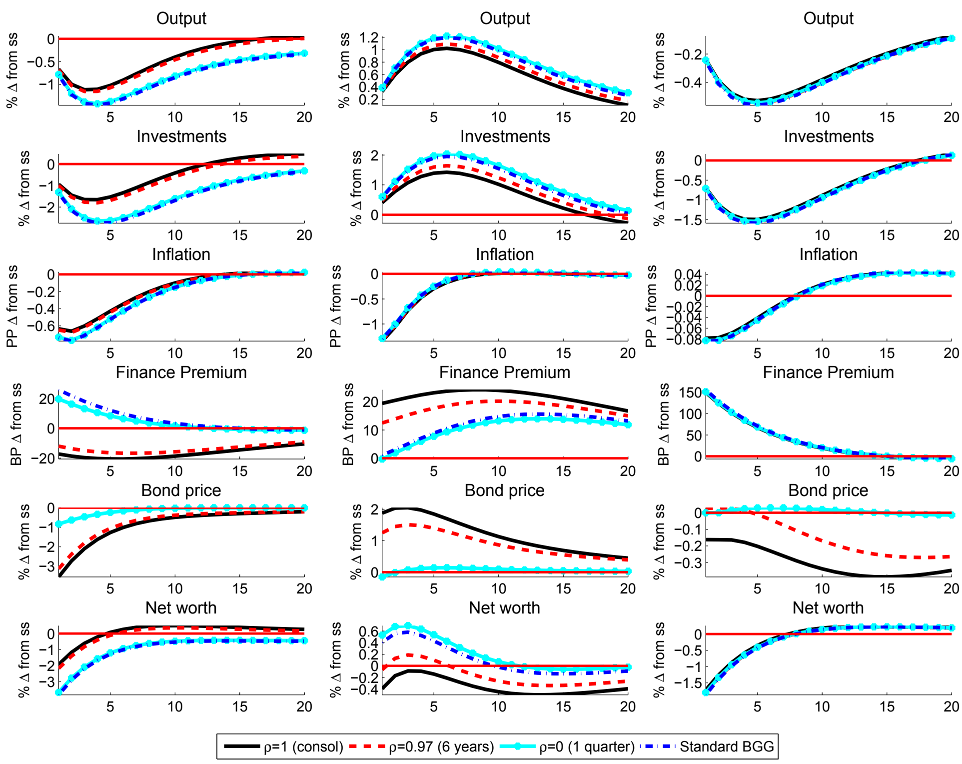

Figure 4: Consequences of Maturities - Monetary Policy Shock (left-hand column), Productivity Shock (middle column), and Risk Shock (right-hand column)

As becomes clear, the case for shorter maturities coincides largely with the standard

[12]We use the duration of the iBoxx corporate bond index for non-financials across all credit ratings as a proxy for the average maturity.

[13]By average maturity we mean the average duration.

BGG case. An unexpected monetary policy shock increases the risk-free rate, which reduces consumption and output. This is the reason why the demand for capital shrinks. The downward pressure on capital prices contracts entrepreneurs' net worth and boosts the finance premium, which makes investments even more expensive. In the case of a longer average maturity, the rise in the risk-free rate depresses the bond price more strongly.[14] The reason for the stronger fall in bond prices is that fewer bonds are repaid every period, which means that the price must fall more sharply to achieve the same return. Falling bond prices now reduce the finance premium so much that it falls below its steady-state value. Since in the model outstanding debt is repaid at market prices every period and the remaining funds are reinvested, lower bond prices ease the debt burden and foster net worth. Investments decrease less than in the standard BGG case, which stabilizes the price of capital and as a consequence entrepreneurs' net worth as well. Inflation also falls less than in the two other cases. From this point of view longer average maturities, as modelled, mitigate the accelerating mechanism following an unexpected monetary policy shock.

The attenuation effect also becomes stronger for longer maturities in the case of the productivity shock. A rise in the aggregate productivity raises the demand for capital. Thus, investment starts to grow and the price of capital rises. Consequently, entrepreneurs' net worth increases, which tends to lower the finance premium. Since inflation is reduced as a result of sunk marginal costs the risk-free rate is lowered in accordance with the monetary policy rule. In the case of a longer average maturity this drop in the risk-free rate initiates a strong rise in the price for bonds. As a result the finance premium widens. Thus, less capital is built up and entrepreneurs' net worth is even depressed.

