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More or less aggressive? Robust monetary policy in a New Keynesian model with financial distress

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Abstract:

This paper investigates the optimal monetary policy response to a shock to collateral when policymakers act under discretion and face model uncertainty. The analysis is based on a New Keynesian model where banks supply loans to transaction constrained consumers. Our results confirm the literature on model uncertainty with respect to a cost-push shock. Insuring against model misspecification leads to a more aggressive policy response. The same is true for a shock to collateral. A preference for robustness leads to a more aggressive policy. Increasing the weight attached to interest rate smoothing raises the degree of aggressiveness. Our results indicate that a preference for robustness crucially depends on the way different types of disturbances affect the economy: in the case of a shock to collateral the policymaker does not need to be as much worried about model misspecification as in the case of a conventional cost-push shock.

Keywords: optimal monetary policy, discretion, model uncertainty, banking, collateral

JEL-Classification: E44, E58, E32

Non technical summary

The recent financial turmoil has shown that shocks to collateral have serious effects on the economy. In this paper we investigate the optimal monetary policy response to such a shock when policymakers act under discretion and face model uncertainty. We use a New Keynesian model where banks supply loans to transaction constrained consumers and explore whether the robust optimal monetary policy becomes more or less aggressive when the economy is exposed to financial distress. Specifically, we analyse in which way the optimal monetary policy under model uncertainty deviates from the optimal monetary policy under full information if in addition to a conventional cost-push shock a shock to collateral hits the economy.

To analyse the implications of model uncertainty, we apply the robust control approach along the lines of Hansen and Sargent (2008). We assume that the true model of the private sector lies in the neighbourhood around a reference model and that the policymaker is not able to formulate a probability distribution over plausible models. One main feature of this approach is that it allows the policymaker to recognise that data may not be generated by the reference model of the economy but by an unknown model in the neighbourhood of the reference model. Robust control then provides a way for the policymaker to find a policy that performs well in the worst possible outcome of a pre-specified set of models.

Our results can be summarised as follows: A preference for robustness leads to a more aggressive policy response to all the shocks considered here. Increasing the weight attached to interest rate smoothing raises the degree of aggressiveness. Yet, our results also indicate that a preference for robustness crucially depends on the way different types of disturbances affect the economy: in the case of a shock to collateral, the policymaker does not need not to be as much worried about model misspecification as in the case of a conventional cost-push shock. Intuitively, the financial shock pushes inflation and the output gap in the same direction and the policymaker, aiming at minimising the volatility of inflation, output gap and smoothing its policy rate, does not have to be very concerned about the trade-off between inflation and the output gap.

Nicht technische Zusammenfassung

Die jüngste Finanzkrise hat gezeigt, dass unvorhergesehene Schocks, die den Wert von Kreditsicherheiten (Kollateral) mindern, beträchtliche Folgen für die gesamte Ökonomie nach sich ziehen. Im vorliegenden Papier untersuchen wir die optimale Reaktion auf einen solchen Schock unter der Annahme diskretionärer Geldpolitik und Modellunsicherheit. Wir verwenden ein neu-keynesianisches Modell, in welchem Geschäftsbanken Kredite an transaktionsbeschränkte Konsumenten vergeben, und analysieren, ob robuste optimale Geldpolitik mehr oder weniger aggressiv auf eine schockartige Veränderung des Kollaterals reagiert. Im Besonderen untersuchen wir, in welcher Art und Weise robuste Geldpolitik bei Modellunsicherheit von optimaler Geldpolitik bei vollständiger Information abweicht, wenn über einen konventionellen Inflationsschock hinaus auch ein unvorhergesehener Schock, der den Wert des Kollaterals verändert, auf die gesamte Ökonomie trifft.

Zur Analyse der Implikationen von Modellunsicherheit verwenden wir den von Hansen und Sargent (2008) entwickelten Ansatz zur robusten Kontrolle. Wir unterstellen dabei, dass sich das wahre Modell des privaten Sektors in der Nähe eines Referenzmodells befindet und dass der Zentralbanker nicht in der Lage ist, eine Wahrscheinlichkeitsverteilung hinsichtlich plausibler Modelle zu formulieren. Im Rahmen dieses Ansatzes ist sich der Zentralbanker bewusst, dass die gesamtwirtschaftlichen Daten möglicherweise nicht vom Referenzmodell erzeugt wurden, sondern von einem ihm nicht bekannten Modell, das sich in der Umgebung des Referenzmodells befindet. Der Ansatz zur robusten Kontrolle ermöglicht dem Zentralbanker eine Politik zu wählen, die für die denkbar ungünstigsten Auswirkungen eines Schocks im Rahmen einer gegebenen Menge von Modellen die gesamtwirtschaftliche Entwicklung vergleichsweise gut stabilisiert.

Unsere Ergebnisse lassen sich wie folgt zusammenfassen: Eine Präferenz für Robustheit (also die Absicherung gegen Unsicherheit) führt zu einer aggressiveren geldpolitischen Reaktion auf alle der hier betrachteten Schocks. Erhöht man die Bedeutung, die der

Entscheidungsträger der Glättung des geldpolitischen Instruments beimisst, steigt der Grad der Aggressivität. Unsere Ergebnisse deuten darauf hin, dass eine Präferenz für Robustheit wesentlich von der Art und Weise abhängt, mit der unterschiedliche Schocks auf die Ökonomie treffen. Im Fall eines Kollateralschocks muss der Zentralbanker sich dabei weniger sorgen als im Fall eines konventionellen Inflationsschocks. Intuitiv lässt sich dies damit begründen, dass der Schock auf das Kollateral sowohl die Inflation als auch die die Produktionslücke in dieselbe Richtung lenkt. Der Zentralbanker, der darauf abzielt, Schwankungen der Inflation und der Produktionslücke – bei Vermeidung allzu großer Zinsschwankungen – zu minimieren, ist daher weniger beunruhigt hinsichtlich eines möglichen Zielkonflikts zwischen Inflation und Produktionslücke.

Contents

Lists of Tables and Figures

> *"Central banks generally recognise the need to cut the interbank rate in response to widespread financial distress."*
> Marvin Goodfriend and Bennett T. McCallum (2007, p. 1503)

More or less aggressive? Robust monetary policy in a New Keynesian model with financial distress[1]

1 Introduction

Thus far, there is no consensus about whether model uncertainty should lead to more aggressive or more cautious policy behaviour relative to the benchmark rational expectations (RE) case. Some economists, following the pioneering work of Brainard (1967), have argued that increased uncertainty about an economic model should lead to more cautious policy behaviour (e.g., Blinder, 1998). In contrast, Craine (1979) and Söderström (2002) have found among others that this result does not necessarily hold in general. Recently, the debate regarding model uncertainty has been analysed applying the robust control approach (Hansen and Sargent, 2008). Several authors have shown that an increased preference for robustness leads to a more aggressive policy (e.g., Giannoni, 2002). These authors rely on numerical methods to solve for the optimal robust policy in the canonical New Keynesian model.[2] Using an open economy version of the New Keynesian model, Leitemo and Söderström (2008) demonstrate that depending on the source of misspecification and the type of disturbance that affects the economy, the optimal robust policy can be either more or less aggressive. Thus, taking model uncertainty into account cannot be handled by a simple rule of thumb such as "if you are concerned about model misspecification just be more aggressive".

