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## Asymmetric information in credit markets, bank leverage cycles and macroeconomic dynamics

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## WORKING PAPER SERIES

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# ASYMMETRIC INFORMATION IN CREDIT MARKETS, BANK LEVERAGE CYCLES AND MACROECONOMIC DYNAMICS

Ansgar Rannenberg

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**MACROPRUDENTIAL  
RESEARCH NETWORK**

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This paper presents research conducted within the Macroprudential Research Network (MaRs). The network is composed of economists from the European System of Central Banks (ESCB), i.e. the 27 national central banks of the European Union (EU) and the European Central Bank. The objective of MaRs is to develop core conceptual frameworks, models and/or tools supporting macro-prudential supervision in the EU.

The research is carried out in three work streams: 1) Macro-financial models linking financial stability and the performance of the economy; 2) Early warning systems and systemic risk indicators; 3) Assessing contagion risks.

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## **Abstract**

I add a moral hazard problem between banks and depositors as in Gertler and Karadi (2009) to a DSGE model with a costly state verification problem between entrepreneurs and banks as in Bernanke et al. (1999) (BGG). This modification amplifies the response of the external finance premium and the overall economy to monetary policy and productivity shocks. It allows my model to match the volatility and correlation with output of the external finance premium, bank leverage, entrepreneurial leverage and other variables in US data better than a BGG-type model. A reasonably calibrated combination of balance sheet shocks produces a downturn of a magnitude similar to the "Great Recession".

**JEL Codes:** E44, E43, E32.

**Keywords:** Leverage cycle, bank capital, financial accelerator, output effects of financial shocks

## Non-technical summary

The ongoing financial crisis has drawn renewed attention to the relationship between bank capital and economic activity. In its Global Financial Stability report of April 2010, the IMF argues that the losses incurred by banks caused a contraction in credit supply which in turn contributed to the economic downturn in the United States and beyond. Several empirical studies find that negative shocks to the capital of banks reduce lending and economic activity. At the same time, there is a long line of evidence saying that investment spending is positively related to the net worth of non-financial firms. All these considerations have led to a strong interest in better understanding the aggregate leverage cycle, in particular in relation to banks and non-financial firms.

This paper makes a contribution to the leverage-cycle debate by combining a costly state verification problem between borrowing entrepreneurs (the agents accumulating the capital stock) and banks as in traditional financial accelerator models with a moral hazard problem between banks and depositors. Therefore the leverage of both the borrowing entrepreneur and the bank lending to him affect the spread between the interest rate on loans and the risk free rate, i.e. the external finance premium, and hence the price of capital goods and investment.

The bank's leverage constraint arises because, after collecting household deposits, a bank can divert a fraction of its assets and declare bankruptcy. Therefore the bank will only be able to attract household deposits if its expected lifetime profitability is sufficiently high such that it has no incentive to divert assets. Hence an increase in the bank's today's leverage and thus the benefit to divert assets has to be matched by an increase in lifetime profitability and thus an increase in the expected profit margin on bank loans. Furthermore, a decline in expected future bank leverage relative to today's also requires an increase in the expected profit margin. Low expected future loan demand relative to the bank's own funds lowers the bank's expected lifetime profitability and thus restricts today's loan supply. Thus an expected banking sector de-leveraging increases today's external finance premium.

Both a monetary tightening and an adverse productivity shock trigger a banking sector de-leveraging. Therefore the response of the external finance premium and thus output and investment both to a monetary tightening and an adverse productivity shock is amplified as compared to a conventional finan-

cial accelerator-type model where only the leverage of entrepreneurs drives the external finance premium. This amplification allows the model to match the volatility of the external finance premium, investment and other variables relative to output in US data better than a conventional financial accelerator model even in the absence of any financial shocks. At the same time, the model developed in this paper also matches the volatility and procyclicality of bank leverage.

Regarding the effect of financial shocks in this model, a negative shock to the net worth of entrepreneurs causes a deeper downturn than in a conventional financial accelerator model. The increase in entrepreneurial borrowing and leverage associated with the sudden loss of funds increases the external finance premium in a conventional financial accelerator model. The increase in entrepreneurial borrowing in turn requires an increase in bank lending and hence bank leverage, which, in the presence of a leverage constraint in the banking sector, requires a further increase in the external finance premium. Furthermore, the bank leverage constraint implies that a negative shock to the net worth of banks causes an economic downturn. The reduction in their net worth forces banks to cut their supply of loans, which increases the external finance premium. Both the shock to firm net worth and bank net worth resemble demand shocks in that they move output and inflation in the same direction. This is in line with recent euro-area evidence by Ciccarelli et al. (2011).

A reasonably calibrated combination of shocks to the balance sheets of banks and entrepreneurs causes a downturn of a magnitude similar to the “Great Recession” associated with the 2007-2009 financial crisis in the United States. Previous dynamic stochastic general equilibrium models, which exhibited no or focused on single financial frictions and did not take the interaction between bank and firm leverage into account, encountered great difficulties in matching the experience of the crisis. In sum, for understanding the macroeconomic sources and implications of widespread financial instability it is essential that macroeconomic models are equipped with rich characterisations of financial sectors, including the multiplicity of frictions that may emerge in them, and how they interact with the debt dynamics of major economic agents.

# 1 Introduction

The ongoing financial crisis has drawn renewed attention to the relationship between bank capital and economic activity. In its Global Financial Stability report, the IMF argues that the losses incurred by banks caused a contraction in credit supply which in turn contributed to the economic downturn in the United States and beyond. Several empirical studies find that negative shocks to the capital of banks reduce lending and economic activity.<sup>1</sup> At the same time, there is a long line of evidence saying that investment spending is positively related to the net worth of non-financial firms.<sup>2</sup>

Therefore, I develop a model where both bank and firm leverage matter for the cost of external funds of firms and thus aggregate demand. I combine a costly state verification (CSV) problem between borrowing entrepreneurs (the firms accumulating the capital stock), as in the well known Bernanke et al. (1999) (henceforth referred to as BGG) financial accelerator model, with a moral hazard problem between banks and depositors as in the more recent contribution of Gertler and Karadi (2015). I assume that after collecting household's deposits, banks can divert a fraction of its assets and declare bankruptcy. Therefore the bank will only be able to attract deposits from households if its' expected profitability is sufficiently high such that it has no incentive to divert assets and thus household deposits are safe. This implies that the banks' ability to attract deposits and thus to expand loans today is positively related to its current net worth and its expected future earnings. If a shock lowers current bank net worth or future loan demand and thus future earnings, individual banks will have to cut loan supply today. Thus an expected banking sector de-leveraging

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<sup>1</sup>See Peek and Rosengreen (1997,2000), Ciccarelli et al. (2011) and Fornari and Stracca (2011).

<sup>2</sup>See Hubbard (1998) for a survey.

increases the cost of external finance today.

My main results can be summarized as follows. First, as compared to a BGG-type model, the response of the economy both to a monetary tightening and an adverse productivity shock is amplified in my model, the former more so than the latter. Both shocks trigger a deleveraging process in the banking sector, implying that banks cut loan supply when the shocks occur, thus amplifying the increase in the cost of external finance relative to the BGG model.

Secondly, in a world with three standard shocks (productivity, monetary policy and government spending), the amplification provided by the moral hazard problem in the bank-depositor relationship allows the model to match the volatility of the external finance premium, investment and other variables relative to output in US data better than the BGG model. My model also performs well at matching the second moments of the bank capital ratio.

Thirdly, in my model, an adverse shock to entrepreneurial net worth causes an output contraction more than twice as big as in a BGG-type model. In line with the existing empirical evidence, an adverse shock to bank net worth causes a persistent decline of GDP. The shock decreases loan supply by individual banks and thus increases the cost of external finance. For a reasonably calibrated combination of both net worth shocks, the model economy enters a downturn of a persistence and magnitude similar to the ongoing "Great Recession" in the United States.

The model has a number of desirable features not present in some recently proposed DSGE models with leverage constraints both in the firm *and* in the banking sector. First, firms and banks are subject to microfounded leverage constraints, unlike in the models of



Gerali et al. (2010) and Dib (2010). Furthermore, the capital stock in my model is owned by entrepreneurs who fund it using their own net worth and bank loans. Thus the leverage constraints banks and entrepreneurs have to obey apply to the whole capital stock. By contrast, in Meh and Moran (2010), households accumulate the capital stock and merely the production of new capital needs to be funded by entrepreneurial net worth and bank loans. Moreover, in my model households require the bank liabilities they hold to be riskless and withdraw their funds otherwise, as is arguably realistic. By contrast, in the models of Meh and Moran (2010) and Hirakata et al. (2009), depositors deliberately take a default risk and price it into the deposit rate.<sup>3</sup> Furthermore, in my model entrepreneurs may default with a cyclically varying probability, a feature absent in Meh and Moran (2010) and Gerali et al. (2010). Finally, the model can easily be extended to analyse the merits of the unconventional monetary policy responses to financial crises considered by Gertler and Karadi (2011) and Gertler and Kiyotaki (2009) and of the macroprudential policies considered in Gertler and Kiyotaki (2010), as well as the effect of frictions in the interbank market considered in Gertler and Kiyotaki (2009).

The remainder of the paper is organized as follows. Section 2 develops the model. Section 3 discusses the calibration while section 4 compares the response of my model and a BGG type model to three standard shocks. Section 5 performs a moment comparison, while section 6 summarizes the result from a series of robustness checks performed in the appendix. Section 7 discusses the response of the economy to financial shocks.

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<sup>3</sup>In Meh and Moran (2010), they even fund a specific entrepreneurial investment project jointly with the bank.

## 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 first order conditions of households, investment good producers and retailers have been relegated to the appendix since these aspects of the model are standard. Section D of the appendix summarizes the linearized equations of the three model variants considered in this paper.

### 2.1 Households

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

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

where  $C_t$  and  $l_t^s$  denote a CES basket of consumption good varieties and labour 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 riskless in nominal terms. Thus they are perfect substitutes and earn the same interest rate. 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  $R_{t-1}$ .

Following Schmitt-Grohe and Uribe (2005), I assume that a central authority inside the household, a union, supplies labour to a continuum of labour markets indexed by  $j = [0, 1]$ ,

with  $l_t(j)$  denoting the labour supplied to market  $j$  and

$$l_t^s = \int_0^1 l_t(j) dj. \quad (1)$$

Labour packers operating under perfect competition buy these varieties at a wage  $W_t(j)$  and aggregate them into a CES basket. Cost minimization by the labour packer implies a demand curve for variety  $j$  given by  $l_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} l_t$ , where  $W_t$  and  $\varepsilon_w$  denote the price index of the labour basket and the elasticity of substitution between varieties, respectively.

$W_t$  is given by

$$W_t = \left[ \int_0^1 W_t^{1-\varepsilon_w}(j) dj \right]^{1/(1-\varepsilon_w)} \quad (2)$$

The union takes  $W_t$  and  $l_t$  as given and sets  $W_t(j)$  such that the households utility is maximized. I assume that in doing so, it is subject to nominal rigidities in the form of Calvo contracts. Each period, the union can reset the wage optimally in a fraction  $1 - \xi^w$  of randomly chosen labour markets. In these markets, wages are indexed to lagged and average inflation according to the rule  $W_t(j) = W_{t-1}(j) \Pi^{1-\gamma_w} \Pi_{t-1}^{\gamma_w}$ , where  $\Pi_t = \frac{P_t}{P_{t-1}}$  and  $P_t$  denotes the price of the CES basket underlying consumption. Using (2), the law of motion of the aggregate nominal wage is given by

$$W_t = \left[ (1 - \xi) \left( \widetilde{W}_t \right)^{1-\varepsilon} + \xi^w \left( W_{t-1} \Pi^{1-\gamma_P} (\Pi_{t-1})^{\gamma_P} \right)^{1-\varepsilon_w} \right]^{\frac{1}{1-\varepsilon_w}}$$

where  $\widetilde{W}_t$  denotes the wage in markets where wages are optimally reset.

Households also derive profit income from owning retail firms and capital good's produc-

ers. Hence their budget constraint is given by

$$P_t C_t = P_t l_t \int_0^1 w_t(j) \left( \frac{w_t(j)}{w_t} \right)^{-\varepsilon_w} dj + P_t \text{profit}_t + P_t T_t + R_{t-1} B_{t-1}^T - B_t^T \quad (3)$$

where  $C_t$ ,  $w_t$ ,  $\Pi_t$  and  $T_t$  denote consumption, the real wage, real profits and real lump sum taxes, 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  $P_t Q_t$ . 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  $\varrho_t$  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 labour  $l_t(i)$  at real wage  $w_t$  from labour packers 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

$$Y_t(i) = (K_t^s(i))^\alpha (\exp(a_t) l_t(i))^{1-\alpha}$$

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  $\psi_L$  and  $\psi_K$ , respectively, of their expenditures on labour 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, total working capital loans to retailers  $L_t^r$  are given by

$$L_t^r = \psi_L w_t l_t + \psi_K r_t^k K_t^s \quad (4)$$

Retailers are subject to nominal rigidities in the form of Calvo (1983) contracts: Only a fraction  $1 - \xi^P$  is allowed to optimize its price in a given period. Those firms not allowed to optimize its price index it to past inflation at a rate  $\gamma_P$  and to the steady-state inflation rate  $\Pi$  at rate  $1 - \gamma_P$ . Denoting the price chosen by those firms allowed to optimize in period  $t$  as  $p_t^*$ , the aggregate price index evolves according to

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

## 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. This assumption ensures that banks never become fully self-financing. The fraction  $1 - \theta$  of bankers who die are replaced by newly born bankers.<sup>4</sup> If banker  $q$  dies, he consumes his accumulated 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.

Banks derive income from offering loans to firms. This is a key difference with respect to Gertler and Karadi (2011), where banks channel funds to firms by buying equity stakes. A banker makes 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 beginning of period  $t+1$ . The second type are riskless intraperiod working capital loans  $L_t^r$  to retailers who need to pay for the labour and capital services used in production and are due at end of period  $t$ .

Following Gertler and Karadi (2011), I assume that after collecting deposits, a banker can choose to divert some of his assets for his own consumption. 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

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<sup>4</sup>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 problem of the entrepreneur.

$V_t^b(q)$  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 household only make deposits if the banker has no incentive to divert assets implies the bank never defaults and thus household deposits are riskless 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 bank-retailer relationship. Hence the loan rate is driven down to the deposit rate, implying that banks earn zero profits on these loans. Thus the intraperiod loan business does not affect  $N_t^b(q)$  and  $V_t^b(q)$ , and thus 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

$$P_t N_t^b(q) = [R_t^b P_{t-1} L_{t-1}^e(q) - R_{t-1} B_{t-1}(q)] \exp(e_t^z) \quad (5)$$

$$= P_{t-1} [(R_t^b - R_{t-1}) L_{t-1}^e(q) + R_{t-1} N_{t-1}^b(q)] \exp(e_t^z) \quad (6)$$

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, which I will use below to simulate the effect of a banking crisis on the macroeconomy.

Like Gertler and Karadi (2011), I will calibrate  $\lambda$  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 chose 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.  $\phi_t^b$  is determined by a complicated non-linear expression, which up to first order however reduces to one equation as we discuss below. In much of the discussion, I will refer to  $\phi_t^b$  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

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

$$z_{t-1,t} = \frac{[(R_t^b - R_{t-1}) \phi_{t-1}^b + R_{t-1}]}{\Pi_t} \exp(e_t^z) \tag{8}$$

where  $z_{t-1,t}$  denotes the growth rate of 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

$$C_t^b = (1 - \theta) z_{t-1,t} N_{t-1}^b \tag{9}$$



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  $\lambda \phi_t^b = \frac{V_t^b}{N_t^b} \cdot \frac{V_t^b}{N_t^b}$  can 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. In appendix B, I show that up to first order, this constraint can be expressed as

$$\widehat{\phi}_t^b = \widehat{\left(\frac{V_t^b}{N_t^b}\right)} = \sum_{i=0}^{\infty} (\theta \beta^2 z^2)^i \phi_t^b \frac{R^b}{R} \left( E_t \widehat{R}_{t+1+i}^b - \widehat{R}_{t+i} \right) \quad (10)$$

with  $\widehat{\phi}_t^b = \widehat{L}_t^e - \widehat{N}_t^b$ . Hence bank leverage 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 thus they are willing to buy more deposits. Hence the bank can expand its lending to entrepreneurs and its leverage  $\widehat{\phi}_t^b$ . Therefore equation (10) may be interpreted as a "credit supply curve". The difference with respect 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.

The forward looking nature of loan supply implies that future loan market equilibria have a direct effect on period  $t$  loan supply. Imagine that in some future period  $t+i$  loan demand is low relative to the own funds of the bank and thus  $\widehat{\phi}_{t+i}^b$  is low, moving the bank down its supply curve. This implies that bank profitability as of period  $t+i$   $\widehat{\left(\frac{V_{t+i}^b}{N_{t+i}^b}\right)}$  declines. As a consequence, period  $t$  profitability  $\widehat{\left(\frac{V_t^b}{N_t^b}\right)}$  and thus the amount of deposits households are

willing to make declines. 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

Investment decisions in the economy are made by risk-neutral entrepreneurs. My assumptions regarding this sector follows Christiano et al. (2010), unless otherwise noted. At the end of period  $t$ , entrepreneur  $j$  buys capital  $K_t^j$  for price  $P_t Q_t$ . In period  $t + 1$ , they rent part of their capital stock to retailers at a rental rate  $P_{t+1} r_{t+1}^k$  and then sell the non-depreciated capital stock at price  $P_{t+1} Q_{t+1}$ . They are subject to capacity utilization costs  $a(U_{t+1})$ , where  $a'(\cdot) > 0$ ,  $a''(\cdot) > 0$ ,  $a'(1) = r^k$  and  $a''(1) = c^U r^k$ . The average return to capital across entrepreneurs is given by

$$R_{t+1}^K = \Pi_{t+1} \frac{r_{t+1}^k U_{t+1} - a(U_{t+1}) + Q_{t+1}(1 - \delta)}{Q_t} \quad (11)$$

where the optimal choice of  $U_t$  implies that

$$r_t^k = a'(U_t) \quad (12)$$

The gross nominal return of entrepreneur  $j$  is given by  $\omega_{t+1}^j R_{t+1}^K$ , where  $\omega_{t+1}^j$  is an idiosyncratic shock creating ex-post heterogeneity among entrepreneurs with density  $f(\omega^j)$ , mean 1 and variance  $\sigma^2$ .

To fund the acquisition of the capital stock, the entrepreneur uses his own net worth  $P_t N_t^j$

and a loan  $P_t L_t^j = P_t (Q_t K_t^j - N_t^j)$ , which is granted by the bank at a gross nominal loan rate  $R_t^L$ . Loan and interest are paid back in period  $t+1$ .

In case of default, i.e. if the realisation of  $\omega_{t+1}^j R_{t+1}^K$  is so low that the entrepreneurs can not repay the loan, the bank seizes the entrepreneurs assets  $\omega_{t+1}^j R_{t+1}^K K_t^j P_t Q_t$  but has to pay a fraction  $\mu$  thereof as bankruptcy cost. Hence one can define a cut-off value  $\bar{\omega}_{t+1}^j$  for  $\omega_{t+1}^j$  such that for values of  $\omega_{t+1}^j$  greater or equal to  $\bar{\omega}_{t+1}^j$ , the entrepreneur is able to repay the loan:  $\bar{\omega}_{t+1}^j R_{t+1}^K P_t Q_t K_t^j = R_t^L P_t L_t^j$ . Furthermore, after the realisation of  $\omega_{t+1}^j R_{t+1}^K$  entrepreneurs die with a fixed probability  $1 - \gamma$ . Dying entrepreneurs consume their equity  $V_t$ . The fraction  $1 - \gamma$  of entrepreneurs who died are replaced by new entrepreneurs each period. This assumption ensures that entrepreneurs never become fully self-financing.

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  $\omega^j$ , the expected revenue of the bank associated with a loan  $L_t^j$  is given by

$$Loanrev_{t+1}^j = R_t^L P_t L_t^j \int_{\bar{\omega}_{t+1}^j}^{\infty} f(\omega^j) d\omega^j + (1 - \mu) R_{t+1}^K P_t Q_t K_t^j \int_0^{\bar{\omega}_{t+1}^j} \omega^j f(\omega^j) d\omega^j \quad (13)$$

where the first term refers to the bank's revenue in case of 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  $E_t \left\{ R_t^L P_t L_t^j \int_{\bar{\omega}_{t+1}^j}^{\infty} f(\omega^j) d\omega^j + (1 - \mu) R_{t+1}^K P_t Q_t K_t^j \int_0^{\bar{\omega}_{t+1}^j} \omega^j f(\omega^j) d\omega^j \right\}$  where expectations are taken over  $R_{t+1}^K$  and  $\bar{\omega}_{t+1}^j$ .

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 (10)). Any debt contract between the entrepreneur and the bank  $(L_t^j, R_t^L)$  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

$$E_t \left\{ R_t^L P_t L_t^j \int_{\bar{\omega}_{t+1}^j}^{\infty} f(\omega^j) d\omega^j + (1 - \mu) R_{t+1}^K P_t Q_t K_t^j \int_0^{\bar{\omega}_{t+1}^j} \omega^j f(\omega^j) d\omega^j \right\} = P_t L_t^j E_t R_{t+1}^b \quad (14)$$

Note that unlike in Christiano et al. (2010)'s version of the BGG model, the loan rate is not state contingent but fixed, i.e. it does not vary with the realisation of  $R_{t+1}^K$ . Hence unexpected aggregate shocks will affect the return on bank loans via the implied unexpected losses which were 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 realisation of  $R_{t+1}^K$  in order to guarantee the bank a nominal return equal to the risk free rate. Hence in their model, the following constraint has to hold in every  $t+1$  aggregate state:

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

However, while adding realism to the setup, the introduction of non-statecontingent contracts has only minor effects on the quantitative results.

The entrepreneurs chooses the level of  $K_t^j$  and thus implicitly a pair  $(L_t^j, R_t^L)$  to maximize

his expected return, which is given by

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

In appendix A.5, I show that all entrepreneurs choose the same leverage  $\phi_t^e = \frac{Q_t K_t}{N_t}$  and derive the first order conditions. Up to first order, these equations give rise to a relationship between  $E_t R_{t+1}^K / E_t R_{t+1}^b$  and the entrepreneurial leverage ratio identical to the relationship between the risk premium  $E_t R_{t+1}^K / R_t$  and the leverage ratio in BGG:

$$E_t \hat{R}_{t+1}^K - E_t \hat{R}_{t+1}^b = \chi^l (\hat{K}_t + \hat{Q}_t - \hat{N}_t) \quad (15)$$

where  $\chi^l \geq 0$ . Hence in the presence of both a CSV problem between firms and banks and the moral hazard problem between banks and depositors assumed here,  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  consists of two spreads,  $E_t \hat{R}_{t+1}^b - \hat{R}_t$  and  $E_t \hat{R}_{t+1}^K - E_t \hat{R}_{t+1}^b$ .  $E_t \hat{R}_{t+1}^b - \hat{R}_t$  is driven by bank leverage as detailed in the previous subsection while  $E_t \hat{R}_{t+1}^K - E_t \hat{R}_{t+1}^b$  is driven by entrepreneurial leverage.

