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Bank leverage cycles and the external finance premium

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Non-technical summary

The financial crisis of 2007-2009 has drawn renewed attention to the interactions between the balance sheets of banks, the external finance premium, and economic activity. Several empirical studies find that negative shocks to the banks' capital reduce lending and economic activity. Furthermore, Adrian et al. (2012) document that bank leverage is procyclical. At the same time, the net worth of non-financial firms appears to have a positive effect on investment spending.

In order to account for these features, I construct a model (which I henceforth refer to as the "full model") where both bank and non-financial firm leverage matter for the cost of external funds of non-financial firms borrowing from banks and thus for aggregate demand. Specifically, I assume that after collecting households' deposits, a bank may divert a fraction of its assets and declare bankruptcy, as suggested by Gertler and Karadi (2011). Households' awareness of this moral hazard problem implies that their willingness to hold deposits, and thus the bank's ability to supply loans, depends on the present value of the bank's expected future profits and its current net worth. Furthermore, as in the seminal financial accelerator model of Bernanke et al. (1999) (henceforth referred to as BGG), the cost of external finance of entrepreneurs is positively related to their leverage.

I then compare the full model to a BGG-type and a Gertler-Karadi-type model. My main results can be summarized as follows: In a world with only a monetary policy and a productivity shock, the full model matches the procyclicality and volatility of bank leverage observed in US data, whereas bank leverage is strongly countercyclical and too volatile in the Gertler-Karadi-type model. The reason is that in the Gertler-Karadi type model, the bank owns the entrepreneurs capital stock and thus its net worth is directly exposed to the decline in the value of capital Q associated with adverse monetary policy and productivity shocks. The resulting strong on-impact decline in bank net worth implies an increase in bank leverage just as GDP declines. By contrast, in the full model the bank earns interest income but does not hold any traded assets, implying a gradual adjustment of bank net worth. Furthermore, the BGG and, to a lesser extent, the GK model generate too low volatility of the cost of external finance relative to GDP, while the full model succeeds on this dimension. In the full model, adverse monetary policy and productivity shocks reduce future bank leverage and thus future profits of banks, thus causing a cut in loan supply today as households worried about the banks' incentives withdraw deposits. This tightening of loan supply amplifies the increase of the external finance premium as compared to a BGG-type model, as well as the response of other financial variables and GDP.

Furthermore, in the full model, an adverse shock to entrepreneurial net worth causes an output contraction more than twice as large as in a BGG-type model. In line with the empirical evidence cited above, an adverse shock to bank net worth causes a persistent decline in GDP both in the full model and the GK-type model. For a reasonably calibrated combination of both net worth shocks, the model reproduces about two thirds of the trough of investment and about three quarters of the peak of the cost of external finance observed during the Great Recession associated with the financial crisis of 2007-2009.

Nichttechnische Zusammenfassung

Durch die Finanzkrise der Jahre 2007 bis 2009 wurde die Aufmerksamkeit erneut auf die Wechselwirkung zwischen Bankbilanzen, externen Finanzierungsprämien und wirtschaftlicher Entwicklung gelenkt. Mehrere empirische Studien belegen, dass Schocks, die sich negativ auf das Eigenkapital der Banken auswirken, die Kreditvergabe und die Wirtschaftstätigkeit bremsen. Adrian et al. (2012) dokumentieren darüber hinaus die Prozyklizität des Verschuldungsgrads der Banken. Unterdessen scheint das Reinvermögen der nichtfinanziellen Unternehmen einen positiven Einfluss auf die Investitionsausgaben zu haben.

Um diesen Merkmalen Rechnung zu tragen, wurde ein Modell entwickelt (im Folgenden als „vollständiges Modell“ bezeichnet), in dem der Verschuldungsgrad der Banken wie auch der nichtfinanziellen Kapitalgesellschaften die Kosten der von nichtfinanziellen Unternehmen bei Banken aufgenommenen Außenfinanzierungsmittel und damit auch die gesamtwirtschaftliche Nachfrage beeinflusst. Insbesondere wird die Annahme gemacht, dass eine Bank nach Hereinnahme von Einlagen privater Haushalte einen Teil ihrer Aktiva abziehen und Insolvenz anmelden kann (wie von Gertler und Karadi (2011) vorgeschlagen). Das Bewusstsein der privaten Haushalte für dieses Moral-Hazard-Problem impliziert, dass ihre Bereitschaft zur Haltung von Einlagen und damit die Fähigkeit der Bank zur Kreditvergabe vom aktuellen Wert der erwarteten künftigen Gewinne der Bank sowie von ihrem derzeitigen Reinvermögen abhängt. Wie in dem wegweisenden Finanzakzelerator-Modell von Bernanke et al. (1999) (im Weiteren „BGG-Modell“) wird ferner angenommen, dass die Kosten der Außenfinanzierung von Unternehmen positiv mit ihrem Verschuldungsgrad korrelieren.

Anschließend wird das vollständige Modell mit einem BGG-Modell und einem Modell nach Gertler und Karadi verglichen. Die wichtigsten Ergebnisse dieser Untersuchung lassen sich wie folgt zusammenfassen: In einem Szenario mit einem geldpolitischen und einem Produktivitätsschock entspricht die Prozyklizität und Volatilität des Verschuldungsgrads der Bank im vollständigen Modell der anhand von US-Daten ermittelten Entwicklung, während der Verschuldungsgrad der Bank im Gertler-Karadi-Modell stark antizyklisch und zu volatil ist. Grund hierfür ist, dass die Bank im Gertler-Karadi-Modell den Kapitalstock der Unternehmen besitzt, wodurch ihr Reinvermögen von dem mit negativen geldpolitischen und Produktivitätsschocks zusammenhängenden Wertverlust des Kapitalstocks unmittelbar beeinflusst wird. Der starke Rückgang des Reinvermögens der Bank bedeutet, dass ihr Verschuldungsgrad genau dann steigt, wenn das BIP sinkt. Im vollständigen Modell erwirtschaftet die Bank hingegen Zinserträge, hält aber keine gehandelten Vermögenswerte, was eine schrittweise Anpassung ihres Reinvermögens zur Folge hat. Darüber hinaus generiert das BGG- und in geringerem Umfang auch das Gertler-Karadi-Modell eine zu geringe Volatilität der Außenfinanzierungskosten in Relation zum BIP, wohingegen das vollständige Modell auch in diesem Bereich gut abschneidet. Im vollständigen Modell verringern negative geldpolitische und Produktivitätsschocks den künftigen Verschuldungsgrad der Bank und damit auch die künftigen Bankgewinne; dies führt nun zu einem Rückgang des Kreditangebots, da private Haushalte aufgrund von Bedenken hinsichtlich der Anreize der Banken ihre Einlagen abziehen. Diese Verringerung des Kreditangebots bewirkt im Vergleich zum BGG-Modell einen größeren Anstieg der externen Finanzierungsprämie und eine verstärkte Reaktion anderer Finanzvariablen und des BIP.

Außerdem verursacht ein negativer Schock in Bezug auf das Reinvermögen der Unternehmen im vollständigen Modell einen Produktionsrückgang, der mehr als doppelt so hoch ausfällt wie im BGG-Modell. Im Einklang mit der oben zitierten empirischen Evidenz erzeugt ein das Reinvermögen der Bank tangierender negativer Schock sowohl im vollständigen Modell als auch im Gertler-Karadi-Modell einen dauerhaften Rückgang des BIP. Bei einer angemessen kalibrierten Kombination beider Schocks auf das Reinvermögen reproduziert das Modell im Vergleich zu den Werten, die in der großen Rezession während der Finanzkrise 2007-2009 verzeichnet wurden, rund zwei Drittel des Tiefststands bei den Investitionen und drei Viertel des Höchststands bei den Außenfinanzierungskosten.

BUNDESBANK DISCUSSION PAPER NO 55/2013

Bank Leverage Cycles and the External Finance Premium*

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Abstract

By combining the approaches of Gertler and Karadi (2011) and Bernanke et al. (1999), I develop a DSGE model with leverage constraints both in the banking and in the non-financial firm sector. I calibrate this "full model" to US data. In a world with only a monetary policy and a productivity shock, the full model matches the relative volatility of the external finance premium, while a BGG model generates too low volatility. The full model also matches the procyclicality of bank leverage, unlike the GK model. For a reasonably calibrated combination shocks to the net worth of banks and non-financial firms, the model reproduces a substantial share of the contraction (increase) of investment (the external finance premium) observed during the "Great Recession".

Keywords: leverage cycle, bank capital, financial accelerator, output effects of financial shocks.

JEL classification: E52, E53, E54.

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1 Introduction

The financial crisis of 2007-2009 has drawn renewed attention to the interactions between the balance sheets of banks, the external finance premium, and economic activity. Several empirical studies find that negative shocks to the banks' capital reduce lending and economic activity.[1] Furthermore, Adrian et al. (2012) document that bank leverage is procyclical. At the same time, the net worth of non-financial firms appears to have a positive effect on investment spending.[2]

In order to account for these features, I construct a model (which I henceforth refer to as the "full model") where both bank and non-financial firm leverage matter for the cost of external funds of non-financial firms borrowing from banks and thus for aggregate demand. Specifically, I assume that after collecting households' deposits, a bank may divert a fraction of its assets and declare bankruptcy, as suggested by Gertler and Karadi (2011). Households' awareness of this moral hazard problem implies that their willingness to hold deposits, and thus the bank's ability to supply loans, depends on the present value of the bank's expected future profits and its current net worth. Furthermore, the relationship between banks and entrepreneurs borrowing from them is subject to a 'costly state verification' (CSV) problem as in the seminal financial accelerator model of Bernanke et al. (1999) (henceforth referred to as BGG), implying that the cost of external finance of entrepreneurs is related to their leverage.

Below, I compare the full model to a BGG-type and a Gertler-Karadi-type model. My main results can be summarized as follows: In a world with only a monetary policy and a productivity shock, the full model matches the procyclicality and volatility of bank leverage observed in the data, whereas bank leverage is strongly countercyclical and too volatile in the Gertler-Karadi-type model. The reason is that in the Gertler-Karadi type model, the bank owns the entrepreneurs capital stock and thus its net worth is directly exposed to the decline in the value of capital Q associated with adverse monetary policy and productivity shocks. The resulting strong on-impact decline in bank net worth implies an increase in bank leverage just as GDP declines. By contrast, in the full model the bank earns interest income but does not hold any traded assets, implying a gradual adjustment of bank net worth. Furthermore, the BGG and, to a lesser extent, the GK model generate too low volatility of the cost of external finance relative to GDP, while the full model succeeds on this dimension. In the full model, adverse monetary policy and productivity shocks reduce future bank leverage and thus future profits of banks, thus causing a cut in loan supply today as households worried about the banks' incentives withdraw deposits.

[1] See Peek and Rosengreen (1997,2000), the IMF (2010), Ciccarelli et al. (2011), and Fornari and Stracca (2011).

[2] See Hubbard (1998) for a survey.

This tightening of loan supply amplifies the increase of the external finance premium as compared to a BGG-type model, as well as the response of other financial variables and GDP.

Furthermore, in the full model, an adverse shock to entrepreneurial net worth causes an output contraction more than twice as large as in a BGG-type model. In line with the empirical evidence cited above, an adverse shock to bank net worth causes a persistent decline in GDP both in the full model and the GK-type model. The shock decreases loan supply by individual banks and thus increases the cost of external finance. Both bank and entrepreneurial net worth shocks resemble demand shocks in that they move output and inflation in the same direction. For a reasonably calibrated combination of both net worth shocks, the model reproduces about two thirds of the trough of investment and about three quarters of the peak of the cost of external finance observed during the Great Recession associated with the financial crisis of 2007-2009.

My paper differs from the emerging literature developing DSGE models with leverage constraints in both the banking and the non-financial firm sector in that I compare the predictions of my model regarding the cyclical properties of bank and entrepreneurial leverage as well as the cost of external finance to the data. By contrast, Hirakata et al. (2011, 2009), Gerali et al. (2010) and Dib (2010) do not attempt to match the cyclical dynamics of bank and entrepreneurial leverage. Meh and Moran (2010) match the procyclicality of bank leverage, but no predictions are made regarding the properties of the external finance premium or the leverage of non-financial firms. Furthermore, by virtue of being an extension of Gertler and Karadi's (2011) model, the full model could be used to analyze unconventional monetary policy responses to financial crises considered by these authors and Gertler and Kiyotaki (2009).

My paper is related to recent estimates of BGG-type models by Christiano et al. (2012), Fuentes-Albero (2012) and Christiano et al. (2010), who rely on shocks directly affecting the contracting problem between the entrepreneur and the bank in order to match the volatility of the cost of external finance. My results suggest that the full model's richer interactions between the real and the financial sector might be an alternative way to achieve this goal, although testing this hypothesis would require estimating the full model.

The remainder of the paper is organized as follows: Section 2 develops the model. Section 3 discusses the calibration and section 4 compares the response of my model and a BGG-type model to the two conventional shocks. Section 5 performs the moment comparison, while section 6 discusses the effects of shocks to the balance sheets of banks and non-financial firms.

2 The model

Sections 2.1 to 2.3 discuss the real side of the economy, while sections 2.5 and 2.4 discuss the banking and entrepreneurial sector. The derivation of the various first order conditions has been relegated to appendix A for reasons of brevity.

2.1 Households

The economy features a large representative household with preferences described by the intertemporal utility function

$$E_t \left\{ \sum_{i=0}^{\infty} \beta^i \left[\ln \left(C_{t+i} - hC_{t+i-1} \right) - \frac{\chi}{1+\varphi} \left(l_{t+i}^s \right)^{1+\varphi} \right] \right\}$$

where C_t and l_t^s denote a CES basket of consumption good varieties and labor effort, respectively, and h denotes the degree of external habit formation. The household saves by depositing funds with banks and by buying government bonds. Both of these assets have a maturity of one quarter, yield a nominal return and, in the equilibrium considered here, are perfectly risk-free in nominal terms. They are therefore perfect substitutes and earn the same interest. I denote the total financial assets of households at the end of period $t-1$ as B_{t-1}^T and the interest rate paid on these assets in period t as R_{t-1}. Households earn wage income from supplying labor to retailers and derive profit income from their ownership of retail firms and capital goods producers. Hence their budget constraint is given by

$$P_t C_t = w_t P_t l_t + P_t prof_t + R_{t-1} B_{t-1}^T - B_t^T \tag{1}$$

where C_t, w_t and $prof_t$ denote consumption, the real wage and real profits, respectively.

2.2 Capital goods producers

Capital goods producers are owned by households. They produce new capital goods using a technology which yields $1 - \frac{\eta_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2$ capital goods for each unit of investment expenditures I_t. Capital goods are sold to entrepreneurs at currency price $P_t Q_t$. The real expected profits of the capital goods producer are then given by

$$E_t \left\{ \sum_{i=0}^{\infty} \frac{\varrho_{t+i}}{\varrho_t} \beta^i I_{t+i} \left[Q_{t+i} \left(1 - \frac{\eta_i}{2} \left(\frac{I_{t+i}}{I_{t+i-1}} - 1 \right)^2 \right) - 1 \right] \right\}$$

where ϱ_t denotes the marginal utility of real income of the household.

2.3 Retailers

The varieties of goods forming the CES basket are produced by a continuum of retail firms indexed by i. Each retailer operates under monopolistic competition and is owned by households, with the demand for its product given by

$$Y_t(i) = \left(\frac{p_t(i)}{P_t}\right)^{-\varepsilon} Y_t$$

where $\varepsilon > 1$ denotes the elasticity of substitution between varieties. Retailers hire labor $l_t(i)$ at real wage w_t from households and capital services $K_t^S(i)$ at rental rate r_t^k from entrepreneurs in economy-wide factor markets. Hence the output of firm i is given by

$$Y_t(i) = \left(K_t^S(i)\right)^{\alpha} \left(\exp(a_t)\, l_t(i)\right)^{1-\alpha}$$

where a_t denotes a transitory technology shock with mean zero following an AR(1) process. I assume that retail firms have to pay fractions -ψ_L and ψ_K, respectively- of their expenditures for labor and capital services in advance and borrow from banks to do so. I show in section 2.4 that the interest rate on these loans equals the risk-free rate R_t. The loans are paid back at the end of period t. Hence, the working capital loan of retailer i $L_t^r(i)$ is given by

$$L_t^r(i) = \psi_L w_t l_t(i) + \psi_K r_t^k K_t^s(i) \tag{2}$$

This assumption helps to match the procyclicality of total loans L_t, which also include (and mainly consist of) loans to entrepreneurs, as will

be discussed below. Retailers are subject to nominal rigidities in the form of Calvo (1983) contracts: Only a fraction, $1-\xi^P$, are allowed to optimize their price in a given period. The firms that are not allowed to optimize their prices index them to past inflation at a rate γ_P and to the steady-state inflation rate Π at rate $1-\gamma_P$. Denoting the price chosen by those firms that are allowed to optimize in period t as p_t^*,, the aggregate price index evolves according to

$$P_t = \left[\left(1-\xi^P\right)\left(p_t^*\right)^{1-\varepsilon} + \xi^P\left(P_{t-1}\Pi^{1-\gamma_P}\left(\Pi_{t-1}\right)^{\gamma_P}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

2.4 Banks

Following Gertler and Karadi (2011), some households in the economy are bankers. They are risk-neutral and die with a fixed probability $1-\theta$ after earning interest income on the loans they made in the previous period.[3] If banker q dies, he consumes his accumulated

[3] I differ from Gertler and Karadi (2010) in assuming that banks are separate risk-neutral agents. Gertler and Karadi (2010) assume that banks are owned by households and transfer their terminal wealth to their household. I adopt the assumption of risk-neutral bankers because a risk-averse bank would complicate the maximization problem of the entrepreneur.

end-of-period t real net worth $N_t^b(q)$. Dying bankers are replaced by new ones who receive a transfer N_n^b from households, which under the calibration considered is very small.[4]

Banks derive income from offering loans to non-financial firms. This is a key difference vis-à-vis Gertler and Karadi (2011), where banks channel funds to firms by buying equity stakes, effectively owning the firm. A banker grants two types of loans. The first type are risky inter-period loans $L_t^e(q)$ to entrepreneurs who need to buy their period $t+1$ capital stock. These loans are due at the beginning of period $t+1$. The second type are risk-free intraperiod working capital loans $L_t^r(q)$to retailers who need to pay for the labor and capital services used in production, which are due at the end of period t.

Following Gertler and Karadi (2011), I assume that after collecting deposits, a banker can choose to divert some of the assets on his balance sheet and add them to his own wealth. Specifically, a banker can divert fraction $0 \leq \lambda \leq 1$ of loans to entrepreneurs and consume it. In this case, the banker declares bankruptcy and households recover the remaining assets. This implies that households will only make deposits if the banker has no incentive to default, i.e. if $V_t^b(q) \geq \lambda L_t^e(q)$, where $V_t^b(q)$ denotes present value of banker q's expected real terminal wealth:

$$V_t^b(q) = E_t \left\{ \sum_{i=0}^{\infty} (1-\theta)\theta^i \left(\frac{1}{\prod_{j=0}^{i} R_{t+1+j}^r} \right) N_{t+1+i}^b(q) \right\}, \quad R_{t+1}^r = \frac{R_t}{\Pi_{t+1}}$$

The fact that households only make deposits if the banker has no incentive to divert assets implies the bank will never default and household deposits will thus be risk-free in equilibrium.

By contrast, in the management of intraperiod loans, there is no moral hazard problem between bankers and depositors, and also no friction in the bank-retailer relationship. Hence the loan rate is driven down to the deposit rate, implying that banks earn zero profits on these loans. The intraperiod loan business thus does not affect $N_t^b(q)$ and $V_t^b(q)$, and therefore has no impact on lending to entrepreneurs.

Let $B_t(q)$ be the amount of nominal deposits collected by the bank in order to fund interperiod loans. It follows that $P_t L_t^e(q) = P_t N_t^b(q) + B_t(q)$ and that the law of motion of banker q's net worth is given by

$$P_t N_t^b(q) = \left[R_t^b P_{t-1} L_{t-1}^e(q) - R_{t-1} B_{t-1}(q) \right] \exp\left(e_t^z\right) \tag{3}$$

$$= P_{t-1} \left[\left(R_t^b - R_{t-1} \right) L_{t-1}^e(q) + R_{t-1} N_{t-1}^b(q) \right] \exp\left(e_t^z\right) \tag{4}$$

[4] Christiano et al. (2010) and Christiano et al. (2012) make an analagous assumption regarding entrepreneurs in their version of the BGG model.

where R_t^b denotes the average return the bank earns on the portfolio of loans to entrepreneurs made in period $t-1$ net of any costs associated with entrepreneurial bankruptcy. e_t^z denotes an exogenous i.i.d. shock to the capital of existing banks. The shock captures the effect of a sudden decline in the value of the assets on the bank's balance sheet for reasons unexplained by the model. Below, I will use this shock to simulate the effect of a banking crisis on the macroeconomy.