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[2] In this context robust policy means that policy takes model uncertainty into account.

We extend the existing literature on model uncertainty as we focus on a shock to collateral, which has played a prominent role since the beginning of the recent financial turmoil. In order to be able to analyse the detrimental effects of this shock, we use a New Keynesian model where banks supply loans to transaction constrained consumers following Goodfriend and McCallum (2007). The motivation in choosing this model is to explore whether the robust optimal monetary policy becomes more or less aggressive when the economy is exposed to financial distress. Specifically, we analyse in which way the robust monetary policy deviates from the optimal monetary policy under rational expectations if in addition to a conventional cost-push shock a shock to collateral hits the economy.

We apply the robust control approach following the seminal work of Hansen and Sargent (2008) and Giordani and Söderlind (2004). Accordingly, we assume that the true model of the private sector lies in the neighbourhood around a reference model and that the policymaker is not able to formulate a probability distribution over plausible models. One main feature of this approach is that it allows the policymaker to recognise that data may not be generated by the reference model of the economy but by an unknown model in the neighbourhood of the reference model. Robust control then provides a way for the policymaker to find a policy that performs well in the worst possible outcome of a pre-specified set of models.

Our results confirm the recent literature on model uncertainty with respect to a cost-push shock. Insuring against model misspecification leads to a more aggressive policy response. The same is true for the case of the shock to collateral: a preference for robustness leads to a more aggressive policy. Increasing the weight attached to interest rate smoothing raises the degree of aggressiveness. Yet, our results also indicate that a preference for robustness crucially depends on the way different types of disturbances affect the economy: in the case of a shock to collateral the policymaker does not need to be as much worried about model misspecification as in the case of a conventional cost-push shock. Intuitively, the financial shock pushes inflation and the output gap in the same direction and the policymaker, aiming at minimising the volatility of inflation, output gap and smoothing its policy rate, does not have to be very concerned about the trade-off between inflation and the output gap. Given our results there is no doubt about the introductory quote of Goodfriend and McCallum (2007): when taking model uncertainty into account and being concerned about interest rate smoothing the policymaker reacts (nevertheless) quite aggressively.

The remainder of the paper is organised as follows. In Section 2 we present the New Keynesian model with a banking sector, introduce the various short-term interest rates and the external finance premium. Then, we describe the steady state, the calibration and the linearised model. In Section 3 we give a short review of the robust control approach. Section 4 corroborates the results found in the literature with respect to a cost-push shock. In Section 5 we analyse the implications of model uncertainty in case of a shock to collateral. Finally, Section 6 concludes.

2 Model

2.1 A bird's eye view

Our analysis is based on the model proposed by Goodfriend and McCallum (2007) which features a goods producing sector and a banking sector. Goods are produced with capital and work effort as in a standard model. The banking sector, supplying loans to transaction constrained consumers, produces loans according to a production function with monitoring effort (i.e. labour) and collateral as inputs. Collateral consists of government bonds and capital. Loans and deposits are costly to produce, in the sense that they require work effort, while collateral services allow for an economisation of that effort. The rates of return on government bonds, deposits, collateralised loans and uncollateralised loans differ and are also different from the return on physical capital. In addition, a nominal (fictitious) security is introduced to provide a benchmark interest rate (for uncollateralised loans). In contrast to bonds, this security does not provide any collateral. We deviate from the exposition in Goodfriend and McCallum (2007), in which one agent simultaneously acts as household, firm and bank, and present a decentralised version of the economy. This makes explicit the interdependencies between the diverse agents of this economy.

2.2 Households

The representative household supplies labour to the goods sector n_t^s and to the banking sector m_t^s. It owns the aggregate capital stock K_t and provides collateral to the banking sector used for loan production. The collateral consists of government bonds B_{t+1} and the capital stock K_{t+1}. Furthermore, the household invests capital following the usual law of motion

$$I_t = K_{t+1} - (1-\delta) K_t. \tag{1}$$

The household maximises its life-time utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\phi \log\left(c_t^A\right) + (1-\phi) \log\left(1 - n_t^s - m_t^s\right) \right] \tag{2}$$

depending on a Dixit-Stiglitz consumption bundle c_t^A and leisure, discounted with a subjective factor β. The household faces two constraints. First, the budget constraint

$$\begin{aligned} & c_t^A + tax_t + \frac{B_{t+1}}{P_t^A\left(1+R_t^B\right)} + \frac{H_t}{P_t^A} + \frac{R_t^T L_t}{P_t^A} + q_t I_t \\ & = w_t\left(n_t^s + m_t^s\right) + \frac{B_t}{P_t^A} + \frac{H_{t-1}}{P_t^A} + \frac{R_t^D D_t}{P_t^A} \\ & + \frac{\tilde{R}_t^B B_{t+1}}{P_t^A\left(1+R_t^B\right)} + \tilde{q}_t q_t K_{t+1} + \tilde{q}_t q_t K_t + \Psi_t, \end{aligned} \tag{3}$$

where tax_t represents real lump-sum tax payments, B_{t+1} are nominal discount bonds held at the end of period *t* and H_t represents nominal holdings of base money at the end of period *t*. The household pays interest on (collateralised) loans $R_t^T L_t$, but earns interest on deposits $R_t^D D_t$. Further, the household receives real wage income $w_t\left(n_t^s + m_t^s\right)$ and payments from the bank of $\tilde{R}_t^B B_{t+1} \big/ \left[P_t^A\left(1+R_t^B\right)\right]$ on government bonds and $\tilde{q}_t q_t K_{t+1}$ on capital both used as collateral in the loan production. In addition, the household gets a rent on the capital used by the firm $\tilde{q}_t q_t K_t$.[3] The real price of capital is denoted by q_t. The shares of the goods producing firm are owned by the household, which therefore receives real profits Ψ_t.

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[3] Regarding the timing of the variables we follow Goodfriend and McCallum (2007).

Second, the household is subject to a transaction constraint, that is, it is required to pay for consumption spending during period *t* with deposits held in that period. The transaction constraint is

$$D_t = \frac{P_t^A}{V} c_t^A, \tag{4}$$

where deposits D_t equal the aggregate price level P_t^A over velocity *V* times aggregate consumption c_t^A.

2.3 Firms

Firms produce and sell a differentiated non-storable good c_t by means of a standard production function

$$c_t = K_t^\eta \left(A1_t n_t \right)^{1-\eta}, \tag{5}$$

where each firm demands (in a competitive market) labour n_t and uses capital K_t. The variable $A1_t$ represents a shock to productivity in goods production. In addition, the firm faces a conventional demand function of the Dixit-Stiglitz type

$$c_t = \left(\frac{P_t}{P_t^A} \right)^{-\sigma} c_t^A, \tag{6}$$

where P_t is the price of the differentiated good. Each firm maximises its profits in real terms, i.e. real revenues minus real factor costs

$$\Psi_t = \frac{profit_t}{P_t^A} = \frac{P_t}{P_t^A} c_t - w_t n_t - \tilde{q}_t q_t K_t. \tag{7}$$

2.4 Banks

Fully competitive banks enable households to conduct transactions in consumption and therefore provide liquidity services. Each bank's balance sheet consists of high-powered (base) money H_t and loans to households L_t as assets and households' deposits D_t as liabilities

$$H_t + L_t = D_t. \tag{8}$$

The bank's ratio of reserves over deposits is assumed to be constant:

$$rr \equiv \frac{H_t}{D_t}, \tag{9}$$

which allows us to rewrite the bank's balance sheet as

$$D_t = \frac{L_t}{1 - rr}. \tag{10}$$

The bank's production of loans in real terms is constrained by the following technology

$$\frac{L_t}{P_t^A} = \mathcal{F}\left(b_{t+1} + A3_t k q_t K_{t+1}\right)^{\alpha}\left(A2_t m_t\right)^{1-\alpha} \tag{11}$$

with $\mathcal{F}$ being a productivity coefficient and k a parameter determining the relative efficiency of capital as collateral. Factor inputs are labour for monitoring m_t and collateral $b_{t+1} + A3_t k q_t K_{t+1}$ with $b_{t+1} = B_{t+1} \big/ \left[P_t^A\left(1 + R_t^B\right)\right]$. The variable $A2_t$ represents a shock to productivity in the banking sector. The variable $A3_t$ captures the consequences of financial distress by affecting the value of capital as collateral in loan production. The production function determines loan supply.