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

$$N_t = \gamma V_t + W^e \quad (16)$$

Entrepreneurial equity and consumption are given by

$$V_t = \left[ \int_{\bar{\omega}_t}^{\infty} f(\omega^j) (\omega^j R_t^K Q_{t-1} K_{t-1} - R_{t-1}^L L_{t-1}^e) d\omega^j \right] \exp(e_t^N) \quad (17)$$

$$C_t^e = (1 - \gamma) V_t \quad (18)$$

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

The period  $t$  cut-off value of  $\omega$  dividing the population of firms into bankrupt and solvent denoted by  $\bar{\omega}_t$  is given by

$$\bar{\omega}_t = \frac{R_{t-1}^L (Q_{t-1} K_{t-1} - N_{t-1})}{R_t^K Q_{t-1} K_{t-1}} \quad (19)$$

Note that the lending rate is predetermined, implying that only  $R_t^K$  has a contemporaneous effect on  $\bar{\omega}_t$ . Finally, dividing both sides of 13 by  $P_t L_t^j$ , iterating one period back and using the fact that entrepreneurial leverage and the cut-off value  $\bar{\omega}_t^j$  are the same across entrepreneurs as well as the law of large numbers, we have

$$R_t^b = \frac{Loanrev_t^j}{P_{t-1} L_{t-1}^j} = \left[ R_{t-1}^L \int_{\bar{\omega}_t}^{\infty} f(\omega^j) d\omega^j + (1 - \mu) R_t^K \frac{\phi_{t-1}^e}{\phi_{t-1}^e - 1} \int_0^{\bar{\omega}_t} \omega^j f(\omega^j) d\omega^j \right] \quad (20)$$

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 thus the deposit rate, following an interest feedback rule of the form

$$R_t - 1 = (1 - \rho_i) \left[ \begin{aligned} & R - 1 + \psi_\pi E_t (\log (\Pi_{t+1}) - \log (\Pi)) \\ & + \psi_{\Delta\pi} (\log (\Pi_t) - \log (\Pi_{t-1})) + \psi_y (\log (GDP_t) - \log (GDP_{t-1})) \end{aligned} \right] \quad (21)$$

$$+ \rho_i (R_{t-1} - 1) + e_{-i} \quad (22)$$

where  $e_{-i}$  denotes an i.i.d. monetary policy shock. This rule is taken from Christiano et al. (2010). I will draw on this paper to calibrate many of the model's parameters, including the monetary policy rule.

The resource constraint is given by

$$S_t = (1 - \xi^P) \left( \frac{\Pi_t}{\Pi_t^*} \right)^\varepsilon + \xi^P \left( \frac{\Pi_t}{\Pi_{t-1}^{\gamma_P} \Pi^{1-\gamma_P}} \right)^\varepsilon S_{t-1} \quad (23)$$

$$C_t^P = C_t + C_t^e + C_t^b \quad (24)$$

$$Y_t = S_t \left( \begin{aligned} & I_t + C_t^P + Gov_t \\ & + a(U_t) K_{t-1} + \frac{R_t^K}{\Pi_t} Q_{t-1} K_{t-1} \mu \int_0^{\bar{\omega}_t} \omega f(\omega) d\omega \end{aligned} \right) \quad (25)$$

$$Y_t = (K_{t-1} U_t)^\alpha (A_t l_t)^{1-\alpha} \quad (26)$$

$$GDP_t = I_t + C_t + Gov_t \quad (27)$$

where  $S_t$  denotes the efficiency loss arising from price dispersion and  $Gov_t$  denotes government

expenditure. The law of motion of capital is given by

$$K_t = (1 - \delta) K_{t-1} + I_t \left( 1 - \frac{\eta_i}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right) \quad (28)$$

## 2.7 Two simplifications of the full model

Below I will compare the response of the model developed in this paper to two simplified versions. The first 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 assume that 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 (2010). The presence of the passive banking sector has no impact on dynamics of the real economy. However, it will be helpful to understand why the economy responds differently to shocks once  $\lambda > 0$ . The second version is a model where households accumulate the capital stock  $K_t$  in order to rent it to retailers in period  $t+1$ . Hence apart from the working capital constraint on retailers, there are no financial frictions.

## 3 Calibration

I calibrate the model to US data over the period from 1990Q1-2010Q1. All data sources are described in appendix G. After setting  $\Pi$  equal to the average percentage change in the GDP deflator,  $\beta$  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.

The parameters pertaining to the entrepreneurial sector are  $\sigma$ ,  $\mu$ ,  $\gamma$  and  $W^e$ .  $\mu$  is set to lie in the range of estimates of bankruptcy costs cited by Carlstrom and Fuerst (1997).  $\sigma$  is calibrated such that firm leverage  $\phi^e$  and the default rate  $F$  meet target values. The target for the probability of default is taken from Bernanke et al. (1999). The target for firm leverage is the average ratio between total liabilities and total net worth of the nonfarm nonfinancial business sector, taken from the Flow of Funds account (FFA) of the Federal Reserve Board.<sup>5</sup>  $\gamma$  is calibrated close to values used by Christiano et al. (2010) and Bernanke et al. (1999), which backs out the transfer to new entrepreneurs  $W^e$ .

The parameters pertaining to the banking sector are the fraction of loans the bank can divert  $\lambda$ , the survival probability of banks  $\theta$  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 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 nonfinancial companies over the period 1997Q1 to 2004Q4. They match the daily effective yield on each individual security issued by the firm to the estimated yield on a treasury coupon

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<sup>5</sup>Both net worth and total liabilities are summed up across the non-farm business sector. The resulting leverage ratio is 1.85. A more restrictive measure of net worth suggested by Fuentes (2009) subtracts total credit market instruments from total tangible (as opposed to financial) assets. This measure implies a leverage ratio of 1.7, which is still close to the target under the baseline calibration. Setting the target for  $\phi^e$  to 1.7 has small effects on the numerical results reported below, which however all go in the direction of somewhat strengthening my conclusions, in particular regarding the performance of the two models relative to the data.

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 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.

I assume that retailers have to fully pre-finance their capital and labour costs via working capital loans, i.e.  $\psi_L = \psi_K = 1$ .

Most parameters not pertaining to the financial frictions in the model are calibrated according to choices and estimates of Christiano et al. (2010), who estimate a model with a financial accelerator. Exceptions are the cost of changing capacity utilization,  $c^U$ , and the cost of adjusting investment,  $\eta_i$ , where Christiano et al.'s estimates are unusually high.

In the moment comparison I will consider three stochastic processes, a monetary policy shock, a transitory productivity shock and a government spending shock. The later both follow AR(1) processes. All stochastic processes are calibrated to the estimates of Christiano et al. (2010). I consider only these three standard shocks in order to let the amplification and propagation mechanisms of the model speak for themselves.

**Table 1: Calibration of non-policy parameters**

Parameter	Description	Full model	BGG model
$\beta$	Household discount factor	0.9958	0.9938
$\varphi$	Inverse Frisch elasticity of labour supply	1	1
$h$	External habit formation	0.63	0.63
$\alpha$	Capital elasticity of output	0.33	0.33
$\delta$	Depreciation rate	0.025	0.025
$\eta_i$	Investment adjustment cost	4	4
$c^U$	Capital utilization cost	1.5	1.5
$\varepsilon$	Elasticity of substitution between varieties	11	11
$\xi^P$	Probability of non-reoptimisation of prices	0.7	0.7
$\iota^P$	Degree of indexing with respect to past inflation	0.841	0.841
$\varepsilon^W$	Elasticity of substitution between labour varieties	21	21
$\xi^W$	Probability of non-reoptimisation of wages <sup>6</sup>	0.947	0.947
$\iota^W$	Wage indexing with respect to past inflation	0.715	0.715
$\theta$	Survival probability of bankers	0.9915	0.9915
$\psi_L$	Share of retailer's labour costs paid in advance	1	1
$\psi_K$	Share of retailer's capital rental costs paid in advance	1	1
$\lambda$	Fraction of bank assets the banker can divert	0.2351	0
$\sigma$	Standard deviation of the idiosyncratic shock	0.3	0.3
$\mu$	Bankruptcy costs	0.2981	0.2981
$\gamma$	Survival probability of entrepreneurs	0.972	0.972

<sup>6</sup>Here the calibration exceeds Christiano et al.'s (2010) estimate because my assumption about wage

<b>Table 2: Policy parameters and shocks</b>		
$\psi_\pi$	Coefficient on inflation in the Taylor rule	1.82
$\psi_{\Delta\pi}$	Coefficient on inflation change in the Taylor rule	0.18
$\psi_y$	Coefficient on GDP growth in the Taylor rule	0.31/4
$\rho_i$	Coefficient on the lagged interest rate in the Taylor rule	0.88
$\rho_a$	Persistence productivity shock	0.816
$\rho_g$	Persistence gov. spending shock	0.93
$\sigma_i$	Sd. monetary policy shock	0.0013
$\sigma_a$	Sd. productivity shock	0.008
$\sigma_g$	Sd. government spending shock	0.021

setting differ from their's. They follow Erceg et al. (2000) in assuming that each household monopolistically supplies one labour variety from the labour basket, implying that with wage stickiness, labour supply will vary across households. By contrast, I follow Schmitt-Grohe and Uribe (2005) and assume that one representative household supplies all varieties. The advantage of this strategy is that we do not have to assume the existence of a set of state contingent securities in order to equalize consumption across households. However, it also implies that an important source of strategic complementarity is absent from my model. Specifically, up to first order, the coefficient on the wage markup in the equation determining the real wage will be  $\frac{(1-\xi^W)(1-\beta\xi^W)}{(1+\beta)\xi^W}$  in my model while it will be  $\frac{(1-\xi^W)(1-\beta\xi^W)}{(1+\beta)\xi^W(1+\varepsilon^W\varphi)}$  in the Christiano et al.'s (2010) framework, implying that given  $\xi^W$ , the coefficient on the wage mark-up in their model will be lower than in mine. Therefore I adjust  $\xi^W$  upwards in order to ensure that the wage mark-up coefficient in my model is the same as in Christiano et al. (2010). This procedure was suggested by Schmitt-Grohe and Uribe (2005).

<b>Table 3: Important steady-state values</b>		
<b>Variable</b>	<b>Description</b>	<b>Value</b>
$R$	Risk free rate, APR	3.97%
$\Pi$	Inflation target, APR	2.23%
$R^L - R$	Spread of the loan rate over the risk free rate, APR	1.35%
$\phi^1$	Leverage in firm sector	1.87
$F(\bar{\omega})$	Quarterly bankruptcy rate, percent	0.75% (calibrated)
$\frac{N^b}{L}$	Bank capital ratio, percent	9.81%

## 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. The response of the three economies to a contractionary one-standard-deviation monetary policy shock is displayed in Figure 1. All charts display log-deviations of the respective variables from their respective steady states, unless the variables are specified in percentage terms. The model developed in this paper is referred to as "Full" model, while the model without financial frictions and the BGG model are labelled "nofr", for "nofriction model", and "BGG", respectively. The response of GDP is the strongest in the full model with a trough of -0.89%, reached in quarter 3, while it is the weakest in the nofriction model, where the trough of GDP equals -0.44%. The response of GDP in the BGG model is in between the full model and the nofriction model, with a trough of -0.62%. Note that the path of GDP in the nofriction model remains persistently above the path of GDP in the two models with financial frictions.

The differences in the GDP declines across the three models are mainly if not exclusively caused by differences in the decline of investment. The trough of investment is -2.59% in the full model, -1.67% in the BGG model and -0.88% in the nofriction model, while the path of consumption is much more similar across the three models.

The reason why the response of output to a monetary policy shock is stronger in the BGG model than in the nofriction model is well understood. The increase in the interest rate reduces the price of capital goods  $\widehat{Q}_t$  since future rental income to capital is discounted more heavily. This directly reduces investment in both models but in the BGG model it also reduces entrepreneurial net worth  $\widehat{N}_t$  and increases entrepreneurial leverage. The increase in leverage requires an increase in  $E_t \widehat{R}_{t+1}^K - \widehat{R}_t$  via (15) since it increases expected bankruptcy costs. Hence  $\widehat{Q}_t$  and thus investment decline even more. The drop in  $\widehat{N}_t$  also causes a drop in entrepreneurial consumption.

To understand why GDP responds more strongly to a monetary policy shock in the full model than in the BGG model, it is useful to examine the response of bank and entrepreneurial 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 until it peaks in quarter 9. The reason for the increase in  $\widehat{N}_t^b$  is the increase in the riskless rate. A higher  $\widehat{R}_t$  increases the (accounting) profits banks earn on loans they fund using their own net worth. At the same time loans to entrepreneurs  $\widehat{L}_t^e$  first increase until quarter 6 since the drop in entrepreneurial net worth temporarily increases their demand for funds, but then persistently decrease since the erosion of the capital stock caused by the persistent decline in investment ultimately reduces it. As a result of the dynamics of  $\widehat{L}_t^e$  and  $\widehat{N}_t^b$ , bank leverage  $\widehat{\phi}_t^b$  decreases very persistently until it is about 0.9% below its steady state in period 23.

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 like in the full model, i.e. in a situation where the "loan supply curve" (10) holds. The below steady-state loan demand relative to the own funds of the bank implies that profitability as of period 23 is also below normal since  $\widehat{\left(\frac{V_{23}^b}{N_{23}^b}\right)} = \widehat{\phi}_{23}^b < 0$ . The market for loans in period 23 has a lot of slack and thus profit margins on loans made in period 23 and/ or after  $E_1 \widehat{R}_{24+i}^b - \widehat{R}_{23+i}$  are driven down by competition among banks. However, the below-steady-state profitability in period 23 also reduces profitability in period one since there is a high probability that existing banks are still in business in period 23. Hence in period one, households are worried that the bank might decide to default. Therefore they 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, which tends to increase bank profitability and thus to reassure depositors.

Figure 1 shows that  $E_t \widehat{R}_{t+1}^b - \widehat{R}_t$  indeed increases on impact by about 0.81% at an annualized rate in the full model and remains positive until quarter 9. The persistent increase in  $E_t \widehat{R}_{t+1}^b - \widehat{R}_t$  accelerates the financial accelerator by adding to the increase of the spread between the expected return on capital  $E_t \widehat{R}_{t+1}^K$  and the risk free rate  $\widehat{R}_t$ .  $E_t \widehat{R}_{t+1}^K - \widehat{R}_t$  increases by 1.5% and 0.37% in the full model and in the BGG model, respectively. Hence more than two thirds of the difference in  $E_t \widehat{R}_{t+1}^K - \widehat{R}_t$  between the two models is explained by the increase in  $E_t \widehat{R}_{t+1}^b - \widehat{R}_t$  in the full model. The higher path of  $E_t \widehat{R}_{t+1}^K$  in the full model in turn causes a stronger drop in  $\widehat{Q}_t$  and entrepreneurial net worth  $\widehat{N}_t$ . The stronger drop in  $\widehat{N}_t$  itself contributes to the stronger increase in  $E_t \widehat{R}_{t+1}^K - \widehat{R}_t$  in the full model since it implies a stronger increase in entrepreneurial leverage, which increases  $E_t \widehat{R}_{t+1}^K - E_t \widehat{R}_{t+1}^b$ . The stronger decline

in  $\widehat{Q}_t$  causes the stronger contraction of investment observed in the full model. Further, the stronger decline in entrepreneurial net worth also means that entrepreneurial consumption declines more strongly in the full model than in the BGG model.

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

The smaller response of output to a monetary policy shock in the BGG model as compared to our full model is in line with euro area evidence by Ciccarelli et al. (2011). They estimate a VAR featuring a survey based measures of the change in the tightness of credit supply of banks with a separate variables for changes in credit supply due to reasons related to the banks own balance sheet. Ciccarelli et al. (2011) find that when they conduct a counterfactual analysis where the impact of the monetary policy shock on changes in credit supply related to bank balance sheet reasons is neutralized, the response of GDP to a monetary policy shock is reduced by 50%.

Note also that, following an on-impact-decline, the full model predicts a persistent increase of loans in response to a monetary tightening while the BGG model predicts a persistent decline. Two recently proposed DSGE models featuring leverage constraints in both the banking and business sector proposed by Meh and Moran (2010) and Gerali et al. (2010), respectively, also find a persistent decline of loans to businesses following a monetary tightening. However, the increase of loans observed 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. On the other hand, den Haan et al. (2007) also find that bank net worth de-



creases in response to a monetary policy shock, a feature captured by Meh and Moran (2010) but neither by our model nor the model of Gerali et al. (2010). The failure of my model to produce a decline in bank net worth might be related to two simplifying assumptions, namely the one quarter maturity of contracts and the absence of any traded assets from the banks portfolio. The re-negotiation of debt contracts after one quarter implies that unexpected entrepreneurial defaults not yet priced into the loan rate can occur only on impact but not afterwards. The absence of traded assets implies that banks profits will be unaffected by the loss in value such assets typically suffer in response to a monetary tightening.

Figure 2 displays the response of the three economies to a contractionary transitory technology shock. The on-impact response is twice as big in the full model as in the BGG model. Over time, as GDP declines further in both models the difference between the two models diminishes. The stronger decline in the full model than in the BGG model is caused both by a stronger drop in consumption and investment, with the latter becoming more important with each passing quarter. The response of GDP in the nofriction model is close to the full model during the first couple of quarters but then becomes visibly stronger than in both models.

The reason for the weaker output response of the BGG model than the nofriction model is that in the presence of a nominal debt contract, the unexpected increase in inflation caused by the technology shock reduces the debt burden of entrepreneurs and thus increases their net worth. At the same time the technology shock persistently lowers the marginal product of capital and therefore investment, the capital stock and loans to entrepreneurs. Hence entrepreneurial leverage and thus  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  persistently decline and therefore the decline in investment, entrepreneurial consumption and GDP is attenuated relative to the nofriction

model. Christiano et al. (2010) also find that with a nominal debt contract, a CSV problem between entrepreneurs and banks attenuates the effect of transitory technology shocks.

The response of bank net worth  $\hat{N}_t^b$ , loans to entrepreneurs  $\hat{L}_t^e$  and bank leverage  $\hat{\phi}_t^b$  in the BGG model is again instructive to understand how the bank leverage cycle amplifies the response of the full relative to the BGG model. We have already noted that  $\hat{L}_t^e$  persistently decreases.  $\hat{N}_t^b$  decreases until quarter four since monetary policy is slow to increase the nominal interest rate in response to the uptick in inflation following the technology shock, but then starts recovering. The declining path of  $\hat{L}_t^e$  and the hump shape of  $\hat{N}_t^b$  generate a declining path of  $\hat{\phi}_t^b$ . In the full model, the low future loan demand relative to the net worth of banks causes a cut in loan supply in period one and after. The banking sector profit margin  $E_t \hat{R}_{t+1}^b - \hat{R}_t$  increases, implying that  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  is positive in the full model and much higher than in BGG model. The higher path of  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  lowers the capital good's price  $\hat{Q}_t$ , entrepreneurial net worth  $\hat{N}_t$  and thus investment and entrepreneurial consumption relative to the BGG model.

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  $\chi^l$  is increased.<sup>7</sup> I increase  $\chi^l$  by increasing  $\mu$ , the share of a bankrupt entrepreneurs assets that has to be paid as bankruptcy cost. Setting  $\mu = 1$ , its maximum and far above available empirical estimates indeed reduces the trough of GDP in the BGG model to -0.78%, not too far away from the -0.89% observed in the full model. However, since, as discussed above, the BGG financial accelerator attenuates technology shocks, a higher  $\chi^l$  further reduces the response of output to a technology shock in the BGG model relative to the full model. What is more, setting

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<sup>7</sup>I thank Hans Dewachter for raising this issue.

$\mu = 1$  would imply an unreasonably high annualized steady-state real return on capital  $\frac{R^K}{\Pi} - 1$  of 21.6%.<sup>8</sup>

By contrast, the response of GDP to an expansionary government spending shock is strongest in the BGG model, followed by the nofriction and the full model. The crowding out of investment and consumption is the smallest in the BGG model. Entrepreneurial net worth persistently increases since the real interest rate initially declines in response to the shock, while loans to entrepreneurs persistently decrease since the capital stock declines. Hence entrepreneurial leverage and  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  fall, thus limiting the decline in investment as compared to the nofriction model. The decline in loans to entrepreneurs drives a persistent decline in bank leverage  $\hat{\phi}_t^b$ . In the full model, this decline causes an increase in the banking sector profit margin and hence  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  rises more in the full model than in the BGG model, implying a stronger crowding-out of investment.

## 5 Moment comparison

I now compare the cyclical properties of some important real and financial variables in the full model and in the BGG model to their counterparts in the data. The real variables considered are GDP, consumption, non-residential investment and hours worked. For the full model, the financial variables considered are the cost of external finance  $R_t^L - R_t$ , entrepreneurial leverage  $\phi_t^e$ , the bank capital ratio  $\frac{N_t^b}{L_t}$ ,  $L_t$  and  $N_t^b$ . In the BGG model, the loan rate on loans made in period  $t$  is determined only in period  $t+1$ , after the realisation of aggregate shocks in period  $t+1$ . Therefore, I choose the spread between the loan rate which borrowers at time  $t$  expect

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<sup>8</sup>An alternative way to increase  $\chi^l$  would be to increase the degree of idiosyncratic capital return uncertainty  $\sigma$ . However, this would also lower entrepreneurial leverage, implying that the response of the economy to a monetary policy shock is actually dampened.

to pay in case of non default and the policy rate,  $E_t R_{t+1}^L - R_t$  as the BGG models measure of the cost of external finance.<sup>9</sup>

As a measure of the cost of external finance in the data, I use the difference between the BAA composite corporate bond rate and the effective federal funds rate, as suggested by Christiano et al. (2010).<sup>10</sup> For the remaining variables, I use the same measures used as targets when calibrating the model. All data except for  $R_t^L - R_t$  and  $\frac{N_t^b}{L_t}$  was logged and HP filtered.