Like Gertler and Karadi (2011), I will calibrate λ such that the incentive compatibility constraint binds locally in equilibrium, hence $V_t^b(q) = \lambda L_t^e(q)$. Appendix A.4 shows that in equilibrium, all banks choose the same ratio between loans to entrepreneurs and their own net worth. Hence we have $L_t^e = \phi_t^b N_t^b$, where L_t^e and N_t^b denote total loans to entrepreneurs and total bank net worth, respectively. ϕ_t^b is determined by a set of non-linear expressions derived in appendix A.4, which up to first order reduces to a single equation, as I discuss below. In much of the discussion, I will refer to ϕ_t^b as 'bank leverage' since its dynamics are both crucial for my results and are the main driver of total leverage, the ratio of total loans to bank net worth $\frac{L_t}{N_t^b}$.

N_t^b consists of the net worth of bankers already in business in period t-1 who did not die at the beginning of period t N_{et}^b and the net worth of new bankers N_n^b, i.e.

$$N_t^b = N_{et}^b + N_n^b$$

N_{et}^b is given by

$$N_{et}^b = \theta z_{t-1,t} N_{t-1}^b \tag{5}$$

$$z_{t-1,t} = \frac{\left[\left(R_t^b - R_{t-1}\right)\phi_{t-1}^b + R_{t-1}\right]}{\Pi_t}\exp\left(e_t^z\right) \tag{6}$$

where $z_{t-1,t}$ denotes the growth rate of the real net worth of bankers already in business in period $t-1$ who did not die at the beginning of period t. The consumption of dying bankers is given by

$$C_t^b = (1-\theta)\, z_{t-1,t} N_{t-1}^b \tag{7}$$

For future reference, it will be useful to divide both sides of the incentive constraint $\lambda L_t^e(q) = V_t^b(q)$ by $N_t^b(q)$, which yields $\lambda \phi_t^b = \frac{V_t^b}{N_t^b}$. $\frac{V_t^b}{N_t^b}$ may be interpreted as a measure of profitability, as it is the ratio of the expected value of being a banker to the own funds of the bank as of period t which generate this value. Up to first order, this constraint can be expressed as

$$\widehat{\phi}_t^b = \widehat{\left(\frac{V_t^b}{N_t^b}\right)} = \sum_{i=0}^{\infty}\left(\theta\beta^2 z^2\right)^i \phi^b \frac{R^b}{R}\left(E_t \widehat{R}_{t+1+i}^b - \widehat{R}_{t+i}\right) \tag{8}$$

with $\widehat{\phi}_t^b = \widehat{L}_t^e - \widehat{N}_t^b$. Bank leverage thus depends positively on the expected weighted sum of profit margins on loans made in period t and after $\widehat{R}_{t+1+i}^b - \widehat{R}_{t+i}$. The intuition behind this relation is as follows: If the profit margin on loans made in period t and/ or after increases, this raises the profitability of the bank $\widehat{\left(\frac{V_t^b}{N_t^b}\right)}$. This in turn reassures depositors that the bank has no incentive to default and they are thus willing to deposit more. Hence the bank can expand its lending to entrepreneurs and its leverage $\widehat{\phi}_t^b$. Equation (8) may therefore be interpreted as a "credit supply curve". The difference in relation to a more conventional supply curve is that it relates the supply of loans in period t not simply to the expected profit margin on loans made in period t, but to the profitability of the bank and thus to the expected profit margins on both period t and future loans.

Equation (8) implies that given profitability $\widehat{\left(\frac{V_t^b}{N_t^b}\right)}$, a negative shock to bank net worth reduces loan supply. Furthermore, the forward looking nature of loan supply implies that future loan market equilibria will have a direct effect on period t loan supply. Imagine that in some future period $t+1+i$ loan demand is low relative to the own funds of the bank and $\widehat{\phi}_{t+1+i}^b$ is therefore low, moving the bank down its supply curve. This implies that bank profitability as of period $t+1+i$ $\widehat{\left(\frac{V_{t+1+i}^b}{N_{t+1+i}^b}\right)}$ will decline. As a consequence, period t profitability $\widehat{\left(\frac{V_t^b}{N_t^b}\right)}$ and hence the amount of deposits households are willing to make declines, as the banker is likely to be still alive in period t+1+i. The loss of funds lowers $\widehat{\phi}_t^b$ and thus period t loan supply. As we will see below, this mechanism has important consequences for the response of the economy to shocks.

2.5 Entrepreneurs

Capital accumulation is carried out by risk-neutral entrepreneurs. My assumptions regarding this sector follow Christiano et al. (2010), unless otherwise stated. At the end of period t, entrepreneur j buys capital K_t^j for price P_tQ_t. In period $t+1$, this entrepreneur rents part of his capital stock to retailers at a rental rate $P_{t+1}r_{t+1}^k$ and then sells the non-depreciated capital stock at price $P_{t+1}Q_{t+1}$. The average return to capital across entrepreneurs is given by

$$R_{t+1}^K = \Pi_{t+1}\frac{r_{t+1}^k + Q_{t+1}(1-\delta)}{Q_t} \tag{9}$$

The gross nominal return of entrepreneur j is given by $\omega_{t+1}^j R_{t+1}^K$, where ω_{t+1}^j is an idiosyncratic shock creating ex-post heterogeneity among entrepreneurs with a log-normal density $f(\omega^j)$, mean 1 and variance σ^2. The entrepreneur's total assets in period $t+1$ are thus given by $\omega_{t+1}^j R_{t+1}^K K_t^j P_t Q_t$.

To fund the acquisition of the capital stock, the entrepreneur uses his own net worth $P_tN_t^j$ and a loan $P_tL_t^j = P_t\left(Q_tK_t^j - N_t^j\right)$, which is granted by the bank at a gross nominal loan rate R_t^L. Loan and interest are paid back in period $t+1$. Hence a cut-off value $\overline{\omega}_{t+1}^j$

can be defined for ω_{t+1}^j such that $\overline{\omega}_{t+1}^j R_{t+1}^K P_t Q_t K_t^j = R_t^L P_t L_t^j$: for values of ω_{t+1}^j smaller than $\overline{\omega}_{t+1}^j$, the entrepreneur defaults. In case of default, the bank is entitled to seize the entrepreneur's assets $\omega_{t+1}^j R_{t+1}^K K_t^j P_t Q_t$ but has to pay a fraction μ thereof to verify their true value.

Furthermore, after the realization of $\omega_{t+1}^j R_{t+1}^K$, entrepreneurs die with a fixed probability $1-\gamma$. Dying entrepreneurs consume their equity V_t. This assumption ensures that entrepreneurs never become fully self-financing. The fraction $1-\gamma$ of entrepreneurs who have died are replaced by new entrepreneurs in each period who receive a transfer W^e from households, which under our calibration is very small.

At the very beginning of period $t+1$, after the realization of aggregate uncertainty and in particular R_{t+1}^K but *before* the realization of ω^j, the expected revenue of the bank associated with a loan L_t^j is given by

$$Loanrev_{t+1}^j = R_t^L P_t L_t^j \int_{\overline{\omega}_{t+1}^j}^{\infty} f\left(\omega^j\right) d\omega^j + (1-\mu) R_{t+1}^K P_t Q_t K_t^j \int_0^{\overline{\omega}_{t+1}^j} \omega^j f\left(\omega^j\right) d\omega^j \quad (10)$$

where the first term refers to the bank's revenue given non-default and the second term refers to the case of default. The expected revenue associated with loan L_t^j as of period t, on the other hand, is given by

$$E_t \left\{ R_t^L P_t L_t^j \int_{\overline{\omega}_{t+1}^j}^{\infty} f\left(\omega^j\right) d\omega^j + (1-\mu) R_{t+1}^K P_t Q_t K_t^j \int_0^{\overline{\omega}_{t+1}^j} \omega^j f\left(\omega^j\right) d\omega^j \right\}$$

where expectations are taken over R_{t+1}^K and $\overline{\omega}_{t+1}^j$.

In the previous section I showed that given current demand for loans and the bank leverage it implies, as well as expected profit margins on loans made in future periods, the incentive compatibility constraint faced by the banker pins down the required expected return on loans made to entrepreneurs $E_t R_{t+1}^b$ (see equation (8)). Any debt contract between the entrepreneur and the bank $\left(L_t^j, R_t^L\right)$ has to yield an expected revenue to the bank such that its expected return on these loans equals $E_t R_{t+1}^b$. Hence the participation constraint of banks in the market for loans to entrepreneurs is given by

$$\begin{aligned} & E_t \left\{ R_t^L P_t L_t^j \int_{\overline{\omega}_{t+1}^j}^{\infty} f\left(\omega^j\right) d\omega^j + (1-\mu) R_{t+1}^K P_t Q_t K_t^j \int_0^{\overline{\omega}_{t+1}^j} \omega^j f\left(\omega^j\right) d\omega^j \right\} \quad (11) \\ = \; & P_t L_t^j E_t R_{t+1}^b \end{aligned}$$

Note that unlike in Christiano et al.'s (2010) version of the BGG model, the loan rate is not contingent on the period $t+1$ state, but is instead determined in period t. Hence it does not vary with the realization of R_{t+1}^K. Unexpected aggregate shocks will therefore affect the return on bank loans via the implied unexpected losses which where not priced into the loan rate when the debt contract was made. Here I follow Zhang (2009). By contrast, in Christiano et al. (2010), the loan rate varies depending on the realization of R^K_{t+1} in order to guarantee the bank a nominal return equal to the risk free rate. In their model, the following constraint thus has to hold in every $t+1$ aggregate state:

$$P_t L^j_t R_t = R^L_{t+1} P_t L^j_t \int_{\overline{\omega}^j_{t+1}}^{\infty} f\left(\omega^j\right) d\omega^j + (1-\mu) R^K_{t+1} P_t Q_t K^j_t \int_0^{\overline{\omega}^j_{t+1}} \omega^j f\left(\omega^j\right) d\omega^j$$

However, while adding realism to the setup, introducing non-state contingent contracts has only minor effects on the quantitative results.

The entrepreneur chooses the level of K^j_t and thus implicitly a combination $\left(L^j_t, R^L_t\right)$ to maximize his expected return, which is given by

$$E_t \left\{ \int_{\overline{\omega}^j_{t+1}}^{\infty} f\left(\omega^j\right) \left(\omega^j R^K_{t+1} P_t Q_t K^j_t - R^L_t P_t L^j_t\right) d\omega^j \right\}$$

In appendix A.5, I show that all entrepreneurs choose the same leverage $\phi^e_t = \frac{Q_t K_t}{N_t}$, implying that $\overline{\omega}^j_{t+1}$ is the same across all firms as well, and derive the first order conditions. Up to first order, these equations give rise to a relationship between $E_t R^K_{t+1}/E_t R^b_{t+1}$ and the entrepreneurial leverage ratio identical to the relationship between the risk premium $E_t R^K_{t+1}/R_t$ and the leverage ratio in BGG:

$$E_t \widehat{R}^K_{t+1} - E_t \widehat{R}^b_{t+1} = \chi^l \left(\widehat{K}_t + \widehat{Q}_t - \widehat{N}_t\right) \tag{12}$$

where $\chi^l \geq 0$. Hence in the presence of both a costly state verification (CSV) problem between firms and banks and the moral hazard problem between banks and depositors described in the previous section, $E_t \widehat{R}^K_{t+1} - \widehat{R}_t$ consists of two spreads: the banking sector profit margin $E_t \widehat{R}^b_{t+1} - \widehat{R}_t$; and the entrepreneurial sector quasi-profit margin $E_t \widehat{R}^K_{t+1} - E_t \widehat{R}^b_{t+1}$.[5] $E_t \widehat{R}^b_{t+1} - \widehat{R}_t$ is driven by bank leverage as detailed in the previous subsection, while $E_t \widehat{R}^K_{t+1} - E_t \widehat{R}^b_{t+1}$ is driven by entrepreneurial leverage.

Total entrepreneurial net worth at the end of period t consists of that part of entrepreneurial equity V_t not consumed by dying entrepreneurs and a transfer from households to entrepreneurs W^e :

$$N_t = \gamma V_t + W^e \tag{13}$$

Entrepreneurial equity and consumption are given by

$$V_t = \left[\int_{\overline{\omega}_t}^{\infty} f\left(\omega^j\right) \left(\omega^j R^K_t Q_{t-1} K_{t-1} - R^L_{t-1} L^e_{t-1}\right) d\omega^j\right] \exp\left(e^N_t\right) \tag{14}$$

$$C^e_t = (1-\gamma) V_t \tag{15}$$

[5] We call $E_t \widehat{R}^K_{t+1} - E_t \widehat{R}^b_{t+1}$ the quasi profit margin since it does not account for the expected costs of banktruptcy, which are borne by the entrepreneur via the loan rate agreed in the debt contract.

where e_t^N denotes an exogenous i.i.d. shock to aggregate entrepreneurial net worth.

The cut-off value of ω_t is given by

$$\overline{\omega}_t = \frac{R_{t-1}^L \left(Q_{t-1}K_{t-1} - N_{t-1}\right)}{R_t^K Q_{t-1}K_{t-1}} \tag{16}$$

Note that the lending rate is predetermined, implying that only R_t^K has a contemporaneous effect on $\overline{\omega}_t$. Finally, dividing both sides of (10) by $P_t L_t^j$, iterating one period back and using the fact that entrepreneurial leverage and the cut-off value $\overline{\omega}_t^j$ are the same across entrepreneurs as well as the law of large numbers, we have

$$R_t^b = \frac{Loanrev_t^j}{P_{t-1}L_{t-1}^j} = \left[R_{t-1}^L \int_{\overline{\omega}_t}^{\infty} f\left(\omega^j\right) d\omega^j + (1-\mu)\, R_t^K \frac{\phi_{t-1}^e}{\phi_{t-1}^e - 1} \int_0^{\overline{\omega}_t} \omega^j f\left(\omega^j\right) d\omega^j\right] \tag{17}$$

for the average return on loans to entrepreneurs made in period t-1.

2.6 Monetary policy and equilibrium

Monetary policy sets the risk-free interest rate, and hence the deposit rate, following an interest feedback rule of the form

$$\begin{aligned} R_t - 1 &= (1-\rho_i)\left[\begin{array}{c} R - 1 + \psi_\pi \left(\log\left(\Pi_t\right) - \log\left(\Pi\right)\right) \\ +\psi_y \left(\log\left(GDP_t\right) - \log\left(GDP_t^*\right)\right) \end{array}\right] && (18) \\ &\quad + \rho_i \left(R_{t-1} - 1\right) + e\_i && (19) \end{aligned}$$

where e_i denotes an i.i.d. monetary policy shock, where GDP_t^* denotes the natural (flexible price equilibrium) level of GDP. Following Gertler and Karadi (2011), we assume for simplicity that $\log\left(GDP_t\right) - \log\left(GDP_t^*\right)$ is proxied by the percentage deviation of real marginal cost from its steady state $\widehat{mc}_t$.

The resource constraint is given by

$$\begin{aligned} S_t &= \left(1-\xi^P\right)\left(\frac{\Pi_t}{\Pi_t^*}\right)^{\varepsilon} + \xi^P \left(\frac{\Pi_t}{\Pi_{t-1}^{\gamma_P}\Pi^{1-\gamma_P}}\right)^{\varepsilon} S_{t-1} && (20) \\ C_t^P &= C_t + C_t^e + C_t^b && (21) \\ Y_t &= S_t\left(I_t + C_t^P + \frac{R_t^K}{\Pi_t} Q_{t-1}K_{t-1}\mu \int_0^{\overline{\omega}_t} \omega f\left(\omega\right) d\omega\right) && (22) \\ Y_t &= \left(K_{t-1}\right)^{\alpha}\left(A_t l_t\right)^{1-\alpha} && (23) \\ GDP_t &= I_t + C_t && (24) \end{aligned}$$

where S_t denotes the efficiency loss arising from price dispersion. Note that S_t does not appear in the first order approximation. The law of motion of capital is given by

$$K_t = (1-\delta)\, K_{t-1} + I_t \left(1 - \frac{\eta_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) \tag{25}$$

while total loans L_t are given by

$$L_t = L_t^e + L_t^r \tag{26}$$

2.7 Model variants

Below I will compare the impulse response functions and cyclical properties of the model developed above (which I refer to as the "full model") and three alternative models. The first alternative is a BGG model with a passive banking sector. Specifically, I assume that there is no moral hazard problem between bankers and depositors ($\lambda = 0$) and that the bankers do not consume when they die.[6] Furthermore, the loan rate on loans made in period t adjusts after period $t+1$ shocks are realized in order to ensure that the bank receives a risk-free nominal return, which, with $\lambda = 0$, equals the risk-free rate R_t. Hence this model features a financial accelerator as in Christiano et al. (2010). The presence of the passive banking sector has no impact on the dynamics of the various rates of return and the real economy. However, it will be helpful to understand why the economy responds differently to shocks once $\lambda > 0$.

In the second alternative model, labelled the GK model, there is a Gertler-Karadi-type moral hazard problem between banks and depositors ($\lambda > 0$) as in the full model. However, as in Gertler and Karadi (2011), the entrepreneur funds his physical capital stock by issuing perfectly state-contingent claims to the entrepreneur's return on capital R_t^k (defined by equation (9)), which are bought by the bank. The bank's income therefore includes capital gains generated by changes in the value of the capital stock Q_t (just as the entrepreneur's does in the BGG and in the full model). The entrepreneur earns zero profits state-by-state and hence accumulates no net worth. As in Gertler and Karadi (2011), there are no frictions in the bank-entrepreneur relationship. Below, I will refer to the entrepreneur's state-contingent debt as "loans to entrepreneurs" in spite of the fact that the debt contract differs from the full model. Hence in the GK model, we have $L_t^e = Q_t K_t$.[7]

In the third alternative model, households accumulate the capital stock K_t in order to rent it out to retailers in period $t+1$. Hence there are no financial frictions affecting the accumulation of physical capital.

For later reference, it is useful to repeat what constitutes the spread between the expected return on capital and the risk free rate $E_t R_{t+1}^K - R_t$. In the full model, $E_t R_{t+1}^K - R_t = (E_t R_{t+1}^K - E_t R_{t+1}^b) + (E_t R_{t+1}^b - R_t)$: movements of the profit margin both in the entrepreneurial and in the banking sector drive $E_t R_{t+1}^K - R_t$. In the BGG model, the return on bank loans always equals the risk free rate R_t and there is hence no profit margin in the banking sector. In the GK model, entrepreneurs earn zero profits as $R_t^K = R_t^b$ state

[6] The latter assumption has a negligible effect on the results.

[7] There are some small differences between my "GK" model and the model originally proposed by Gertler and Karadi (2010). Household deposits are in nominal terms in the GK model while they are in real terms in Gertler and Karadi (2011). Furthermore, Gertler and Karadi's (2011) assume variable capacity utilization. However, my results are robust against including this feature, as mentioned above.

by state, but $E_t R^b_{t+1} - R_t$ may be different from zero. Finally, in the nofriction model, $R^K_t = R_t$ and there is thus no spread between the return on capital and the risk free rate.

3 Calibration

I calibrate the model to US data over the period from 1990Q1 to 2010Q1. All data sources are described in appendix B. After setting Π equal to the average percentage change in the GDP deflator, β is set such that the deposit rate R equals the average federal funds rate. Some of the parameters pertaining to the various financial frictions in the banking and entrepreneurial sector are calibrated such that the steady state values of important financial variables in the model equal averages of certain financial data time series for the financial and non-farm business sector. This route is also followed by Christiano et al. (2010), Meh and Moran (2010), Nolan and Thoenissen (2009) and Bernanke et al. (1999). Each of the targets is displayed in table 3.

I proceed by first assuming that retailers have to fully pre-finance their capital and labor costs via working capital loans, i.e. $\psi_L = \psi_K = 1$. I then turn to the parameters pertaining to the entrepreneurial sector, namely σ, μ, γ and W^e. μ is set to lie in the range of estimates of bankruptcy costs cited by Carlstrom and Fuerst (1997). σ is calibrated such that the steady state leverage of the total non-financial firm sector $\phi^{e+r} = \frac{N+L}{N}$ and the default rate F meet target values. The target for the probability of default is taken from Bernanke et al. (1999), and is close to the estimate by Christiano et al. (2012). The target for firm leverage is the ratio between total liabilities and total net worth of the non-farm non-financial business sector, taken from the Flow of Funds account (FFA) of the Federal Reserve Board.[8] All data sources are described in the appendix. γ is calibrated close to the values used by Christiano et al. (2010) and Bernanke et al. (1999), which allows to back the transfer to new entrepreneurs W^e.