The bank maximises its net interest rate income (consisting of interest received on loans $R_t^T L_t$ minus interest paid on deposits $R_t^D D_t$) minus costs spent on labour for monitoring loans $w_t m_t$, and costs for capital and bonds used as collateral, $\tilde{q}_t q_t K_{t+1}$ and $\tilde{R}_t^B B_{t+1} \big/ \left[P_t^A\left(1 + R_t^B\right)\right]$. The bank's profit function is

$$\frac{bankprofit_t}{P_t^A} = \frac{R_t^T L_t}{P_t^A} + \frac{S_t}{P_t^A} - \frac{R_t^D D_t}{P_t^A} - w_t m_t - \tilde{q}_t q_t K_{t+1} - \frac{\tilde{R}_t^B B_{t+1}}{P_t^A\left(1 + R_t^B\right)} - \frac{S_{t+1}}{P_t^A\left(1 + R_t^T\right)}, \tag{12}$$

where S_t is a (fictitious) one-period default-free security.[4] Because of the no-arbitrage condition that is imposed the bank lends to the household at (gross) rate R_t^T. As the bank pays for the collateral provided by the household $\tilde{q}_t q_t K_{t+1}$ and $\tilde{R}_t^B B_{t+1} \Big/ \left[P_t^A \left(1 + R_t^B \right) \right]$ the difference between those rates implies a (net) lending rate R_t^L.

2.5 Interest rates

Thus far we have not explored in which way the bond rate R_t^B relates to the rate of the nominal security R_t^T. The interest rate differential between these two rates can be obtained by substituting the Euler equation for the nominal security in the Euler equation for bonds

$$\frac{1+R_t^B}{1+R_t^T} = 1 - \left(\phi \frac{1}{c_t \lambda_t} - 1 \right) \Omega_t \tag{13}$$

with

$$\Omega_t \equiv \frac{\alpha c_t}{\frac{B_{t+1}}{P_t \left(1+R_t^B\right)} + A3_t k q_t K_{t+1}} \tag{14}$$

as the marginal value of collateral. Only if $\Omega_t = 0$ and/or $\left(\phi / \left(c_t \lambda_t \right) - 1 \right) = 0,$ these two rates are equal. As $\Omega_t \geq 0$ can be interpreted as the partial derivative of transaction constraint (4) with respect to collateral, the two rates differ as long as collateral services are valued at the margin. Goodfriend and McCallum (2007) note that with a production function (11) and $0 < \alpha < 1,$ both Ω_t and $\left(\phi / \left(c_t \lambda_t \right) - 1 \right)$ will be positive in all periods. Thus we can interpret $\left(\phi / \left(c_t \lambda_t \right) - 1 \right) \Omega_t$ as the liquidity service yield on bonds, LSY_t^B. The liquidity services are high when either the value of collateral is high or when the marginal utility is high relative to the household's value of internal funds (Gilchrist, 2007). Approximately the liquidity service yield on bonds is $LSY_t^B \approx R_t^T - R_t^B$. Capital

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[4] This security allows us to introduce the benchmark rate R_t^T that represents a pure intertemporal

will have the same risk properties as bonds in steady state. However, capital is less effective as collateral than bonds and therefore the liquidity service yield on capital is smaller, namely $LSY_t^K = k \cdot LSY_t^B$.

Monetary policy has not yet been introduced in the model and therefore there is no interest rate for monetary policy. We assume that banks can obtain funds directly from the central bank at a rate R_t^{IB} (or equivalently from the interbank market). Banks loan these funds to households at the rate R_t^T as the nominal security pays the same benchmark interest, reflecting a no-arbitrage condition between loan and asset markets. However, loan production requires monitoring as well as collateral provided by the households as factor inputs.[5] At the cost-minimising optimum the real marginal cost of loan production equals the factor price divided by that factor's marginal product (for each factor of production).[6] Thus, marginal cost can be calculated by dividing the real wage by the partial derivative of L_t/P_t with respect to m_t. However, as loans are collateralised in equilibrium and since $(1-\alpha)$ is the factor share for monitoring, the marginal costs of collateralised loans are

$$(1-\alpha)\cdot\frac{w_t}{(1-\alpha)(L_t/P_t)/m_t} = \frac{w_t}{(L_t/P_t)/m_t} = \frac{Vm_t w_t}{(1-rr)c_t}. \tag{15}$$

Profit maximisation by banks implies then

$$\left(1+R_t^{IB}\right)\left(1+\frac{Vm_t w_t}{(1-rr)c_t}\right) = \left(1+R_t^L\right). \tag{16}$$

If banks could also provide uncollateralised loans, the marginal costs for these loans would be higher. Specifically, full marginal costs would then be

$$\frac{1}{(1-\alpha)}\cdot\frac{Vm_t w_t}{(1-rr)c_t}. \tag{17}$$

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interest rate.

[5] The fact that households provide collateral to the bank affects their optimal decision regarding B_{t+1} and K_{t+1}.

[6] The marginal costs of loan management can be obtained by choosing the optimal mixture of factor inputs.

Because of the no-arbitrage condition between the loan market and the asset market (banks can also invest in the nominal security) banks would provide uncollateralised loans to households at the rate R_t^T, implying a differential between the policy rate R_t^{IB} and the benchmark rate R_t^T given by

$$\left(1+R_t^{IB}\right)\left(1+\frac{Vm_t w_t}{(1-\alpha)(1-rr)c_t}\right)=\left(1+R_t^T\right). \tag{18}$$

Finally, as banks pay households a rate R_t^D on their deposits and given that a fraction *rr* of interest-bearing deposits cannot be loaned implies

$$R_t^D=R_t^{IB}\left(1-rr\right). \tag{19}$$

To shed further light upon the links between the various interest rates, we follow Goodfriend and McCallum (2007) and identify the external finance premium (EFP) with the real marginal costs of loan production, since these costs reflect the cost of external finance emphasised by Bernanke, Gertler and Gilchrist (1999) among others. Households pay a loan rate that covers the real marginal cost to the policy (interbank) rate, which equals the deposit rate except for a small discrepancy due to the non-zero reserve ratio. Hence, the real marginal cost of loan production is an EFP from the household's perspective.