<b>Table 4: Standard deviations relative to GDP</b>			
<b>Variable</b>	<b>Data</b>	<b>Full model</b>	<b>BGG model</b>
$\widehat{GDP}_t$	1	1	1
$\widehat{C}_t$	0.81	0.91	0.93
$\widehat{I}_t$	4.44	2.81	2.34
$\widehat{l}_t$	1.61	1.29	1.39
$\widehat{R}_t^L - \widehat{R}_t; E_t \widehat{R}_{t+1}^L - \widehat{R}_t, \text{ APR}$	0.99	0.95	0.11
$\widehat{\phi}_t^e$	1.99	1.37	1.00
$\widehat{N}_t$	4.53	3.03	2.08
$\widehat{\left(\frac{N_t^b}{L_t}\right)}$	0.4	0.53	0.07
$\widehat{L}_t$	2.45	0.66	0.77
$\widehat{N}_t^b$	2.42	5.46	0.89

Table 4 displays the standard deviations of the various variables relative to GDP. Both

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<sup>9</sup>Christiano et al. (2010) suggest to use an alternative variable as the model's measure of the cost of external finance: the actual transfer of resources from entrepreneurs to banks per unit of loans made minus the policy rate. Using this variable yields virtually identical results both in the full and in the BGG model.

<sup>10</sup>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.

models match the relative volatility of consumption. The full model generates considerably more volatility than the BGG model for  $I_t, \phi_t^e$ , and  $N_t$  and thus comes closer to the data, although the relative volatilities of all these variables are still too low compared to the data. Both models also produce a too low relative volatility of loans. By contrast, the full model closely matches the relative volatility of the cost of external finance. Here the full model greatly improves upon the BGG model, which generates only one tenth of the relative volatility of this variable observed in the data. This is in line with Christiano et al. (2010), who find that in their estimated version of the BGG model, shocks directly hitting the entrepreneurial sector, i.e. shocks to entrepreneurial net worth or the degree of idiosyncratic capital return uncertainty, explain about 99% of the variation of the cost of external finance at the business cycle frequency. Using a different methodology, Nolan and Thoenissen (2009) also carry a BGG type model to the data and find that financial shocks explain a large share of the variation of the cost of external finance. By contrast, my full model explains the relative volatility of cost of external finance relying purely on conventional shocks. The fact that the relative volatility of the cost of external finance is higher in the full model than in the BGG model is due to the dynamics of the banking sector profit margin  $E_t \hat{R}_{t+1}^b - \hat{R}_t$  in the full model discussed in the previous section.<sup>11</sup>

The full model also performs much better at matching the relative volatility of the capital

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<sup>11</sup>The attentive reader might notice that while the impulse responses of  $E_t R_{t+1}^K - R_t$  discussed in the previous section suggest a higher volatility of the cost of external finance in the full model than in the BGG model, they do not suggest a volatility more than 10 times as high, which is what is table 4 says. However, note that table 4 is based on the standard deviations of  $R_t^L - R_t$  and  $E_t R_{t+1}^L - R_t$ , the spread of the (observable) loan rate over the risk free rate, in the two models, while what I was discussing in the previous section are the responses of  $E_t R_{t+1}^K - R_t$ , the spread of the (unobservable) expected return to capital over the risk free rate, in the two models. The impulse responses of the cost of external finance are qualitatively very similar to the responses of  $E_t R_{t+1}^K - R_t$  in both models but differ quantitatively. For instance, the on impact response of the cost of external finance to a monetary policy shock is indeed more than 10 times as high in the full model as in the BGG model, even though the response of  $E_t R_{t+1}^K - R_t$  is only a bit more than four times as high.

ratio  $\widehat{\left(\frac{N_t^b}{L_t}\right)}$  than the BGG model, where it is far too low. By contrast, the relative volatility of  $\widehat{N}_t^b$  in the model is much higher than in the data. Section 4 mentioned two mechanisms absent from the model, namely multi-period debt contracts and securities in the loan portfolio of the bank, which could potentially dampen or reverse the increase in bank net worth in response to a monetary policy shock. The too high volatility of  $\widehat{N}_t^b$  might be partly due to the absence of these features.

<b>Table 5: Correlations with GDP</b>			
<b>Variable</b>	<b>Data</b>	<b>Full model</b>	<b>BGG model</b>
$\widehat{GDP}_t$	1	1	1
$\widehat{C}_t$	0.89	0.89	0.85
$\widehat{I}_t$	0.88	0.89	0.87
$\widehat{l}_t$	0.86	0.9	0.86
$\widehat{R}_t^L - \widehat{R}_t, E_t \widehat{R}_{t+1}^L - \widehat{R}_t, \text{APR}$	-0.62	-0.77	-0.56
$\widehat{\phi}_t^e$	-0.61	-0.75	-0.53
$\widehat{N}_t$	0.73	0.79	0.73
$\widehat{\left(\frac{N_t^b}{L_t}\right)}$	-0.44	-0.32	-0.56
$\widehat{L}_t$	0.37	0.60	0.66
$\widehat{N}_t^b$	-0.12	-0.25	0.15

Turning to the cyclicity of the various variables, in the full model all correlations with GDP are correctly signed. Both models perform similarly well at matching the correlations of  $\widehat{C}_t$ ,  $\widehat{I}_t$ , the cost of external finance,  $\widehat{\phi}_t^e$ ,  $\widehat{N}_t$ ,  $\widehat{L}_t$  and  $\widehat{\left(\frac{N_t^b}{L_t}\right)}$  with output. The ability of the two models to match the countercyclicality of the bank capital ratio  $\widehat{\left(\frac{N_t^b}{L_t}\right)}$  (and thus the procyclicality of bank leverage  $\widehat{\left(\frac{L_t}{N_t^b}\right)}$ ) is apparent from its increases in response to the

contractionary monetary policy- and technology shocks in both models as displayed in the panels in the lower right corners of figures 1 and 2. The rise of  $\widehat{\left(\frac{N_t^b}{L_t}\right)}$  is driven by the decline of  $\widehat{\phi}_t^b$  in response to these shocks, which was discussed in the previous section. Finally, only the full model is able to reproduce the mild countercyclicality of bank net worth  $\widehat{N}_t^b$  observed in the data, while this variable is mildly procyclical in the BGG model.

Note that in the data, there is an interesting discrepancy between the firm and banking sector as far as the cyclicity of leverage and net worth is concerned. While in the firm sector, leverage is countercyclical and net worth is procyclical, the opposite is true in the banking sector.<sup>12</sup> The full model is able to reproduce this phenomenon.

<b>Table 6 Autocorrelations</b>			
<b>Variable</b>	<b>Data</b>	<b>Full model</b>	<b>BGG model</b>
$\widehat{GDP}_t$	0.85	0.83	0.84
$\widehat{C}_t$	0.88	0.78	0.84
$\widehat{I}_t$	0.91	0.92	0.93
$\widehat{l}_t$	0.93	0.78	0.75
$\widehat{R}_t^L - \widehat{R}_t$ APR	0.91	0.72	0.68
$\widehat{\phi}_t^e$	0.94	0.66	0.68
$\widehat{N}_t$	0.94	0.62	0.62
$\frac{\widehat{N}_t^b}{\widehat{L}_t}$	0.83	0.95	0.92
$\widehat{L}_t$	0.93	0.86	0.91
$\widehat{N}_t^b$	0.81	0.95	0.94

Regarding the models' ability to reproduce the persistence in the data, both models

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<sup>12</sup>Note that banking sector leverage is simply the inverse of the bank capital ratio  $\frac{N_t^b}{L_t}$ .

perform well at matching the autocorrelations of  $GDP_t$ ,  $C_t$ ,  $I_t$  and  $L_t$ . The autocorrelations of  $R_t^L - R_t$ ,  $\phi_t^e$  and  $N_t$  are very similar but too low in both models. Both the autocorrelations of  $\frac{N_t^b}{L_t}$  and  $N_t^b$  are somewhat too high in both models.

Overall, it seems that the amplification provided by the informational frictions in the banking-depositor relationship allows my model to perform better than the BGG model at matching the volatility of the external finance premium, investment and other variables relative to output. Furthermore, the full model performs well at reproducing the statistical properties of the bank capital ratio aka bank leverage, which is instrumental in generating the extra volatility of  $R_t^L - R_t$  in the full model.

## 6 Robustness

In appendix G.1, I investigate the robustness of my key results so far. I redo the exercises of the previous two sections under numerous deviations from the baseline calibration and the baseline assumptions regarding monetary policy, described in detail in section G.1. As in section 4, I find that typically in the full model the response of output and investment both to monetary policy shocks and to technology shocks is amplified, with the amplification typically being more persistent for monetary policy shocks. The relative performance of the two models at matching the second moments of the data is also broadly robust across the various experiments.



## 7 Financial shocks and crisis experiment

In this section I examine how the model economy responds to shocks to the balance sheets of entrepreneurs and banks, and whether a reasonably calibrated combination of those shocks can produce a downturn of a magnitude comparable to the "Great Recession" currently observed in the United States.

Figure 4 displays the response of the full model and the BGG model to one-off -1% exogenous shock to entrepreneurial net worth  $\hat{N}_t$ , 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 in both models but at the trough more than twice as much in the full model than in the BGG model, mainly due to a stronger decline in investment. In both models, the reduction in  $\hat{N}_t$  increases entrepreneurial leverage  $\hat{\phi}_t^e$  since entrepreneurs need to borrow more to fund their capital stock. The resulting increase in leverage  $\hat{\phi}_t^e$  causes an increase in the spread between the expected return on capital and the risk free rate  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  thus a drop in  $\hat{Q}_t$ , which enhances the initial drop in  $\hat{N}_t$  and lowers investment and entrepreneurial consumption. Turning to the passive banking of the BGG model, the immediate and persistent increase in entrepreneurial borrowing causes an immediate persistent increase in bank leverage  $\hat{\phi}_t^b$ .  $\hat{\phi}_t^b$  then gradually declines as the decline in the capital stock and the recovery of  $\hat{N}_t$  gradually lowers entrepreneurial borrowing. In the full model, depositors will only accommodate such an expansion 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 of the banking sector profit margin  $E_t \hat{R}_{t+1}^b - \hat{R}_t$ . Hence the increase in  $E_t \hat{R}_{t+1}^K - \hat{R}_t$ ,  $\hat{Q}_t$ , investment,  $\hat{N}_t$  and entrepreneurial consumption are all much

stronger than in the BGG model.

Figure 5 displays the response of the full model to a negative exogenous one-off shock to bank capital  $N_t^b$  of 5%. For that purpose I set  $e_t^z = -0.05$  for one period. GDP contracts in response to the shock and reaches a trough of -0.28% in quarter 2. The GDP decline is mainly driven by a drop in investment, which declines by -0.56% on impact and reaches a trough of -1.2% in quarter 4. The GDP decline is very persistent. After 20 quarters, it is still 1.1% below its steady state. Given loan demand, the decline in  $\hat{N}_t^b$  of about 5% increases bank leverage  $\hat{\phi}_t^b$ , which requires a higher profitability  $\widehat{\left(\frac{V_t^b}{N_t^b}\right)}$  and thus a higher banking sector profit margin  $E_t \hat{R}_{t+1}^b - \hat{R}_t$ . The implied increase in  $E_t \hat{R}_{t+1}^K - \hat{R}_t$  causes a contraction of  $\hat{Q}_t$ , entrepreneurial net worth and thus the observed decline in investment and consumption.

Loans to entrepreneurs decline on impact, then move somewhat above the steady state from quarter three to eight, and then again move very persistently and substantially below steady state. The decline in their net worth implies that entrepreneurs have to borrow more. As their net worth gradually recovers and the gradual decline of the capital stock lowers their need for external funds, loans to entrepreneurs persistently decline. The non-monotonic path of loans to entrepreneurs results in a qualitatively similar path of total loans.

Note that in my 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 trying to empirically estimate the macroeconomic effects of a shock to bank capital reach mixed results. Ciccarelli et al. (2011), for the euro area, find that 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 find that a negative shock to bank capital persistently reduces GDP, but do not find a statistically significant and robust decline of inflation.

I now examine to which extent a reasonably calibrated sequence of shocks to the net worth of banks can generate a downturn similar in magnitude to the "Great Recession" experienced by the US economy as a consequence of the financial crisis of 2007-2009. 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 loose an amount of their net worth equivalent to 7% of their assets. The losses spread equally over the first 15 quarters and are implemented by a series of 15 consecutive unexpected shocks to bank net worth  $e_t^z$ , where each shock equals -0.0476.

Figure 6 displays the log-deviation of per capita GDP, consumption, non-residential investment and our measure of credit to non-financial businesses in the US economy from a quadratic trend from 2007Q2 to 2010Q2, 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 2007Q2, all labelled by an "\_Data". The declines of US consumption and GDP relative to trend start in 2007Q2 and 2007Q3, respectively, while investment continues to increase relative to trend until 2008Q1. The troughs of GDP, consumption and investment are -7.9%, -8.4% and -22.5 and are reached in 2009Q3, 2010Q2 and 2009Q4, respectively. Our measure of the cost of external finance, the difference between the BAA composite corporate bond rate and the effective federal funds rate, increases continuously until peaking in 2008Q4 at 7.29% and then slowly declines.<sup>13</sup> Furthermore, note that our measure of loans to non-financial

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<sup>13</sup>The alternative measures of the cost of external finance mentioned in footnote 11 closely track this

firms actually increases relative to trend until peaking in 2008Q1 at 6.7% and by 2008Q4 is still 5.9% above trend, when GDP and investment have already declined -5.1 and -7.7% relative to trend, respectively. The absence of a marked decline in aggregate lending to non-financial firms by the end of 2008, in spite of the financial crisis, is also noted by Chari et al. (2008).

Figure 6 also displays the path of these variables in the model, labelled " $\_ez$ ". The economic downturn observed in the model has a similar persistence but a much lower magnitude, with the maximum deviation of investment, GDP and consumption relative to trend equalling about one half (-11%), one third (-2.5%) and one seventh (-1.2%) of what is observed in the data. Similarly, the cost of external finance increases with a similar persistence as in the data but peaks at 3.1% above its steady state, or about two fifths of its peak in the data. Furthermore loans decline, rather than displaying the strong increase observed in the data during the first year. However, the decline in loans is much more gradual than the decline in GDP.

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. Figure 6 shows that in response to the series of shocks to bank net worth, entrepreneurial net worth is only 7% below its steady state in 2009Q4 (quarter 11). Therefore I add a series of 11 consecutive unexpected shocks to entrepreneurial net worth  $e_t^N$  to the above experiment, where each shock equals -0.0045. These shocks induce a decline of entrepreneurial net worth of 20% by 2009Q4. The result is also reported in Figure 7, labelled " $\_ez\_eN$ ". The magnitude of the contraction

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measure.

of investment, consumption and GDP roughly doubles. The model now closely matches the magnitude of both the downturn in investment and the increase in the cost of external finance. The maximum deviation of GDP and consumption from trend in the model are almost two thirds and one third, respectively, of what is observed in the data. Furthermore, the model now generates a persistent increase in loans alongside the economic downturn, albeit smaller and more gradual than in the data, followed by a persistent decline.

## 8 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 (2010) 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. Quantitatively, 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 the Bernanke et al. (1999) 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, as well as investment and other variables. The model also performs reasonably well at matching the cyclical properties of the bank capital ratio and bank leverage. An adverse shock to entrepreneurial net worth causes an output contraction more than twice as big as in a BGG-type model. In line with the existing empirical evidence, an adverse shock to bank net worth of causes a persistent decline of both GDP and inflation. Finally, in

response to a reasonably calibrated shock to entrepreneurial- and bank balance sheets, the economy enters a downturn of a magnitude similar to the ongoing Great Recession in the United States.

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

### A.1 Households

Denoting the lagrange multiplier on (3) as  $\varrho_t$  and on (1) as  $\frac{\varrho_t w_t}{\mu_t}$ , the first order conditions with respect to consumption, riskless assets (i.e. deposits and bonds) and total labour supply  $l_t^s$  are given by

$$\varrho_t = \frac{1}{C_t - hC_{t-1}} \quad (29)$$

$$\varrho_t = \beta E_t \left[ \varrho_{t+1} \frac{R_t}{\Pi_{t+1}} \right] \quad (30)$$

$$\frac{\varrho_t w_t}{\mu_t} = \chi (l_t^s)^\varphi \quad (31)$$

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

Since labour demand curve faced by the labour union and the cost of supplying labour are the same across all markets, wage and employment is going to be the same across all those markets where the union is allowed to re-optimize the price. Let  $\tilde{w}_t$  be the real wage prevailing in the labour markets where the union is allowed to optimally reset the wage in

period  $t$ . In period  $t+1$ , the flow utility associated with this wage is given by

$$\varrho_t \frac{\tilde{w}_t}{\prod_{k=1}^s \frac{\Pi_{t+k}}{\Pi^{1-\gamma_w} (\Pi_{t+k-1})^{\gamma_w}}} \left( \frac{\tilde{w}_t}{w_t \prod_{k=1}^s \frac{\Pi_{t+k}}{\Pi^{1-\gamma_w} (\Pi_{t+k-1})^{\gamma_w}}} \right)^{-\varepsilon_w} l_t - \left( \frac{\tilde{w}_t}{w_t \prod_{k=1}^s \frac{\Pi_{t+k}}{\Pi^{1-\gamma_w} (\Pi_{t+k-1})^{\gamma_w}}} \right)^{-\varepsilon_w} l_t \frac{\varrho_t w_t}{\mu_t}$$

Hence the unions objective is given by

$$E_t \left\{ \sum_{i=0}^{\infty} (\beta \xi^w)^i \varrho_{t+i} w_{t+i}^{\varepsilon_w} l_{t+i} \left( \prod_{k=1}^i \frac{\Pi_{t+k}}{\Pi^{1-\gamma_w} (\Pi_{t+k-1})^{\gamma_w}} \right)^{\varepsilon_w} \left[ \tilde{w}_t^{1-\varepsilon_w} \left( \prod_{k=1}^i \frac{\Pi_{t+k}}{\Pi^{1-\gamma_w} (\Pi_{t+k-1})^{\gamma_w}} \right)^{-1} - \tilde{w}_t^{-\varepsilon_w} \frac{w_{t+i}}{\mu_{t+i}} \right] \right\}$$

with the first order condition given by

$$0 = E_t \left\{ \sum_{i=0}^{\infty} (\beta \xi^w)^i \varrho_{t+i} w_{t+i}^{\varepsilon_w} l_{t+i} \left( \prod_{k=1}^i \frac{\Pi_{t+k}}{\Pi^{1-\gamma_w} (\Pi_{t+k-1})^{\gamma_w}} \right)^{\varepsilon_w} \left[ \frac{\varepsilon_w - 1}{\varepsilon_w} \frac{\tilde{w}_t}{\prod_{k=1}^i \frac{\Pi_{t+k}}{\Pi^{1-\gamma_w} (\Pi_{t+k-1})^{\gamma_w}}} - \frac{w_{t+i}}{\mu_{t+i}} \right] \right\} \quad (32)$$

Using (2), the law of motion of the aggregate nominal wage is given by

$$W_t = \left[ (1 - \xi) \left( \tilde{W}_t \right)^{1-\varepsilon} + \xi^w \left( W_{t-1} \Pi^{1-\gamma_P} (\Pi_{t-1})^{\gamma_P} \right)^{1-\varepsilon_w} \right]^{\frac{1}{1-\varepsilon_w}} \quad (33)$$

where  $\tilde{W}_t = \tilde{w}_t P_t$ .

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 to retailers in period  $t+1$ . Furthermore, they choose the degree of utilization of the capital stock they acquired in period  $t-1$   $K_{t-1}$ . In

doing so, they face a capacity utilization cost  $a(U_t) K_t$ . Hence the budget constraint becomes

$$P_t C_t + Q_t (K_t - K_{t-1}) + a(U_t) K_{t-1} \quad (34)$$

$$= P_t l_t \int_0^1 w_t(j) \left( \frac{w_t(j)}{w_t} \right)^{-\varepsilon_w} dj + P_t profit + P_t T_t + R_{t-1} B_{t-1}^T - B_t^T + r_t^K U_t K_{t-1} \quad (35)$$

This modification leaves the first order conditions derived above unchanged, but adds first order conditions with respect to  $K_t$  and  $U_t$ , respectively:

$$Q_t = E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} [r_t^K U_t - a(U_t) + Q_{t+1} (1 - \delta)] \right\} \quad (36)$$

$$r_t^K = a'(U_t) \quad (37)$$

## A.2 Capital goods producers

The first order condition with respect to  $I_t$  is given by

$$Q_t \left( 1 - \frac{\eta_i}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right) = 1 + Q_t \eta_i \left( \frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} - E_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} Q_{t+1} \eta_i \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 \right\} \quad (38)$$

The law of motion of capital is given by

$$K_t = (1 - \delta) K_{t-1} + I_t \left( 1 - \frac{\eta_i}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right) \quad (39)$$

### A.3 Retailers

Cost minimization and the assumption of economy wide factor markets imply that

$$w_t (1 + \psi_l (R_t - 1)) = (1 - \alpha) mc_t \frac{Y_t}{l_t} \quad (40)$$

$$r_t^k (1 + \psi_K (R_t - 1)) = \alpha mc_t \frac{Y_t}{K_t^s} \quad (41)$$

$$L_t^r = \psi_L w_t l_t + \psi_K r_t^k U_t K_{t-1} \quad (42)$$

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 not allowed to optimize its price index it to past inflation at a rate  $\gamma_P$  and to the steady state inflation rate  $\Pi$  at rate  $1 - \gamma_P$ . The firm's problem is then to choose  $p_t(i)$  in order to maximise

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

The first order condition is given by

$$\tilde{p}_t = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \left\{ \sum_{i=0}^{\infty} (\xi^P \beta)^i \frac{\varrho_{t+i}}{\varrho_t} \left( \frac{\prod_{k=1}^i \Pi^{1-\gamma_P} \Pi_{t+k-1}^{\gamma_P}}{\prod_{k=1}^i \Pi_{t+k}} \right)^{-\varepsilon} mc_{t+i} Y_{t+i} \right\}}{E_t \left\{ \sum_{i=0}^{\infty} (\xi^P \beta)^i \frac{\varrho_{t+i}}{\varrho_t} \left( \frac{\prod_{k=1}^i \Pi^{1-\gamma_P} \Pi_{t+k-1}^{\gamma_P}}{\prod_{k=1}^i \Pi_{t+k}} \right)^{1-\varepsilon} Y_{t+i} \right\}} \quad (43)$$

with  $\tilde{p}_t = \frac{p_t^*}{P_t^*}$ , where  $p_t^*$  denotes the price chosen by those firms allowed to optimize in period

t. The law of motion of the price index is given by

$$P_t = \left[ (1 - \xi^P) (p_t^*)^{1-\varepsilon} + \xi^P (P_{t-1} \Pi^{1-\gamma_P} (\Pi_{t-1})^{\gamma_P})^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \quad (44)$$

## A.4 Bankers

Combining (5) with the definition of  $V_t^b(q)$  allows to express the later as

$$V_t^b(q) = v_t L_t^e(q) + \eta_t N_t^b(q) \quad (45)$$

with

$$v_t = E_t \left\{ (1 - \theta) \frac{(R_{t+1}^b - R_t)}{R_t} + \frac{\theta x_{t,t+1} v_{t+1} \Pi_{t+1}}{R_t} \right\} \quad (46)$$

$$\eta_t = E_t \left\{ (1 - \theta) + \frac{\theta z_{t,t+1} \eta_{t+1} \Pi_{t+1}}{R_t} \right\} \quad (47)$$

$$x_{t,t+1} = \frac{L_{t+1}^e(q)}{L_t^e(q)}, \quad z_{t,t+1} = \frac{N_{t+1}^b(q)}{N_t^b(q)} \quad (48)$$

Using  $V_t^b(q) = \lambda L_t^e(q)$  yields

$$L_t^e(q) = \phi_t^b N_t^b(q) \quad (49)$$

$$\phi_t^b(q) = \frac{\eta_t}{\lambda - v_t} \quad (50)$$

where  $\phi_t^b(q)$  denotes bank q's leverage ratio. Note that for the incentive constraint to bind, a necessary condition is  $0 < v_t < \lambda$ .<sup>14</sup> Substituting (5) and (49) into (48) allows to write  $z_{t,t+1}$

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<sup>14</sup>For an interpretation of this condition see Gertler and Karadi (2010).

and  $x_{t,t+1}$  as

$$z_{t,t+1} = \frac{(R_{t+1}^b - R_t) \phi_t^b(q) + R_t}{\Pi_{t+1}} \exp(e_{t+1}^z) \quad (51)$$

$$x_{t,t+1} = \frac{\phi_{t+1}^b(q)}{\phi_t^b(q)} z_{t,t+1} \quad (52)$$

Equations (50), (46), (47), (51) and (52) imply that  $\eta_t$ ,  $v_t$ ,  $\phi_t^b(q)$ ,  $z_{t,t+1}$  and  $x_{t,t+1}$  depend only on economy wide variables and  $\phi_{t+1}^b(q)$ , implying that they all depend on economy wide variables alone. This allows for easy aggregation across bankers, implying that

$$L_t^e = \phi_t^b N_t^b \quad (53)$$

where  $N_t^b$  denotes the total net worth of banks.