The parameters pertaining to the banking sector are the fraction of loans the bank can divert λ, the survival probability of banks θ and the transfer to new bankers W^b. They are calibrated to meet targets for the cost of external finance of entrepreneurs $R^L - R$, the bank capital ratio $\frac{N^b}{L}$ and the probability of bank death $1-\theta$. The target for $R^L - R$ is an estimate of Levin et al. (2006), who estimate the cost of external finance of 796 publicly-traded non-financial corporations over the period 1997Q1 to 2004Q4. They match the daily effective yield on each individual security issued by the firm to the estimated yield

[8] Both net worth and total liabilities are summed up across the non-farm business sector. The resulting non-financial firm leverage ratio ϕ^{e+r} is 1.89. The associated value of entrepreneurial leverage ϕ^e is 1.68, as the fraction of loans to retailers L^r in the total amounts to only 23%. Furthermore, this number is almost identical to the value of entrepreneurial leverage implied by following the procedure suggested by Fuentes-Albero (2012).

on a treasury coupon security of the same maturity, and also correct for the differential tax treatment of government and corporate bonds. The target for $\frac{N^b}{L}$ is the average ratio between tangible common equity (TCE) and risk weighted assets (RWA) of Federal Deposit Insurance Corporation (FDIC)-insured institutions. Among the available empirical measures of bank net worth, TCE comes closest to the definition of bank net worth in my model. The calculation of RWA attaches weights between 0 and 1 to individual assets according to their risk and liquidity as specified by the Basel I agreement. The probability of bank death $1-\theta$ is set close to the median probability of bank default as estimated by Carlson et al. (2008) over the sample period.

Table 1: Calibration of non-policy parameters

Parameter	Description	Full model	BGG model	GK model
β	Household discount factor	0.9958	0.9958	0.9958
φ	Inverse Frisch elasticity of labour supply	0.25	0.25	0.25
h	Habit formation	0.6	0.6	0.6
α	Capital elasticity of output	0.33	0.33	0.33
δ	Depreciation rate	0.025	0.025	0.025
η_i	Investment adjustment cost	4	4	4
ε	Elasticity of substitution between varieties	6	6	6
ξ^P	Probability of non-reoptimization of prices	0.67	0.67	0.67
λ	Fraction of bank assets the banker can divert	0.2351	0	0.2351
θ	Survival probability of bankers	0.9915	0.9915	0.9915
N_n^b	Transfer to new bankers	0.0001	0.0012	0.0004
ψ_L	Share of retailer's labour costs paid in advance	1	1	1
ψ_K	Share of retailer's capital rental costs paid in advance	1	1	1
σ	Standard deviation of the idiosyncratic shock	0.35	0.35	–
μ	Bankruptcy costs	0.2981	0.2981	–
γ	Survival probability of entrepreneurs	0.975	0.975	–
W^e	Transfer to new entrepreneurs	0.0088	0.0107	–

The parameters not pertaining to the various financial frictions are calibrated according to consensus values used in the literature. The output elasticity of capital α and the depreciation rate are set to 0.33 and 0.025, respectively. The elasticity of substitution between different goods varieties ε equals 6. The probability of a retailer being unable to reoptimize its price ξ^P equals 0.67, in line with the empirical evidence of Nakamura and Steinsson (2008). The values of the parameters indexing the degree of habit formation in consumption h and the cost of adjusting investment η_i are within the range of values estimated by Smets and Wouters (2007) and Christiano et al. (2005). The value of the inverse Frisch elasticity of labor supply φ equals the value found by Smets and Wouters (2007) when they estimate their model variant without nominal wage stickiness.[9] For the

[9] The results discussed below are broadly robust against the introduction of nominal wage stickiness à

policy rule, we use the conventional Taylor rule parameters of 1.5 for the inflation coefficient ψ_π, and 0.5 for the output gap coefficient ψ_y, along with a smoothing parameter $\rho_i = 0.8$.

Table 2: Policy parameters and shocks		
ψ_π	Coefficient on inflation in the Taylor rule	1.5
ψ_y	Coefficient on the output gap in the Taylor rule	0.5/4
ρ_i	Coefficient on the lagged interest rate in the Taylor rule	0.8
ρ_a	AR-coefficient of productivity shock	0.9
σ_i	Sd. monetary policy shock	0.0016
σ_a	Sd. productivity shock	0.012

In the moment comparison I will consider two stochastic processes: a monetary policy shock and a transitory productivity shock. The standard deviation of the monetary policy shock σ_i equals 0.0016, in line with the empirical evidence by Christiano et al. (2005) showing that a one-standard-deviation monetary policy shock increases the policy rate R_t by 0.6 percentage points annualized. The persistence of total factor productivity ρ_a is set to 0.9, while the standard deviation of the productivity shock σ_a is calibrated such that the standard deviation of GDP matches the data.

The properties of the various model variants discussed in the following sections are broadly robust against a number of pertubations to the modelling setup and the calibration. These pertubations include dropping consumption habits, lowering the degree of investment adjustment cost η_i, the introduction of variable capacity utilization, nominal wage stickiness à la Erceg et al. (2000), dropping advance payment for capital and labor services (i.e. setting $\psi_L = \psi_K = 0$), a lower bankruptcy cost parameter μ and setting the output response in the monetary policy rule ψ_y equal to zero. Results are available upon request.[10]

Table 3: Important steady-state values		
Variable	Description	Value
R	Risk free rate, APR	3.97%
Π	Inflation target, APR	2.23%
$R^L - R$	Spread of the loan rate over the risk free rate, APR	1.38%
ϕ^{e+r}	Leverage in non-financial firm sector	1.89
$F(\overline{\omega})$	Quarterly bankruptcy rate, percent	0.75%
$\frac{N^b}{L}$	Bank capital ratio, percent	9.55%

la Erceg et al. (2000), with a calvo parameter for wage setting of 0.75 and an inverse Frisch elasticity of labor supply φ of 1.5.

[10] Specifically, I reduce η_i to 2. In the version of the four model variants with variable capacity utilization, the elasticity of the capital utilization adjustment cost function is set equal to 1.5. In the version with nominal wage stickiness, we set the Calvo-parameter for wages equal to 0.75 and the inverse Frisch elasticity of labor supply φ equal to 1.5, while the elasticity of substitution between labor varieties ε^w equals 4. The alternative value for the monitoring cost parameter μ equals 0.2.

4 Impulse responses

I now discuss the response of the three variants of the model described in section 2.7 to the monetary policy shock, the government spending shock and the TFP shock. All charts display percentage deviations or -in the case of rates of return and ratios- percentage point deviations of the respective variable from its steady state. The model developed in this paper is referred to as the "full model", while the BGG model, the Gertler Karadi model and the model without financial frictions are labelled "BGG", "GK" and "nofr" respectively. All results presented below are based on a first-order approximation of the models' equilibrium conditions.

4.1 Monetary policy shock

The response of the four model variants to a contractionary one-standard-deviation monetary policy shock is displayed in Figures 1a and 1b. The decline in GDP is much stronger in the full model than in the BGG model and the GK model, which display similar on-impact responses, while the GDP response is weakest in the no-friction model. However, the GDP decline in the GK model is more persistent than in both the BGG and in the full model. The differences in the GDP paths across the four models are mainly -though not exclusively- caused by differences in the decline in investment, although the decline of consumption also differs.

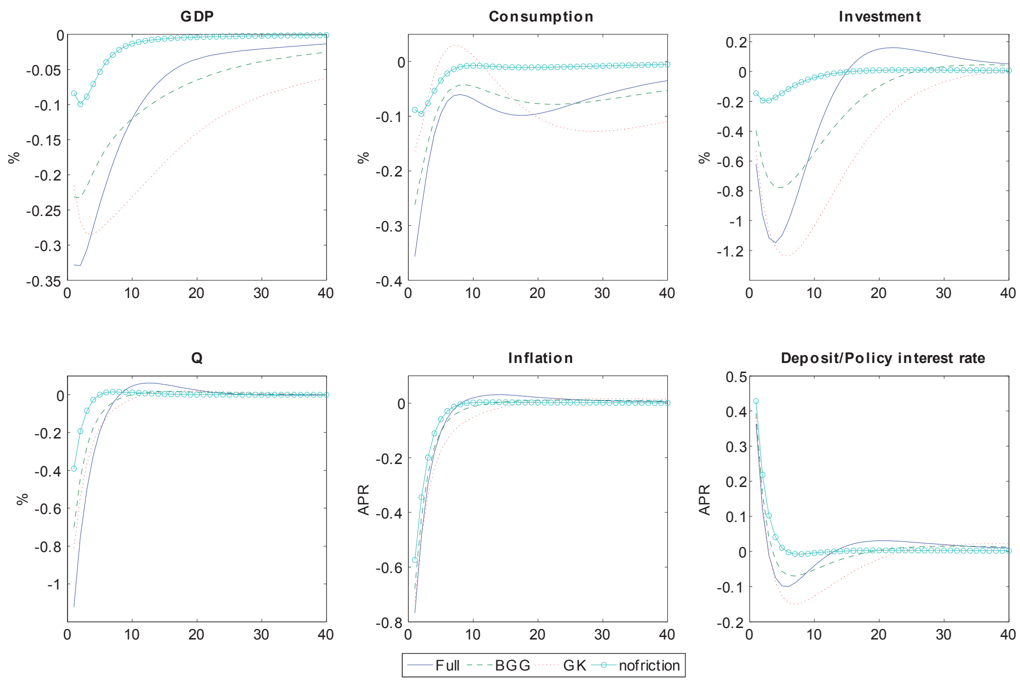

Figure 1a: Monetary policy shock

The mechanisms driving the amplification of the output response in the BGG and the GK models compared to the no-friction model are very similar. The increase in the interest rate reduces the price of capital goods $\widehat{Q}_t$ since future rental income derived from capital r_t^k is discounted more heavily. The decline in $\widehat{Q}_t$ directly reduces investment in all models. However, in the BGG model it lowers entrepreneurial net worth $\widehat{N}_t$ and increases leverage. The rise in leverage increases the bankruptcy risk and therefore requires an increase in $E_t\widehat{R}_{t+1}^K - E_t\widehat{R}_{t+1}$ via (12). Hence $\widehat{Q}_t$ and investment decline even more. The drop in $\widehat{N}_t$ also causes a fall in entrepreneurial consumption. Similarly, in the GK model the the drop in $\widehat{Q}_t$ lowers bank net worth (since the bank owns the capital stock), causing a reduction in the banks' demand for physical capital and thus also causing an increase in $E_t\widehat{R}_{t+1}^K - E_t\widehat{R}_{t+1}$.

To understand the stronger GDP response in the full model than in the BGG model, it is useful to examine the response of bank net worth, entrepreneurial loans and bank leverage in the passive banking sector of the BGG model. Bank net worth $\widehat{N}_t^b$ persistently increases due to the increase in the deposit (policy) rate $\widehat{R}_t$(Figure 1b). A higher $\widehat{R}_t$ increases the (accounting) profits banks earn on loans they fund using their own net worth. Loans to entrepreneurs $\widehat{L}_t^e$ first increase because the drop in entrepreneurial net worth temporarily increases their demand for external funds. Ultimately however, the erosion of the capital stock associated with the persistent decline in investment lowers entrepreneurial loan demand below steady-state. These dynamics of $\widehat{L}_t^e$ and $\widehat{N}_t^b$ decrease bank leverage $\widehat{\phi}_t^b$ very persistently until it is about 0.5% below its steady state in period 23.

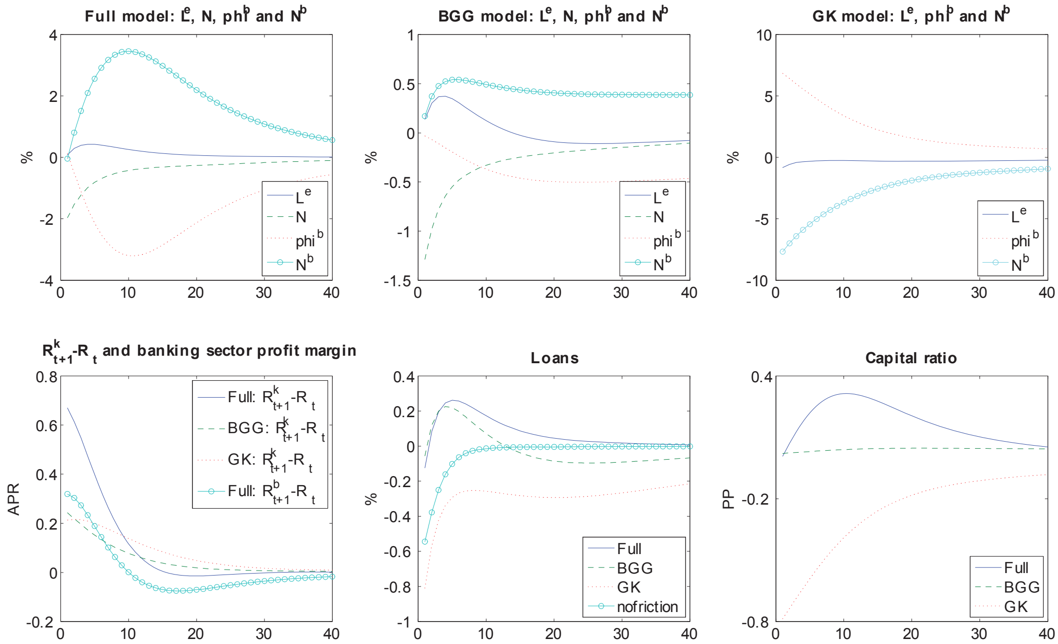

Figure 1b: Monetary policy shock

Now imagine the consequences such a declining path of bank leverage would have in the presence of a moral hazard problem in the banking sector as in the full model, i.e. in a situation where the "loan supply curve" (8) holds. The low loan demand relative to the own funds of the bank implies that profitability as of period 23 is also below steady-state since $\widehat{\left(\frac{V_{23}^b}{N_{23}^b}\right)} = \widehat{\phi}_{23}^b < 0$. Intuitively, the market for loans in period 23 has a lot of slack and profit margins on loans made in period 23 and/ or after $E_1\widehat{R}^b_{24+i} - \widehat{R}_{23+i}$ are therefore driven down by competition among banks. However, the low profitability in period 23 also lowers expected profitability as of period one. Hence in period one, households are concerned that the bank might find it profitable to default. They therefore withdraw deposits, thus forcing individual banks to restrict their supply of loans. The tightened loan supply increases the profit margins on loans made in period one and/or after. Figure 1b shows that $E_t\widehat{R}^b_{t+1} - \widehat{R}_t$ does indeed increase and remains positive for 10 quarters.

The increase in $E_t\widehat{R}^b_{t+1} - \widehat{R}_t$ in the full model implies that the spread between the expected return on capital and the risk-free rate $E_t\widehat{R}^K_{t+1} - \widehat{R}_t$ increases more than twice as much as in the BGG model where banks do not earn a profit margin on bank loans. As a result, $\widehat{Q}_t$ and investment decline more than in the BGG model. Most of the difference in $E_t\widehat{R}^K_{t+1} - \widehat{R}_t$ between the two models is directly caused by the increase in $E_t\widehat{R}^b_{t+1} - \widehat{R}_t$ in the full model. However, the decline in $\widehat{N}_t$ and thus the jump in entrepreneurial leverage are also larger than in the BGG model due to the larger drop in $\widehat{Q}_t$, implying that $E_t\widehat{R}^K_{t+1} - E_t\widehat{R}^b_{t+1}$ increases as well.

The increase in $E_t\widehat{R}^b_{t+1} - \widehat{R}_t$ in the full model is driven to a large extent by an internal acceleration mechanism in the banking sector. The increase in $\widehat{R}^b_{t+1} - \widehat{R}_t$ magnifies the growth of bank net worth relative to the BGG model. As a consequence, the decline in bank leverage $\widehat{\phi}^b_t$ is much steeper than in the passive banking sector of the BGG model.

The amplification of the monetary policy shock's effect on GDP in the full model, which features a bank balance sheet constraint, relative to the BGG model, which does not, is in line with the euro area evidence provided by Ciccarelli et al. (2011). They estimate a VAR featuring survey-based measures of the change in the tightness of banks' credit supply due to reasons related to the banks' own balance sheets and the debtors' balance sheets. They find that when they neutralize the effect of bank balance sheet-related changes in credit supply on GDP, thereby creating a situation comparable to the BGG model, the response of GDP to a monetary policy shock is substantially reduced.

Note that the bank balance sheet variables behave very differently in the GK as compared to the full model. Total loans decrease on impact in the GK model, while they increase in the full model. Furthermore, in the GK model, bank net worth drops substantially on impact, mirrored by an on-impact increase in bank leverage. By contrast, bank net worth in the full model gradually increases, mirrored by a decrease in bank leverage. The decrease in loans in the GK model is due to the fact that in the GK model, the entrepreneur has no net worth of his own and his debt therefore equals the real value of the capital stock $\widehat{Q}_t + \widehat{K}_t$, which declines due to the on-impact drop in $\widehat{Q}_t$ and a gradual decline in $\widehat{K}_t$. The sudden drop in $\widehat{Q}_t$ also causes the on-impact decline in bank net worth and the associated increase in bank leverage observed in the GK model. By contrast, in the full model the bank earns revenue from interest payments made by entrepreneurs but does not hold any traded assets, implying a far more gradual evolution of bank net worth than in the GK model. It suffers a small loss during the first quarter due to an unexpected increase in the entrepreneurial bankruptcy rate. However, the one-quarter maturity of contracts implies that in the following quarters, the increased bankruptcy risk is priced into the loan rate, thus insulating the bank against bankruptcy-related losses. The increase in the profit margin $\widehat{R}^b_{t+1} - \widehat{R}_t$ implies a rise in profits and a gradual increase in bank net worth, which generates a declining path for bank leverage, thus making it procyclical.

The increase in total loans in response to a monetary tightening in the full model is in line with evidence provided by den Haan et al. (2007), who estimate a VAR featuring loans to businesses and bank net worth. In this respect the full model improves on the GK model, but also on the models proposed by Meh and Moran (2010) and Gerali et al. (2010), which both feature leverage constraints -similar to the full model- in the banking and the non-financial business sectors. As in the GK model, they predict a persistent decline in loans to businesses following a monetary tightening. On the other hand, den Haan et al. (2007) also find that bank net worth persistently decreases in response to a monetary policy shock, a feature captured by the GK and the Meh and Moran (2010) models but by neither the full model nor the model of Gerali et al. (2010). Presumably, the failure of the full model to produce a persistent decline in bank net worth could be remedied by extending the maturity of the loans to entrepreneurs, which would increase the importance of bankruptcy-related losses, and by allowing the bank to hold a fraction of its portfolio in the form of long-term traded assets, thereby exposing the bank to capital gains or losses.

4.2 Technology shock

Figures 2a and 2b display the response of the four model variants to a contractionary technology shock. The on-impact response of GDP is strongest in the full model, closely followed by the GK model. It is considerably weaker in the BGG and the no-friction model. As GDP declines further, the difference between the BGG and full models diminishes. The response of GDP in the no-friction model is weaker than in the full model during the first few quarters but then becomes visibly stronger. The GDP response in the GK model quickly becomes much stronger than in the full model.

The weaker GDP response in the BGG model than the no-friction model is due to the presence of a nominal debt contract. As also found by Christiano et al. (2010), the unexpected increase in inflation caused by the technology shock tends to reduce the debt burden of entrepreneurs. This debt reduction quickly results in a small but persistent decline of the external finance premium, thus limiting the decline in investment.