It is possible to distinguish between a collateralised and an uncollateralised EFP. On the one hand, the EFP on a collateralised loan would be $R_t^L-R_t^{IB}$ as this interest rate spread covers the portion of real marginal cost due to the monitoring effort, given that the household provides the requisite collateral. In effect, households who demand a collateralised loan get a deduction on the loan rate equal to the share α of collateral in loan costs. On the other hand, the uncollateralised EFP given by the spread between the uncollateralised loan rate and the interbank rate is $R_t^T-R_t^{IB}$, because this interest rate spread reflects the full marginal cost of loan production.

2.6 Steady state and calibration

The steady state is characterised by zero inflation and all variables growing (or shrinking) along a deterministic growth path. Specifically, the shock terms $A1_t$ and $A2_t$ in the production function for goods and loans grow at rate γ. Therefore, in the absence of any stochastic shock, the deterministic expressions for these two variables can be written as $A1_t = A_{10}(1+\gamma)^t$ and $A2_t = A_{20}(1+\gamma)^t$ with $A_{10} = A_{20} = 1$. The Lagrange multiplier λ_t of the household's optimisation problem shrinks at the rate γ. The aggregate capital stock K_t is kept constant over time at its endogenously determined steady-state value. The relative price of capital equals 1 as the model abstracts from any capital adjustment costs. The calibration of the model and its steady state are identical to Goodfriend and McCallum (2007) to which we refer for details. The steady state is calculated numerically starting with bonds over capital calibrated to 0.56. Table 1 gives a summary of the calibrated parameters.

Table 1: Calibration of parameters

α	β	γ	δ	η	κ	ϕ	σ	$\mathcal{F}$	k	rr	V
0.65	0.99	0.005	0.025	0.36	0.05	0.4	11	9	0.2	0.005	0.31

2.7 Linearised model

Assuming that prices are adjusted according to the Calvo (1983) mechanism, we get the following Phillips curve in log-linear terms

$$\Delta\hat{p}_t = \beta E_t \Delta\hat{p}_{t+1} + \kappa\widehat{mc_t} + u_t \tag{20}$$

where $\kappa > 0$ and u_t is a cost-push shock. Here $\hat{p}_t = \log P_t = \log P_t^A$ such that $\Delta\hat{p}_t$ denotes the inflation rate, while $\widehat{mc_t}$ is the log-deviation of the real marginal cost of goods production from its steady state. With Calvo pricing marginal costs depend on the ratio of the Lagrange multiplier of the goods market clearing condition ξ_t over the household's Lagrange multiplier λ_t

$$mc_t = \frac{\xi_t}{\lambda_t}. \tag{21}$$

We specify the cost-push shock u_t in the Phillips curve (20) and the collateral shock $a3_t$ in the banking sector as exogenous first-order autoregressive processes with $\rho^u = \rho^{a3} = 0.6.$[7] In linearised form we get

$$u_t = \rho^u u_{t-1} + \varepsilon_t^u \tag{22}$$

$$a3_t = \rho^{a3} a3_{t-1} + \varepsilon_t^{a3}. \tag{23}$$

The collateral shock $a3_t$ affects the parameter *k* in the loan production function (11) and can be interpreted as financial distress.

Except for the introduction of a cost-push shock, the linearised model derived so far is virtually identical to the one in Goodfriend and McCallum (2007, p. 1494-96). In the following sections, we extend the analysis of Goodfriend and McCallum (2007) to derive the optimal monetary policy response to shocks under model uncertainty. Specifically, we assume that the central bank sets the interbank interest rate R_t^{IB} according to the optimal solution under discretion, where the policymaker re-optimises every period by taking the process by which private agents form their expectations as given (see Söderlind, 1999 for a formal exposition). While optimal monetary policy under commitment may be interpreted as a "first best solution" we focus on optimal monetary policy under discretion as we assume that there is no commitment device. We derive the optimal policy rule numerically following Söderlind (1999) and Giordani and Söderlind (2004).

3 Taking into account model uncertainty: Robust control

Up to now we have assumed that the economic agents of the model know the true model of the economy with certainty. Uncertainty is implemented merely by additive errors such that certainty equivalence holds, that is, the actions of the agents depend solely on their expectations of future variables but not on the uncertainty surrounding those expectations.[8]

In the following we describe formally the general uncertainty surrounding the reference model along the lines of Hansen and Sargent (2008).[9] We follow the standard approach from the robust control literature and augment the so-called reference model with a vector of misspecification terms η_{t+1}. In state-space form the model including the potential misspecification terms can be described as

$$A_0 \begin{bmatrix} x_{1,t+1} \\ E_t x_{2,t+1} \end{bmatrix} = A_1 \begin{bmatrix} x_{1,t} \\ x_{2,t} \end{bmatrix} + B u_t + C\left(\eta_{t+1} + \xi_{t+1}\right), \tag{24}$$

where A_0, A_1 and B are matrices of model parameters, C is a vector that scales the impact of the vector of error terms ξ_{t+1}, $x_{1,t}$ is the vector of predetermined variables with $x_{1,0}$ given, $x_{2,t}$ is a vector of forward-looking variables and u_t is a vector of policy instruments.

The misspecification is assumed to be bounded as

$$E_0 \sum_{t=0}^{\infty} \beta^t \eta_{t+1}^{'} \eta_{t+1} \leq \eta_0, \tag{25}$$

where η_0 reflects the size of the potential misspecification.

The policymaker assumes that misspecifications are of the worst kind and maximises a loss function L_t subject to the constraint (25). Hansen and Sargent (2008) and Giordani and Söderlind (2004) show that this problem can be formulated as

$$\min_{u_t} \max_{\eta_t} E_0 \sum_{t=0}^{\infty} \beta^t \left(L_t - \theta\, \eta_{t+1}^{'} \eta_{t+1}\right) \tag{26}$$

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[7] Shocks are implemented as unit shocks and uncorrelated with each other. However, in the following dynamic analysis we drop the productivity shocks in the goods production sector $a1_t$ and in the banking sector $a2_t$, as well as a shock on government bonds b_t.

[8] If error terms enter differently, certainty equivalence will not hold anymore (Walsh, 2003).

[9] This exposition closely follows Kilponen and Leitemo (2008).

subject to (24). The parameter θ summarises the central bank's attitude towards model misspecification in setting its policy. In particular, $\theta > 0$ is related to η_0 such that in the case of no misspecification allowed $\lim_{\eta_0 \to 0} \theta = \infty$, while a smaller value of θ implies greater misspecification.

The equilibrium in the worst-case model can be described by substituting the solution in (24) and then solving for the reduced form in the usual way. The resulting system describes the worst-case model the central bank and the private sector wants to guard against. The approximating equilibrium can be obtained by assuming that there are no misspecification errors, but retaining the robust policy and expectation formation under the worst-case model. This gives the equilibrium dynamics under robust decision making by the central bank and the private sector.

In order to calibrate the parameter θ the concept of a detection error probability is adopted. The detection error probability is the probability of making the wrong choice between the approximating model and the worst-case model. Smaller values of θ allow for greater specification error, which make it easier for the econometrician to statistically distinguish between the two possible equilibriums. Hence, a smaller θ reduces the detection error probability.