Unlike the previous two cases, there are nearly no quantitative and qualitative effects following a risk shock resulting from the average maturity on the dynamics except the bond price. The reason is that the risk shock dominates the behavior of the external finance premium.

5.3 Impact of frictions

In order to see how sensitive the propagation mechanism reacts on the severity of financial frictions following the introduction of market-based debt, we vary the share μ^f that controls the monitoring costs. An increase in the share can be interpreted as an intensification of the financial frictions. To present the pure effects stemming from the increase in monitoring costs related to the market price effect, we take the difference between the responses from the modified model and the responses from the standard BGG model. The maturity parameter is set to reflect the US experience. In Fig. 5, the x-axis presents the periods following a shock while the y-axis provides the different values for the monitoring costs. The z-axis gives then the differences in responses between the models, as described, of selected variables for each combination. We draw on the finance premium, net worth and output for the three already treated shocks. Responses on the monetary shock can be found in the first row, on the productivity shock in the middle row and on the risk shock in the third row.

As can be seen the maturity effect, i.e. the attenuation, becomes stronger for more

[14]Note that the magnitude of the original shock, and therefore the trajectory of the interest rate, are nearly identical across the cases.

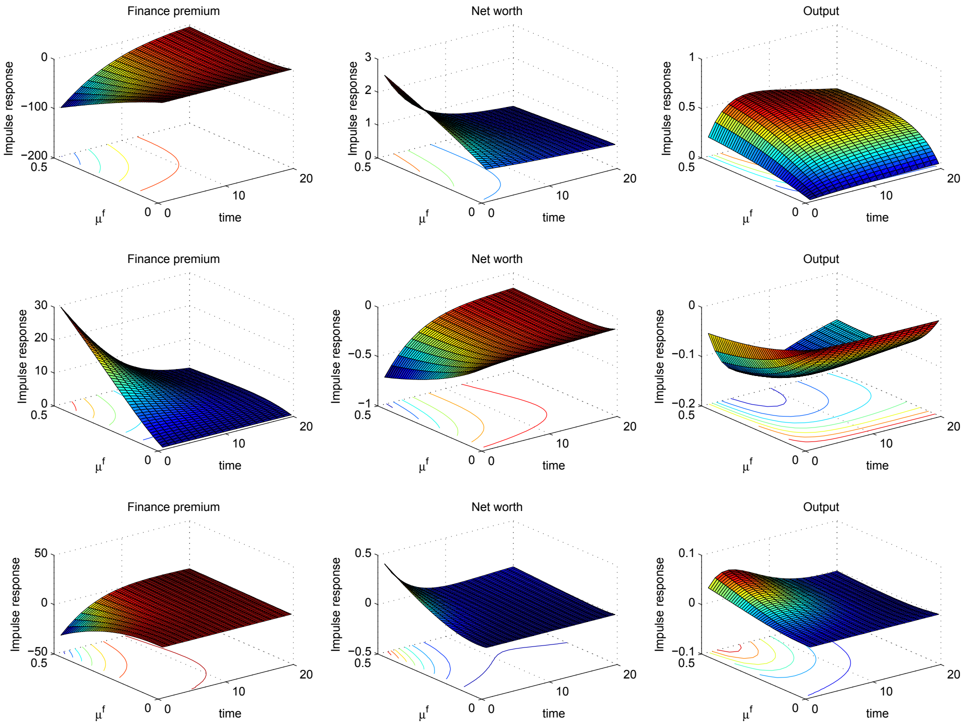

Figure 5: Impact of Financial Frictions on Propagation Mechanism - Monetary Policy Shock (first row), Productivity Shock (middle row), and Risk Shock (last row)
Note: The Figure shows the difference in responses between the modified model and the standard BGG model on specific shocks.