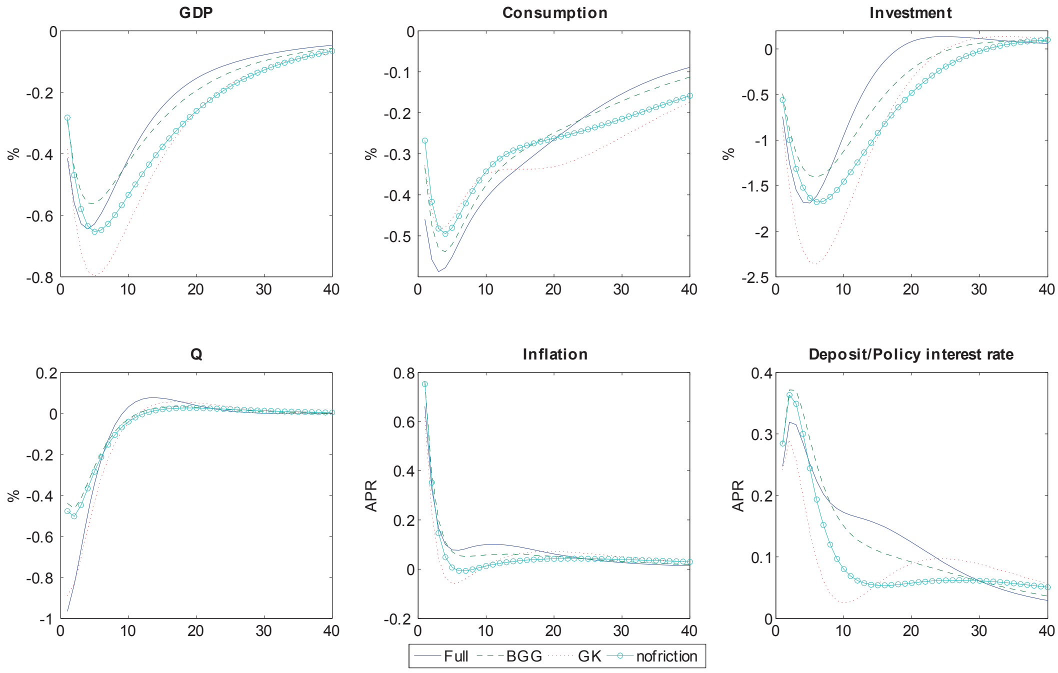

Figure 2a: Productivity shock

The amplification of the technology shock's effect on GDP in the full model as compared to the BGG model works in similar ways to the amplification of the monetary policy shock's effect. The anticipation of future slack in the loan market -and therefore low future profits- induces households to reduce their holdings of deposits, thus forcing individual banks to restrict their supply of loans today. The tightened loan supply increases the banking sector profit margin $E_t\widehat{R}^b_{t+1} - \widehat{R}_t$ (Figure 2b), thus increasing $E_t\widehat{R}^K_{t+1} - \widehat{R}_t$ and lowering investment and entrepreneurial consumption.

Note that both in response to a monetary policy shock and a productivity shock, bank leverage behaves procyclically in the full model but countercyclically in the GK model. In the next section we will see that the corresponding dynamic of bank leverage allows the full model to match the cyclical properties of bank leverage but prevents the GK model from doing so.

I now check whether and how the BGG model is able to generate the same response of output to monetary policy and productivity shocks if the financial accelerator χ^l is increased by raising μ, the share of a bankrupt entrepreneur's assets that has to be paid as bankruptcy cost. Setting $\mu = 1$, which is its maximum and far above available empirical estimates does indeed allow the GDP decline in the BGG model to match the one observed in the full model. However, since the BGG financial accelerator attenuates technology shocks, a higher χ^l further reduces the decline in output in response to an adverse technology shock in the BGG model relative to the full model. Moreover, $\mu = 1$

implies an unreasonably high annualized steady-state real return on capital $\frac{R^K}{\Pi} - 1$ of 17.6%.[11]

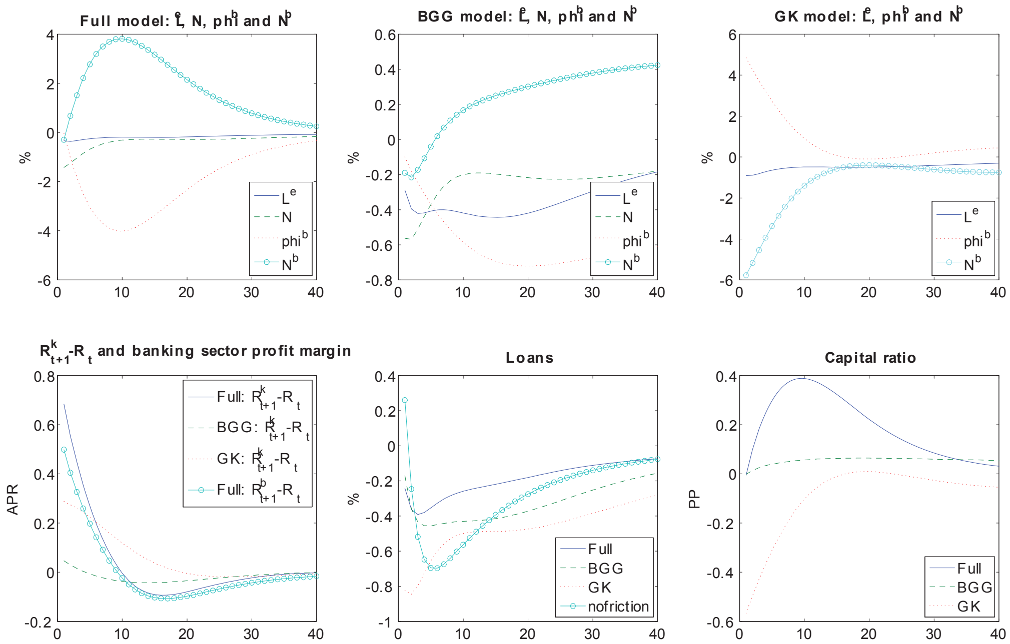

Figure 2b: Productivity shock

5 Moment comparison

I now compare the ability of the three models with financial frictions to match the business cycle statistics of important variables in US data. The real variables considered are GDP, consumption, non-residential investment and hours worked. The financial variables include a measure of the cost of external finance, non-financial firm leverage, the bank capital ratio (i.e. $\frac{N_t^b}{L_t}$), the liabilities of non-financial firms and bank net worth. In the full model, the cost of external finance is naturally given by the spread between the loan rate and the risk-free (policy) rate $R_t^L - R_t$. Although the discussion in the previous section focussed on the dynamics of $E_t R_{t+1}^K - R_t$ (which is strictly speaking an unobservable variable), the impulse response functions (IRFs) of the two spreads are in fact qualitatively similar. In the BGG model, due to the state-contingent loan contract, the loan rate on loans made in period t is determined only in period $t+1$, after the realization of aggregate shocks in period $t+1$. I therefore choose the spread between the loan rate which borrowers

[11] An alternative way of increasing χ^l would be to increase the degree of idiosyncratic capital return uncertainty σ.However, this would also lower entrepreneurial leverage, implying that the response of the economy to a monetary policy shock is actually dampened as compared to my baseline calibration.

expect to pay at time t in the event of non-default and the policy rate, $E_tR^L_{t+1} - R_t$ as the BGG model's measure of the cost of external finance.[12] The dynamics of this variable qualitatively resemble those of $E_tR^K_{t+1} - R_t$.[13] In the GK model, the cost of external finance equals the spread between the expected return to capital and the risk-free rate $E_tR^K_{t+1} - R_t$.

Following Christiano et al. (2010), I measure the cost of external finance in the data as the difference between the BAA composite corporate bond rate and the effective federal funds rate.[14] For the remaining variables, I use the same data employed for calculating the target values discussed in the calibration section. Both the data and the models' variables were logged (except those naturally expressed in percentage terms) and HP filtered.

Table 4 displays the standard deviations of the various variables relative to GDP. While the BGG and the GK model generate far too low volatility for the cost of external finance, the full model closely matches it. The increase in the volatility of the external finance premium as compared to the BGG model is due to the dynamics of the banking sector profit margin $E_t\widehat{R}^b_{t+1} - \widehat{R}_t$ in the full model discussed in the previous section. The higher volatility of investment, non-financial firm leverage $\widehat{\phi}^{e+r}_t$ and non-financial firm net worth $\widehat{N}_t$ in the full model has the same roots and also represents an improvement upon the BGG model.

[12] Simply using $\widehat{R}^L_t - \widehat{R}_t$ as the measure for the BGG model yields virtually identical results. The same is true of a measure suggested by Christiano at al. (2010): the actual transfer of recources from entrepreneurs to banks per unit of loans made minus the risk free rate.

[13] Some authors (e.g. Nolan and Thoenissen (2009)) interpret $E_t\widehat{R}^K_{t+1} - \widehat{R}_t$ as the appropriate measure of the cost of external finance in the BGG model, although $E_t\widehat{R}^K_{t+1}$ is strictly speaking not an observable variable. Using this measure does not affect the relative performance of the three models at matching the relative volatility of the cost of external finance.

[14] I also considered the spread between BAA-rated bonds and the three-month treasury bill rate, between AAA-rated bonds and the effective federal funds and between AAA-rated bonds and the three-month treasury bill rate, used by Nolan and Thoenissen (2009). The cyclical properties of these measures of the cost of external finance differ only slightly from the difference between BAA-rated bonds and the federal funds rate.

Table 4: Standard deviations relative to GDP				
Variable	Data	Full	BGG	GK
$\widehat{GDP}_t$	1	1	1	1
$\widehat{C}_t$	0.81	0.86	0.94	0.57
$\widehat{I}_t$	4.44	3.11	2.75	3.28
$\widehat{l}_t$	1.61	0.92	1.19	1.0
$\widehat{R}^L_t - \widehat{R}_t$, $E_t\widehat{R}^L_{t+1} - \widehat{R}_t$, $E_t\widehat{R}^K_{t+1} - \widehat{R}_t$, APR	0.99	0.97	0.12	0.47
$\widehat{\phi}^{e+r}_t$	1.99	1.25	0.99	–
$\widehat{N}_t$	4.53	2.84	2.03	–
$\widehat{\left(\frac{N^b_t}{L_t}\right)}$	0.4	0.55	0.07	1.16
$\widehat{L}_t$	2.45	0.64	0.81	1.23
$\widehat{N}^b_t$	2.42	5.78	0.93	11.21

Table 5: Correlations with GDP				
Variable	Data	Full	BGG	GK
$\widehat{GDP}_t$	1	1	1	1
$\widehat{C}_t$	0.89	0.95	0.96	0.83
$\widehat{I}_t$	0.88	0.94	0.93	0.97
$\widehat{l}_t$	0.86	0.22	0.01	0.48
$\widehat{R}^L_t - \widehat{R}_t$, $E_t\widehat{R}^L_{t+1} - \widehat{R}_t$, $E_t\widehat{R}^K_{t+1} - \widehat{R}_t$, APR	−0.62	−0.80	−0.43	−0.84
$\widehat{\phi}^{e+r}_t$	−0.61	−0.68	−0.40	–
$\widehat{N}_t$	0.73	0.76	0.66	–
$\widehat{\left(\frac{N^b_t}{L_t}\right)}$	−0.44	−0.40	−0.58	0.65
$\widehat{L}_t$	0.37	0.56	0.58	0.73
$\widehat{N}^b_t$	−0.12	−0.33	0.04	0.66

Table 6 Autocorrelations				
Variable	Data	Full	BGG	GK
$\widehat{GDP}_t$	0.85	0.85	0.88	0.9
$\widehat{C}_t$	0.88	0.77	0.82	0.82
$\widehat{I}_t$	0.91	0.92	0.93	0.94
$\widehat{l}_t$	0.93	0.57	0.53	0.68
$\widehat{R}^L_t - \widehat{R}_t$, $E_t\widehat{R}^L_{t+1} - \widehat{R}_t$, $E_t\widehat{R}^K_{t+1} - \widehat{R}_t$, APR	0.91	0.72	0.7	0.77
$\widehat{\phi}^{e+r}_t$	0.94	0.64	0.69	–
$\widehat{N}_t$	0.94	0.61	0.60	–
$\frac{\widehat{N}^b_t}{\widehat{L}_t}$	0.83	0.95	0.9	0.71
$\widehat{L}_t$	0.93	0.82	0.88	0.62
$\widehat{N}^b_t$	0.81	0.95	0.89	0.7

The failure of the BGG model to match the relative volatility of the external finance premium in our moment comparison exercise is in line with recent estimates of BGG-type models by Christiano et al. (2012), Fuentes-Albero (2012) and Christiano et al. (2010), who rely on shocks directly affecting the contracting problem between the entrepreneur and the bank -for instance shocks to the degree of idiosyncratic capital return uncertainty σ, the share of bankruptcy cost μ and to entrepreneurial net worth- in order generate the observed variation of the cost of external finance. Nolan and Thoenissen (2009) report a similar result. The full model's richer interactions between the real and the financial sector might offer an alternative way to achieve this goal, although testing this hypothesis would require estimating the full model.

Regarding the bank balance sheet variables, the full model matches the relative volatility of the bank capital ratio $\widehat{\left(\frac{N_t^b}{L_t}\right)}$ (the inverse of bank leverage), while it is much too low in the BGG and much too high in the GK model. None of the three models matches the relative volatility of bank capital $\widehat{N}_t^b$, which is too low in the BGG model, too high in the full model and extremely high in the GK model. The high volatility of $\widehat{N}_t^b$ and $\widehat{\left(\frac{N_t^b}{L_t}\right)}$ in the GK model is related to the direct impact of changes in the value of capital $\widehat{Q}_t$ on bank net worth and leverage.

Turning to the cyclicality of the various variables, note that in the data the bank capital ratio $\widehat{\left(\frac{N_t^b}{L_t}\right)}$ is countercyclical, implying procyclical bank leverage. The procyclicality of bank leverage is also documented by Adrian et al. (2012) and Adrian and Shin (2011) using alternative data sources. The full model and the BGG model are able to match this feature of the data. By contrast, the direct and procyclical impact of changes in $\widehat{Q}_t$ on bank net worth in the GK model generate strongly procyclical bank net worth and strongly countercyclical bank leverage (a procyclical capital ratio). Unsurprisingly, all models match the countercyclicality of the cost of external finance, although the crosscorrelation is a bit too negative in the GK and the full model, and a bit too positive in the BGG model. Loans are somewhat too procyclical in all models. The full model and the BGG model match the procyclicality of non-financial firm net worth and the countercyclicality of non-financial firm leverage, although it is perhaps a bit too low in the BGG model. Regarding the real variables, all models match the crosscorrelation of $\widehat{C}_t$ and $\widehat{I}_t$ but generate a far too low crosscorrelation of hours.[15]

The three models perform similarly at matching the persistence in the data. All models perform well at matching the autocorrelations of $\widehat{GDP}_t$, $\widehat{C}_t$ and $\widehat{I}_t$. The autocorrelation of the cost of external finance is very similar across the three models but slightly too low. The same is true of the autocorrelations of $\widehat{\phi}_t^{e+r}$ and $\widehat{N}_t$ in the full and the BGG models, and the autocorrelation of $\widehat{L}_t$ in the GK model

Overall, the above discussion suggests that the amplification provided by the infor-

[15] All models strongly improve on this dimension once nominal wage stickiness is introduced.

mational frictions in the banking-depositor relationship allows the full model to perform better than the BGG model at matching the volatility of the cost of external finance, investment and other variables relative to output. Furthermore, the full model performs well at reproducing the statistical properties of the bank capital ratio (and thus bank leverage), which is instrumental in generating the extra volatility of the cost of external finance in the full model. By contrast, the GK model displays a procyclical bank capital ratio (countercyclical bank leverage), which is at odds with the data, as well as far too high volatility of the bank capital ratio (and thus bank leverage).

6 Financial shocks and crisis experiment

I now examine how the model economy responds to shocks to the balance sheets of entrepreneurs and banks, and to what extent a reasonably calibrated sequence of these shocks can replicate features of the Great Recession in the US economy associated with the financial crisis of 2007-2009. Figures 3a and 3b display the response of the full model and the BGG model to a one-off -1% exogenous shock to entrepreneurial net worth $\widehat{N}_t$, which I implement by setting $e_t^N = -0.01$ for one period. This type of shock has been used by numerous authors using BGG-type models, including Christiano et al. (2010) and Nolan and Thoenissen (2009). GDP declines at the trough almost twice as much in the full model as in the BGG model, mainly due to a stronger decline in investment. In both models, the reduction in $\widehat{N}_t$ increases entrepreneurial leverage $\widehat{\phi}_t^e$ and borrowing since the capital stock and hence the need for funding adjust only gradually. The rise in $\widehat{\phi}_t^e$ causes an increase in the spread between the expected return on capital and the risk-free rate $E_t\widehat{R}_{t+1}^K - \widehat{R}_t$ and hence a drop in $\widehat{Q}_t$, which enhances the initial decline in $\widehat{N}_t$ and lowers investment and entrepreneurial consumption. Turning to the passive banking sector of the BGG model, the immediate and persistent rise in entrepreneurial borrowing causes an immediate and persistent increase in bank leverage $\widehat{\phi}_t^b$. $\widehat{\phi}_t^b$ then gradually declines as the gradual decline in the capital stock and the recovery of $\widehat{N}_t$ lower entrepreneurial borrowing. In the full model, depositors will only accommodate such an expansion in the banks' balance sheet and leverage if bank profitability $\widehat{\left(\frac{V_t^b}{N_t^b}\right)}$ increases as well, which requires an increase in the banking sector profit margin $E_t\widehat{R}_{t+1}^b - \widehat{R}_t$. Hence the increase in $E_t\widehat{R}_{t+1}^K - \widehat{R}_t$ and the decline in $\widehat{Q}_t$, investment, $\widehat{N}_t$ and entrepreneurial consumption are all much stronger than in the BGG model.

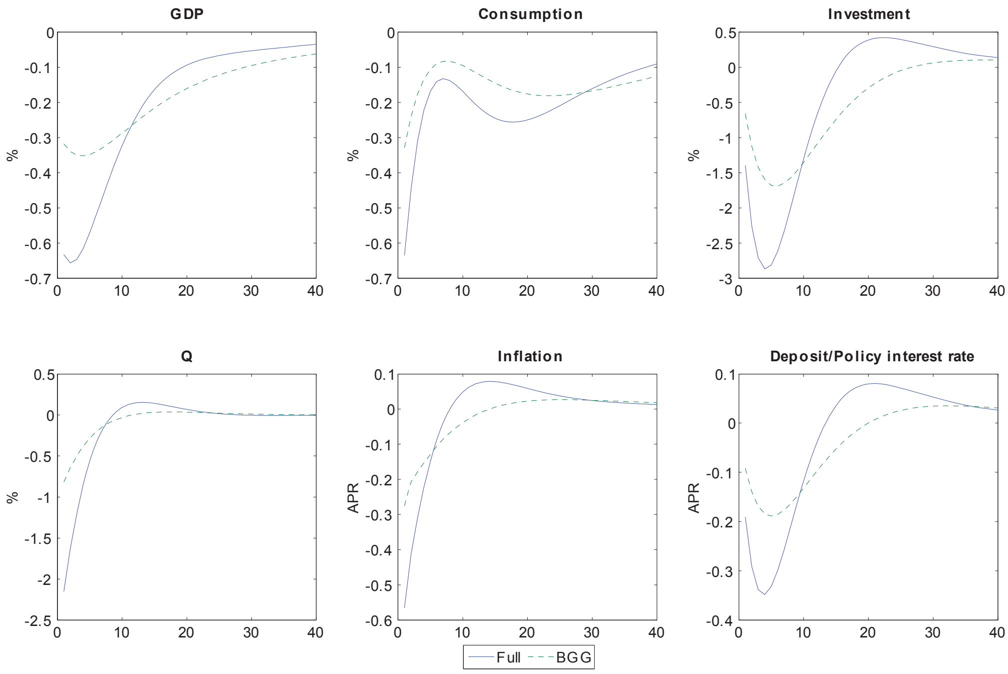

Figure 3a: Entrepreneurial net worth shock

Figures 4a and 4b display the response of the full model and the GK model to a negative exogenous one-off shock of 5% to bank capital N_t^b. For that purpose I set $e_t^z = -0.05$ for one period. In the full model, GDP contracts persistently due to a persistent drop in investment and entrepreneurial consumption. The decrease in $\widehat{N}_t^b$ induces households to withdraw their deposits, thus forcing banks to cut their loan supply. Hence the banking sector profit margin $E_t\widehat{R}_{t+1}^b - \widehat{R}_t$ persistently increases. The implied increase in $E_t\widehat{R}_{t+1}^K - \widehat{R}_t$ lowers $\widehat{Q}_t$, entrepreneurial net worth and therefore investment and consumption. However, the capital stock and thus entrepreneurial loan demand adjust only gradually to the tightened loan supply. Entrepreneurial loans actually marginally increase over the first couple of quarters due to the decline of entrepreneurial net worth. Therefore, total loans decline very slowly and lag significantly behind GDP and investment, while bank leverage mirrors the path of bank net worth.