## A.5 Entrepreneurs: full model and BGG model

Using  $\bar{\omega}_{t+1}^j R_{t+1}^K P_t Q_t K_t^j = R_t^L P_t L_t^j$  and  $L_t^j = P_t Q_t K_t^j - P_t N_t^j$ , rewrite the participation constraint of the bank (14) as

$$(P_t Q_t K_t^j - P_t N_t^j) E_t R_{t+1}^b = E_t \left\{ R_{t+1}^K P_t Q_t K_t^j \left[ \bar{\omega}_{t+1}^j \int_{\bar{\omega}_{t+1}^j}^{\infty} f(\omega^j) d\omega^j + (1 - \mu) \int_0^{\bar{\omega}_{t+1}^j} \omega^j f(\omega^j) d\omega^j \right] \right\}$$

or

$$(\phi_t^e(j) - 1) E_t R_{t+1}^b = \phi_t^{e,j} E_t \left\{ R_{t+1}^K [\Gamma(\bar{\omega}_{t+1}^j) - \mu G(\bar{\omega}_{t+1}^j)] \right\} \quad (54)$$

where  $\phi_t^e(j) = \frac{Q_t K_t^j}{N_t^j}$ ,  $\Gamma(\bar{\omega}_{t+1}^j) = \bar{\omega}_{t+1}^j \int_{\bar{\omega}_{t+1}^j}^{\infty} f(\omega^j) d\omega^j + \int_0^{\bar{\omega}_{t+1}^j} \omega^j f(\omega^j) d\omega^j$  and  $G(\bar{\omega}_{t+1}^j) = \int_0^{\bar{\omega}_{t+1}^j} \omega^j f(\omega^j) d\omega_{t+1}^j$ . Using  $\bar{\omega}_{t+1}^j R_{t+1}^K Q_t K_t^j = R_t^L L_t^j$  and  $E(\omega_{t+1}) = 1 = \int_0^{\bar{\omega}_{t+1}^j} \omega^j f(\omega^j) d\omega_{t+1}^j +$

$\int_{\bar{\omega}_{t+1}^j}^{\infty} \omega^j f(\omega^j) d\omega_{t+1}^j$ , rewrite the entrepreneur's objective as

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

where  $s_{t+1} = \frac{R_{t+1}^K}{E_t R_{t+1}^b}$ . Recall that entrepreneurs differ only in their net worth  $N_t^j$ . Since  $\bar{\omega}_{t+1}^j = \frac{R_t^L (1 - \frac{1}{\phi_t^e(j)})}{R_{t+1}^K}$ , the values of  $\phi_t^{e,j}$  and  $R_t^L$  maximizing  $\phi_t^e(j) E_t \{s_{t+1} [1 - \Gamma(\bar{\omega}_{t+1}^j)]\} N_t^j E_t R_{t+1}^b$  subject to (64) are going to be the same across entrepreneurs. The same is true for the cut off value  $\bar{\omega}_{t+1}^j$ . Hence the problem of the entrepreneur is to maximize

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

The first order conditions with respect to  $\phi_t^e$ ,  $R_t^L$  and  $\xi_t$  are given by

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

$$E_t \{-\Gamma'(\bar{\omega}_{t+1}) + \xi_t [\Gamma'(\bar{\omega}_{t+1}) - \mu G'(\bar{\omega}_{t+1})]\} = 0 \quad (56)$$

$$E_t \{\phi_t^e R_{t+1}^K [\Gamma(\bar{\omega}_{t+1}) - \mu G(\bar{\omega}_{t+1})] - R_{t+1}^b (\phi_t^e - 1)\} = 0 \quad (57)$$

where  $\xi_t$  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

$$V_t = Q_{t-1} K_{t-1} \frac{R_t^K}{\Pi_t} [1 - \Gamma(\bar{\omega}_t)] \exp(e_t^N) \quad (58)$$

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

$$\phi_t^e R_{t+1}^K [\Gamma(\bar{\omega}_{t+1}) - \mu G(\bar{\omega}_{t+1})] - R_t (\phi_t^e - 1) = 0 \quad (59)$$

The optimisation problem then becomes to maximise

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

with respect to  $\phi_t^e$ ,  $\bar{\omega}_{t+1}$  and  $\xi_t$ . The first order conditions are

$$E_t \{ R_{t+1}^K [1 - \Gamma(\bar{\omega}_{t+1})] + \xi_t \{ R_{t+1}^K [\Gamma(\bar{\omega}_{t+1}) - \mu G(\bar{\omega}_{t+1})] - R_t \} \} = 0 \quad (60)$$

$$\frac{\Gamma'(\bar{\omega}_{t+1})}{[\Gamma'(\bar{\omega}_{t+1}) - \mu G'(\bar{\omega}_{t+1})]} = \xi_t \quad (61)$$

$$R_t^K [\Gamma(\bar{\omega}_t) - \mu G(\bar{\omega}_t)] = R_{t-1} \frac{(\phi_{t-1}^e - 1)}{\phi_{t-1}^e} \quad (62)$$

The loan rate in this setup is only determined once the loan is paid back, in order to ensure

that (59) holds. It is determined by

$$\frac{R_t^L (Q_{t-1}K_{t-1} - N_{t-1})}{R_t^K Q_{t-1}K_{t-1}} = \bar{\omega}_t \quad (63)$$

## B Derivation of the linearized bank leverage constraint

I linearize equations (46), (47) and (50) – (52) to express leverage in the banking sector as a function of the current and future spread of  $R_{t+1}^b$  over  $R_t$ . Linearising (50) yields

$$\widehat{\phi}_t^b = \widehat{\eta}_t + \frac{v}{\lambda - v} \widehat{v}_t = \widehat{\eta}_t + \phi^b \frac{v}{\eta} \widehat{v}_t \quad (64)$$

where a hat denotes percentage deviation of this variable from its steady state. Linearising (46), (47), and (52) yields

$$v\widehat{v}_t = E_t \left\{ (1 - \theta) \frac{R^b}{R} \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) + \theta v z \beta \left( \widehat{x}_{t+1} + \widehat{v}_{t+1} + \widehat{\Pi}_{t+1} - \widehat{R}_t \right) \right\} \quad (65)$$

$$\widehat{\eta}_t = \theta z \beta E_t \left\{ \widehat{z}_{t+1} + \widehat{\eta}_{t+1} + \widehat{\Pi}_{t+1} - \widehat{R}_t \right\} \quad (66)$$

$$\widehat{x}_t = \widehat{\phi}_t^b - \widehat{\phi}_{t-1}^b + \widehat{z}_t \quad (67)$$

Rewriting (51) as  $\frac{z_{t+1,t}\Pi_t}{R_t} = \frac{(R_{t+1}^b - R_t)}{R_t} \phi_t^b + 1$ , we have

$$\begin{aligned} \widehat{z}_{t+1} + \widehat{\Pi}_{t+1} - \widehat{R}_t &= \frac{\phi^b \frac{R^b}{R} \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) + \left( \frac{R^b}{R} - 1 \right) \phi^b \widehat{\phi}_t^b}{\left( \frac{R^b}{R} - 1 \right) \phi^b + 1} + e_{t+1}^z \\ &= \frac{\phi^b \frac{R^b}{R} \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) + \left( \frac{R^b}{R} - 1 \right) \phi^b \widehat{\phi}_t^b}{z\beta} + e_{t+1}^z \end{aligned} \quad (68)$$

using the fact that  $\left(\frac{R^b}{R} - 1\right) \phi^b + 1 = z\beta$ . Substituting (68) into (65) yields

$$\begin{aligned} v\widehat{v}_t &= E_t \left\{ \frac{R^b}{R} [(1 - \theta) + \theta v \phi^b] \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) + \theta v \left( z\beta \widehat{\phi}_{t+1}^b + \left[ \left( \frac{R^b}{R} - 1 \right) \phi^b - z\beta \right] \widehat{\phi}_t^b + z\beta \widehat{v}_{t+1} \right) \right\} \\ &= E_t \left\{ \frac{R^b}{R} [(1 - \theta) + \theta v \phi^b] \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) + \theta v \left( z\beta \widehat{\phi}_{t+1}^b + -\widehat{\phi}_t^b + z\beta \widehat{v}_{t+1} \right) \right\} \end{aligned} \quad (69)$$

using the fact that  $\left(\frac{R^b}{R} - 1\right) \phi^b - z\beta = -1$ . Similarly, substituting (68) into (65) yields

$$\widehat{\eta}_t = \theta E_t \left\{ \phi^b \frac{R^b}{R} \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) + \left( \frac{R^b}{R} - 1 \right) \phi^b \widehat{\phi}_t^b + z\beta \widehat{\eta}_{t+1} \right\} \quad (70)$$

Substituting (69) and (70) into (19) yields

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

This can be rearranged as

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

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

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

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

$$\begin{aligned} \widehat{\phi}_t^b &= E_t \left\{ \theta\beta z \left( 1 + \left( \frac{R^b}{R} - 1 \right) \phi^b \right) \widehat{\phi}_{t+1}^b + \phi^b \frac{R^b}{R} \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) \right\} \\ &= E_t \left\{ \theta\beta^2 z^2 \widehat{\phi}_{t+1}^b + \phi^b \frac{R^b}{R} \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) \right\} \end{aligned} \quad (71)$$

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

## C Derivation of the relationship between firm leverage and $E_t \left\{ \widehat{R}_{t+1}^K - \widehat{R}_{t+1}^b \right\}$ in the full model and $E_t \left\{ \widehat{R}_{t+1}^K - \widehat{R}_t \right\}$ 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  $E_t R_{t+1}^b$  with  $R_t$  wherever it appears.

After defining  $\Upsilon(\bar{\omega}) = 1 - \Gamma(\bar{\omega}) + \xi [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]$ , we can rewrite (55) as

$$E_t \left\{ R_{t+1}^K \Upsilon(\bar{\omega}_{t+1}) - \xi_t R_{t+1}^b \right\} = 0 \quad (72)$$

Linearising (57) yields

$$E_t \left\{ \begin{aligned} & \phi^e R^K \left[ [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] \left[ \frac{d\phi_t^e}{\phi^e} + \hat{R}_{t+1}^K \right] + [\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})] d\bar{\omega}_{t+1} \right] \\ & - R^b (\phi^e - 1) \hat{R}_{t+1}^b - R^b \phi^e \frac{d\phi_t^e}{\phi^e} \end{aligned} \right\} = 0$$

or

$$E_t d\bar{\omega}_{t+1} = \frac{\partial \bar{\omega}}{\partial \phi^e} d\phi_t^e + \frac{\partial \bar{\omega}}{\partial s} E_t ds 1_{t+1} \quad (73)$$

$$\begin{aligned} E_t ds 1_{t+1} &= s 1 E_t \left\{ \hat{R}_{t+1}^K - \hat{R}_{t+1}^b \right\} \\ s 1 &= \frac{R^K}{R^b} \end{aligned} \quad (74)$$

$$\begin{aligned} \frac{d\bar{\omega}}{\phi^e} &= \frac{1}{(\phi^e)^2 s 1 [\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]} \\ \frac{\partial \bar{\omega}}{\partial s 1} &= \frac{-[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]}{s 1 [\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]} \end{aligned}$$

where we have used the fact that (57) implies that  $\phi^e R^K [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] - R^b \phi^e = -R^b$ . We

then solve 56 for  $\xi_t$  and totally differentiate, which yields

$$\begin{aligned} d\xi_t &= \xi'(\bar{\omega}) E_t d\bar{\omega}_{t+1} = \xi'(\bar{\omega}) \left[ \frac{\partial \bar{\omega}}{\partial \phi^e} d\phi_t^e + \frac{\partial \bar{\omega}}{\partial s} E_t ds 1_{t+1} \right] \\ \xi'(\bar{\omega}) &= \frac{\mu [\Gamma'(\bar{\omega}) G''(\bar{\omega}) - \Gamma''(\bar{\omega}) G'(\bar{\omega})]}{[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]^2} \end{aligned} \quad (75)$$

Totally differentiating (72) yields

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

or

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

Using (73) and (75) yields

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

or

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

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

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

## D Linearized equations

### D.1 Full model

I assume an explicit functional form for the capacity utilization cost function  $a(U_t)$ , namely

$a(U_t) = r^K (U_t - 1) + \frac{c^U r^K}{2} (U_t - 1)^2$ . Furthermore, using (19), (20) can be rewritten as

$$R_t^k [\Gamma(\bar{\omega}_t) - \mu G(\bar{\omega}_t)] \exp(e_t^{R^b}) = \frac{(\phi_{t-1}^e - 1)}{\phi_{t-1}^e} R_t^b \quad (76)$$

Furthermore, I define  $\varpi'_t = \frac{R_t^L(Q_t K_t - N_t)}{Q_t K_t} = R_t^L \frac{\phi_t^e - 1}{\phi_t^e}$  and use  $\bar{\omega}_t = \frac{\varpi'_{t-1}}{R_t^k}$  to eliminate  $\bar{\omega}_t$  wherever it appears.

I now linearize the various equations:

$$\hat{\varrho}_t = \frac{-(\hat{C}_t - h\hat{C}_{t-1})}{1 - h} \text{ from (29)}$$

$$\hat{\varrho}_t = E_t \left\{ \hat{\varrho}_{t+1} + \hat{R}_t - \hat{\Pi}_{t+1} \right\} \text{ from (30)}$$

$$\hat{w}_t = \frac{1}{1 + \beta} \left[ \beta E_t \hat{w}_{t+1} + \hat{w}_{t-1} + \beta E_t \hat{\Pi}_{t+1} - (1 + \beta \gamma_w) \hat{\Pi}_t + \gamma_w \hat{\Pi}_{t-1} - \frac{(1 - \beta \xi^w)(1 - \xi^w)}{\xi^w} [\hat{w}_t + \hat{\varrho}_t - \varphi \hat{l}_t] \right] \text{ from (31) - (33)}$$

$$\widehat{wm}_t = \hat{w}_t + \hat{\varrho}_t - \varphi \hat{l}_t$$

$$\hat{\Pi}_t = \frac{1}{1 + \beta \gamma_P} \left[ \beta E_t \hat{\Pi}_{t+1} + \gamma_P \hat{\Pi}_{t-1} + \frac{(1 - \beta \xi^P)(1 - \xi^P)}{\xi^P} \widehat{mc}_t \right] \text{ from (43) - (44)}$$

$$\hat{w}_t + \frac{\psi_l R \hat{R}_t}{1 + \psi_l (R - 1)} = \widehat{mc}_t + \hat{Y}_t - \hat{l}_t \text{ from (40)}$$

$$\frac{dr_t^k}{r^k} + \frac{\psi_K R \hat{R}_t}{1 + \psi_K (R - 1)} = \widehat{mc}_t + \hat{Y}_t - \hat{K}_{t-1} - \hat{U}_t \text{ from (41)}$$

$$L^r \hat{L}_t^r = \psi_l w l (\hat{w}_t + \hat{l}_t) + \psi_K r^k K \left( \frac{dr_t^k}{r^k} + \hat{U}_t + \hat{K}_{t-1} \right) \text{ from (4)}$$

$$\widehat{K}_t = (1 - \delta) \widehat{K}_{t-1} + \delta \widehat{I}_t \text{ from (38)}$$

$$\widehat{I}_t = \frac{1}{1 + \beta} \left[ \widehat{I}_{t-1} + \beta E_t \widehat{I}_{t+1} + \frac{\widehat{Q}_t}{\eta_i} \right] \text{ from (39)}$$

$$\widehat{L}_t^e = \widehat{\phi}_t^b + \widehat{N}_t^b \text{ from (53)}$$

$$\widehat{\phi}_t^b = E_t \left\{ \theta \beta^2 z^2 \widehat{\phi}_{t+1}^b + \phi^b \beta R^b \left( \widehat{R}_{t+1}^b - \widehat{R}_t \right) \right\} \text{ from (71)}$$

$$\widehat{z}_t = \frac{\phi^b \left( R^b \widehat{R}_t^b - R \widehat{R}_{t-1} \right) + \phi^b \left( R^b - R \right) \widehat{\phi}_{t-1}^b + R \widehat{R}_{t-1}}{z \Pi} - \widehat{\Pi}_t + e_t^z \text{ from (8)}$$

$$\widehat{N}_t^b = z \theta \widehat{z}_t + z \theta \widehat{N}_{t-1}^b \text{ from (7)}$$

$$\widehat{C}_t^b = \widehat{z}_t + \widehat{N}_{t-1}^b \text{ from (9)}$$

$$\widehat{R}_t^K = \widehat{\Pi}_t + \frac{\Pi \left( d r_t^k + \widehat{Q}_t (1 - \delta) \right)}{R^k} - \widehat{Q}_{t-1} \text{ from (11)}$$

$$d r_t^k = c^U r^k \widehat{U}_t \text{ from (12)}$$

$$\widehat{\phi}_t^e = \widehat{Q}_t + \widehat{K}_t - \widehat{N}_t \text{ from the definition of } \phi_t^e$$

$$E_t \widehat{R}_{t+1}^K = E_t \widehat{R}_{t+1}^b + \chi^{\phi^e} \widehat{\phi}_t^e \text{ from section C}$$

$$\widehat{\varpi}_t' = \widehat{R}_t^L + \frac{1}{\phi^e - 1} \widehat{\phi}_t^e \text{ from the definition of } \varpi_t'$$

$$R^b \frac{\widehat{\phi}_{t-1}^e}{\phi^e} = -R^K Expr1 e_t^{R^b} + \widehat{R}_t^K \left[ R^K Expr1 - \varpi' Expr2 \right] + \varpi' Expr2 \widehat{\varpi}_{t-1}' - R^b \frac{\phi^e - 1}{\phi^e} \widehat{R}_t^b \text{ from (20)}$$

$$\widehat{N}_t = \gamma \frac{V}{N} \widehat{V}_t \text{ from (16)}$$

$$\widehat{V}_t = \widehat{N}_{t-1} + \widehat{R}_t^K - \widehat{\Pi}_t + \widehat{\phi}_{t-1}^e - \frac{\Gamma'(\bar{\omega}) \bar{\omega}}{1 - \Gamma(\bar{\omega})} \left[ \widehat{\varpi}_{t-1}' - \widehat{R}_t^K \right] + e_t^N \text{ from (58)}$$

$$\widehat{L}_t^e = \widehat{N}_t + \frac{\phi^e}{\phi^e - 1} \widehat{\phi}_t^e \text{ from the definition of } L_t^e, \text{ divided by } N_t$$

$$\widehat{C}_t^e = \widehat{V}_t \text{ from (18)}$$

$$\widehat{R}_t R = (1 - \rho_i) \left[ \psi_\pi E_t \widehat{\Pi}_{t+1} + \psi_{\Delta\pi} \left( \widehat{\Pi}_t - \widehat{\Pi}_{t-1} \right) + \psi_y \left( \widehat{GDP}_t - \widehat{GDP}_{t-1} \right) \right] + \rho_i \widehat{R}_{t-1} + e_t^i \text{ from (21)}$$

$$\widehat{Y}_t = \alpha \left( \widehat{U}_t + \widehat{K}_{t-1} \right) + (1 - \alpha) \left( \widehat{a}_t + \widehat{l}_t \right) \text{ from (26)}$$



$$\begin{aligned}
\widehat{Y}_t &= \frac{I}{Y}\widehat{I}_t + \frac{C^P}{Y}\widehat{C}_t^P + \frac{G}{Y}\widehat{g}_t \\
&\quad + \frac{R^K}{\Pi} \frac{K}{Y} \mu G(\varpi) \left( \widehat{R}_t^K - \widehat{\Pi}_t + \widehat{Q}_{t-1} + \widehat{K}_{t-1} + \frac{G'(\varpi)}{G(\varpi)} \varpi \left( \widehat{\varpi}'_{t-1} - \widehat{R}_t^K \right) \right) + r^k \frac{K}{Y} \widehat{U}_t \text{ from (25)} \\
\widehat{C}_t^P &= \frac{C}{C^P} \widehat{C}_t + \frac{C^b}{C^P} \widehat{C}_t^b + \frac{C^e}{C^P} \widehat{C}_t^e \text{ from (24)} \\
\widehat{GDP}_t &= \frac{I}{GDP} \widehat{I}_t + \frac{C^P}{GDP} \widehat{C}_t^P + \frac{Gov}{GDP} \widehat{g}_t \text{ from (27)} \\
\widehat{s1\_4} &= 4 \left( E_t \widehat{R}_{t+1}^K - E_t \widehat{R}_{t+1}^b \right) \text{ from } s1\_4 = \left( \frac{E_t R_{t+1}^K}{E_t R_{t+1}^b} \right)^4 \\
\widehat{s2\_4} &= 4 \left( E_t \widehat{R}_{t+1}^b - \widehat{R}_t \right) \text{ from } s2\_4 = \left( \frac{E_t R_{t+1}^b}{R_t} \right)^4 \\
\widehat{s3\_4} &= 4 \left( E_t \widehat{R}_{t+1}^K - \widehat{R}_t \right) \text{ from } s3\_4 = \left( \frac{E_t R_{t+1}^K}{R_t} \right)^4 \\
\widehat{s4\_4} &= 4 \left( \widehat{R}_t^L - \widehat{R}_t \right) \text{ from } s4\_4 = \left( \frac{R_t^L}{R_t} \right)^4 \\
\widehat{L}_t &= \frac{L^e}{L} \widehat{L}_t^e + \frac{L^r}{L} \widehat{L}_t^r \text{ from (4)} \\
\frac{dRat_t}{Rat} &= \widehat{N}_t^b - \widehat{L}_t \text{ from } Rat = \frac{N_t}{L_t} \\
\widehat{a}_t &= \rho_a \widehat{a}_{t-1} + e_t^a \\
\widehat{g}_t &= \rho_g \widehat{g}_{t-1} + e_t^g
\end{aligned}$$