intensified financial frictions. Compared to the standard BGG model net worth raises more and causes the finance premium to drop by more if financial frictions are intensified. As a consequence the fall in output is strongly attenuated for higher degrees of financial frictions. A similar result is also true for the productivity shock. The increase in net worth is sharply dampened which results in a stronger rise in the finance premium. Consequently, the rise in output is attenuated. Even in the case of the risk shock, an attenuation effect arises for higher degrees of financial frictions. Net worth decreases by less which mitigates the increase in the finance premium. The reason for these results can be seen in Eq. (12). In the standard BGG case the risk finance premium depends on the risk-free rate while it depends in the modified model on the risk-free bond return which is determined by the bond price. Bond prices react more strongly following the inital shock for more intensified financial frictions so that they affect net worth to a greater extent.

6 Conclusion

We modified the standard BGG model embedded in a medium-sized DNK model to allow for market-based debt instruments that have a price. Our results show that, compared to the standard BGG framework, countervailing effects can occur due to the price component in debt instruments. This result crucially depends on the average maturity of the bond portfolio. By introducing bond prices, it is assumed that debt must be repaid at market prices every period. Price changes will then contribute positively to the finance premium because the ability to service the debt is affected. The use of the period return leads to different dynamics, particularly when the average maturity of the bonds is long, because more debt must be prolonged every period. As opposed to longer maturities, shorter maturities tend to produce similar quantitative and qualitative dynamics to those obtained by the standard BGG case because the price effect vanishes. Nevertheless, we take the perspective of the investor in our model which means that the investor does not hold bonds until maturity by drawing on the formulation in Woodford (2001). Related to this fact the channel for entrepreneurs results. It would be of interest to take the perspective of the entrepreneurs which requires a further modification of the model.

In a broader sense, our results could explain why the financial accelerator, captured by the link between credit spreads and economic activity, seems to have broken down in the USA (De Pace and Weber, 2013). If a prolongation risk becomes apparent, it could already affect current yield spreads. This might be particularly relevant in an economic recovery while the financial sector is still under stress. In cases where maturities matter, our results correspond to the findings of Andreasen et al. (2013). As opposed to them, however, we do not draw on maturity transformation, but it would be interesting to extend our model in this respect.

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A Model equations

A.1 Real sector

- Marginal Utility of Consumption

$$\lambda_t = (C_t - h\, C_{t-1})^{(-\sigma)}$$

- Euler Equation

$$E_t \left(\frac{\beta\, \lambda_{t+1}}{\lambda_t} \, \frac{(1+i_t)}{\pi_{t+1}} \right) = 1$$

- Production

$$Y_t = A e^{\epsilon_t^A} \, (u_t\, K_t)^{\alpha} \, N_t^{1-\alpha} - \Omega$$

- Capital-Labor Ratio

$$\frac{r_t^k \, (1-\alpha)}{\alpha\, w_t} = \frac{N_t}{u_t\, K_t}$$

- Capital Accumulation

$$K_t = (1-\delta)\, K_{t-1} + I_t \, (1 - \Psi_t)$$

- Price of Capital

$$Q_t^K = \frac{1 - E_t \left(\frac{\lambda_{t+1}\, \beta\, Q_{t+1}^K}{\lambda_t} \right) \upsilon \left(\frac{E_t(I_{t+1})}{I_t} \right)^2 \left(\frac{E_t(I_{t+1})}{I_t} - 1 \right)}{\left(1 - \frac{\upsilon}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{\upsilon\, I_t}{I_{t-1}} \right)}$$

- Marginal Costs

$$mc_t = \frac{w_t}{e^{\epsilon_t^A} \, (1-\alpha)} \left(\frac{r_t^k \, (1-\alpha)}{\alpha\, w_t} \right)^{\alpha}$$

- Capital Adjustment Costs

$$\Psi_t = \frac{\upsilon}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2$$

- Capital Utilization Costs

$$\Gamma_t = \frac{r_s^k}{\psi} \, (exp\,(\psi \, (u_t - 1)) - 1)$$

- Price Equation

$$1 = \gamma \left(\frac{\tilde{\pi}_t}{\pi_t} \right)^{1-\theta} + (1-\gamma)\, \pi_t^{*\,1-\theta}$$