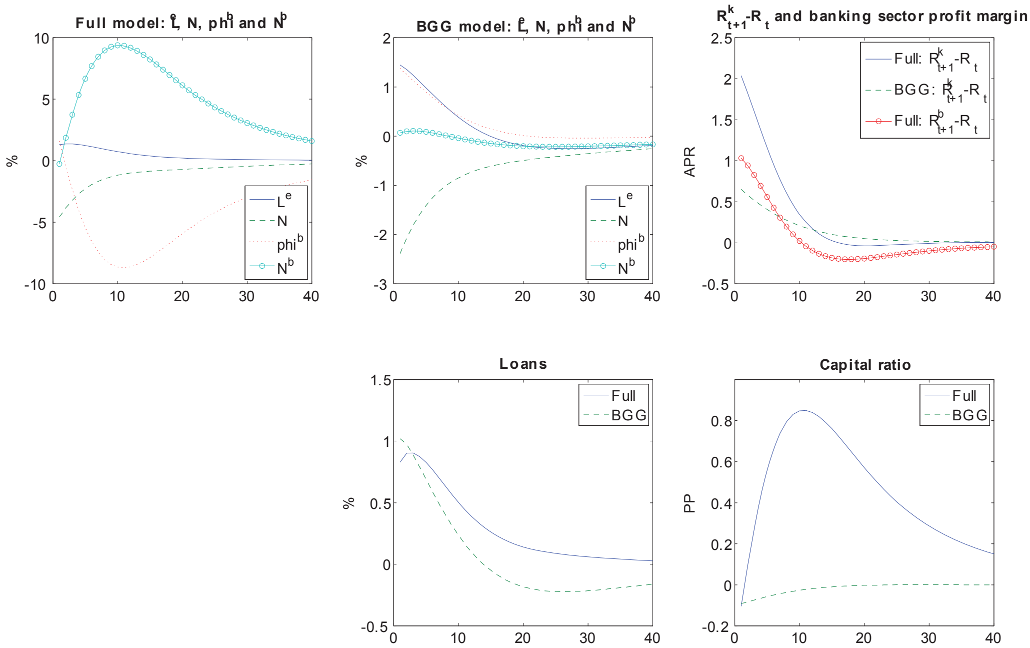

Figure 3b: Entrepreneurial net worth shock

In the GK model, the exogenous negative shock to bank capital induces banks to sell part of their claims to the capital stock of entrepreneurs. This behavior lowers the price of capital goods $\widehat{Q}_t$, which results in a further decline in bank net worth and $\widehat{Q}_t$, implying a much stronger decline in investment and GDP than in the full model.

Note that in the full model the shock to bank capital resembles a demand shock in that it reduces both output and inflation. By contrast, in the models of Gerali et al. (2010) and Meh and Moran (2010) it appears to resemble a supply shock in that it lowers output but increases inflation. The few studies which try to empirically estimate the macroeconomic effects of a shock to bank capital record mixed results. Ciccarelli et al. (2011) find that, for the euro area, their proxy for a shock to bank capital moves output and inflation in the same direction. On the other hand, Fornari and Stracca (2011), using a multi-country panel VAR and a different identification scheme, also estimate that a negative shock to bank capital persistently reduces GDP, but do not find a statistically significant effect on inflation.

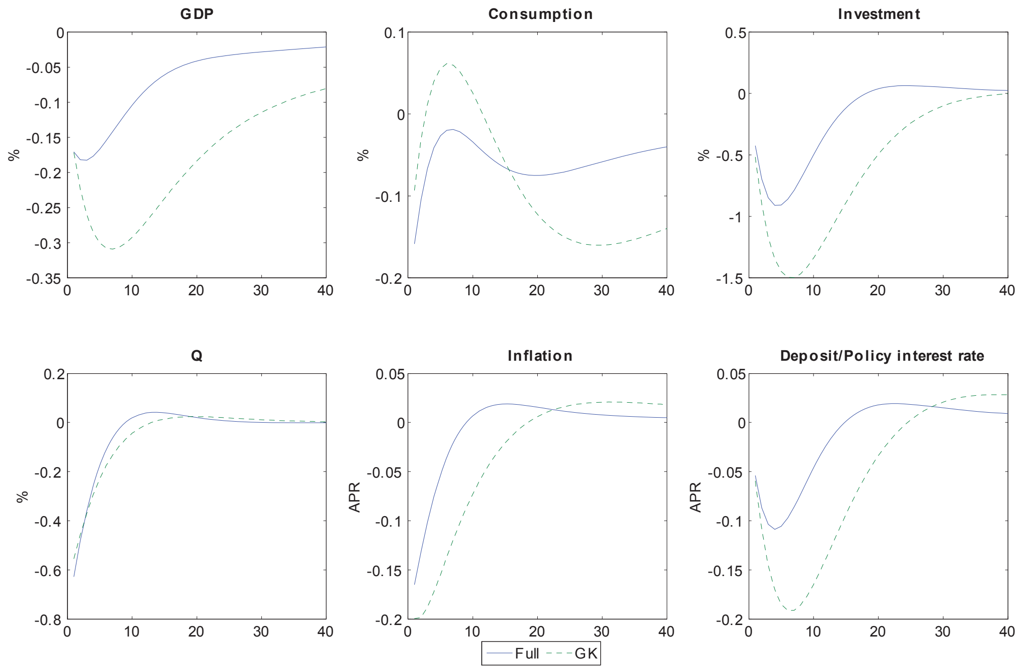

Figure 4a: Bank net worth shock

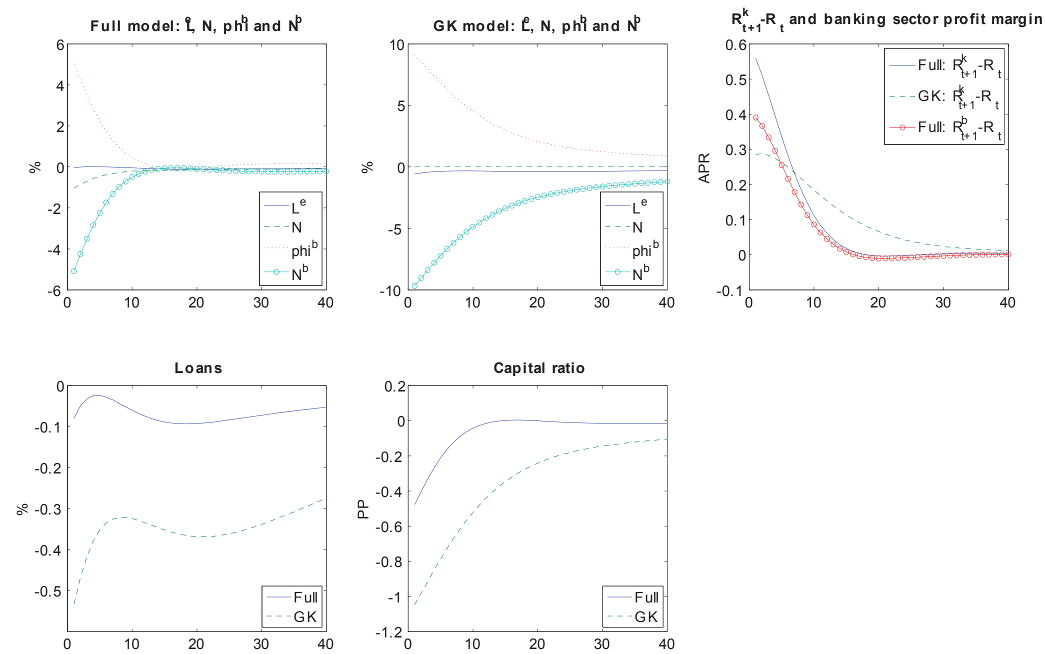

Figure 4b: Bank net worth shock

I now investigate whether the full model can generate an investment contraction and an increase in the cost of external finance of a magnitude similar to the experience of the

US economy during the Great Recession by subjecting the full model to a sequence of shocks to the net worth of banks and entrepreneurs. In the April (2010) version of its global financial stability report (GFS), the IMF estimates that US banks had to write off 7% of the total value of the customer loans and securities on their balance sheets over the period 2007Q2-2010Q4. To assess the consequences of this type of event in the full model, I assume that banks lose an amount of their net worth equivalent to 7% of their assets. The losses are implemented by a series of 15 consecutive and equal-sized unexpected shocks to bank net worth. Furthermore, according to the Flow of Funds Accounts, the net worth of non-financial firms in the United States also declined during the crisis. Relative to a quadratic trend, real per-capita net worth declined by about 40% from 2007Q2 to 2009Q4. Therefore I add a series of 11 consecutive unexpected shocks to entrepreneurial net worth e_t^N, such that given the sequence of shocks to bank net worth, the decline of entrepreneurial net worth amounts to 20% by 2009Q4. For this simulation, I use a version of the model with nominal wage stickiness à la Erceg et al. (2000) and variable capacity utilization.

Figure 5 displays the log-deviation of per capita GDP, consumption, fixed non-residential investment and our measure of credit to non-financial businesses in the US economy from a quadratic trend from 2007Q2 to 2011Q4, normalized by their log-deviation from trend in 2007Q1, and the deviation of our measure of the cost of external finance from its value in 2007Q1, all labeled as "Data". Investment increases somewhat over the first three quarters, but then declines until it reaches a trough located about 30% below trend in quarter 11 (2009Q4). By contrast, credit to non-financial businesses substantially increased relative to trend until peaking at 7.5% above trend in the fifth quarter (2008Q2), and fall below their 2007Q1 value only in quarter 11, followed by a persistent decline. The bank capital ratio gradually declines until it is almost 1 percentage point below its steady state in quarter 7 (2008Q4), then quickly recovers and moves substantially above its pre-crisis value. Finally, our measure of the cost of external finance increases continuously until peaking at almost 7.5% in the seventh quarter (2008Q4).[16]

The model reproduces about two thirds of the trough of investment and about three quarters of the peak of the cost of external finance, respectively. Most likely due to the absence of any frictions constraining the ability of households to borrow, the model fails to reproduce the decline in consumption. As a result, it reproduces about half of the trough of GDP. The model also closely matches the path of the bank capital ratio. Finally, it does not reproduce the observed increase in the debt of non-financial firms during the course of 2008. This increase has been attributed by Ivashina and Scharfstein (2010) as well

[16]The alternative measures of the cost of external finance mentioned in footnote 11 closely track this measure.

as Adrian et al. (2012) to a precautionary take-down of credit lines by firms concerned about the solvency and liquidity of the banking sector. Such motives for credit demand are absent from the model.

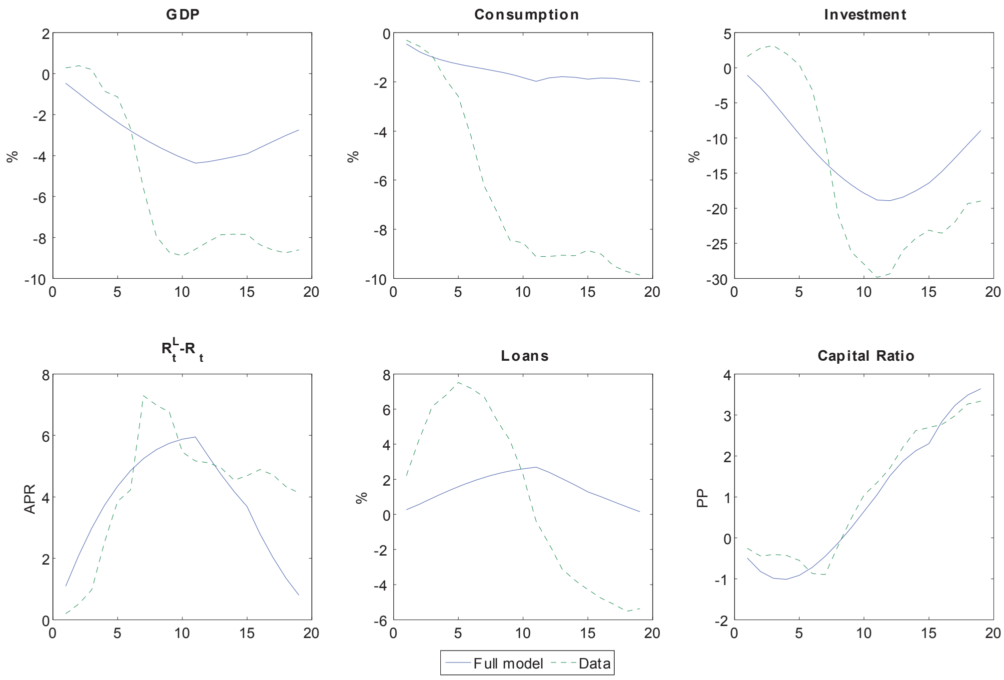

Figure 5: Crisis experiment

7 Conclusion

I develop a general equilibrium model combining informational frictions between banks and entrepreneurs as well as banks and depositors. I do so by adding a moral hazard problem between banks and depositors along the lines of Gertler and Karadi (2011) to the Bernanke et al. (1999) financial accelerator model. As a result, both entrepreneurial and bank leverage matter for the cost of external funds of firms. I compare my model to a BGG-type financial accelerator model and a Gertler-Karadi-type model. I find that adding the friction between banks and depositors amplifies the response of the cost of external finance and the overall economy to monetary policy and productivity shocks as compared to a BGG-type financial accelerator model. The additional amplification provided by this "bank capital channel" allows my model to improve upon the BGG model's ability to match the volatility of the cost of external finance in the data, as well as investment and other variables. Moreover, in the full model bank leverage declines in response to contractionary monetary policy and productivity shocks, which allows the full model to match the procyclicality of bank leverage in US data. By contrast, bank leverage in the Gertler-Karadi-type model is strongly countercyclical.

Furthermore, an adverse shock to entrepreneurial net worth causes an output contraction more than twice as large as in a BGG-type model. In line with the existing empirical evidence, an adverse shock to bank net worth causes a persistent decline in GDP. For a reasonably calibrated combination of both balance shocks, the model economy displays a contraction of investment and an increase in the cost of external finance of magnitudes similar to the experience of the US economy during the Great Recession associated with the financial crisis of 2007-2009.

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A First order conditions of households, retailers, capital goods producers, bankers and entrepreneurs

A.1 Households

The first order conditions with respect to consumption, riskless assets (i.e. deposits and bonds) and labor l_t are given by

$$\varrho_t = \frac{1}{C_t - hC_{t-1}} \tag{27}$$

$$\varrho_t = \beta E_t \left[\varrho_{t+1} \frac{R_t}{\Pi_{t+1}} \right] \tag{28}$$

$$\varrho_t w_t = \chi \left(l_t \right)^{\varphi} \tag{29}$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$.

In the model without a financial sector, I assume that households buy the capital stock K_t from capital goods producers in order to rent it out to retailers in period $t+1$. Hence the budget constraint becomes

$$P_t C_t + Q_t \left(K_t - K_{t-1} \right) \tag{30}$$

$$= P_t l_t w_t + P_t prof_t + R_{t-1} B_{t-1}^T - B_t^T \tag{31}$$

This modification leaves the first order conditions derived above unchanged, but adds a first order condition with respect to K_t:

$$Q_t = E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[r_{t+1}^K + Q_{t+1} \left(1 - \delta \right) \right] \right\} \tag{32}$$

A.2 Capital goods producers

The first order condition with respect to I_t is given by

$$Q_t \left(1 - \frac{\eta_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) = 1 + Q_t \eta_i \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} - E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} Q_{t+1} \eta_i \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right\} \tag{33}$$

The law of motion of capital is given by

$$K_t = \left(1 - \delta \right) K_{t-1} + I_t \left(1 - \frac{\eta_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) \tag{34}$$

A.3 Retailers

Cost minimization, the assumption of economy wide-factor markets and $\int K_t^S(i) = K_{t-1}$ imply that

$$
\begin{aligned}
w_t\left(1+\psi_l\left(R_t-1\right)\right) &= (1-\alpha)\, mc_t \frac{Y_t}{l_t} && (35)\\
r_t^k\left(1+\psi_K\left(R_t-1\right)\right) &= \alpha mc_t \frac{Y_t}{K_{t-1}} && (36)\\
L_t^r &= \psi_L w_t l_t + \psi_K r_t^k K_{t-1} && (37)
\end{aligned}
$$

where mc_t denotes the real marginal cost of production.

Retail firms are subject to nominal rigidities in the form of Calvo (1983) contracts: Only a fraction $1-\xi$ is allowed to optimize its price in a given period. Those firms that are not allowed to optimize their prices index them to past inflation at a rate of γ_P and to the steady state inflation rate Π at rate $1-\gamma_P$. The firm's problem is then to choose $p_t(i)$ in order to maximize

$$
E_t\left\{\sum_{i=0}^{\infty}\left(\xi^P\beta\right)^i \frac{\varrho_{t+i}}{\varrho_t}\left[\left(\frac{p_t(i)}{P_{t+i}}\prod_{k=1}^{i}\Pi^{1-\gamma_P}\Pi_{t+k-1}^{\gamma_P}\right)^{1-\varepsilon} - mc_{t+i}\left(\frac{p_t(i)}{P_{t+i}}\prod_{k=1}^{i}\Pi^{1-\gamma_P}\Pi_{t+k-1}^{\gamma_P}\right)^{-\varepsilon}\right]Y_{t+i}\right\}
$$

The first order condition is given by

$$
\widetilde{p}_t = \frac{\varepsilon}{\varepsilon-1}\frac{E_t\left\{\sum_{i=0}^{\infty}\left(\xi^P\beta\right)^i \frac{\varrho_{t+i}}{\varrho_t}\left(\frac{\prod_{k=1}^{i}\Pi^{1-\gamma_P}\Pi_{t+k-1}^{\gamma_P}}{\prod_{k=1}^{i}\Pi_{t+k}}\right)^{-\varepsilon} mc_{t+i}Y_{t+i}\right\}}{E_t\left\{\sum_{i=0}^{\infty}\left(\xi^P\beta\right)^i \frac{\varrho_{t+i}}{\varrho_t}\left(\frac{\prod_{k=1}^{i}\Pi^{1-\gamma_P}\Pi_{t+k-1}^{\gamma_P}}{\prod_{k=1}^{i}\Pi_{t+k}}\right)^{1-\varepsilon} Y_{t+i}\right\}} \tag{38}
$$

with $\widetilde{p}_t = \frac{p_t^*}{P_t}$, where p_t^* denotes the price chosen by those firms hat are allowed to optimize in period t. The law of motion of the price index is given by

$$
P_t = \left[\left(1-\xi^P\right)\left(p_t^*\right)^{1-\varepsilon} + \xi^P\left(P_{t-1}\Pi^{1-\gamma_P}\left(\Pi_{t-1}\right)^{\gamma_P}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{39}
$$

A.4 Bankers

Combining (3) with the definition of $V_t^b(q)$ allows the latter to be expressed as

$$
V_t^b(q) = \upsilon_t L_t^e(q) + \eta_t N_t^b(q) \tag{40}
$$

with

$$
\begin{aligned}
v_t &= E_t\left\{(1-\theta)\frac{\left(R^b_{t+1}-R_t\right)}{R_t}+\frac{\theta x_{t,t+1}v_{t+1}\Pi_{t+1}}{R_t}\right\} \quad (41)\\
\eta_t &= E_t\left\{(1-\theta)+\frac{\theta z_{t,t+1}\eta_{t+1}\Pi_{t+1}}{R_t}\right\} \quad (42)\\
x_{t,t+1} &= \frac{L^e_{t+1}(q)}{L^e_t(q)},\ z_{t,t+1}=\frac{N^b_{t+1}(q)}{N^b_t(q)} \quad (43)
\end{aligned}
$$

Using $V^b_t(q)=\lambda L^e_t(q)$ yields

$$
\begin{aligned}
L^e_t(q) &= \phi^b_t N^b_t(q) \quad (44)\\
\phi^b_t(q) &= \frac{\eta_t}{\lambda-v_t} \quad (45)
\end{aligned}
$$

where $\phi^b_t(q)$ denotes bank q's leverage ratio. Note that a necessary condition for the incentive constraint to bind is $0<v_t<\lambda$.[17] Substituting (3) and (44) into (43) allows $z_{t,t+1}$ and $x_{t,t+1}$ to be written as

$$
\begin{aligned}
z_{t,t+1} &= \frac{\left(R^b_{t+1}-R_t\right)\phi^b_t(q)+R_t}{\Pi_{t+1}}\exp\left(e^z_{t+1}\right) \quad (46)\\
x_{t,t+1} &= \frac{\phi^b_{t+1}(q)}{\phi^b_t(q)}z_{t,t+1} \quad (47)
\end{aligned}
$$

Equations (45), (41), (42), (46) and (47) imply that η_t, v_t, $\phi^b_t(q)$, $z_{t,t+1}$ and $x_{t,t+1}$ depend solely on economy-wide variables and $\phi^b_{t+1}(q)$, implying that they all depend on economy wide-variables alone. This allows for easy aggregation across bankers, implying that

$$
L^e_t=\phi^b_t N^b_t \quad (48)
$$

where N^b_t denotes the total net worth of banks.