## D.2 BGG model

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

$$\hat{\varrho}_t = \frac{-(\hat{C}_t - h\hat{C}_{t-1})}{1-h} \text{ from (29)}$$

$$\hat{\varrho}_t = E_t \left\{ \hat{\varrho}_{t+1} + \hat{R}_t - \hat{\Pi}_{t+1} \right\} \text{ from (30)}$$

$$\hat{w}_t = \frac{1}{1+\beta} \left[ \begin{aligned} &\beta E_t \hat{w}_{t+1} + \hat{w}_{t-1} + \beta E_t \hat{\Pi}_{t+1} - (1 + \beta \gamma_w) \hat{\Pi}_t \\ &+ \gamma_w \hat{\Pi}_{t-1} - \frac{(1-\beta\xi^w)(1-\xi^w)}{\xi^w} [\hat{w}_t + \hat{\varrho}_t - \varphi \hat{l}_t] \end{aligned} \right] \text{ from (43) - (44)}$$

$$\widehat{wm}_t = \hat{w}_t + \hat{\varrho}_t - \varphi \hat{l}_t$$

$$\hat{\Pi}_t = \frac{1}{1+\beta\gamma_P} \left[ \beta E_t \hat{\Pi}_{t+1} + \gamma_P \hat{\Pi}_{t-1} + \frac{(1-\beta\xi^P)(1-\xi^P)}{\xi^P} \widehat{mc}_t \right] \text{ from (43) - (44)}$$

$$\hat{w}_t + \frac{\psi_l R \hat{R}_t}{1 + \psi_l (R-1)} = \widehat{mc}_t + \hat{Y}_t - \hat{l}_t \text{ from (40)}$$

$$\frac{dr_t^k}{r^k} + \frac{\psi_K R \hat{R}_t}{1 + \psi_K (R-1)} = \widehat{mc}_t + \hat{Y}_t - \hat{K}_{t-1} - \hat{U}_t \text{ from (41)}$$

$$L^r \hat{L}_t^r = \psi_l w l (\hat{w}_t + \hat{l}_t) + \psi_K r^k K \left( \frac{dr_t^k}{r^k} + \hat{U}_t + \hat{K}_{t-1} \right) \text{ from (4)}$$

$$\hat{K}_t = (1-\delta) \hat{K}_{t-1} + \delta \hat{I}_t \text{ from (38)}$$

$$\hat{I}_t = \frac{1}{1+\beta} \left[ \hat{I}_{t-1} + \beta E_t \hat{I}_{t+1} + \frac{\hat{Q}_t}{\eta_i} \right] \text{ from (39)}$$

$$\hat{L}_t^e = \hat{\phi}_t^b + \hat{N}_t^b \text{ from (53)}$$

$$\hat{z}_t = \frac{R \hat{R}_{t-1}}{z \Pi} - \hat{\Pi}_t \text{ from (8), after using the fact that with } \lambda = 0, R_t^b = R_{t-1}$$

$$\hat{N}_t^b = z \theta \hat{z}_t + z \theta \hat{N}_{t-1}^b \text{ from (7)}$$

$$\hat{R}_t^K = \hat{\Pi}_t + \frac{\Pi (dr_t^k + \hat{Q}_t (1-\delta))}{R^k} - \hat{Q}_{t-1} \text{ from (11)}$$

$$dr_t^k = c^U r^k \hat{U}_t \text{ from (12)}$$

$$\widehat{\phi}_t^e = \widehat{Q}_t + \widehat{K}_t - \widehat{N}_t \text{ from the definition of } \phi_t^e$$

$$E_t \widehat{R}_{t+1}^K - \widehat{R}_t = \chi^{\phi^e} \widehat{\phi}_t^e \text{ from section (C)}$$

$$\widehat{\varpi}_t + \widehat{R}_t^K = \widehat{R}_t^L + \frac{1}{\phi^e - 1} \widehat{\phi}_{t-1}^e \text{ from (62)}$$

$$R \frac{\widehat{\phi}_{t-1}^e}{\phi^e} = e_t^{R^b} R^K Expr1 + \widehat{R}_t^K R^K Expr1 + R^K Expr2 \varpi \widehat{\varpi}_t - R \frac{\phi^e - 1}{\phi^e} \widehat{R}_{t-1} \text{ from (62)}$$

$$\widehat{N}_t = \gamma \frac{V}{N} \widehat{V}_t \text{ from (16)}$$

$$\widehat{V}_t = \widehat{N}_{t-1} + \widehat{R}_t^K - \widehat{\Pi}_t + \widehat{\phi}_{t-1}^e - \frac{\Gamma'(\overline{\varpi}) \overline{\varpi}}{1 - \Gamma(\overline{\varpi})} \widehat{\varpi}_t + e_t^N \text{ from (58)}$$

$$\widehat{L}_t^e = \widehat{N}_t + \frac{\phi^e}{\phi^e - 1} \widehat{\phi}_t^e \text{ from the definition of } L_t^e, \text{ divided by } N_t$$

$$\widehat{C}_t^e = \widehat{V}_t \text{ from (18)}$$

$$\begin{aligned} \widehat{R}_t R &= (1 - \rho_i) \left[ \psi_\pi E_t \widehat{\Pi}_{t+1} + \psi_{\Delta\pi} \left( \widehat{\Pi}_t - \widehat{\Pi}_{t-1} \right) + \psi_y \left( \widehat{GDP}_t - \widehat{GDP}_{t-1} \right) \right] + \rho_i \widehat{R}_{t-1} \\ &\quad + e_t^i \text{ from (21)} \end{aligned}$$

$$\widehat{Y}_t = \alpha \left( \widehat{U}_t + \widehat{K}_{t-1} \right) + (1 - \alpha) \left( \widehat{a}_t + \widehat{l}_t \right) \text{ from (26)}$$

$$\begin{aligned} \widehat{Y}_t &= \frac{I}{Y} \widehat{I}_t + \frac{C^P}{Y} \widehat{C}_t^P + \frac{Gov}{Y} \widehat{g}_t \\ &\quad + \frac{R^K}{\Pi} \frac{K}{Y} \mu G(\varpi) \left( \widehat{R}_t^K - \widehat{\Pi}_t + \widehat{Q}_{t-1} + \widehat{K}_{t-1} + \frac{G'(\varpi)}{G(\varpi)} \varpi \widehat{\varpi}_t \right) + r^k \frac{K}{Y} \widehat{U}_t \text{ from (25)} \end{aligned}$$

$$\widehat{C}_t^P = \frac{C}{C^P} \widehat{C}_t + \frac{C^e}{C^P} \widehat{C}_t^e \text{ from (24)}$$

$$\widehat{GDP}_t = \frac{I}{GDP} \widehat{I}_t + \frac{C^P}{GDP} \widehat{C}_t^P + \frac{Gov}{GDP} \widehat{g}_t \text{ from (27)}$$

$$\widehat{s3\_4} = 4 \left( E_t \widehat{R}_{t+1}^K - \widehat{R}_t \right) \text{ from } s3\_4 = \left( \frac{E_t R_{t+1}^K}{R_t} \right)^4$$

$$\widehat{s4\_4} = 4 \left( \widehat{R}_t^L - \widehat{R}_t \right) \text{ from } s4\_4 = \left( \frac{R_t^L}{R_t} \right)^4$$

$$\widehat{L}_t = \frac{L^e}{L} \widehat{L}_t^e + \frac{L^r}{L} \widehat{L}_t^r \text{ from (4)}$$

$$\frac{dRat_t}{Rat} = \widehat{N}_t^b - \widehat{L}_t \text{ from } Rat = \frac{N_t}{L_t}$$

$$\widehat{a}_t = \rho_a \widehat{a}_{t-1} + e_t^a$$

$$\widehat{g}_t = \rho_g \widehat{g}_{t-1} + e_t^g$$

### D.3 Model without financial frictions

$$\begin{aligned}
\widehat{\varrho}_t &= \frac{-\left(\widehat{C}_t - h\widehat{C}_{t-1}\right)}{1-h} \text{ from (29)} \\
\widehat{\varrho}_t &= E_t \left\{ \widehat{\varrho}_{t+1} + \widehat{R}_t - \widehat{\Pi}_{t+1} \right\} \text{ from (30)} \\
\widehat{w}_t &= \frac{1}{1+\beta} \left[ \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 \right. \\
&\quad \left. + \gamma_w \widehat{\Pi}_{t-1} - \frac{(1-\beta\xi^w)(1-\xi^w)}{\xi^w} [\widehat{w}_t + \widehat{\varrho}_t - \varphi \widehat{l}_t] \right] \text{ from (43) - (44)} \\
\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{(1-\beta\xi^P)(1-\xi^P)}{\xi^P} \widehat{mc}_t \right] \text{ from (43) - (44)} \\
\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 (40)} \\
\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 (41)} \\
\widehat{K}_t &= (1-\delta) \widehat{K}_{t-1} + \delta \widehat{I}_t \text{ from (38)} \\
\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 (39)} \\
\widehat{Q}_t &= \beta E_t \left\{ [\widehat{\varrho}_{t+1} - \widehat{\varrho}_t] [r^k + (1-\delta)] + dr_{t+1}^k + (1-\delta) \widehat{Q}_{t+1} \right\} \text{ from (36)} \\
dr_t^k &= c^U r^k \widehat{U}_t \text{ from (37)} \\
\widehat{R}_t R &= (1-\rho_i) \left[ \psi_\pi E_t \widehat{\Pi}_{t+1} + \psi_{\Delta\pi} \left( \widehat{\Pi}_t - \widehat{\Pi}_{t-1} \right) + \psi_y \left( \widehat{GDP}_t - \widehat{GDP}_{t-1} \right) \right] + \rho_i \widehat{R}_{t-1} + e_t^i \text{ from (21)} \\
\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 (26)} \\
\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 (25)} \\
\widehat{GDP}_t &= \frac{I}{GDP} \widehat{I}_t + \frac{C}{GDP} \widehat{C}_t + \frac{Gov}{GDP} \widehat{g}_t \text{ from (27), noting that now } C_t^P = C_t \\
\widehat{a}_t &= \rho_a \widehat{a}_{t-1} + e_t^a \\
\widehat{g}_t &= \rho_g \widehat{g}_{t-1} + e_t^g
\end{aligned}$$

## E Steady state for the full model and the BGG Model

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 is almost identical. It only differs in that in the BGG model,  $\lambda$  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 of the passive banking sector in the BGG model do not consume when they die. This assumption has a negligible effect on my results but ensures that the dynamics of all variables not pertaining to the banking sector are not affected by the existence of the banking sector.

The calibration strategy adopted here implies that the steady state is computed by assuming values for the parameters  $\Pi$ ,  $h$ ,  $\varepsilon$ ,  $\varepsilon_w$ ,  $\xi^P$ ,  $\xi^w$ ,  $\alpha$ ,  $\delta$  and  $\mu$ .  $\beta$ ,  $\chi$ ,  $\theta$ ,  $\lambda$ ,  $W^b$ ,  $\sigma$ ,  $\gamma$ ,  $W^b$  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,  $R^L - R$ ,  $F$ ,  $\phi^e$ , 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  $\sigma$ , given  $\log \omega \sim N\left(-\frac{\sigma^2}{2}, \sigma^2\right)$ , we can calculate

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

where  $Ncdf$  denotes the cumulative distribution function of the standard normal distribution.

Given  $\mu$ , I can calculate  $\xi$ ,  $\frac{R^K}{R^b}$ ,  $\phi^e$  and  $R^L$  using the entrepreneur's first order conditions:

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

I adjust  $\sigma$  in order to set  $\phi^e$  to my target.

I then calibrate  $\frac{R^b}{R}$  such that, given the calibration of the entrepreneurial sector parame-

ters,  $\frac{R^L}{R}$  is close to target. Hence we have

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

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

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

Given  $\gamma$ , 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.

Then I calibrate  $\phi^b$  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.<sup>15</sup> I can then calculate all steady state values

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<sup>15</sup>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.



pertaining to the banking sector:

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

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:

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

This allows to back out  $\chi$ , the weight of labour in the utility function:

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

Finally, the auxiliary variables associated with price and wage setting (all only relevant for the nonlinear model) are calculated as

$$\begin{aligned} F &= \frac{Y}{(1 - \beta\xi) X} \\ Z &= \frac{Y}{1 - \beta\xi} \\ S &= 1 \\ F^w &= \frac{\chi l^{1+\varphi}}{1 - \beta\xi^w} \\ Z^w &= \frac{\varepsilon_w - 1}{\varepsilon_w} \frac{w \varrho l}{1 - \beta\xi^w} \\ S^w &= 1 \end{aligned}$$

## F Steady state for the nofriction model

In the nofriction model, the steady state is computed by assuming values for  $\Pi$ ,  $h$ ,  $\varepsilon$ ,  $\varepsilon_w$ ,  $\xi^P$ ,  $\xi^w$ ,  $\alpha$  and  $\delta$ .  $\beta$ ,  $\chi$  and  $Gov$  are calibrated to to achieve targets for  $l$ ,  $R$  and  $\frac{Gov}{Y}$ . This allows to

calculate

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

The calculation of the auxiliary variables pertaining to wage and price setting is exactly the same in both models.

## G Data sources

All components of GDP were divided by the labour 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 labour force.

- Labour 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
- GDP: Bureau of Economic Analysis (BEA), from NIPA Table 1.1.6. Real Gross Domestic Product, Chained 2005 Dollars, seasonally adjusted
- Consumption: Personal consumption expenditures, BEA, from NIPA Table 1.1.6. Real Gross Domestic Product, Chained 2005 Dollars, seasonally adjusted
- Non-residential Investment: BEA, from NIPA Table 5.3.3. Real Private Fixed Investment by Type, Quantity Indexes, seasonally adjusted
- 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 entrepreneurs: 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: Loans/TCE. 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.

## G.1 Robustness

This section investigates the robustness of my key findings regarding the dynamics of the full model and the BGG model in response to standard shocks as well as their relative performance in matching the second moments of US data. For that purpose, I redo the exercises of the previous two sections, each time considering one of the following deviations from the baseline setup:

- a lower bankruptcy cost parameter  $\mu$  equal to 0.2 (at the lower end of the values cited by Calrstrom and Fuerst (1997))
- in the interest feedback rule, we replace current with expected inflation. In the table, this rule is referred to as "Rule1".
- no response to the change of inflation in the monetary policy rule
- a monetary policy rule as in Gertler and Karadi et al. (2009), where the interest rate responds positively to current inflation, the deviation of output from it's level in the absence of nominal rigidities, and lagged inflation, with the long run coefficients on inflation and the output gap being 1.5 and 0.5/4 and the coefficient on the lagged interest rate being 0.8, respectively. The deviation of output from its flexible price/flexible wage level is proxied by the negative of the deviation of the markup of retailers from its steady state.<sup>16</sup> In the table, this rule is referred to as "Rule2".
- a monetary policy rule where the interest rate responds positively to current inflation, the deviation of output from it's steady state, and lagged inflation, with the long run

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<sup>16</sup>As in Gertler and Karadi (2009), the coefficients on inflation, the output gap and lagged inflation are 1.5, 0.125 and 0.8, respectively.

coefficients on inflation and the output gap being 1.5 and 0.5/4 and the coefficient on the lagged interest rate being 0.8, respectively. In the table, this rule is referred to as "Rule3".

- flexible prices,  $\xi^P = 0$
- flexible wages,  $\xi^W = 0$
- no consumption habits,  $h = 0$
- no working capital requirement by retailers,  $\psi_K = \psi_l = 0$ .
- The parameters determining the degree of nominal rigidity, the policy rule parameters and the law of motions of the three shocks are calibrated to Christiano et al.'s (2010) estimate of a model featuring not just a financial accelerator, but also a banking sector providing liquidity services.<sup>17</sup> In the table, this rule is referred to as Chr\_altest.

Figure 7 to 9 display the impulse responses of GDP to the three standard shocks in the full and the BGG model. Consistent with my findings in section 4, the peak effect of monetary policy shocks is amplified in the full model relative the BGG model by between a bit less and a third and a half, and the effect of government spending shocks is attenuated somewhat. Furthermore, the on impact decline of GDP in response to a technology shock ranges is between one third and two times stronger (when using the alternative calibration of Christiano (2010) et al.) in the full model than in the BGG model. An exception is the case of flexible prices, where the deterioration of technology persistently increases GDP in the full model, while in the BGG model, GDP first decreases and then increases. However, the

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<sup>17</sup>This is Christiano et al.'s (2010) "baseline" model, see table 4, pp. 94-95. The parameters used in our baseline calibration are taken from their "Financial accelerator Model".

output expansion is due to the fact that monetary policy responds to expected as opposed to current inflation and therefore does not respond to the on impact boost to inflation caused by the shock.

The second moments generated by the two models under the various calibrations are displayed in table A.1-A.3 in appendix G.1, where the respective "a" and "b" tables refer to the full model and the BGG model, respectively.  $EFP_t$  denotes  $R_t^L - R_t$  in the full model and  $E_t R_{t+1}^L - R_t$  in the BGG model, both at annualised rates. In table A.1, deteriorations or improvement of a relative standard deviation relative to the data larger than or equal to 0.3 in black or italics, respectively. Similarly, in tables A2 and A3, deteriorations and improvements larger than or equal to 0.1 relative to the data are also marked in black and italics, respectively. For the policy rule with a response to current as opposed to expected future inflation ("rule1"),  $\psi_{\Delta\pi} = 0$  and Christiano et al.'s (2010) alternative estimates, the moments generated by the two models are virtually the same. With  $\mu = 0.2$ , one moment worsens in both models. With  $\psi_K = \psi_l = 0$ , one moment worsens in the full model while three moments somewhat improve in the BGG model. With the Gertler/ Karadi type policy rule ("rule 2"), 4 two moments worsen in the full model while four moments worsen in the BGG model. For the remaining experiments (rule 3,  $\xi^P = 0$ ,  $\xi^W = 0$  and  $h = 0$ ) several moments change substantially. However, even for these experiments, the full model still outperforms the BGG model at matching the second moments of the data.



Table A.1a: Full Model, Standard deviations relative to GDP, various deviations from the baseline setup												
Variable	Data	Baseline	$\mu = 0.2$	Rule1	Rule2	Rule3	$\psi_{\Delta\pi} = 0$	$\xi^P = 0$	$\xi^W = 0$	$h = 0$	$\psi_K = \psi_l = 0$	Chr_altest
$GDP_t$	1	1	1	1	1	1	1	1	1	1	1	1
$C_t$	0.81	0.91	0.93	0.91	0.9	1.03	0.91	1.06	1.07	1.05	0.89	0.87
$I_t$	4.44	2.81	2.56	2.82	2.83	2.67	2.8	3.18	2.69	2.62	2.8	2.94
$l_t$	1.61	1.29	1.31	1.22	1.11	1.35	1.29	1.50	1.35	1.23	1.33	1.28
$EFP_t$	0.99	0.95	0.85	0.94	0.91	0.86	0.95	1.27	1.03	0.88	1.96	0.99
$\phi_t^e$	1.99	1.37	1.19	1.27	1.1	<b>1.07</b>	1.37	<b>2.66</b>	2.32	1.29	1.44	1.46
$N_t$	4.53	3.03	<b>2.64</b>	2.89	<b>2.59</b>	<b>2.36</b>	3.03	4.56	4.35	2.83	3.15	3.17
$\frac{N_t^b}{L_t}$	0.4	0.53	0.51	0.53	0.53	0.52	0.53	0.69	0.53	0.49	0.66	0.55
$L_t$	2.45	0.66	0.69	0.65	0.67	1.03	0.67	1.5	1.25	0.6	0.63	0.52
$N_t^b$	2.42	5.46	5.16	5.41	5.31	5.03	5.45	<b>7.25</b>	<b>5.96</b>	5.09	5.53	5.74

Table A.1b: BGG model, standard deviations relative to GDP, various deviations from the baseline setup												
Variable	Data	Baseline	$\mu = 0.2$	Rule1	Rule2	Rule3	$\psi_{\Delta\pi} = 0$	$\xi^P = 0$	$\xi^W = 0$	$h = 0$	$\psi_K = \psi_l = 0$	Chr_altest
$GDP_t$	1	1	1	1	1	1	1	1	1	1	1	1
$C_t$	0.81	0.93	0.92	0.93	0.92	0.99	0.93	1.05	1.05	1.11	0.91	0.91
$I_t$	4.44	2.34	2.24	2.42	2.44	2.32	2.34	2.08	1.96	2.22	2.29	2.36
$l_t$	1.61	1.39	1.4	1.31	1.21	1.44	1.39	1.48	1.45	1.29	1.44	1.37
$EFP_t$	0.99	0.11	0.08	0.1	0.08	0.09	0.11	0.24	0.22	0.11	0.12	0.12
$\phi_t^e$	1.99	1.00	0.88	0.91	0.73	0.82	1.01	2.15	1.98	0.97	1.11	1.14
$N_t$	4.53	2.08	1.83	1.94	<b>1.65</b>	<b>1.55</b>	2.08	3.07	3.36	1.97	2.24	2.27
$\frac{N_t^b}{L_t}$	0.4	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.06	0.07	0.07
$L_t$	2.45	0.77	0.8	0.77	0.82	1.14	0.79	1.87	1.38	0.68	0.74	0.63
$N_t^b$	2.42	0.89	0.88	0.83	0.79	1.08	0.89	2.19	1.59	0.79	0.88	0.84