4 Cost-push shock

4.1 Optimal discretion

We start by focussing on a cost-push shock because the presence of u_t in the Phillips curve (20) does not only generate a conflict between a policy designed to maintain inflation and the output gap (here: marginal costs) equal to zero but also illustrates in which ways the introduction of model uncertainty has an impact on the optimal policy response.[10] In the canonical New Keynesian model, uncertainty gives rise to a more aggressive policy response (e.g., Giannoni, 2002 and Giordani and Söderlind, 2004).[11]

In the following, we assume a loss function of the form

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[10] Much of the recent literature has focused on a change of the optimal policy response in the presence of a cost-push shock.

[11] A more aggressive policy allows the central bank to stabilise inflation and the output gap around their target values more effectively (see, e.g. Giannoni, 2002).

$$L_t = E_t \sum_{i=0}^{\infty} \beta^i \left(\Delta \hat{p}_{t+i}^2 + \lambda_{mc} \widehat{mc}_{t+i}^2 + \lambda_{\Delta i} \left(\Delta \widehat{R_{t+i}^{IB}} \right)^2 \right) \tag{27}$$

such that the central bank not only worries about the volatility of inflation and the output gap but also tries smoothing its own interest rate path. Our model's core is identical to the canonical New Keynesian model and we therefore follow Woodford (2003, p. 400) by setting $\lambda_{mc} = \kappa/\theta = 0.0045$. For the weight on interest rate smoothing we are agnostic and assume a range of $\lambda_{\Delta i} = [0.1, 1.0]$. This loss function is obviously not derived from a social welfare function related to household's preferences over consumption and leisure. Instead, we assume that society has delegated a concern for financial conditions to the central bank. Recent theoretical contributions such as Kobayashi (2008) and Teranishi (2008) show that in economies in which the financial sector has a non-trivial role, the loss function should be given a weight to a financial variable. More specifically, these authors derive a micro-founded loss function that entails interest rate smoothing.[12] We further assume that the central bank operates with discretion, that is, it does not bind itself to future policy and therefore is not able to affect the private sector's expectations about future inflation.

The blue (solid) lines in Figure 1 show the respective responses for the rational expectations (RE) equilibrium under optimal discretion. Although incorporating a banking sector, the model features qualitatively the same dynamics as the canonical New Keynesian model: The cost-push shock in the Phillips curve drives inflation up and the central bank reacts by increasing its policy instrument R_t^{IB}. Interest rate smoothing generates a hump-shaped response, which is also reflected in most other variables. Because of the persistence of the inflationary shock, the central bank increases its policy instrument for a prolonged period of time in order to keep the output gap (i.e. marginal costs) below its steady-state value for more than just one period. Tighter monetary conditions also dampen consumption, wages and employment in the goods producing as

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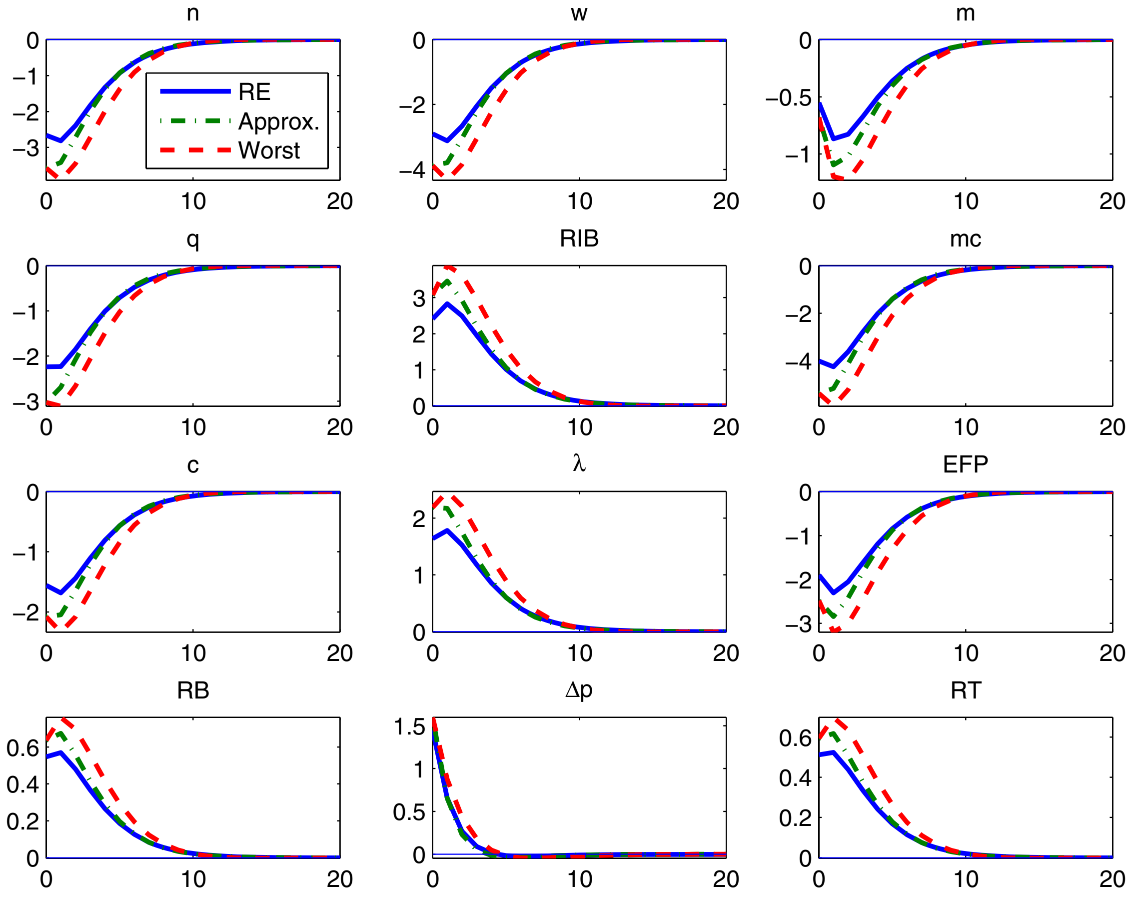
[12] In practice, central banks devote considerable effort analysing the financial conditions of households and firms. An array of estimated monetary policy rules suggests that central banks are concerned with respect to the evolution of financial market conditions as, for instance, too volatile interest rates may decrease potential output as the cost of capital increases due to a higher term premium stemming from agents having observed a large variance in the past (Tinsley, 1999). Therefore, interest rate changes may come at a cost in terms of welfare and central banks tend to smooth interest rates (Goodfriend, 1991).

well as the banking sector. These changes in turn lead to a decline of the external finance premium such that it moves procyclically. Remarkably, the pronounced rise in the policy rate is not mirrored by similarly sized increases in the interest rates R_t^B and R_t^T. Consequently, a central bank unaware of possibly varying effects on interest rate spreads would err in expecting all interest rates to behave like the benchmark rate R_t^T. Therefore, the benchmark rate R_t^T would be little helpful as an indicator regarding the stance of monetary policy. If the central bank would set the policy rate according to R_t^T it would not stabilise appropriately the economy in response to a purely transitory cost-push shock.