A.5 Entrepreneurs: full model and BGG model

Using $\overline{\omega}^j_{t+1}R^K_{t+1}P_tQ_tK^j_t=R^L_tP_tL^j_t$ and $P_tL^j_t=P_tQ_tK^j_t-P_tN^j_t$, rewrite the participation constraint of the bank (11) as

$$
\left(P_tQ_tK^j_t-P_tN^j_t\right)E_tR^b_{t+1}=E_t\left\{R^K_{t+1}P_tQ_tK^j_t\left[\overline{\omega}^j_{t+1}\int_{\overline{\omega}^j_{t+1}}^{\infty}f\left(\omega^j\right)d\omega^j+(1-\mu)\int_0^{\overline{\omega}^j_{t+1}}\omega^jf\left(\omega^j\right)d\omega^j\right]\right\}
$$

or

$$
\left(\phi^e_t(j)-1\right)E_tR^b_{t+1}=\phi^{e,j}_tE_t\left\{R^K_{t+1}\left[\Gamma\left(\overline{\omega}^j_{t+1}\right)-\mu G\left(\overline{\omega}^j_{t+1}\right)\right]\right\} \quad (49)
$$

[17]For an interpretation of this condition see Gertler and Karadi (2010).

where $\phi_t^e(j) = \frac{Q_t K_t^j}{N_t^j}$, $\Gamma\left(\overline{\omega}_{t+1}^j\right) = \overline{\omega}_{t+1}^j \int_{\overline{\omega}_{t+1}^j}^{\infty} f\left(\omega^j\right) d\omega^j + \int_0^{\overline{\omega}_{t+1}^j} \omega^j f\left(\omega^j\right) d\omega^j$ and $G\left(\overline{\omega}_{t+1}^j\right) = \int_0^{\overline{\omega}_{t+1}^j} \omega^j f\left(\omega^j\right) d\omega_{t+1}^j$. Using $\overline{\omega}_{t+1}^j R_{t+1}^K Q_t K_t^j = R_t^L L_t^j$ and $E\left(\omega_{t+1}\right) = 1 = \int_0^{\overline{\omega}_{t+1}^j} \omega^j f\left(\omega^j\right) d\omega_{t+1}^j + \int_{\overline{\omega}_{t+1}^j}^{\infty} \omega^j f\left(\omega^j\right) d\omega_{t+1}^j$, rewrite the entrepreneur's objective as

$$\begin{aligned}
& P_t Q_t K_t^j E_t \left\{ \int_{\overline{\omega}_{t+1}^j}^{\infty} R_{t+1}^K f\left(\omega^j\right)\left(\omega^j - \overline{\omega}_{t+1}^j\right) d\omega^j \right\} \\
= \; & P_t Q_t K_t^j E_t \left\{ R_{t+1}^K \left[1 - \int_0^{\overline{\omega}_{t+1}^j} \omega^j f\left(\omega^j\right) d\omega^j - \overline{\omega}_{t+1}^j \int_{\overline{\omega}_{t+1}^j}^{\infty} f\left(\omega^j\right) d\omega^j \right] \right\} \\
= \; & P_t Q_t K_t^j E_t \left\{ R_{t+1}^K \left[1 - \Gamma\left(\overline{\omega}_{t+1}^j\right) \right] \right\} \\
= \; & \phi_t^e(j) E_t \left\{ R_{t+1}^K \left[1 - \Gamma\left(\overline{\omega}_{t+1}^j\right) \right] \right\} N_t^j
\end{aligned}$$

Recall that entrepreneurs differ only in their net worth N_t^j. Since $\overline{\omega}_{t+1}^j = \frac{R_t^L\left(1 - \frac{1}{\phi_t^e(j)}\right)}{R_{t+1}^K}$, the values of $\phi_t^e(j)$ and R_t^L maximizing $\phi_t^e(j) E_t \left\{ R_{t+1}^K \left[1 - \Gamma\left(\overline{\omega}_{t+1}^j\right) \right] \right\} N_t^j$ subject to (49) will be the same across entrepreneurs. The same is true of the cut off value $\overline{\omega}_{t+1}^j$. Hence the entrepreneur's problem is to maximize

$$\phi_t^e E_t \left\{ R_{t+1}^K \left[1 - \Gamma\left(\overline{\omega}_{t+1}\right) \right] \right\} + \xi_t E_t \left\{ \phi_t^e R_{t+1}^K \left[\Gamma\left(\overline{\omega}_{t+1}\right) - \mu G\left(\overline{\omega}_{t+1}\right) \right] - R_{t+1}^b \left(\phi_t^e - 1 \right) \right\}$$

The first order conditions with respect to ϕ_t^e, R_t^L and ξ_t are given by

$$E_t \left\{ R_{t+1}^K \left[1 - \Gamma\left(\overline{\omega}_{t+1}\right) \right] \right\} + \xi_t E_t \left\{ R_{t+1}^K \left[\Gamma\left(\overline{\omega}_{t+1}\right) - \mu G\left(\overline{\omega}_{t+1}\right) \right] - R_{t+1}^b \right\} = 0 \quad (50)$$

$$E_t \left\{ -\Gamma'\left(\overline{\omega}_{t+1}\right) + \xi_t \left[\Gamma'\left(\overline{\omega}_{t+1}\right) - \mu G'\left(\overline{\omega}_{t+1}\right) \right] \right\} = 0 \quad (51)$$

$$E_t \left\{ \phi_t^e R_{t+1}^K \left[\Gamma\left(\overline{\omega}_{t+1}\right) - \mu G\left(\overline{\omega}_{t+1}\right) \right] - R_{t+1}^b \left(\phi_t^e - 1 \right) \right\} = 0 \quad (52)$$

where ξ_t denotes the lagrange multiplier on the banks' participation constraint. Given that we can rewrite the entrepreneur's objective as we have, both in the full model and in the BGG model, total real entrepreneurial equity at the beginning of period t (i.e. before some entrepreneurs die) V_t is given by

$$V_t = Q_{t-1} K_{t-1} \frac{R_t^K}{\Pi_t} \left[1 - \Gamma\left(\overline{\omega}_t\right) \right] \exp\left(e_t^N\right) \quad (53)$$

In the BGG model, the constraint on the return on the portfolio of loans to entrepreneurs holds not just in expectation, but in every $t+1$ state. Furthermore, due to the absence of a moral hazard problem in the banking sector, the return on bank loans made in period t equals the deposit rate. Hence the bank's participation constraint is given by

$$\phi_t^e R_{t+1}^K \left[\Gamma\left(\overline{\omega}_{t+1}\right) - \mu G\left(\overline{\omega}_{t+1}\right) \right] - R_t \left(\phi_t^e - 1 \right) = 0 \quad (54)$$

The optimization problem then becomes to maximize

$$\phi_t^e E_t \left\{ R_{t+1}^K \left[1 - \Gamma\left(\overline{\omega}_{t+1}\right) \right] \right\} + \xi_t \left[\phi_t^e R_{t+1}^K \left[\Gamma\left(\overline{\omega}_{t+1}\right) - \mu G\left(\overline{\omega}_{t+1}\right) \right] - R_t \left(\phi_t^e - 1 \right) \right]$$

with respect to ϕ_t^e, $\overline{\omega}_{t+1}$ and ξ_t. The first order conditions are

$$E_t \left\{ R_{t+1}^K \left[1 - \Gamma\left(\overline{\omega}_{t+1}\right) \right] + \xi_t \left\{ R_{t+1}^K \left[\Gamma\left(\overline{\omega}_{t+1}\right) - \mu G\left(\overline{\omega}_{t+1}\right) \right] - R_t \right\} \right\} = 0 \quad (55)$$

$$\frac{\Gamma'\left(\overline{\omega}_{t+1}\right)}{\left[\Gamma'\left(\overline{\omega}_{t+1}\right) - \mu G'\left(\overline{\omega}_{t+1}\right) \right]} = \xi_t \quad (56)$$

$$R_t^K \left[\Gamma\left(\overline{\omega}_t\right) - \mu G\left(\overline{\omega}_t\right) \right] = R_{t-1} \frac{\left(\phi_{t-1}^e - 1 \right)}{\phi_{t-1}^e} \quad (57)$$

The loan rate in this setup is only determined once the loan is paid back, in order to ensure that (54) holds. It is determined by

$$\frac{R_t^L \left(Q_{t-1} K_{t-1} - N_{t-1} \right)}{R_t^K Q_{t-1} K_{t-1}} = \overline{\omega}_t \quad (58)$$

B Data sources

All components of GDP were divided by the labor force. Except the interest rates or interest rate spreads, all data series reported in nominal terms by the respective data provider were deflated using the GDP deflator and divided by the labor force.

- Labor force: Bureau of Labor Statistics (BLS) "Civilian noninstitutional population" series, ID LNS10000000Q. The series was seasonally adjusted.
- GDP deflator: BEA, NIPA Table 1.1.9. Implicit Price Deflators for Gross Domestic Product.
- Real Gross Domestic Product, quantitiy index, seasonally adjusted: Bureau of Economic Analysis (BEA), NIPA Table 1.1.3.
- Real Personal Consumption Expenditures, quantity index , seasonally adjusted, BEA, NIPA Table 1.1.3.
- Real Gross Private Domestic Investment - Fixed Nonresidential, Quantity Index, seasonally adjusted, BEA, NIPA Table 1.1.3.
- Net worth of entrepreneurs: Flow of Funds Account (FFA) of the Federal Reserve Board, sum of "Nonfarm nonfinancial corporate business; net worth", series ID FL102090005.Q, and "Nonfarm noncorporate business; proprietors' equity in noncorporate business", series ID FL112090205.Q. The series was seasonally adjusted.

- Leverage of of the non-financial sector: FFA. The numerator is the sum of "Nonfarm nonfinancial corporate business; total assets", series ID FL102000005.Q and "Nonfarm noncorporate business; total assets", series ID FL112000005.Q. The denominator is "Net worth of entrepreneurs" as described above. The resulting series was seasonally adjusted.

- Loans: FFA. Sum of "Nonfarm nonfinancial corporate business; credit market instruments", series ID FL104104005.Q, and "Nonfarm noncorporate business; credit market instruments", series ID FL114104005.Q. "Credit market instruments" consists of six debt instruments: commercial paper, municipal securities and loans, corporate bonds, bank loans not elsewhere

  classified, other loans and advances and mortgages. The resulting series was seasonally adjusted.

- Net worth of banks: Federal Deposit Insurance Corporation (FDIC). Tangible Common Equity (TCE), calculated using the FDIC's "Quarterly Banking Profile" (QBP), table "Assets and Liabilities of FDIC-Insured Commercial Banks and Savings Institutions". TCE is calculated as Total equity capital-Perpetual preferred stock- Intangible assets. The resulting series was seasonally adjusted.

- Capital ratio: The numerator is TCE. The denominator is "Risk-Weighted Assets" of FDIC-Insured Commercial Banks and Savings Institutions, available from the FDIC on request. The resulting series was seasonally adjusted.

- Cost of external finance: Federal Reserve Bank of St. Louis, Moody's Seasoned Baa Corporate Bond Yield-Effective Federal Funds Rate. Alternative measures: Moody's Seasoned Baa Corporate Bond Yield-three month treasury bill rate, Moody's Seasoned Aaa Corporate Bond Yield-Effective Federal Funds Rate, Moody's Seasoned Aaa Corporate Bond Yield-three month treasury bill rate.

C Technical appendix

C.1 Derivation of the linearized bank leverage constraint

I linearize equations (41), (42) and (45) – (47) to express leverage in the banking sector as a function of the current and future spread of R^b_{t+1} over R_t. Linearizing (45) yields

$$\widehat{\phi}^b_t = \widehat{\eta}_t + \frac{\upsilon}{\lambda - \upsilon}\widehat{\upsilon}_t = \widehat{\eta}_t + \phi^b \frac{\upsilon}{\eta}\widehat{\upsilon}_t \tag{59}$$

where a hat denotes percentage deviation of this variable from its steady state. Linearizing (41) , (42), and (47) yields

$$v\widehat{v}_t = E_t\left\{(1-\theta)\frac{R^b}{R}\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\theta vz\beta\left(\widehat{x}_{t+1}+\widehat{v}_{t+1}+\widehat{\Pi}_{t+1}-\widehat{R}_t\right)\right\} \quad (60)$$

$$\widehat{\eta}_t = \theta z\beta E_t\left\{\widehat{z}_{t+1}+\widehat{\eta}_{t+1}+\widehat{\Pi}_{t+1}-\widehat{R}_t\right\} \quad (61)$$

$$\widehat{x}_t = \widehat{\phi}^b_t-\widehat{\phi}^b_{t-1}+\widehat{z}_t \quad (62)$$

Rewriting (46) as $\frac{z_{t+1,t}\Pi_t}{R_t}=\frac{\left(R^b_{t+1}-R_t\right)}{R_t}\phi^b_t+1$, we have

$$\begin{aligned}\widehat{z}_{t+1}+\widehat{\Pi}_{t+1}-\widehat{R}_t &= \frac{\phi^b\frac{R^b}{R}\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\left(\frac{R^b}{R}-1\right)\phi^b\widehat{\phi}^b_t}{\left(\frac{R^b}{R}-1\right)\phi^b+1}+e^z_{t+1}\\ &= \frac{\phi^b\frac{R^b}{R}\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\left(\frac{R^b}{R}-1\right)\phi^b\widehat{\phi}^b_t}{z\beta}+e^z_{t+1} \quad (63)\end{aligned}$$

using the fact that $\left(\frac{R^b}{R}-1\right)\phi^b+1=z\beta$. Substituting (63) into (60) yields

$$\begin{aligned}v\widehat{v}_t &= E_t\left\{\frac{R^b}{R}\left[(1-\theta)+\theta v\phi^b\right]\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\theta v\left(z\beta\widehat{\phi}^b_{t+1}+\left[\left(\frac{R^b}{R}-1\right)\phi^b-z\beta\right]\widehat{\phi}^b_t+z\beta\widehat{v}_{t+1}\right)\right\}\\ &= E_t\left\{\frac{R^b}{R}\left[(1-\theta)+\theta v\phi^b\right]\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\theta v\left(z\beta\widehat{\phi}^b_{t+1}+-\widehat{\phi}^b_t+z\beta\widehat{v}_{t+1}\right)\right\} \quad (64)\end{aligned}$$

using the fact that $\left(\frac{R^b}{R}-1\right)\phi^b-z\beta=-1$. Similarly, substituting (63) into (60) yields

$$\widehat{\eta}_t=\theta E_t\left\{\phi^b\frac{R^b}{R}\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\left(\frac{R^b}{R}-1\right)\phi^b\widehat{\phi}^b_t+z\beta\widehat{\eta}_{t+1}\right\} \quad (65)$$

Substituting (64) and (65) into (16) yields

$$\begin{aligned}\widehat{\phi}^b_t &= \widehat{\eta}_t+\phi^b\frac{v}{\eta}\widehat{v}_t\\ &= \theta E_t\left\{\phi^b\frac{R^b}{R}\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\left(\frac{R^b}{R}-1\right)\phi^b\widehat{\phi}^b_t+z\beta\widehat{\eta}_{t+1}\right\}\\ &\quad +\frac{\phi^b}{\eta}E_t\left\{\frac{R^b}{R}\left[(1-\theta)+\theta v\phi^b\right]\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\theta v\left(z\beta\widehat{\phi}^b_{t+1}+-\widehat{\phi}^b_t+z\beta\widehat{v}_{t+1}\right)\right\}\end{aligned}$$

This can be rearranged as

$$\begin{aligned}&\widehat{\phi}^b_t\left(1-\theta\phi^b\left(\frac{R^b}{R}-1\right)+\frac{\phi^b}{\eta}\theta v\right)\\ &= E_t\left\{\theta\beta z\left(\widehat{\eta}_{t+1}+\frac{\phi^b}{\eta}v\widehat{v}_{t+1}\right)+\phi^b\frac{R^b}{R}\left(\theta+\frac{1}{\eta}\left(1-\theta+\theta v\phi^b\right)\right)\left(\widehat{R}^b_{t+1}-\widehat{R}_t\right)+\frac{\phi^b\theta vz\beta}{\eta}\widehat{\phi}^b_{t+1}\right\}\end{aligned}$$

The fact that $\eta = \frac{1-\theta}{1-\beta\theta z}$ and $\frac{v}{\eta} = \frac{R^b}{R} - 1$ implies

$$
\begin{aligned}
1 - \theta\phi^b\left(\frac{R^b}{R} - 1\right) + \frac{\phi^b}{\eta}\theta v &= 1 \\
\theta + \frac{1}{\eta}\left(1 - \theta + \theta v \phi^b\right) &= \theta\left(1 - z\beta + \left(\frac{R^b}{R} - 1\right)\phi^b\right) + 1 = 1
\end{aligned}
$$

Using these results and the fact that $\widehat{\eta}_{t+1} + \phi^b \frac{v}{\eta}\widehat{v}_{t+1} = \widehat{\phi}^b_{t+1}$ yields

$$
\begin{aligned}
\widehat{\phi}^b_t &= E_t\left\{\theta\beta z\left(1 + \left(\frac{R^b}{R} - 1\right)\phi^b\right)\widehat{\phi}^b_{t+1} + \phi^b\frac{R^b}{R}\left(\widehat{R}^b_{t+1} - \widehat{R}_t\right)\right\} \\
&= E_t\left\{\theta\beta^2 z^2 \widehat{\phi}^b_{t+1} + \phi^b\frac{R^b}{R}\left(\widehat{R}^b_{t+1} - \widehat{R}_t\right)\right\} \qquad (66)
\end{aligned}
$$

using $\left(\frac{R^b}{R} - 1\right)\phi^b + 1 = z\beta$.

C.2 Derivation of the relationship between firm leverage and $E_t\left\{\widehat{R}^K_{t+1} - \widehat{R}^b_{t+1}\right\}$ in the full model and $E_t\left\{\widehat{R}^K_{t+1} - \widehat{R}_t\right\}$ in the BGG model

This section derives the first order relationship between firm leverage and the spread between the expected return on capital and the expected return on bank loans for the full model. The derivation is, however, identical for the BGG model: One simply has to replace $E_t R^b_{t+1}$ with R_t wherever it appears.