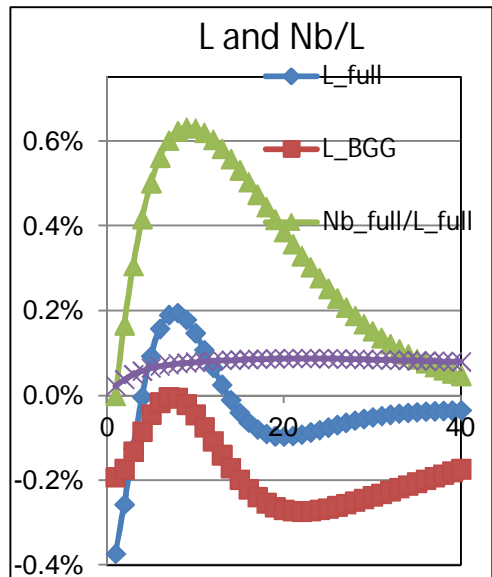
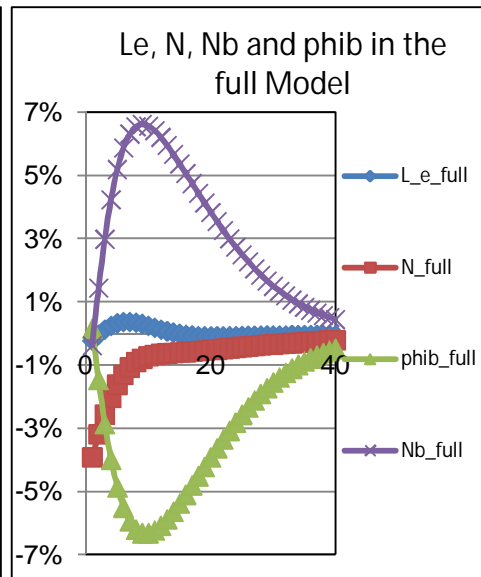
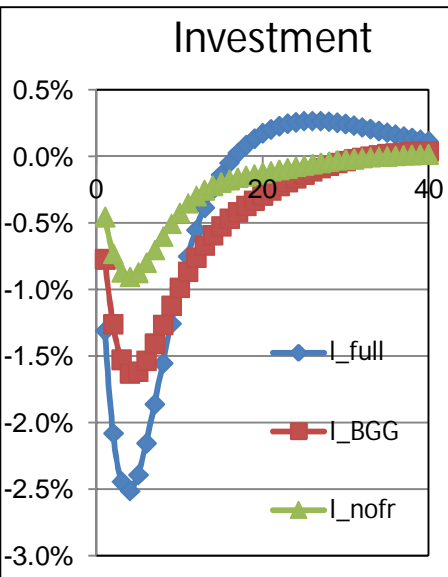
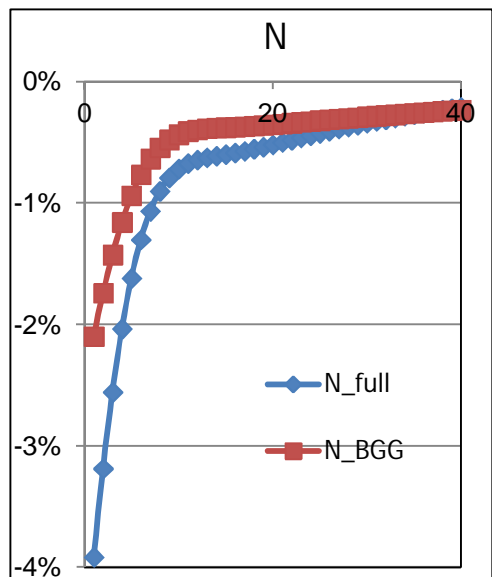
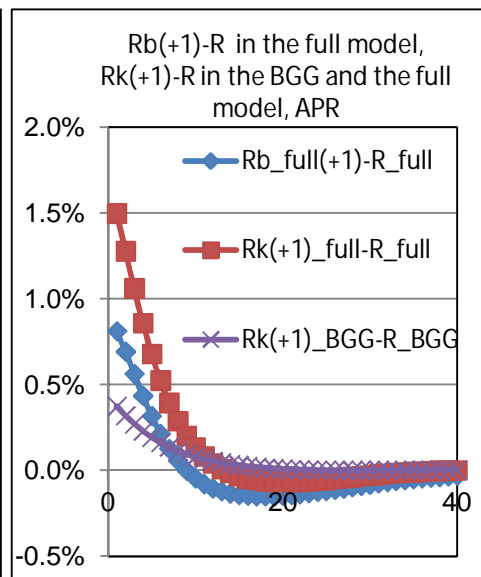
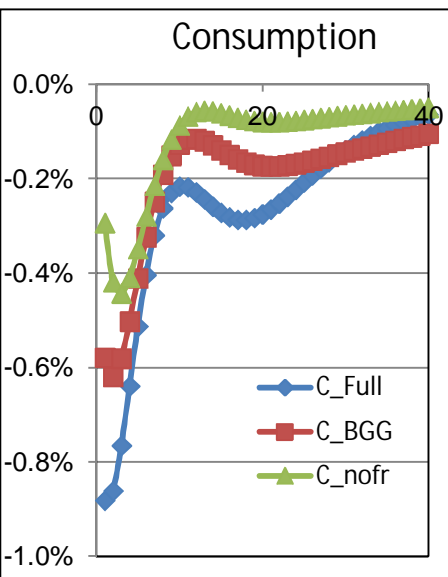
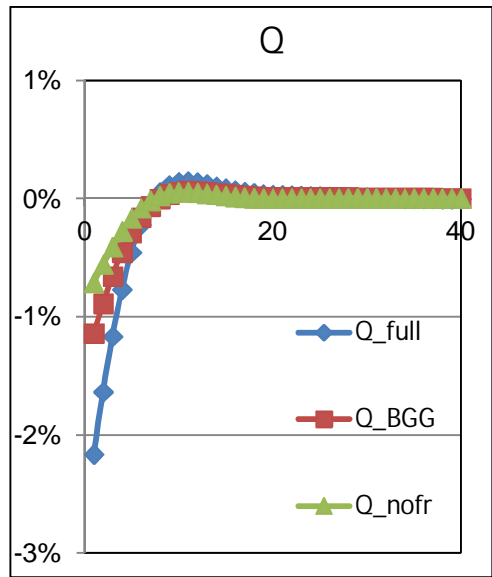
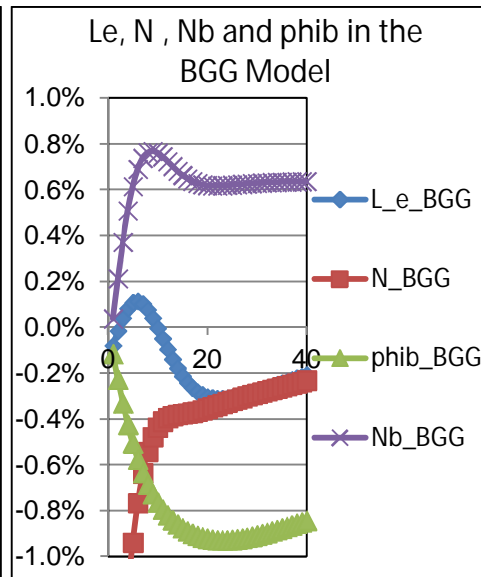
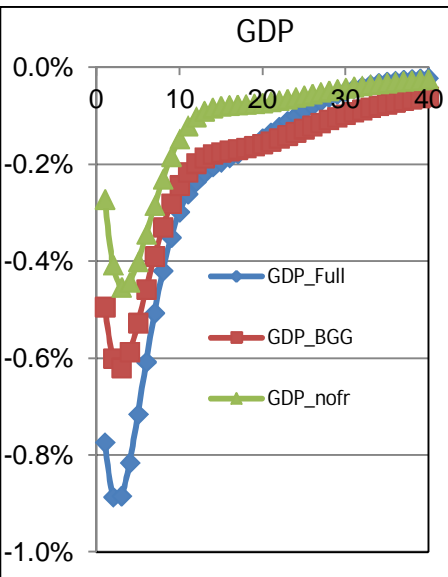
Table A.2a: Full model, Correlations with GDP, various deviations from the baseline setup												
Variable	Data	Baseline	$\mu = 0.2$	Rule1	Rule2	Rule3	$\psi_{\Delta\pi} = 0$	$\xi^P = 0$	$\xi^W = 0$	$h = 0$	$\psi_K = \psi_l = 0$	Chr_altest
$GDP_t$	1	1	1	1	1	1	1	1	1	1	1	1
$C_t$	0.89	0.89	0.89	0.9	0.90	0.80	0.89	<b>0.75</b>	<b>0.75</b>	0.89	0.87	0.87
$I_t$	0.88	0.89	0.89	0.9	0.91	<b>0.79</b>	0.89	<b>0.68</b>	<b>0.66</b>	0.84	0.87	0.89
$l_t$	0.86	0.9	0.89	0.91	0.89	<b>0.73</b>	0.9	0.92	<b>0.79</b>	0.92	0.89	0.91
$EFP_t$	-0.62	-0.77	-0.75	-0.76	-0.71	-0.42	-0.77	-0.71	-0.71	<b>-0.88</b>	-0.8	-0.81
$\phi_t^e$	-0.61	-0.75	-0.72	-0.74	-0.67	<b>-0.25</b>	-0.75	-0.67	-0.78	-0.83	-0.8	-0.82
$N_t$	0.73	0.79	0.78	0.78	0.74	<b>0.52</b>	0.79	0.76	0.83	0.88	0.81	0.81
$\frac{N_t^b}{L_t}$	-0.44	-0.32	-0.35	-0.35	-0.41	<i>-0.47</i>	-0.32	<b>-0.21</b>	<b>0.01</b>	<b>-0.18</b>	-0.25	-0.3
$L_t$	0.37	0.60	0.59	0.68	<b>0.77</b>	<b>0.78</b>	0.60	<b>-0.05</b>	0.22	0.66	<b>0.11</b>	0.52
$N_t^b$	-0.12	-0.25	-0.27	-0.27	-0.32	-0.34	-0.24	-0.22	0.05	<i>-0.1</i>	-0.22	-0.24

Table A.2b: BGG model, correlations with GDP, various deviations from the baseline setup												
Variable	Data	Baseline	$\mu = 0.2$	Rule1	Rule2	Rule3	$\psi_{\Delta\pi} = 0$	$\xi^P = 0$	$\xi^W = 0$	$h = 0$	$\psi_K = \psi_l = 0$	Chr_altest
$GDP_t$	1	1	1	1	1	1	1	1	1	1	1	1
$C_t$	0.89	0.85	0.85	0.87	0.87	<b>0.76</b>	0.85	<b>0.76</b>	<b>0.69</b>	0.85	0.82	0.81
$I_t$	0.88	0.87	0.87	0.89	0.90	0.82	0.87	<b>0.69</b>	<b>0.62</b>	0.8	0.84	0.83
$l_t$	0.86	0.86	0.86	0.88	0.86	<b>0.74</b>	0.87	0.84	<b>0.72</b>	0.88	0.85	0.86
$EFP_t$	-0.62	-0.56	-0.52	-0.54	<b>-0.44</b>	<b>-0.02</b>	-0.56	<b>-0.31</b>	-0.63	-0.67	-0.64	-0.68
$\phi_t^e$	-0.61	-0.53	-0.52	-0.54	-0.44	<b>-0.02</b>	-0.56	<b>-0.31</b>	-0.63	<b>-0.67</b>	-0.64	-0.68
$N_t$	0.73	0.73	0.72	0.73	0.72	<b>0.52</b>	0.73	<b>0.56</b>	0.74	<b>0.82</b>	0.74	0.75
$\frac{N_t^b}{L_t}$	-0.44	-0.56	-0.55	-0.55	-0.53	-0.52	-0.56	-0.48	<b>-0.69</b>	<i>-0.43</i>	-0.28	-0.59
$L_t$	0.37	0.66	0.66	0.73	<b>0.81</b>	<b>0.80</b>	0.66	<i>0.26</i>	<i>0.26</i>	0.67	<i>0.18</i>	<i>0.48</i>
$N_t^b$	-0.12	0.15	0.18	0.22	<b>0.37</b>	<b>0.52</b>	0.15	0.07	<i>-0.15</i>	<b>0.25</b>	<i>-0.03</i>	<i>-0.13</i>

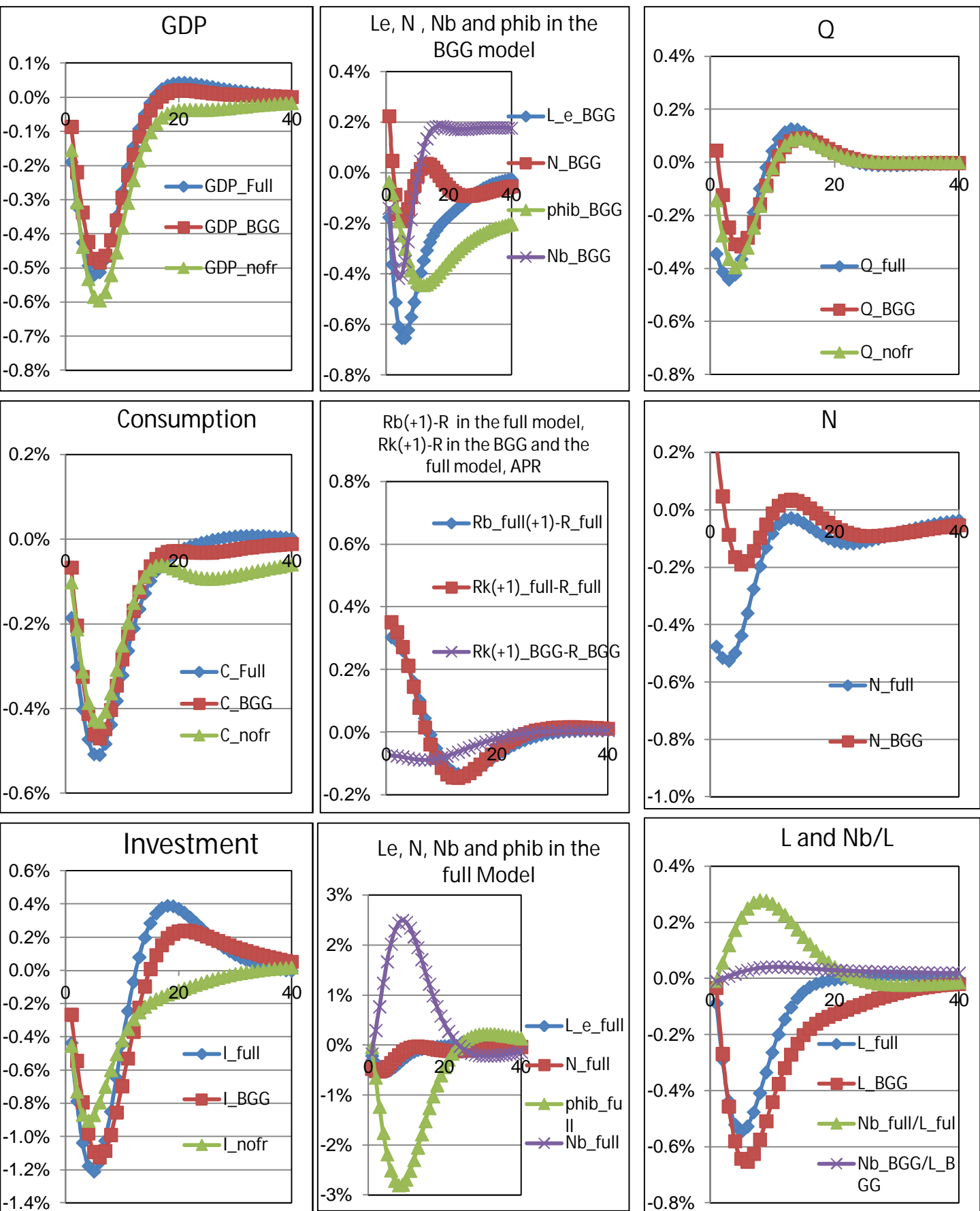
Table A3a: Full model, autocorrelations, various deviations from the baseline setup												
Variable	Data	Baseline	$\mu = 0.2$	Rule1	Rule2	Rule3	$\psi_{\Delta\pi} = 0$	$\xi^P = 0$	$\xi^W = 0$	$h = 0$	$\psi_K = \psi_l = 0$	Chr_altest
$GDP_t$	0.85	0.83	0.83	0.84	0.85	0.85	0.83	<b>0.70</b>	<b>0.69</b>	0.76	0.81	0.82
$C_t$	0.88	0.78	0.78	0.79	0.82	0.86	0.78	<b>0.65</b>	<b>0.67</b>	<b>0.66</b>	0.75	0.74
$I_t$	0.91	0.92	0.92	0.92	0.92	0.93	0.92	0.92	0.9	0.92	0.92	0.92
$l_t$	0.93	0.78	0.78	0.8	0.81	<b>0.67</b>	0.78	<b>0.62</b>	<b>0.61</b>	0.73	0.76	0.78
$EFP_t$	0.91	0.72	0.72	0.72	0.73	0.74	0.72	0.70	0.73	0.73	0.71	0.72
$\phi_t^e$	0.94	0.66	0.66	0.65	0.65	0.67	0.66	0.68	0.68	0.66	0.66	0.66
$N_t$	0.94	0.62	0.62	0.63	0.64	0.62	0.62	0.56	0.57	0.62	0.61	0.61
$\frac{N_t^b}{L_t}$	0.83	0.95	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.95	0.95	0.95
$L_t$	0.93	0.86	0.88	0.87	0.88	0.90	0.86	0.88	0.81	0.83	0.88	0.79
$N_t^b$	0.81	0.95	0.95	0.95	0.95	0.95	0.94	0.95	0.95	0.95	0.94	0.95

Table A3b: BGG model, autocorrelations, various deviations from the baseline setup												
Variable	Data	Baseline	$\mu = 0.2$	Rule1	Rule2	Rule3	$\psi_{\Delta\pi} = 0$	$\xi^P = 0$	$\xi^W = 0$	$h = 0$	$\psi_K = \psi_l = 0$	Chr_altest
$GDP_t$	0.85	0.84	0.85	0.85	0.86	0.84	0.84	<b>0.74</b>	<b>0.69</b>	0.77	0.81	0.81
$C_t$	0.88	0.84	0.84	0.85	0.88	0.89	0.84	0.75	<b>0.73</b>	<b>0.71</b>	0.81	0.81
$I_t$	0.91	0.93	0.93	0.93	0.93	0.94	0.93	0.92	0.9	0.93	0.92	0.92
$l_t$	0.93	0.75	0.75	0.78	0.78	0.66	0.75	<b>0.59</b>	<b>0.57</b>	0.71	0.73	0.74
$EFP_t$	0.91	0.68	0.69	0.68	0.69	0.71	0.68	0.7	0.7	0.68	0.68	0.68
$\phi_t^e$	0.94	0.68	0.69	0.68	0.69	0.71	0.68	0.7	0.7	0.68	0.68	0.68
$N_t$	0.94	0.62	0.63	0.64	0.66	0.6	0.62	0.53	0.55	0.63	0.61	0.61
$\frac{N_t^b}{L_t}$	0.83	0.92	0.92	0.93	0.93	0.9	0.92	0.87	0.7	0.91	0.96	0.91
$L_t$	0.93	0.91	0.91	0.91	0.91	0.92	0.91	0.87	0.84	0.89	0.93	0.88
$N_t^b$	0.81	0.94	0.94	0.94	0.94	0.93	0.94	0.86	0.91	0.94	0.93	0.93