Figure 1: Responses to cost-push shock for $\lambda_{\Delta i} = 0.1$



4.2 Optimal discretion under model uncertainty

We now allow for model uncertainty. As shown in Figure 1, the impulse responses for the worst-case equilibrium (red, dashed lines) and the approximating equilibrium (green, dash-dotted lines) deviate substantially from the standard RE equilibrium. Most variables react stronger than in the RE equilibrium and return more slowly after some quarters to their steady-state values. Exactly these more volatile responses imply higher variances and therefore a greater loss for the risk-averse policymaker (Table 2). It is worthwhile to highlight the differences between the worst-case equilibrium and the approximating equilibrium. Evidently, the insurance against model misspecification already gives rise to more persistent responses in comparison to the RE equilibrium. In the worst-case equilibrium, where the model is indeed misspecified, the corresponding responses become even more persistent. Accordingly, the loss in the worst case turns out to be higher. The difference between the loss of the approximating equilibrium and the loss of the RE equilibrium over the difference between the worst-case equilibrium and the RE equilibrium gives an insurance premium of roughly 56%.

Table 2: Losses with $\lambda_{\Delta i} = 0.1$, $\theta = 33.84$, $p(\theta) = 0.25$

RE equilibrium	Worst-case equilibrium	Approximating equilibrium	Insurance premium in %
3.62	5.37	4.61	56.45

Note: Differences due to rounding errors.

Taking model uncertainty into account, the robust policymaker reacts more aggressive as the response of R_t^{IB} is more pronounced in both the worst-case and the approximating equilibrium compared to the RE equilibrium. The robust policy is reflected in the coefficients of the optimal instrument rule of Table 3, where the response to the cost-push shock increases from 2.41 to 3.08.[13]

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[13] In other words, monetary policy becomes more aggressive when taking into account uncertainty surrounding the Phillips curve. Being more aggressive is not a unique result for the model at hand, as others (e.g., Giannoni, 2002) have also concluded that robustness leads to more aggressive policies. However, this result is not general as the outcome will depend both on the model and on the loss function (Hansen and Sargent, 2008 and Leitemo and Söderström, 2008).

Table 3: Parameters of optimal instrument rules for a loss function with $\lambda_{\Delta i} = 0.1$, $\theta = 33.84$, $p(\theta) = 0.25$

	$a3_t$	u_t	P_{t-1}	R_{t-1}^{IB}
RE rule	0.27	2.41	0.00	0.57
Robust rule	0.30	3.08	0.00	0.53

Two remarks are in order. First, a central bank using the benchmark rate R_t^T as an indicator for stabilising the economy would move its policy rate not appropriately in response to a transitory cost-push shock. Thus, a central bank ignoring or being unaware of possibly varying effects on interest rate spreads would err in expecting all interest rates to behave like the benchmark rate R_t^T. Second, model uncertainty comes at a cost by increasing the volatility of key variables. Similar to the canonical New Keynesian model, the central bank's reaction becomes more aggressive.

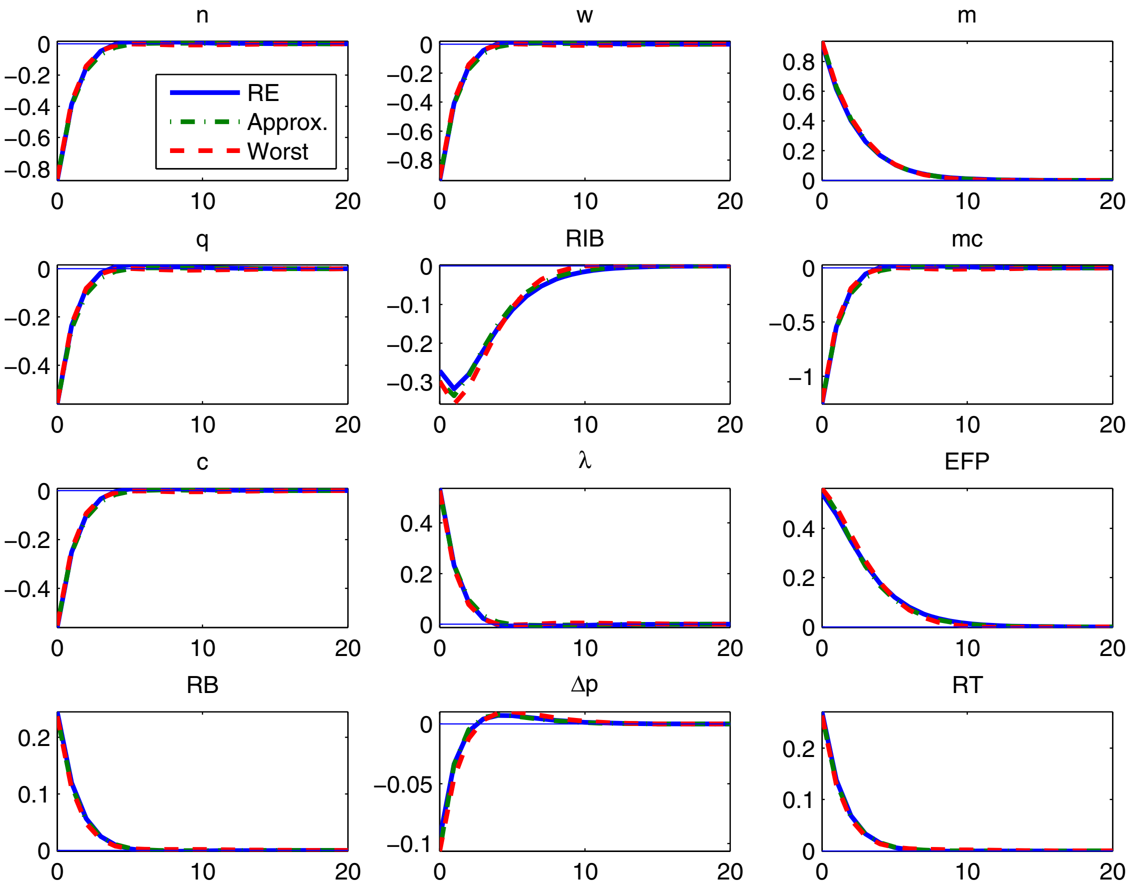
5 Financial distress

5.1 Optimal discretion

Now we turn to a shock to collateral $a3_t$ that emanates from the banking sector itself. This shock makes capital less productive in securing and producing loans and thereby captures the consequences of financial distress. Formally, financial distress is modelled as a shock to k in the loan production function (11). As illustrated in Figure 2, optimal monetary policy under discretion (blue, solid lines) does not fully stabilise inflation and real marginal costs. The central bank avoids large changes of its policy rate R_t^{IB} following the aim of interest rate smoothing.

The transmission of the shock works as follows. The household does not provide enough additional collateral to compensate the fall in k leading to a lower value of household's collateral and thereby inducing a decline in consumption. Lower consumption decreases employment in the goods production sector n_t. Following the transaction constraint (4) there is less need to hold deposits. As therefore the demand for loans decreases the bank only partly compensates the decline in effective collateral by increasing hours worked in banking m_t. This rise of employment in the banking sector is, however, dominated by the decline of employment in the larger goods production sector such that the total effect on wages w_t is negative. By reducing consumption the shock to the efficiency of collateral reduces marginal costs and thereby inflation. The central bank cuts its policy rate R_t^{IB}. This decrease together with the increase in R_t^T triggers an increase of the external finance premium. In contrast to the cost-push shock, the shock to collateral induces the external finance premium to move countercyclically.