After defining $\Upsilon(\overline{\omega}) = 1 - \Gamma(\overline{\omega}) + \xi\left[\Gamma(\overline{\omega}) - \mu G(\overline{\omega})\right]$, we can rewrite (50) as

$$
E_t\left\{R^K_{t+1}\Upsilon(\overline{\omega}_{t+1}) - \xi_t R^b_{t+1}\right\} = 0 \qquad (67)
$$

Linearizing (52) yields

$$
E_t\left\{\begin{array}{c} \phi^e R^K\left[\left[\Gamma(\overline{\omega}) - \mu G(\overline{\omega})\right]\left[\frac{d\phi^e_t}{\phi^e} + \widehat{R}^K_{t+1}\right] + \left[\Gamma'(\overline{\omega}) - \mu G'(\overline{\omega})\right]d\overline{\omega}_{t+1}\right] \\ -R^b\left(\phi^e - 1\right)\widehat{R}^b_{t+1} - R^b\phi^e\frac{d\phi^e_t}{\phi^e} \end{array}\right\} = 0
$$

or

$$
\begin{aligned}
E_t d\overline{\omega}_{t+1} &= \frac{\partial\overline{\omega}}{\partial\phi^e}d\phi^e_t + \frac{\partial\overline{\omega}}{\partial s}E_t ds1_{t+1} \qquad (68) \\
E_t ds1_{t+1} &= s1 E_t\left\{\widehat{R}^K_{t+1} - \widehat{R}^b_{t+1}\right\} \\
s1 &= \frac{R^K}{R^b} \qquad (69) \\
\frac{d\overline{\omega}}{\phi^e} &= \frac{1}{\left(\phi^e\right)^2 s1\left[\Gamma'(\overline{\omega}) - \mu G'(\overline{\omega})\right]} \\
\frac{\partial\overline{\omega}}{\partial s1} &= \frac{-\left[\Gamma(\overline{\omega}) - \mu G(\overline{\omega})\right]}{s1\left[\Gamma'(\overline{\omega}) - \mu G'(\overline{\omega})\right]}
\end{aligned}
$$

where we have used the fact that (52) implies that $\phi^e R^K \left[\Gamma\left(\overline{\omega}\right) - \mu G\left(\overline{\omega}\right)\right] - R^b \phi^e = -R^b$. We then solve 51 for ξ_t and totally differentiate, which yields

$$\begin{aligned} d\xi_t &= \xi'\left(\overline{\omega}\right) E_t d\overline{\omega}_{t+1} = \xi'\left(\overline{\omega}\right)\left[\frac{\partial \overline{\omega}}{\partial \phi^e} d\phi_t^e + \frac{\partial \overline{\omega}}{\partial s} E_t ds1_{t+1}\right] \qquad (70) \\ \xi'\left(\overline{\omega}\right) &= \frac{\mu\left[\Gamma'\left(\overline{\omega}\right) G''\left(\overline{\omega}\right) - \Gamma''\left(\overline{\omega}\right) G'\left(\overline{\omega}\right)\right]}{\left[\Gamma'\left(\overline{\omega}\right) - \mu G'\left(\overline{\omega}\right)\right]^2} \end{aligned}$$

Totally differentiating (67) yields

$$E_t\left\{dR_{t+1}^K \Upsilon\left(\overline{\omega}\right) + R^K \Upsilon'\left(\overline{\omega}\right) d\overline{\omega}_{t+1} - d\xi_t R^b - \xi dR_{t+1}^b\right\} = 0$$

or

$$E_t\left\{ds1_{t+1} \Upsilon\left(\overline{\omega}\right) + s1 \Upsilon'\left(\overline{\omega}\right) d\overline{\omega}_{t+1} - d\xi_t\right\} = 0$$

Using (68) and (70) yields

$$E_t\left\{ds1_{t+1}\Upsilon\left(\overline{\omega}\right) + s1\Upsilon'\left(\overline{\omega}\right)\left[\frac{\partial \overline{\omega}}{\partial \phi^e} d\phi_t^e + \frac{\partial \overline{\omega}}{\partial s} E_t ds1_{t+1}\right] - \xi'\left(\overline{\omega}\right)\left[\frac{\partial \overline{\omega}}{\partial \phi^e} d\phi_t^e + \frac{\partial \overline{\omega}}{\partial s1} E_t ds1_{t+1}\right]\right\} = 0$$

or

$$d\phi_t^e = \frac{d\phi^e}{ds1} E_t ds1_{t+1}$$

Using $E_t ds_{t+1} = s1 E_t\left\{\widehat{R}_{t+1}^K - \widehat{R}_{t+1}^b\right\}$, this can be rearranged as

$$\begin{aligned} E_t\left\{\widehat{R}_{t+1}^K - \widehat{R}_{t+1}^b\right\} &= \chi^{\phi^e} \widehat{\phi}_t^e \qquad (71) \\ Expr1 &= \left[\Gamma\left(\overline{\omega}\right) - \mu G\left(\overline{\omega}\right)\right] \\ Expr2 &= \left[\Gamma'\left(\overline{\omega}\right) - \mu G'\left(\overline{\omega}\right)\right] \\ \Upsilon\left(\overline{\omega}\right) &= 1 - \Gamma\left(\overline{\omega}\right) + \xi\left[\Gamma\left(\overline{\omega}\right) - \mu G\left(\overline{\omega}\right)\right] \\ \frac{\partial \overline{\omega}}{\partial s1} &= \frac{-Expr1}{s1 Expr2} \\ \frac{d\overline{\omega}}{\phi^e} &= \frac{1}{\left(\phi^e\right)^2 s1 Expr2} \\ \xi'\left(\overline{\omega}\right) &= \frac{\mu\left[\Gamma'\left(\overline{\omega}\right) G''\left(\overline{\omega}\right) - \Gamma''\left(\overline{\omega}\right) G'\left(\overline{\omega}\right)\right]}{\left[\Gamma'\left(\overline{\omega}\right) - \mu G'\left(\overline{\omega}\right)\right]^2} \\ \Upsilon'\left(\overline{\omega}\right) &= \xi'\left(\overline{\omega}\right) Expr1 \\ \frac{d\phi^e}{ds1} &= \frac{\Upsilon\left(\overline{\omega}\right) + \frac{\partial \overline{\omega}}{\partial s1}\left[s1\Upsilon'\left(\overline{\omega}\right) - \xi'\left(\overline{\omega}\right)\right]}{\left[\xi'\left(\overline{\omega}\right) - s1\Upsilon'\left(\overline{\omega}\right)\right]\frac{\partial \overline{\omega}}{\partial \phi^e}} \\ \chi^{\phi^e} &= \frac{\phi^e}{s1\frac{d\phi^e}{ds1}} \end{aligned}$$

C.3 Linearized equations

The equations below correspond to the versions of the four model variants with nominal wage stickiness à la Erceg et al. (2000) and indexation of wages and prices to lagged inflation and average inflation, as well variable capacity utilization. The degree of indexation with respect to average inflation is given by γ_w and γ_P, respectively, ξ^w denotes the Calvo-parameter for wages, while ε^w denotes the elasticity of substitution between labour varieties. The cost of capacity utilization is given by $a(U_t) K_{t-1}$ of capacity utilization, with $a(1) = 0$, $a'(.) > 0$, $a''(.) > 0$, $a'(1) = r^k$ and $a''(1) = c^U r^k$. In the full model, the BGG model and the GK model, the average return to capital is then given by

$$R^K_{t+1} = \Pi_{t+1} \frac{r^k_{t+1} U_{t+1} - a(U_{t+1}) + Q_{t+1}(1-\delta)}{Q_t} \tag{72}$$

while in the nofriction model, the asset pricing equation (32) becomes

$$Q_t = E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[r^K_{t+1} U_{t+1} + Q_{t+1}(1-\delta) \right] \right\} \tag{73}$$

Furthermore, in all four model variants,

$$r^k_t = a'(U_t) \tag{74}$$

while, the aggregate production function becomes

$$Y_t = (K_{t-1} U_t)^\alpha (\exp(a_t) l_t)^{1-\alpha} \tag{75}$$

C.3.1 Full model

Using (16), it is useful to rewrite (17)as

$$R^k_t \left[\Gamma(\overline{\omega}_t) - \mu G(\overline{\omega}_t) \right] \exp\left(e^{R^b}_t \right) = \frac{\left(\phi^e_{t-1} - 1 \right)}{\phi^e_{t-1}} R^b_t \tag{76}$$

Furthermore, I define $\varpi'_t = \frac{R^L_t (Q_t K_t - N_t)}{Q_t K_t} = R^L_t \frac{\phi^e_t - 1}{\phi^e_t}$ and use $\overline{\omega}_t = \frac{\varpi'_{t-1}}{R^k_t}$ to eliminate $\overline{\omega}_t$ wherever it appears.

I now linearize the various equations:

$$
\begin{aligned}
\widehat{\varrho}_t &= \frac{-\left(\widehat{C}_t - h\widehat{C}_{t-1}\right)}{1-h} \text{ from (27)} \\
\widehat{\varrho}_t &= E_t\left\{\widehat{\varrho}_{t+1} + \widehat{R}_t - \widehat{\Pi}_{t+1}\right\} \text{ from (28)} \\
\widehat{w}_t &= \frac{1}{1+\beta}\left[\begin{array}{c} \beta E_t\widehat{w}_{t+1} + \widehat{w}_{t-1} + \beta E_t\widehat{\Pi}_{t+1} - (1+\beta\gamma_w)\,\widehat{\Pi}_t \\ +\gamma_w\widehat{\Pi}_{t-1} - \frac{(1-\beta\xi^w)(1-\xi^w)}{\xi^w(1+\varepsilon^w\varphi)}\left[\widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t\right] \end{array}\right] \\
\widehat{wm}_t &= \widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t \\
\widehat{\Pi}_t &= \frac{1}{1+\beta\gamma_P}\left[\beta E_t\widehat{\Pi}_{t+1} + \gamma_P\widehat{\Pi}_{t-1} + \frac{\left(1-\beta\xi^P\right)\left(1-\xi^P\right)}{\xi^P}\widehat{mc}_t\right] \text{ from (38)} - (39) \\
\widehat{w}_t + \frac{\psi_l R\widehat{R}_t}{1+\psi_l\,(R-1)} &= \widehat{mc}_t + \widehat{Y}_t - \widehat{l}_t \text{ from (35)} \\
\frac{dr_t^k}{r^k} + \frac{\psi_K R\widehat{R}_t}{1+\psi_K\,(R-1)} &= \widehat{mc}_t + \widehat{Y}_t - \widehat{K}_{t-1} - \widehat{U}_t \text{ from (36)} \\
L^r\widehat{L}_t^r &= \psi_l wl\left(\widehat{w}_t + \widehat{l}_t\right) + \psi_K r^k K\left(\frac{dr_t^k}{r^k} + \widehat{U}_t + \widehat{K}_{t-1}\right) \text{ from (2)}
\end{aligned}
$$

$$
\begin{aligned}
\widehat{K}_t &= (1-\delta)\,\widehat{K}_{t-1} + \delta \widehat{I}_t \text{ from (34)} \\
\widehat{I}_t &= \frac{1}{1+\beta}\left[\widehat{I}_{t-1} + \beta E_t \widehat{I}_{t+1} + \frac{\widehat{Q}_t}{\eta_i}\right] \text{ from (33)} \\
\widehat{L}^e_t &= \widehat{\phi}^b_t + \widehat{N}^b_t \text{ from (48)} \\
\widehat{\phi}^b_t &= E_t\left\{\theta\beta^2 z^2 \widehat{\phi}^b_{t+1} + \phi^b \beta R^b \left(\widehat{R}^b_{t+1} - \widehat{R}_t\right)\right\} \text{ from (66)} \\
\widehat{z}_t &= \frac{\phi^b\left(R^b \widehat{R}^b_t - R\widehat{R}_{t-1}\right) + \phi^b\left(R^b - R\right)\widehat{\phi}^b_{t-1} + R\widehat{R}_{t-1}}{z\Pi} - \widehat{\Pi}_t + e^z_t \text{from (6)} \\
\widehat{N}^b_t &= z\theta\widehat{z}_t + z\theta\widehat{N}^b_{t-1} \text{ from (5)} \\
\widehat{C}^b_t &= \widehat{z}_t + \widehat{N}^b_{t-1} \text{ from (7)} \\
\widehat{R}^K_t &= \widehat{\Pi}_t + \frac{\Pi\left(dr^k_t + \widehat{Q}_t\,(1-\delta)\right)}{R^k} - \widehat{Q}_{t-1} \text{ from (9)} \\
dr^k_t &= c^U r^k \widehat{U}_t \text{ from (74)} \\
\widehat{\phi}^e_t &= \widehat{Q}_t + \widehat{K}_t - \widehat{N}_t \text{ from } \phi^e_t = \frac{Q_t K_t}{N_t} \\
E_t \widehat{R}^K_{t+1} &= E_t \widehat{R}^b_{t+1} + \chi^{\phi^e}\widehat{\phi}^e_t \text{ from (71)} \\
\widehat{\varpi}'_t &= \widehat{R}^L_t + \frac{1}{\phi^e - 1}\widehat{\phi}^e_t \text{ from } \varpi'_t = R^L_t \frac{\phi^e_t - 1}{\phi^e_t} \\
R^b \frac{\widehat{\phi}^e_{t-1}}{\phi^e} &= -R^K Expr1 e^{R^b}_t + \widehat{R}^K_t\left[R^K Expr1 - \varpi' Expr2\right] + \varpi' Expr2 \widehat{\varpi}'_{t-1} - R^b \frac{\phi^e - 1}{\phi^e}\widehat{R}^b_t \text{ from (76)} \\
\widehat{N}_t &= \gamma \frac{V}{N}\widehat{V}_t \text{ from (13)} \\
\widehat{V}_t &= \widehat{N}_{t-1} + \widehat{R}^K_t - \widehat{\Pi}_t + \widehat{\phi}^e_{t-1} - \frac{\Gamma'\left(\overline{\omega}\right)\overline{\omega}}{1-\Gamma\left(\overline{\omega}\right)}\left[\widehat{\varpi}'_{t-1} - \widehat{R}^K_t\right] + e^N_t \text{ from (53)} \\
\widehat{L}^e_t &= \widehat{N}_t + \frac{\phi^e}{\phi^e - 1}\widehat{\phi}^e_t \text{ from } \frac{L^e_t}{N_t} = \frac{Q_t K_t - N_t}{N_t} = \phi^e_t - 1 \\
\widehat{C}^e_t &= \widehat{V}_t \text{ from (15)} \\
\widehat{R}_t R &= (1-\rho_i)\left[\psi_\pi \widehat{\Pi}_t + \psi_y \widehat{mc}_t\right] + \rho_i \widehat{R}_{t-1} + e^i_t \text{ from (18)} \\
\widehat{Y}_t &= \alpha\left(\widehat{U}_t + \widehat{K}_{t-1}\right) + (1-\alpha)\left(\widehat{a}_t + \widehat{l}_t\right) \text{ from (75)}
\end{aligned}
$$

$$
\begin{aligned}
\widehat{Y}_t &= \frac{I}{Y}\widehat{I}_t + \frac{C^P}{Y}\widehat{C}_t^P + \frac{G}{Y}\widehat{g}_t \\
&\quad + \frac{R^K}{\Pi}\frac{K}{Y}\mu G(\varpi)\left(\widehat{R}_t^K - \widehat{\Pi}_t + \widehat{Q}_{t-1} + \widehat{K}_{t-1} + \frac{G'(\varpi)}{G(\varpi)}\varpi\left(\widehat{\varpi}'_{t-1} - \widehat{R}_t^K\right)\right) + r^k\frac{K}{Y}\widehat{U}_t \text{ from (22)} \\
\widehat{C}_t^P &= \frac{C}{C^P}\widehat{C}_t + \frac{C^b}{C^P}\widehat{C}_t^b + \frac{C^e}{C^P}\widehat{C}_t^e \text{ from (21)} \\
\widehat{GDP}_t &= \frac{I}{GDP}\widehat{I}_t + \frac{C^P}{GDP}\widehat{C}_t^P + \frac{Gov}{GDP}\widehat{g}_t \text{ from (24)} \\
\widehat{s1\_4} &= 4\left(E_t\widehat{R}_{t+1}^K - E_t\widehat{R}_{t+1}^b\right) \text{ from } s1\_4 = \left(\frac{E_tR_{t+1}^K}{E_tR_{t+1}^b}\right)^4 \\
\widehat{s2\_4} &= 4\left(E_t\widehat{R}_{t+1}^b - \widehat{R}_t\right) \text{ from } s2\_4 = \left(\frac{E_tR_{t+1}^b}{R_t}\right)^4 \\
\widehat{s3\_4} &= 4\left(E_t\widehat{R}_{t+1}^K - \widehat{R}_t\right) \text{ from } s3\_4 = \left(\frac{E_tR_{t+1}^K}{R_t}\right)^4 \\
\widehat{s4\_4} &= 4\left(\widehat{R}_t^L - \widehat{R}_t\right) \text{ from } s4\_4 = \left(\frac{R_t^L}{R_t}\right)^4 \\
\widehat{L}_t &= \frac{L^e}{L}\widehat{L}_t^e + \frac{L^r}{L}\widehat{L}_t^r \text{ from (26)} \\
\frac{dRat_t}{Rat} &= \widehat{N}_t^b - \widehat{L}_t \text{ from } Rat = \frac{N_t}{L_t} \\
\widehat{a}_t &= \rho_a\widehat{a}_{t-1} + e_t^a
\end{aligned}
$$

C.3.2 BGG model

Unlike in the full model, there is no need for the auxiliary variable ϖ_t'. Hence I do not eliminate $\overline{\omega}_t$.

$$\begin{aligned}
\widehat{\varrho}_t &= \frac{-\left(\widehat{C}_t - h\widehat{C}_{t-1}\right)}{1-h} \text{ from (27)} \\
\widehat{\varrho}_t &= E_t\left\{\widehat{\varrho}_{t+1} + \widehat{R}_t - \widehat{\Pi}_{t+1}\right\} \text{ from (28)} \\
\widehat{w}_t &= \frac{1}{1+\beta}\left[\begin{array}{c} \beta E_t\widehat{w}_{t+1} + \widehat{w}_{t-1} + \beta E_t\widehat{\Pi}_{t+1} - (1+\beta\gamma_w)\widehat{\Pi}_t \\ +\gamma_w\widehat{\Pi}_{t-1} - \frac{(1-\beta\xi^w)(1-\xi^w)}{\xi^w(1+\varepsilon^w\varphi)}\left[\widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t\right] \end{array}\right] \\
\widehat{wm}_t &= \widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t \\
\widehat{\Pi}_t &= \frac{1}{1+\beta\gamma_P}\left[\beta E_t\widehat{\Pi}_{t+1} + \gamma_P\widehat{\Pi}_{t-1} + \frac{\left(1-\beta\xi^P\right)\left(1-\xi^P\right)}{\xi^P}\widehat{mc}_t\right] \text{ from (38)} - (39) \\
\widehat{w}_t + \frac{\psi_l R\widehat{R}_t}{1+\psi_l(R-1)} &= \widehat{mc}_t + \widehat{Y}_t - \widehat{l}_t \text{ from (35)} \\
\frac{dr_t^k}{r^k} + \frac{\psi_K R\widehat{R}_t}{1+\psi_K(R-1)} &= \widehat{mc}_t + \widehat{Y}_t - \widehat{K}_{t-1} - \widehat{U}_t \text{ from (36)} \\
L^r\widehat{L}_t^r &= \psi_l wl\left(\widehat{w}_t + \widehat{l}_t\right) + \psi_K r^k K\left(\frac{dr_t^k}{r^k} + \widehat{U}_t + \widehat{K}_{t-1}\right) \text{ from (2)} \\
\widehat{K}_t &= (1-\delta)\widehat{K}_{t-1} + \delta\widehat{I}_t \text{ from (34)} \\
\widehat{I}_t &= \frac{1}{1+\beta}\left[\widehat{I}_{t-1} + \beta E_t\widehat{I}_{t+1} + \frac{\widehat{Q}_t}{\eta_i}\right] \text{ from (33)} \\
\widehat{L}_t^e &= \widehat{\phi}_t^b + \widehat{N}_t^b \text{ from (48)} \\
\widehat{z}_t &= \frac{R\widehat{R}_{t-1}}{z\Pi} - \widehat{\Pi}_t \text{ from (6), after using the fact that with } \lambda = 0,\ R_t^b = R_{t-1} \\
\widehat{N}_t^b &= z\theta\widehat{z}_t + z\theta\widehat{N}_{t-1}^b \text{ from (5)} \\
\widehat{R}_t^K &= \widehat{\Pi}_t + \frac{\Pi\left(dr_t^k + \widehat{Q}_t(1-\delta)\right)}{R^k} - \widehat{Q}_{t-1} \text{ from (9)} \\
dr_t^k &= c^U r^k\widehat{U}_t \text{ from (74)}
\end{aligned}$$

$$
\begin{aligned}
\widehat{\phi}^e_t &= \widehat{Q}_t + \widehat{K}_t - \widehat{N}_t \text{ from } \phi^e_t = \frac{Q_t K_t}{N_t} \\
E_t \widehat{R}^K_{t+1} - \widehat{R}_t &= \chi^{\phi^e} \widehat{\phi}^e_t \text{ from section (C.2)} \\
\widehat{\varpi}_t + \widehat{R}^K_t &= \widehat{R}^L_t + \frac{1}{\phi^e - 1} \widehat{\phi}^e_{t-1} \text{ from } \overline{\omega}_t = \frac{R^L_t \left(1 - \frac{1}{\phi^e_{t-1}}\right)}{R^K_t} \\
R \frac{\widehat{\phi}^e_{t-1}}{\phi^e} &= e^{R^b}_t R^K Expr1 + \widehat{R}^K_t R^K Expr1 + R^K Expr2 \varpi \widehat{\varpi}_t - R \frac{\phi^e - 1}{\phi^e} \widehat{R}_{t-1} \text{ from (57)} \\
\widehat{N}_t &= \gamma \frac{V}{N} \widehat{V}_t \text{ from (13)} \\
\widehat{V}_t &= \widehat{N}_{t-1} + \widehat{R}^K_t - \widehat{\Pi}_t + \widehat{\phi}^e_{t-1} - \frac{\Gamma'(\overline{\omega})\, \overline{\omega}}{1 - \Gamma(\overline{\omega})} \widehat{\varpi}_t + e^N_t \text{ from (53)} \\
\widehat{L}^e_t &= \widehat{N}_t + \frac{\phi^e}{\phi^e - 1} \widehat{\phi}^e_t \text{ from } \frac{L^e_t}{N_t} = \frac{Q_t K_t - N_t}{N_t} = \phi^e_t - 1 \\
\widehat{C}^e_t &= \widehat{V}_t \text{ from (15)} \\
\widehat{R}_t R &= (1 - \rho_i) \left[\psi_\pi \widehat{\Pi}_t + \psi_y \widehat{mc}_t\right] + \rho_i \widehat{R}_{t-1} + e^i_t \text{ from (18)} \\
\widehat{Y}_t &= \alpha \left(\widehat{U}_t + \widehat{K}_{t-1}\right) + (1 - \alpha) \left(\widehat{a}_t + \widehat{l}_t\right) \text{ from (75)} \\
\widehat{Y}_t &= \frac{I}{Y} \widehat{I}_t + \frac{C^P}{Y} \widehat{C}^P_t + \frac{Gov}{Y} \widehat{g}_t \\
&\quad + \frac{R^K}{\Pi} \frac{K}{Y} \mu G(\varpi) \left(\widehat{R}^K_t - \widehat{\Pi}_t + \widehat{Q}_{t-1} + \widehat{K}_{t-1} + \frac{G'(\varpi)}{G(\varpi)} \varpi \widehat{\varpi}_t\right) + r^k \frac{K}{Y} \widehat{U}_t \text{ from (22)} \\
\widehat{C}^P_t &= \frac{C}{C^P} \widehat{C}_t + \frac{C^e}{C^P} \widehat{C}^e_t \text{ from (21)} \\
\widehat{GDP}_t &= \frac{I}{GDP} \widehat{I}_t + \frac{C^P}{GDP} \widehat{C}^P_t + \frac{Gov}{GDP} \widehat{g}_t \text{ from (24)} \\
\widehat{s3\_4} &= 4 \left(E_t \widehat{R}^K_{t+1} - \widehat{R}_t\right) \text{ from } s3\_4 = \left(\frac{E_t R^K_{t+1}}{R_t}\right)^4 \\
\widehat{s4\_4} &= 4 \left(\widehat{R}^L_t - \widehat{R}_t\right) \text{ from } s4\_4 = \left(\frac{R^L_t}{R_t}\right)^4 \\
\widehat{L}_t &= \frac{L^e}{L} \widehat{L}^e_t + \frac{L^r}{L} \widehat{L}^r_t \text{ from (26)} \\
\frac{dRat_t}{Rat} &= \widehat{N}^b_t - \widehat{L}_t \text{ from } Rat = \frac{N_t}{L_t} \\
\widehat{a}_t &= \rho_a \widehat{a}_{t-1} + e^a_t
\end{aligned}
$$

C.3.3 Gertler-Karadi-type model

In the Gertler-Karadi type model, the bank owns the capital stock. As a consequence, $R^K_{t+1} = R^b_{t+1}$, and all equations dealing with the entrepreneur drop out.