- Price Indexation

$$\tilde{\pi}_t = \pi_{t-1}^{\xi}\, \pi_s^{1-\xi}$$

- Optimizing Price

$$\pi_t^* = \frac{\theta}{\theta - 1} \frac{NP_t}{DP_t}$$

  - Numerator

$$NP_t = mc_t \lambda_t Y_t + \beta \gamma E_t \left[\left(\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}} \right)^{(-\theta)} NP_{t+1} \right]$$

  - Denominator

$$DP_t = \lambda_t Y_t + \beta \gamma E_t \left[\left(\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}} \right)^{1-\theta} DP_{t+1} \right]$$

- Resource Constraint

$$Y_t = C_t + I_t + G_t + K_t \Gamma_t + K_t Q_{t-1}^K \frac{\left(1 + R_t^k\right) \mu^f G(\omega_t)}{\pi_t}$$

- Wage Equation

$$w_t^{1-\theta^W} = \left(1 - \gamma^W\right) w_t^{\star 1-\theta^W} + \gamma^W \left(\frac{\tilde{w}_t}{\pi_t} \right)^{1-\theta^W}$$

- Wage Indexation

$$\tilde{w}_t = \left(\pi_{t-1}^{\xi^W} \pi_s^{1-\xi^W} \right) w_{t-1}$$

- Optimizing Wage

$$w_t^{\star} = \left(\frac{\frac{\theta^W \kappa}{\theta^W - 1} NW_t}{DW_t} \right)^{\frac{1}{1+\theta^W \varphi}}$$

  - Numerator

$$NW_t = \left(N_t w_t^{\theta^W} \right)^{1+\varphi} + \beta \gamma^W E_t \left[\left(\frac{\tilde{\pi^w}_{t+1}}{\pi_{t+1}} \right)^{(1+\varphi)\left(-\theta^W\right)} NW_{t+1} \right]$$

  - Denominator

$$DW_t = N_t \lambda_t w_t^{\theta^W} + \beta \gamma^W E_t \left[\left(\frac{\tilde{\pi^w}_{t+1}}{\pi_{t+1}} \right)^{1-\theta^W} DW_{t+1} \right]$$

A.2 Financial sector

- Return on Capital

$$1 + R_t^k = \frac{\pi_t \left(r_t^k u_t - \frac{r_s^k}{\psi} \left(exp \left(\psi \left(u_t - 1 \right) \right) - 1 \right) + Q_t^K (1 - \delta) \right)}{Q_{t-1}^K}$$

- Euler Equation for Bonds

$$E_t \left(\frac{\beta\, \lambda_{t+1}}{\lambda_t} \frac{\left(1 + r^B_{t+1}\right)}{\pi_{t+1}} \right) = 1$$

- Entrepreneurial Net Worth

$$NW_t = \frac{1}{\pi_t}\, \gamma_t \, \left(\left(1 + R^k_t\right)\, \left(1 - \mu^f\, G(\omega_t)\right) Q^K_{t-1} K_t - \frac{\pi_t\, \left(\rho^B\, Q^B_t + i0\right)}{Q^B_{t-1}}\, Q^B_{t-1} B_t \right) + \xi Q^K_{t-1} K_t$$

- Budget Constraint

$$1 + \frac{K_t\, Q^K_t\, \left(\Gamma(\omega_t) - \mu^f\, G(\omega_t)\right)\, FP_{t+1}}{NW_t} - \frac{Q^K_t\, K_t}{NW_t} = 0$$

- FOC

$$\begin{aligned} &0 = FP_{t+1}\, \left(1 - \Gamma(\omega_{t+1})\right) \\ &+ \tfrac{\Gamma_\omega(\omega_{t+1})}{\Gamma_\omega(\omega_{t+1}) - \mu^f\, G_\omega(\omega_{t+1})}\, \left(FP_{t+1}\, \left(\Gamma(\omega_{t+1}) - \mu^f\, G(\omega_{t+1})\right) - 1\right) \end{aligned}$$

- Finance Premium

$$FP_{t+1} = \frac{1 + R^k_{t+1}}{1 + E_t\left(r^B_{t+1}\right)}$$