# Figure 1 - Monetary policy shock

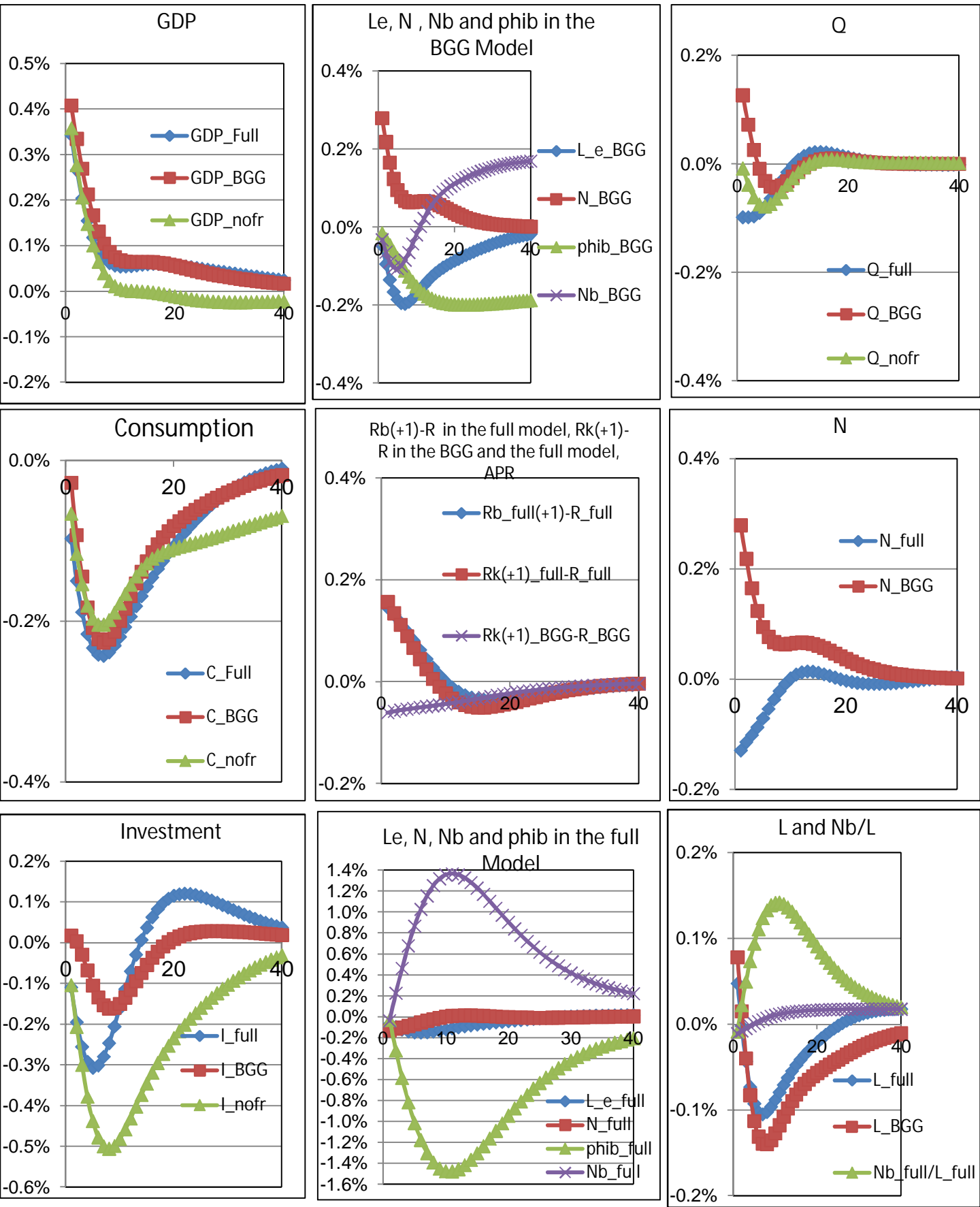


# Figure 2 - Technology shock





# Figure 3 - Government spending shock



# Figure 4 - -1% Shock to entrepreneurial net worth

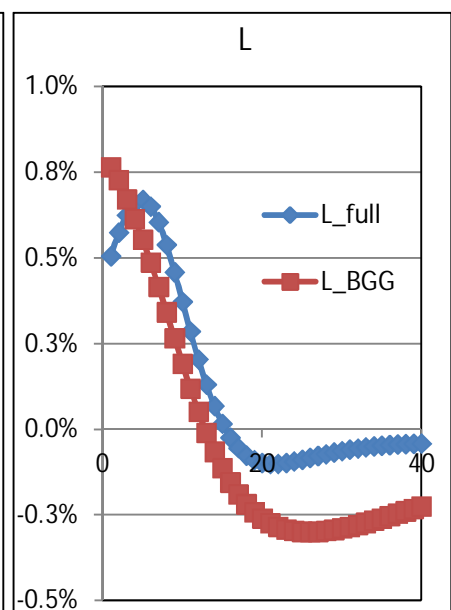
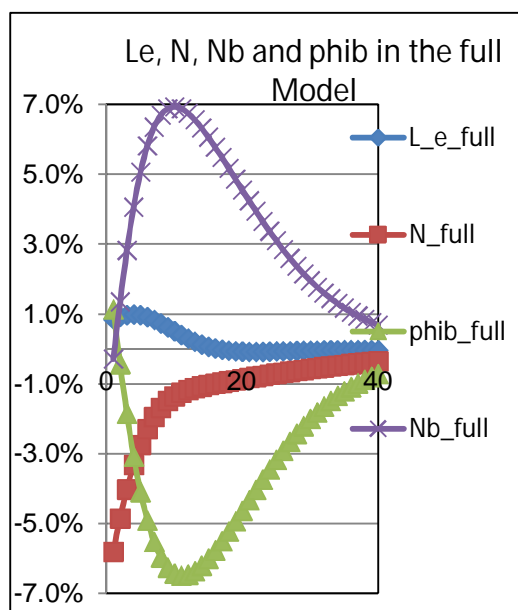
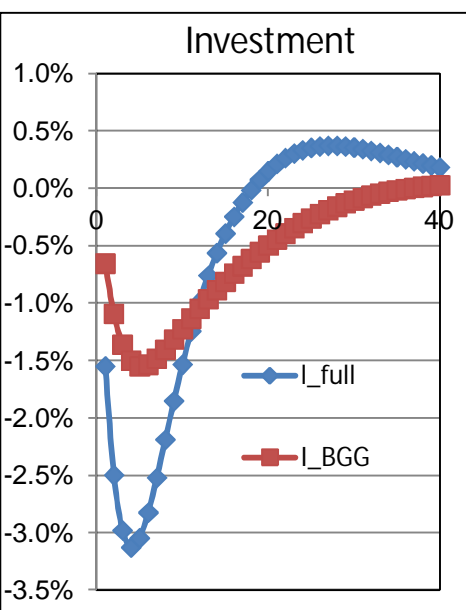
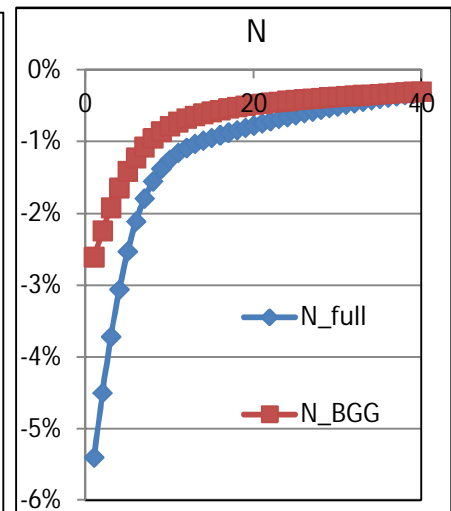
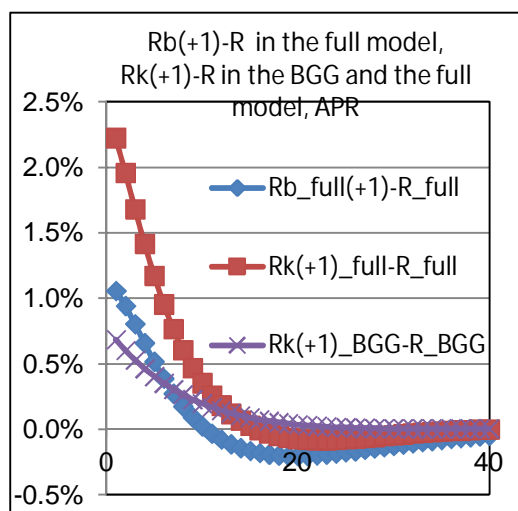
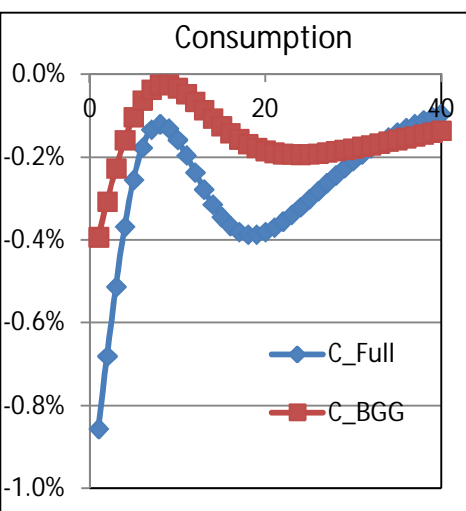
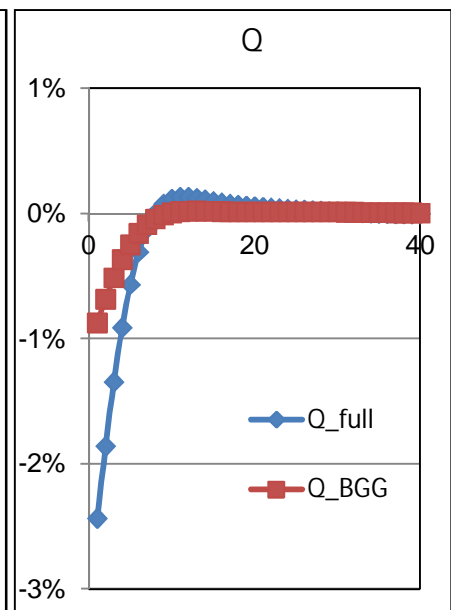
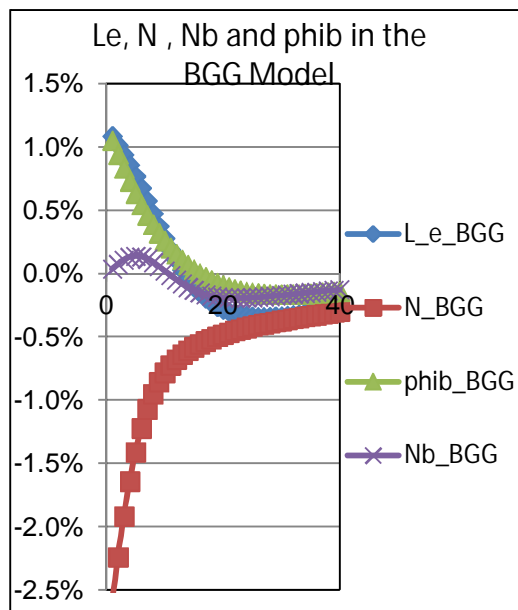
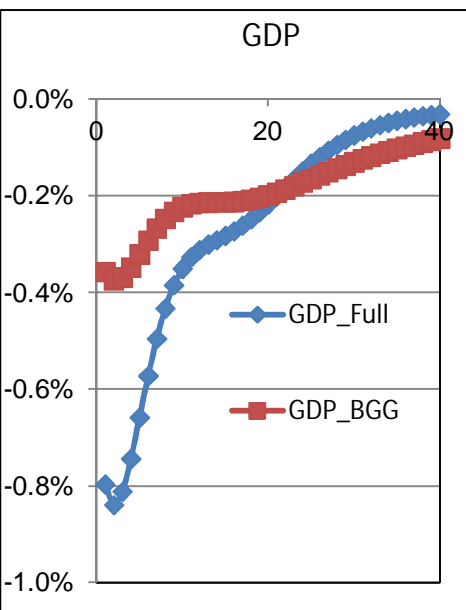
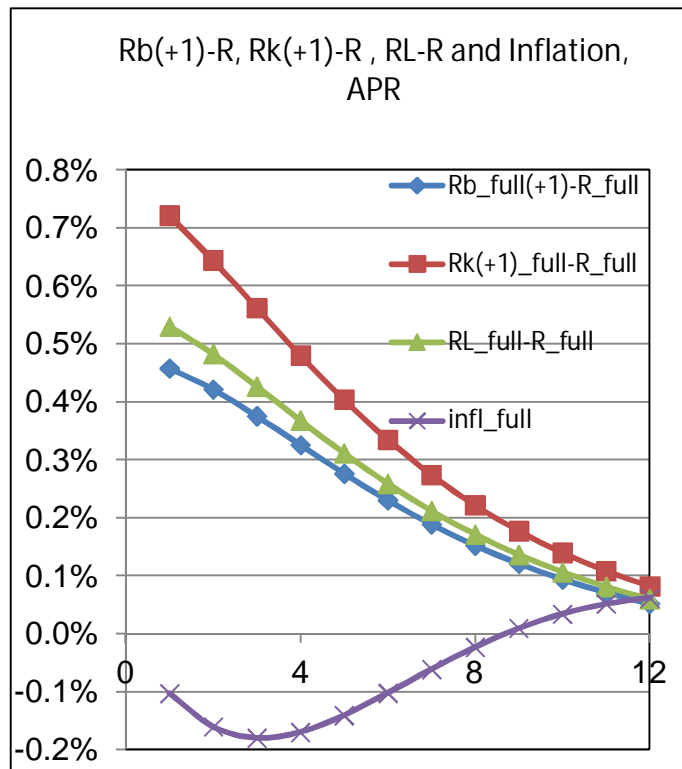
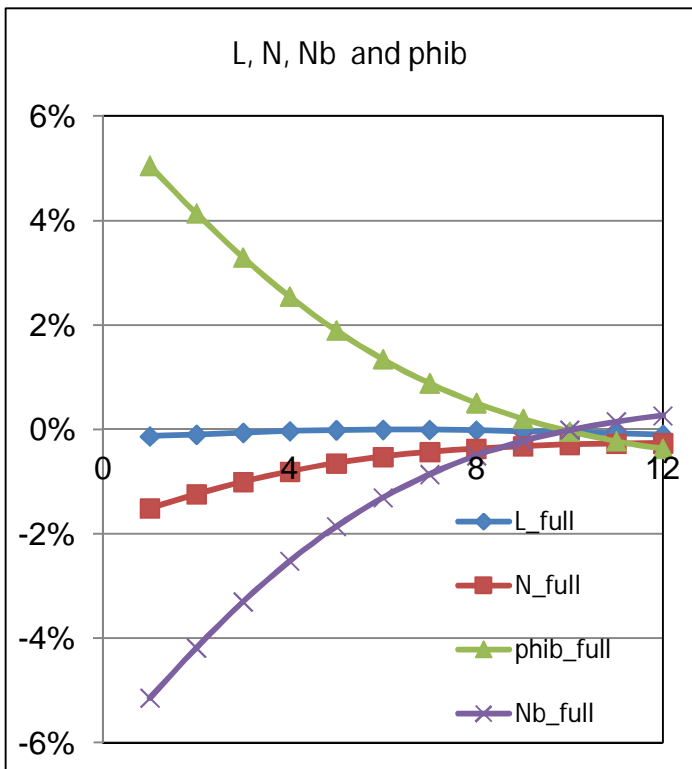
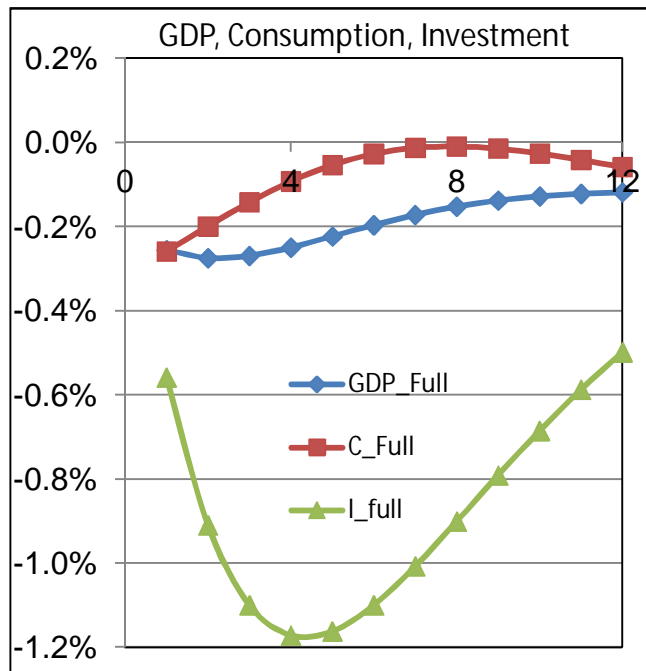
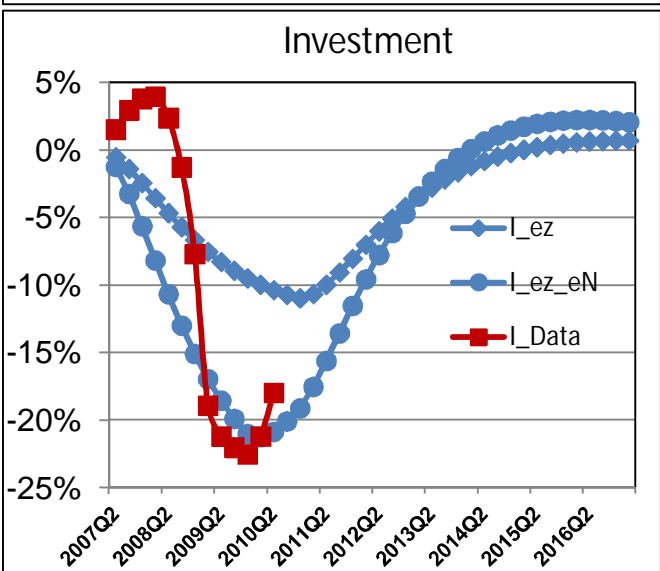
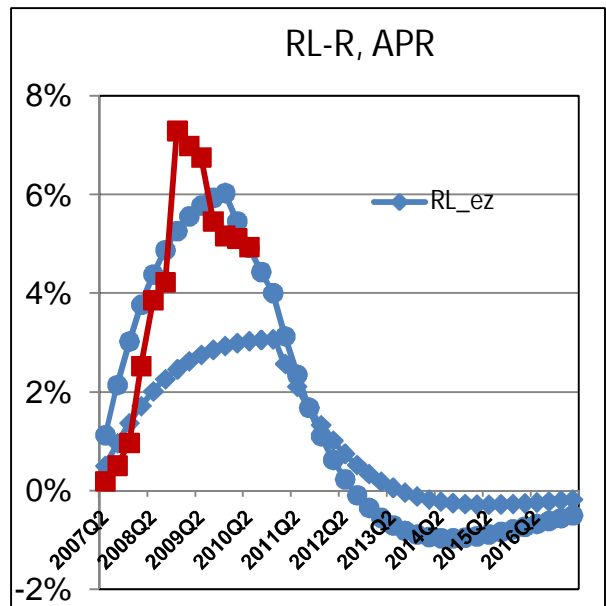
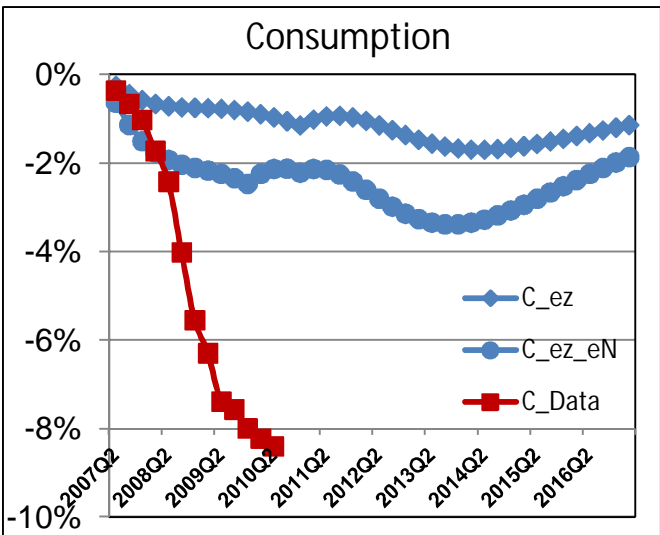
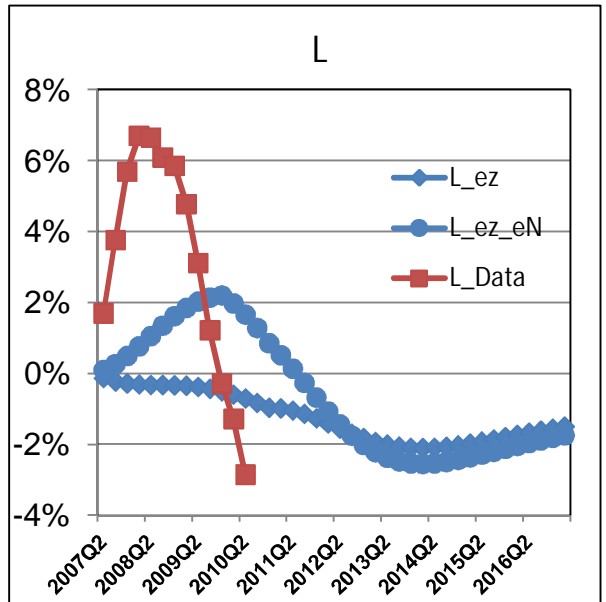
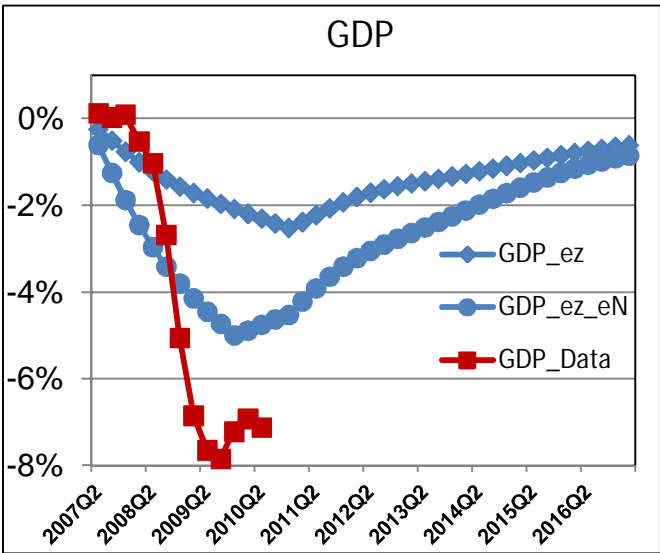


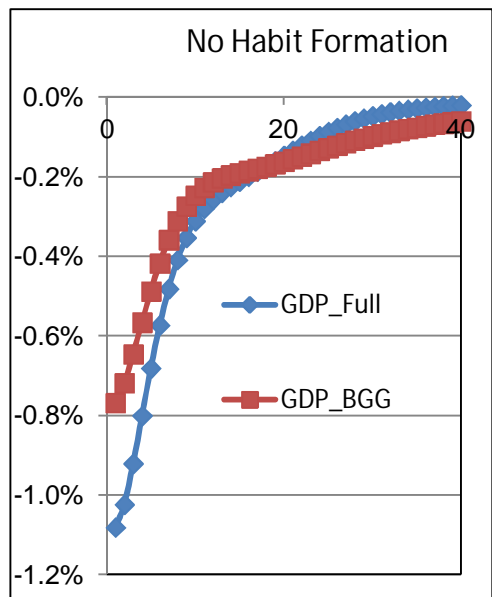
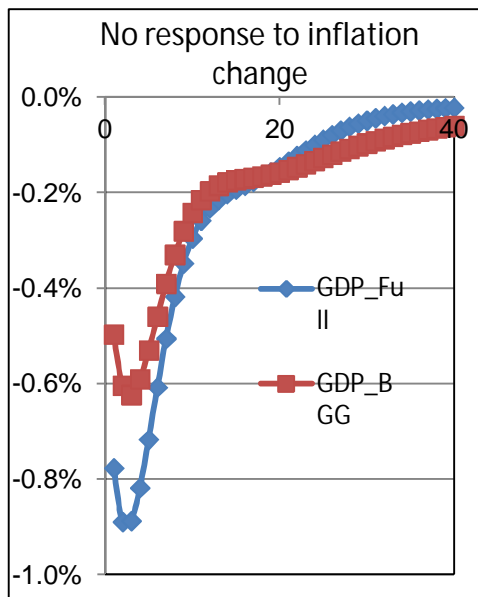
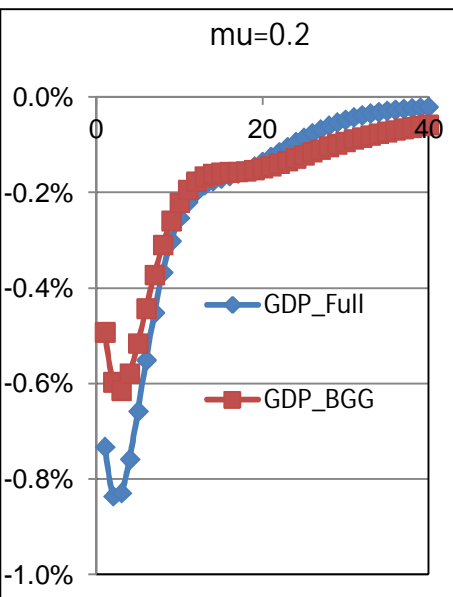
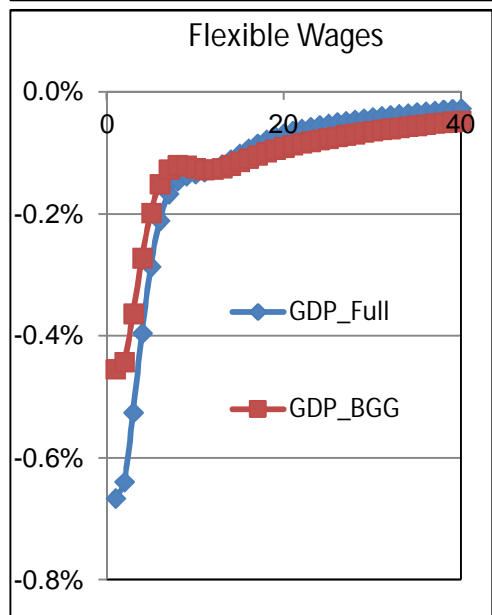
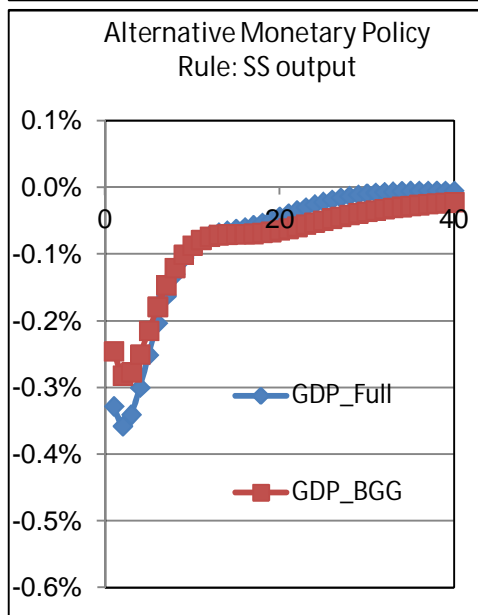
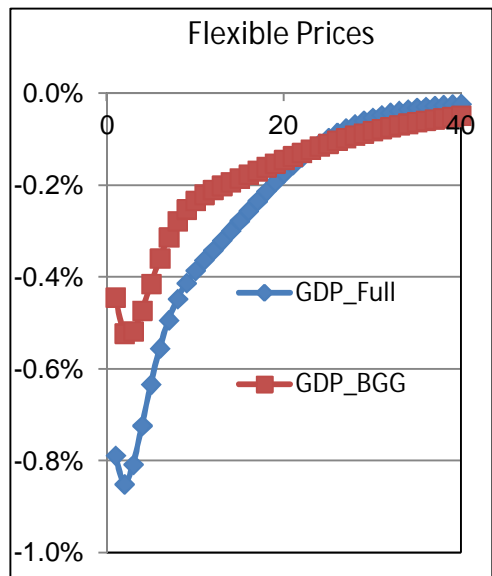
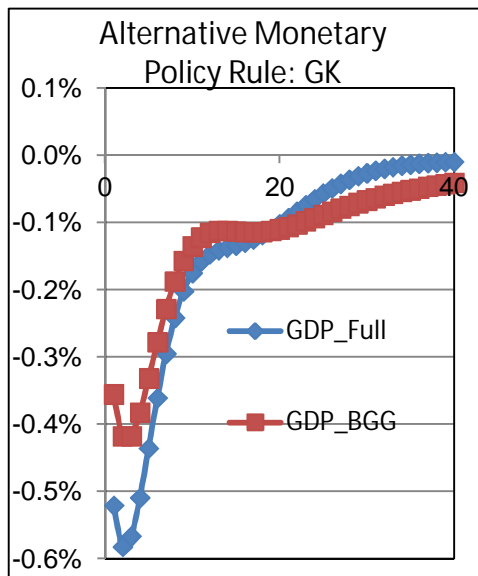
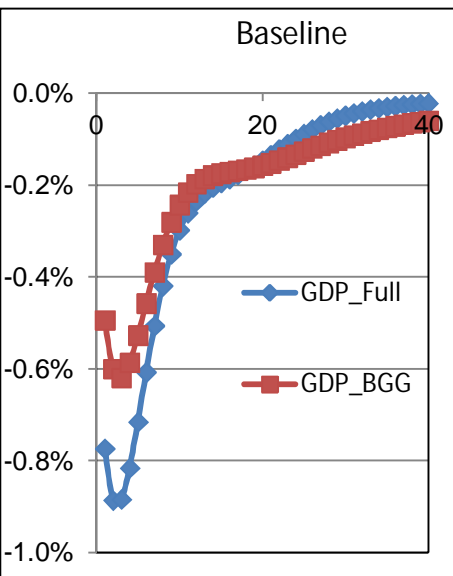
Figure 5 - -5% Shock to bank net worth