I now linearize the various equations:

$$
\begin{aligned}
\widehat{\varrho}_t &= \frac{-\left(\widehat{C}_t - h\widehat{C}_{t-1}\right)}{1-h} \text{ from (27)} \\
\widehat{\varrho}_t &= E_t\left\{\widehat{\varrho}_{t+1} + \widehat{R}_t - \widehat{\Pi}_{t+1}\right\} \text{ from (28)} \\
\widehat{w}_t &= \frac{1}{1+\beta}\left[\begin{array}{c} \beta E_t \widehat{w}_{t+1} + \widehat{w}_{t-1} + \beta E_t \widehat{\Pi}_{t+1} - (1+\beta\gamma_w)\widehat{\Pi}_t \\ +\gamma_w \widehat{\Pi}_{t-1} - \frac{(1-\beta\xi^w)(1-\xi^w)}{\xi^w(1+\varepsilon^w\varphi)}\left[\widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t\right] \end{array}\right] \\
\widehat{wm}_t &= \widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t \\
\widehat{\Pi}_t &= \frac{1}{1+\beta\gamma_P}\left[\beta E_t\widehat{\Pi}_{t+1} + \gamma_P\widehat{\Pi}_{t-1} + \frac{\left(1-\beta\xi^P\right)\left(1-\xi^P\right)}{\xi^P}\widehat{mc}_t\right] \text{ from (38)} - (39) \\
\widehat{w}_t + \frac{\psi_l R\widehat{R}_t}{1+\psi_l(R-1)} &= \widehat{mc}_t + \widehat{Y}_t - \widehat{l}_t \text{ from (35)} \\
\frac{dr_t^k}{r^k} + \frac{\psi_K R\widehat{R}_t}{1+\psi_K(R-1)} &= \widehat{mc}_t + \widehat{Y}_t - \widehat{K}_{t-1} - \widehat{U}_t \text{ from (36)} \\
L^r\widehat{L}_t^r &= \psi_l wl\left(\widehat{w}_t + \widehat{l}_t\right) + \psi_K r^k K\left(\frac{dr_t^k}{r^k} + \widehat{U}_t + \widehat{K}_{t-1}\right) \text{ from (2)}
\end{aligned}
$$

$$
\begin{aligned}
\widehat{K}_t &= (1-\delta)\widehat{K}_{t-1} + \delta\widehat{I}_t \text{ from (34)} \\
\widehat{I}_t &= \frac{1}{1+\beta}\left[\widehat{I}_{t-1} + \beta E_t\widehat{I}_{t+1} + \frac{\widehat{Q}_t}{\eta_i}\right] \text{ from (33)} \\
\widehat{L}_t^e &= \widehat{\phi}_t^b + \widehat{N}_t^b \text{ from (48)} \\
\widehat{\phi}_t^b &= E_t\left\{\theta\beta^2 z^2\widehat{\phi}_{t+1}^b + \phi^b\beta R^b\left(\widehat{R}_{t+1}^b - \widehat{R}_t\right)\right\} \text{ from (66)} \\
\widehat{z}_t &= \frac{\phi^b\left(R^b\widehat{R}_t^b - R\widehat{R}_{t-1}\right) + \phi^b\left(R^b - R\right)\widehat{\phi}_{t-1}^b + R\widehat{R}_{t-1}}{z\Pi} - \widehat{\Pi}_t + e_t^z \text{from (6)} \\
\widehat{N}_t^b &= z\theta\widehat{z}_t + z\theta\widehat{N}_{t-1}^b \text{ from (5)} \\
\widehat{C}_t^b &= \widehat{z}_t + \widehat{N}_{t-1}^b \text{ from (7)} \\
\widehat{R}_t^b &= \widehat{\Pi}_t + \frac{\Pi\left(dr_t^k + \widehat{Q}_t(1-\delta)\right)}{R^k} - \widehat{Q}_{t-1} \text{ from (9)} \\
dr_t^k &= c^U r^k\widehat{U}_t \text{ from (74)} \\
\widehat{L}_t^e &= \widehat{K}_t + \widehat{Q}_t \\
\widehat{R}_t R &= (1-\rho_i)\left[\psi_\pi\widehat{\Pi}_t + \psi_y\widehat{mc}_t\right] + \rho_i\widehat{R}_{t-1} + e_t^i \text{ from (18)} \\
\widehat{Y}_t &= \alpha\left(\widehat{U}_t + \widehat{K}_{t-1}\right) + (1-\alpha)\left(\widehat{a}_t + \widehat{l}_t\right) \text{ from (75)}
\end{aligned}
$$

$$
\begin{aligned}
\widehat{Y}_t &= \frac{I}{Y}\widehat{I}_t + \frac{C^P}{Y}\widehat{C}_t^P + \frac{G}{Y}\widehat{g}_t \\
&\quad + \frac{R^K}{\Pi}\frac{K}{Y}\mu G(\varpi)\left(\widehat{R}_t^K - \widehat{\Pi}_t + \widehat{Q}_{t-1} + \widehat{K}_{t-1}\right) + r^k\frac{K}{Y}\widehat{U}_t \text{ from (22)} \\
\widehat{C}_t^P &= \frac{C}{C^P}\widehat{C}_t + \frac{C^b}{C^P}\widehat{C}_t^b \text{from (21)} \\
\widehat{GDP}_t &= \frac{I}{GDP}\widehat{I}_t + \frac{C^P}{GDP}\widehat{C}_t^P + \frac{Gov}{GDP}\widehat{g}_t \text{ from (24)} \\
\widehat{s2\_4} &= 4\left(E_t\widehat{R}_{t+1}^b - \widehat{R}_t\right) \text{ from } s2\_4 = \left(\frac{E_t R_{t+1}^b}{R_t}\right)^4 \\
\widehat{s3\_4} &= 4\left(E_t\widehat{R}_{t+1}^K - \widehat{R}_t\right) \text{ from } s3\_4 = \left(\frac{E_t R_{t+1}^K}{R_t}\right)^4 \\
\widehat{L}_t &= \frac{L^e}{L}\widehat{L}_t^e + \frac{L^r}{L}\widehat{L}_t^r \text{ from (26)} \\
\frac{dRat_t}{Rat} &= \widehat{N}_t^b - \widehat{L}_t \text{ from } Rat = \frac{N_t}{L_t} \\
\widehat{a}_t &= \rho_a\widehat{a}_{t-1} + e_t^a
\end{aligned}
$$

C.3.4 Model without financial frictions

$$
\begin{aligned}
\widehat{\varrho}_t &= \frac{-\left(\widehat{C}_t - h\widehat{C}_{t-1}\right)}{1-h} \text{from (27)} \\
\widehat{\varrho}_t &= E_t\left\{\widehat{\varrho}_{t+1} + \widehat{R}_t - \widehat{\Pi}_{t+1}\right\} \text{ from (28)} \\
\widehat{w}_t &= \frac{1}{1+\beta}\left[\begin{array}{c} \beta E_t \widehat{w}_{t+1} + \widehat{w}_{t-1} + \beta E_t \widehat{\Pi}_{t+1} - (1+\beta\gamma_w)\widehat{\Pi}_t \\ +\gamma_w \widehat{\Pi}_{t-1} - \frac{(1-\beta\xi^w)(1-\xi^w)}{\xi^w(1+\varepsilon^w\varphi)}\left[\widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t\right] \end{array}\right] \\
\widehat{wm}_t &= \widehat{w}_t + \widehat{\varrho}_t - \varphi\widehat{l}_t \\
\widehat{\Pi}_t &= \frac{1}{1+\beta\gamma_P}\left[\beta E_t\widehat{\Pi}_{t+1} + \gamma_P\widehat{\Pi}_{t-1} + \frac{\left(1-\beta\xi^P\right)\left(1-\xi^P\right)}{\xi^P}\widehat{mc}_t\right] \text{ from (38)} - (39) \\
\widehat{w}_t &= -\frac{\psi_l R\widehat{R}_t}{1+\psi_l(R-1)}\widehat{mc}_t + \widehat{Y}_t - \widehat{l}_t \text{ from (35)} \\
\frac{dr_t^k}{r^k} &= -\frac{\psi_K R\widehat{R}_t}{1+\psi_K(R-1)}\widehat{mc}_t + \widehat{Y}_t - \widehat{K}_{t-1} - \widehat{U}_t \text{ from (36)} \\
\widehat{K}_t &= (1-\delta)\widehat{K}_{t-1} + \delta\widehat{I}_t \text{ from (34)} \\
\widehat{I}_t &= \frac{1}{1+\beta}\left[\widehat{I}_{t-1} + \beta E_t\widehat{I}_{t+1} + \frac{\widehat{Q}_t}{\eta_i}\right] \text{ from (33)} \\
\widehat{Q}_t &= \beta E_t\left\{\left[\widehat{\varrho}_{t+1} - \widehat{\varrho}_t\right]\left[r^k + (1-\delta)\right] + dr_{t+1}^k + (1-\delta)\widehat{Q}_{t+1}\right\} \text{ from (73)} \\
dr_t^k &= c^U r^k \widehat{U}_t \text{ from (??)} \\
\widehat{R}_t R &= (1-\rho_i)\left[\psi_\pi\widehat{\Pi}_t + \psi_y\widehat{mc}_t\right] + \rho_i\widehat{R}_{t-1} + e_t^i \text{ from (18)} \\
\widehat{Y}_t &= \alpha\left(\widehat{U}_t + \widehat{K}_{t-1}\right) + (1-\alpha)\left(\widehat{a}_t + \widehat{l}_t\right) \text{ from (75)} \\
\widehat{Y}_t &= \frac{I}{Y}\widehat{I}_t + \frac{C}{Y}\widehat{C}_t + \frac{Gov}{Y}\widehat{g}_t + r^k\frac{K}{Y}\widehat{U}_t \text{ from (22)} \\
\widehat{GDP}_t &= \frac{I}{GDP}\widehat{I}_t + \frac{C}{GDP}\widehat{C}_t + \frac{Gov}{GDP}\widehat{g}_t \text{ from (24), noting that now } C_t^P = C_t \\
\widehat{a}_t &= \rho_a\widehat{a}_{t-1} + e_t^a
\end{aligned}
$$

C.4 Steady state

This section shows how the steady state of the full model can be calibrated recursively by assuming targets for some of the real and financial variables. The calculation of the steady state for the BGG model with the passive (frictionless) banking sector differs in that in the BGG model, λ equals 0 and $\frac{R^b}{R}$ equals 1 (i.e. banks earn zero profits on loans funded using deposits). Furthermore, I assume that the bankers in the passive banking sector in the BGG model do not consume when they die. This assumption has a negligible effect on the results, but ensures that the dynamics of all variables not pertaining to the passive banking sector are not affected by the existence of the passive banking sector. For the steady-state calculation in the Gertler-Karadi-type model, I drop all those calculations below pertaining to the entrepreneurial sector and set $R^K = R^b$, since the bank owns the entrepreneur's capital stock and the entrepreneur earns zero profits in every state of the world. Finally, in the nofriction model, we have $R^K = R$.

The calibration strategy adopted here implies that the steady state is computed by assuming values for the parameters Π, h, ε, ε_w, ξ^P, ξ^w, α, δ and μ. β, χ, θ, λ, W^b, σ, γ, W^b and Gov are calibrated to to achieve targets for l R, $\frac{N_t^b}{L_t}$, the flow of funds out of bankers equity, $R^L - R$, F, ϕ^e, the flow of funds out of entrepreneurial equity and $\frac{Gov}{Y}$.

I first use

$$\beta = \frac{\Pi}{R}$$

Turning to the entrepreneurial sector and assuming a target value for the bankruptcy rate and setting a trial value for σ, given $\log \omega \sim N\left(-\frac{\sigma^2}{2}, \sigma^2\right)$, we can calculate

$$\begin{aligned}
brate &= F(\overline{\omega}), \text{ gives } \overline{\omega} \\
F(\overline{\omega}) &= Ncdf\left(\frac{\log(\overline{\omega}) + \frac{1}{2}\sigma^2}{\sigma}\right) \\
F'(\overline{\omega}) &= \frac{1}{\overline{\omega\sigma}} Npdf\left(\frac{\log(\overline{\omega}) + \frac{1}{2}\sigma^2}{\sigma}\right) \\
F''(\overline{\omega}) &= \frac{-F'(\overline{\omega})}{\overline{\omega}}\left[1 + \frac{\left(\log(\overline{\omega}) + \frac{1}{2}\sigma^2\right)}{\sigma^2}\right] \\
G(\overline{\omega}) &= \int_0^{\overline{\omega}} \omega dF(\omega) = Ncdf\left[v < \frac{\log(\overline{\omega}) + \frac{1}{2}\sigma^2}{\sigma} - \sigma\right] \\
G'(\overline{\omega}) &= \overline{\omega} F'(\overline{\omega}) \\
G''(\overline{\omega}) &= F'(\overline{\omega}) + \overline{\omega} F''(\overline{\omega}) \\
\Gamma(\overline{\omega}) &= \overline{\omega}\left[1 - F(\overline{\omega})\right] + G(\overline{\omega}) \\
\Gamma'(\overline{\omega}) &= 1 - F(\overline{\omega}) \\
\Gamma''(\overline{\omega}) &= -F'(\overline{\omega})
\end{aligned}$$

where $Ncdf$ denotes the cumulative distribution function of the standard normal distribution. Given μ, I can calculate ξ, $\frac{R^K}{R^b}$, ϕ^e and R^L using the entrepreneur's first order conditions:

$$\begin{aligned}
\xi &= \frac{\Gamma'(\overline{\omega})}{\Gamma'(\overline{\omega}) - \mu G'(\overline{\omega})} \\
\frac{R^K}{R^b} &= \frac{\Gamma'(\overline{\omega})}{\Gamma'(\overline{\omega}) - \left[\mu\left[G'(\overline{\omega})\left(1 - \Gamma(\overline{\omega})\right) + \Gamma'(\overline{\omega}) G(\overline{\omega})\right]\right]} \\
\phi^e &= \frac{1}{1 - \frac{R^K}{R^b}\left[\Gamma(\overline{\omega}) - \mu G(\overline{\omega})\right]}
\end{aligned}$$

I adjust σ in order to set ϕ^e to my target.

I then calibrate $\frac{R^b}{R}$ such that, given the calibration of the entrepreneurial sector parameters, $\frac{R^L}{R}$ is close to target. Hence we have

$$\begin{aligned} R^b &= \left(\frac{R^b}{R}\right) R \\ R^K &= R^b \left(\frac{R^K}{R^b}\right) \\ R^L &= \frac{\overline{\omega} R^K}{\left(1 - \frac{1}{\phi^e}\right)} \end{aligned}$$

Given R^K, it is possible to calculate most of the steady state values for the "real" side of the economy:

$$\begin{aligned} X &= \frac{\varepsilon}{\varepsilon - 1} \\ Q &= 1 \\ r^K &= \frac{R^K}{\Pi} - (1 - \delta) \\ \frac{K}{l} &= k = \left(\frac{\alpha}{X(1+\psi_K)(R-1)\left(\frac{R^K}{\Pi} - 1 + \delta\right)}\right)^{(1/(1-\alpha))} \\ w &= \frac{(1-\alpha)(k)^\alpha}{X(1+\psi_l)(R-1)} \\ \frac{Y}{K} &= \frac{X(1+\psi_K)(R-1)\left(\frac{R^K}{\Pi} - 1 + \delta\right)}{\alpha} \\ K &= lk \\ Y &= \left(\frac{Y}{K}\right) K \\ Gov &= \frac{Gov}{Y} \cdot Y \\ I &= \delta K \\ l^s &= l \end{aligned}$$

Then calculate

$$\begin{aligned} \varpi' &= \overline{\omega} R^K \\ V &= \frac{K R^K}{\Pi} \left[1 - \Gamma(\overline{\omega})\right] \\ N &= \frac{K}{\phi^e} \\ L^e &= K - N \\ L^r &= \psi_L w l + \psi_K r^K K \\ L &= L^e + L^r \end{aligned}$$

Given γ, this allows to compute W^e as

$$W^e = N - \gamma V$$

If this results in $W^e < 0$, the calibration is not permissible and needs to be modified.

I then calibrate ϕ^b such that

$$\phi^b = \frac{1}{\left(\frac{N_t^b}{L_t^e}\right)}$$

where $\frac{N_t^b}{L_t^e}$ equals the target for this variable.[18] I can then calculate all steady state values pertaining to the banking sector:

$$\begin{aligned}
z &= \frac{\left(R^b - R\right)\phi^b + R}{\Pi} \\
x &= z \\
\eta &= \frac{1-\theta}{1-\beta\theta z} \\
v &= \frac{(1-\theta)\frac{\left(R^b-R\right)}{R}}{1-\beta\theta z} \\
\lambda &= \frac{\eta + \phi^b v}{\phi^b} \\
N^b &= \frac{L^e}{\phi^b} \\
N_e^b &= \theta z N^b \\
N_n^b &= N^b - N_e^b \\
W^b &= N_n^b
\end{aligned}$$

If this results in $N_n^b = W^b < 0$, the calibration is not permissible and needs to be modified.

I then calculate the steady state values of the remaining real variables:

$$\begin{aligned}
C^e &= (1-\gamma) V \\
C^b &= (1-\theta) z N^b \\
C &= Y - I - C^e - C^b - Gov - \mu G(\overline{\omega}) \frac{R^K}{\Pi} K \\
C^P &= C + C^e + C^b \\
GDP &= C^P + I \\
\varrho &= \frac{1}{C(1-h)}
\end{aligned}$$

This allows me to back out χ, the weight of labour in the utility function:

$$\chi = \frac{\varepsilon_w - 1}{\varepsilon_w} \frac{\varrho w}{l^\varphi}$$

[18] Since the actual counterpart in the data is for $\frac{N^b}{L}$, I later adjust $\frac{N^b}{L^e}$ to achieve this target.