Figure 2: Responses to shock to collateral for $\lambda_{\Delta i} = 0.1$



As the interest rates responses differ from each other, financial market conditions cannot be summarised in a single variable. The benchmark rate would not be an appropriate indicator for the monetary policy stance. As emphasised in our introductory quote by Goodfriend and McCallum (2007) the central bank fully aware of the financial shock would recognise the need to decrease their policy rates substantially. Yet, given the absence of banking in the canonical New Keynesian model, there would be no direct way to judge by how much the policy rate had to be cut. Our results indicate that a 1% decline in effective collateral requires a sizeable cut of the policy rate of annualised 1.2 percentage points.

5.2 Optimal discretion under model uncertainty

For the shock to collateral, the impulse response functions of the worst-case equilibrium (red, dashed lines) in Figure 2 almost coincide with the RE equilibrium. The robust policy (green, dash-dotted lines) only slightly differs to the policy without concern for misspecification. This result also holds for lower values of the robustness parameter θ until the degree of misspecification becomes so large that the model collapses due to instable solutions. As already mentioned, model uncertainty comes at a cost. Yet, as the impulse responses of the three equilibriums are close to each other, the loss associated with model uncertainty in Table 2 can be attributed largely to the uncertainty surrounding the cost-push shock.

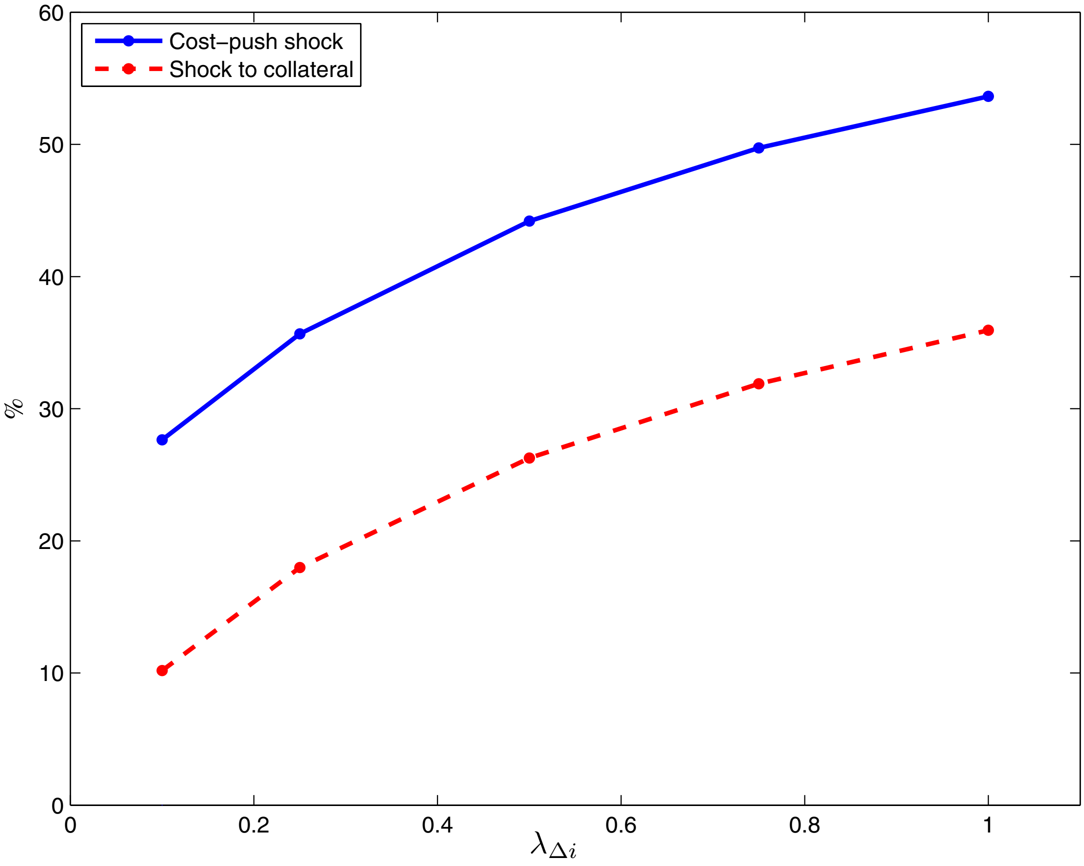
Relative to the coefficient associated with the cost-push shock, Table 3 shows that the coefficient of financial distress $a3_t$ changes by less when moving to the robust policy rule. Thus, the shock to collateral does not induce an as great concern for model misspecification as the cost-push shock. The policymaker can be quite confident that decreasing the policy rate in response to financial distress is an appropriate policy response.

Our results were based on a fairly small weight given to interest rate smoothing in the loss function. This choice was motivated by the academic literature, which sets a weight ranging between 0.1 and 0.5 (e.g., Rudebusch, 2006). Yet, we are agnostic whether our chosen weight of $\lambda_{\Delta i} = 0.1$ is adequate for our model.

In the following we therefore vary the weight on interest rate smoothing. This allows us to investigate whether two of our main results remain valid. First, does model uncertainty induce a more aggressive policy response to both shocks? Second, has the policymaker to be less concerned about the uncertainty surrounding the shock to collateral? We illustrate how the aggressiveness of the robust policy rule increases by raising the weight $\lambda_{\Delta i}$ from 0.1 to 1.0.[14] More precisely, we show the percentage increase of the coefficient of the robust rule compared to the respective coefficient of the RE rule, for example $\left(a3^{Robust} - a3^{RE}\right) / a3^{RE}$. In order to be able to compare the influence of varying $\lambda_{\Delta i}$ we keep the size of the potential misspecification constant implying a detection error probability $p(\theta)$ of 0.25.

The blue (solid) line in Figure 3 corresponds to the cost-push shock, whereas the red (dashed) line corresponds to the shock to collateral. As might be expected, for the cost-push shock the degree of aggressiveness increases with a higher $\lambda_{\Delta i}$. Perhaps less expected, the same holds for the shock to collateral. Interestingly, the degree of aggressiveness is always higher for the cost-push shock. In short, the result of being more aggressive does not hinge on the underlying weight for interest rate smoothing.

Figure 3: Increases of aggressiveness in percent for different weights of $\lambda_{\Delta i}$