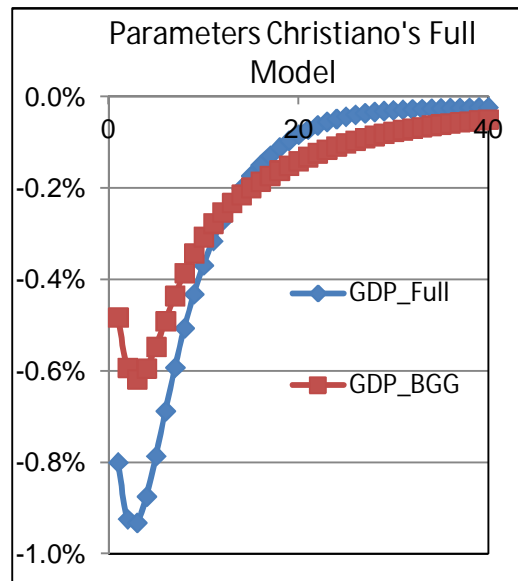
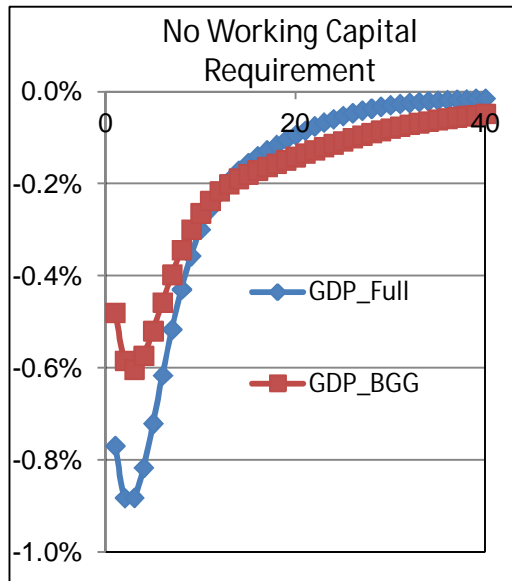
# Figure 6 - Crisis experiment



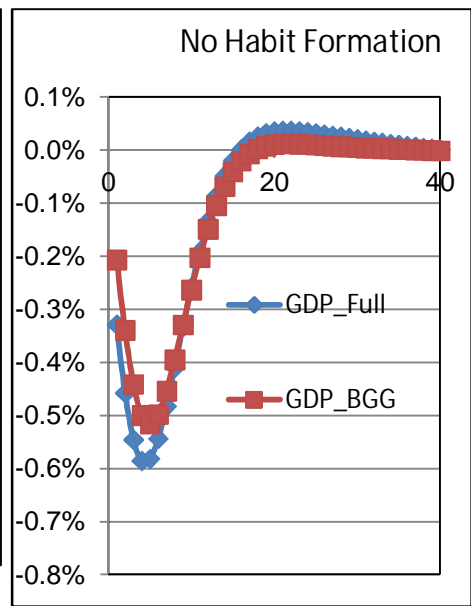
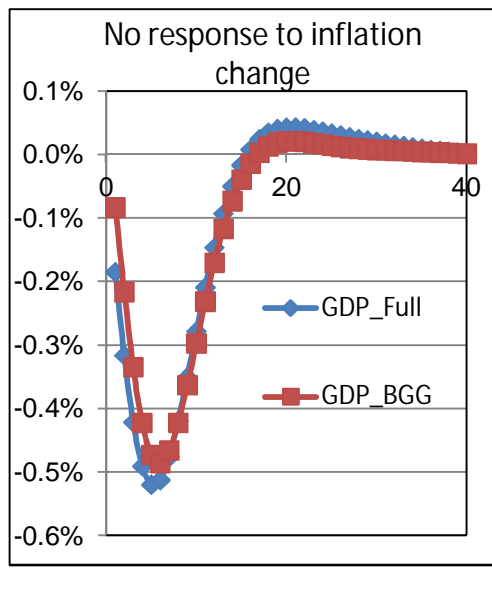
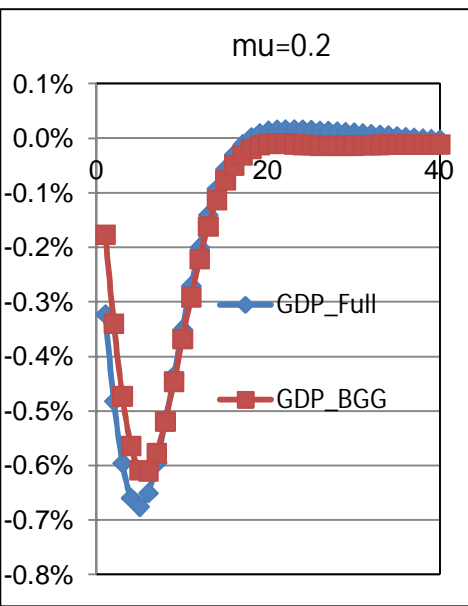
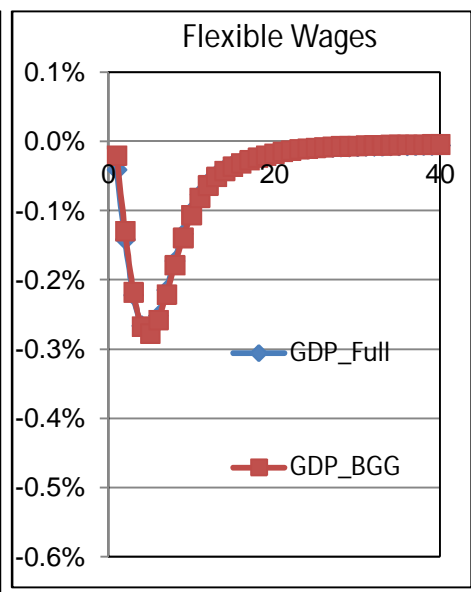
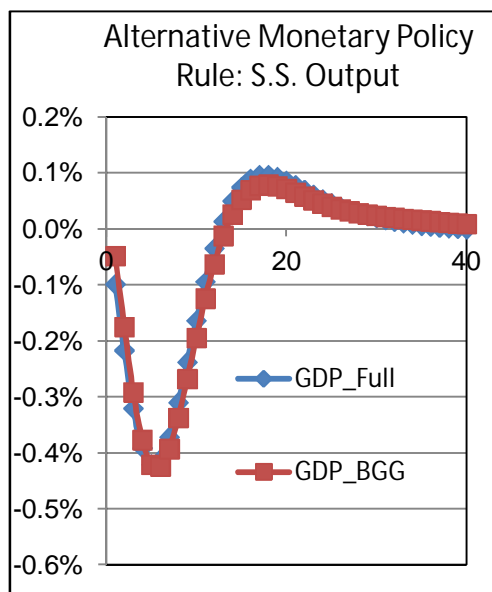
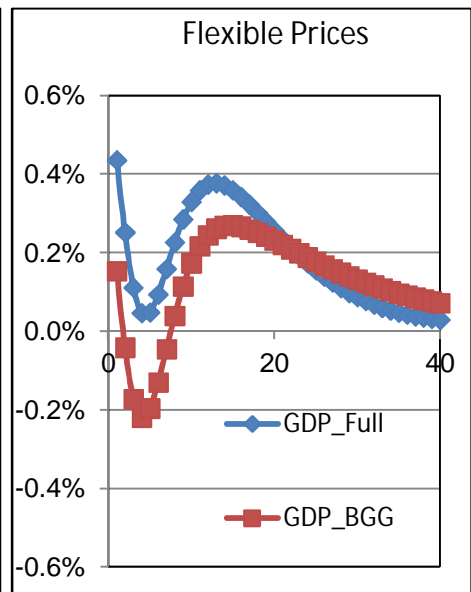
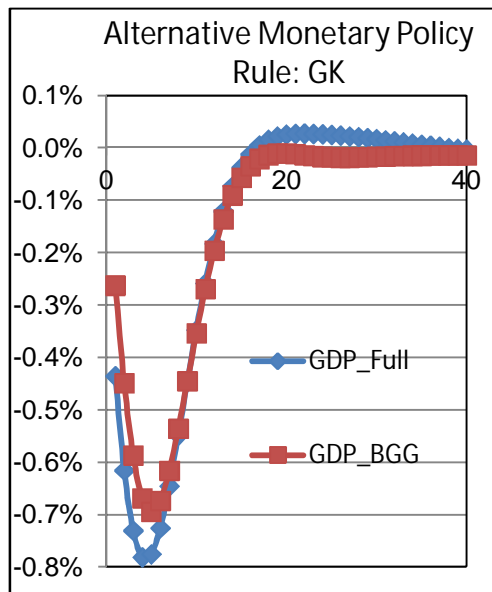
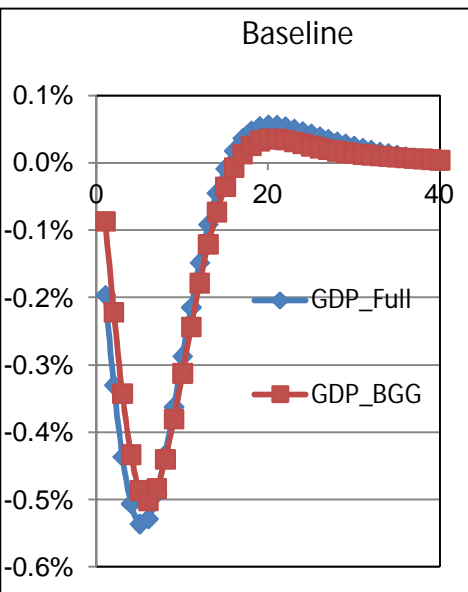
# Figure 7a: Monetary Policy Shock - Robustness



# Figure 7b: Monetary Policy Shock - Robustness, continued



# Figure 8a: Technology Shock - Robustness



# Figure 8b: Technology Shock - Robustness, continued

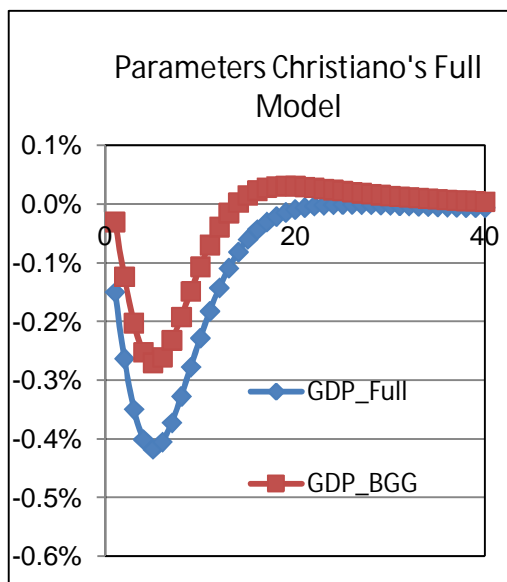
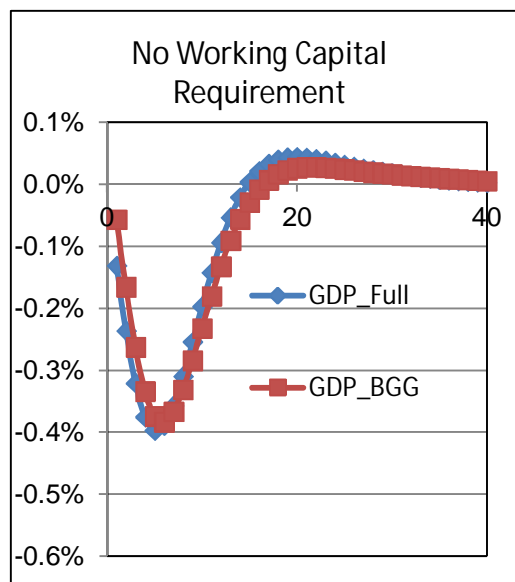




Figure 9a: Government Spending Shock - Robustness

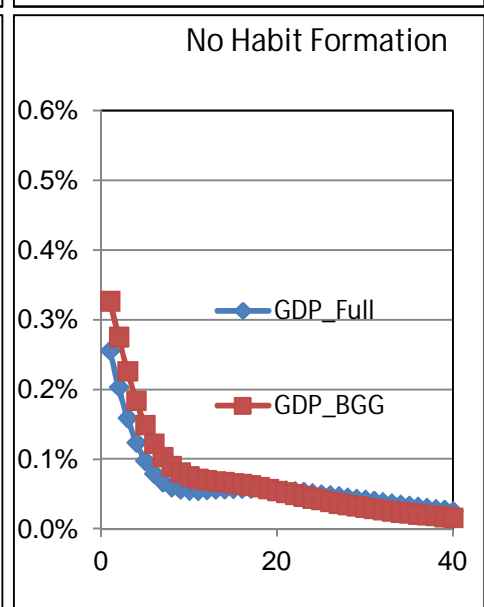
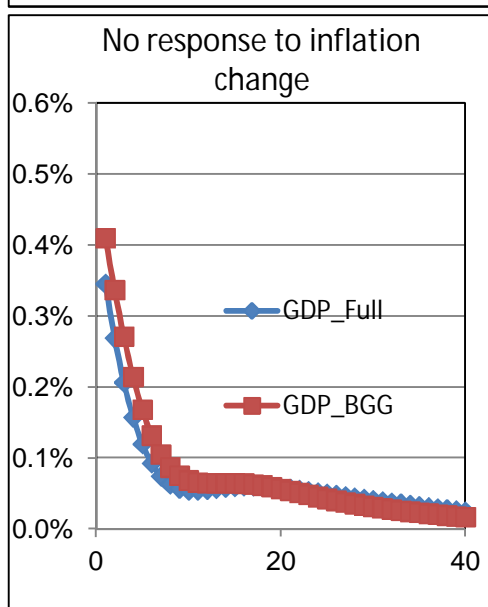
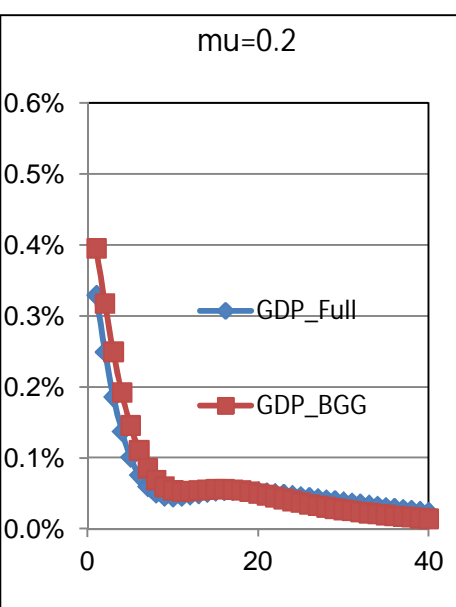
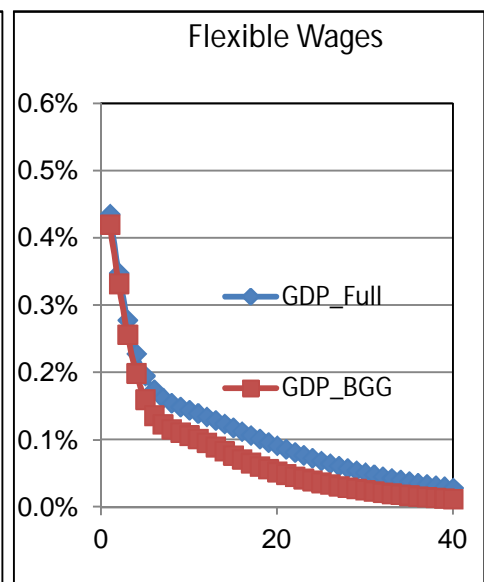
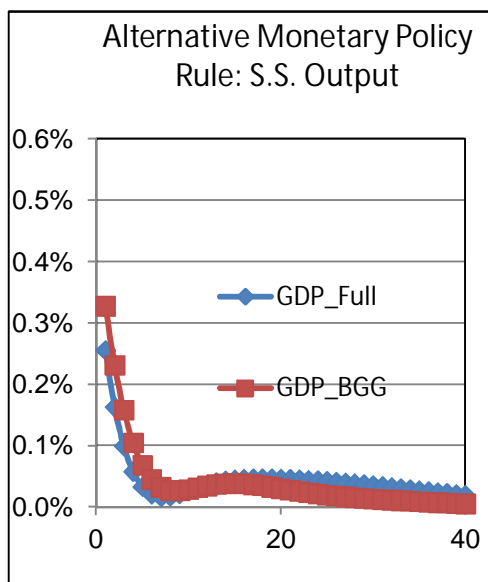
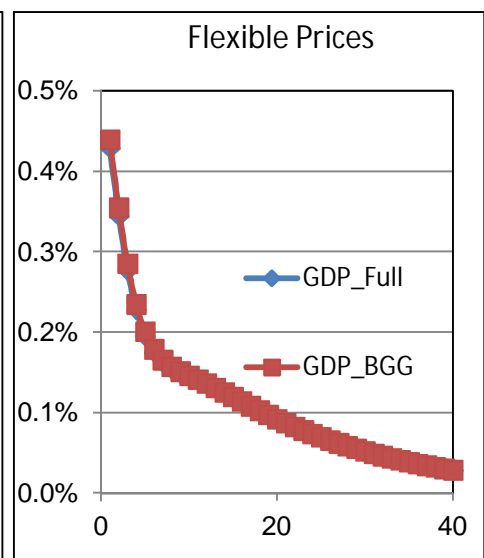
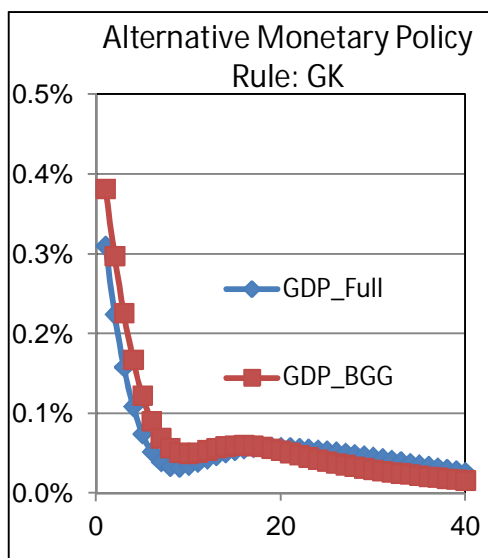
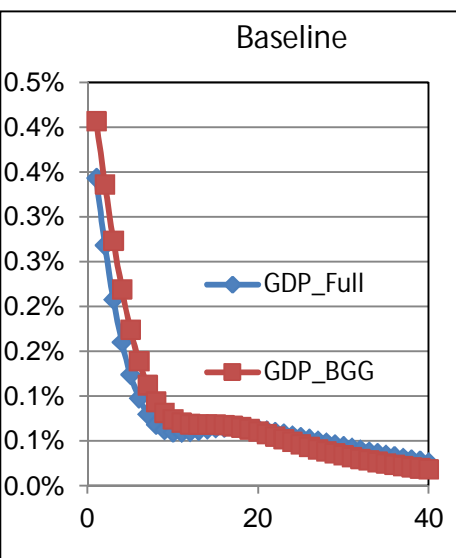


Figure 9 b: Government Spending Shock - Robustness, continued