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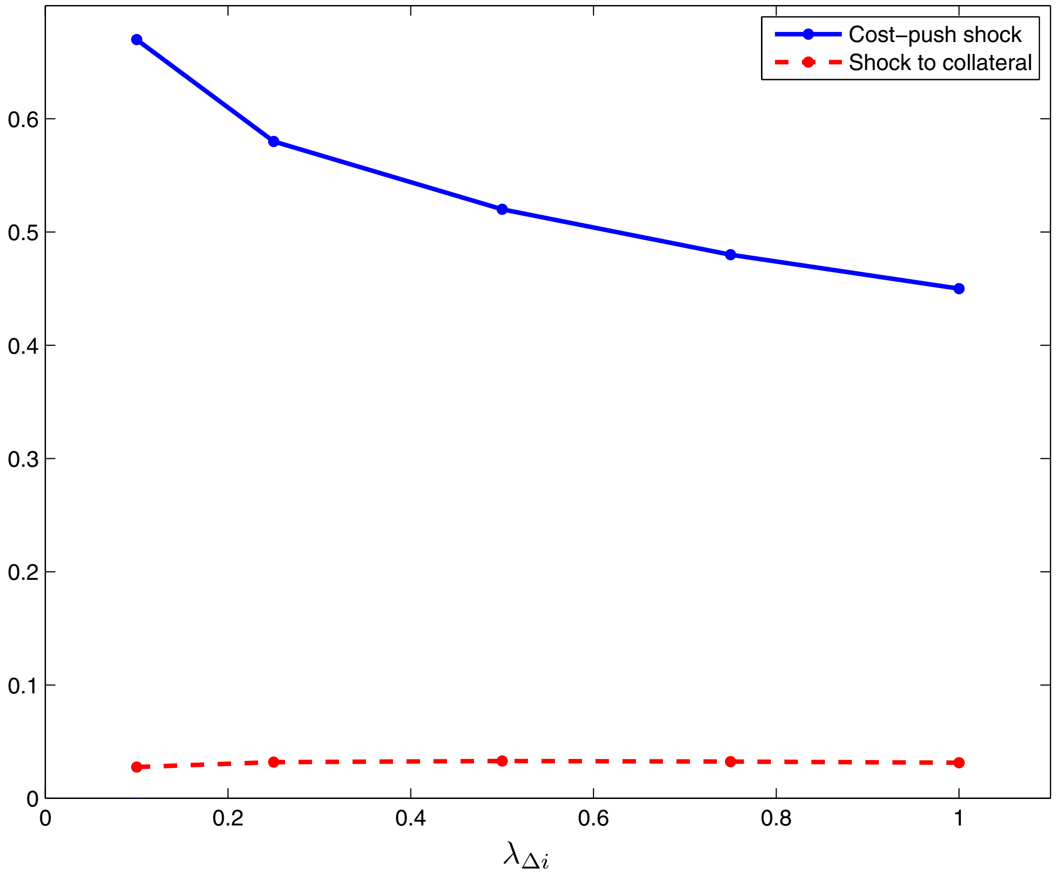
[14] Appendix Tables 1a to 3a provide detailed results.

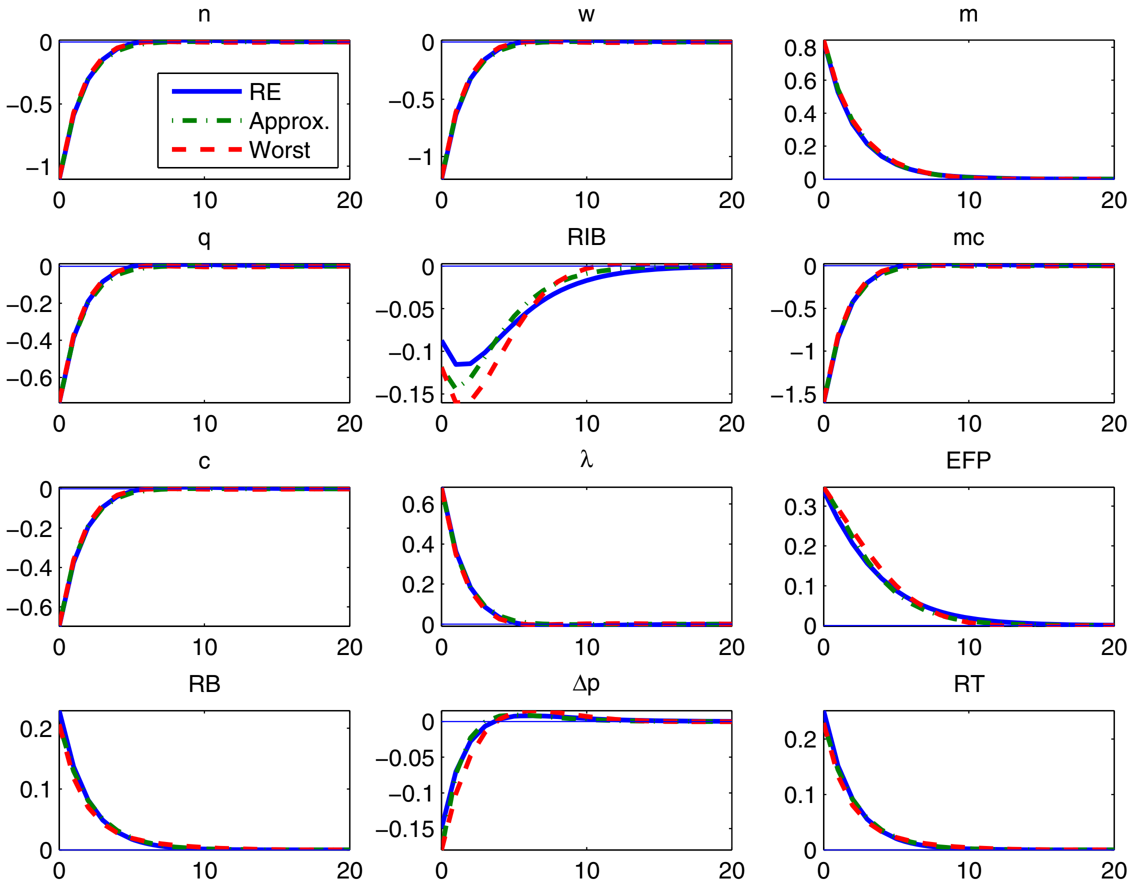
Three remarks are in order. First, when focussing on the absolute difference between the coefficient of the robust rule and the RE rule, for example $a3^{Robust} - a3^{RE}$, we find that aggressiveness decreases in the case of a cost-push shock but remains roughly constant at 0.03 for the shock to collateral (Figure 4). Second, for a value of $\lambda_{\Delta i} = 0$ (not shown) a shock to collateral does not induce the policymaker to become more aggressive. Instead, the impulse responses for all three equilibriums coincide. This is not true for the respective responses to a cost-push shock. Third, if the central bank does not penalise changes in the policy rate but deviations of the policy rate from its steady state (e.g., Woodford, 2003, p. 429) our results carry over. However, the degree of aggressiveness remains largely unchanged if the weight on the policy rate is increased.

Figure 4: Absolute changes in aggressiveness for different weights of $\lambda_{\Delta i}$



With respect to our second question, it is sufficient to present a snapshot for $\lambda_{\Delta i} = 1$. Figure 5 shows that increasing the weight does change the transmission of the shock to collateral. As expected the higher weight on interest rate smoothing gives rise for a more muted policy response compared to Figure 2. Consequently, the economy as a whole is less stabilised in the sense that the initial deviations from steady state are more pronounced and the impulse responses are somewhat more persistent.

Figure 5: Responses to shock to collateral for $\lambda_{\Delta i} = 1$



The worst-case and the approximate equilibrium deviate only slightly from the RE equilibrium with one exception.[15] The policy rate R_t^{IB} decreases visibly by more than in the RE case. Accordingly, the robust policy response is more aggressive in both the

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[15] The close correspondence of the three equilibriums also holds for much higher weights on interest rate smoothing.

worst-case and the approximating equilibrium (Table 4). In the present model, the more aggressive policy associated with the increase of $\lambda_{\Delta i} = 0.1$ to $\lambda_{\Delta i} = 1$ comes at a cost: the insurance premium raises from 56% to 62% (Table 5).

Table 4: Parameters of optimal instrument rules for a loss function with $\lambda_{\Delta i} = 1, \ \theta = 57.75, \ \ p(\theta) = 0.25$

	$a3_t$	u_t	P_{t-1}	R_{t-1}^{IB}
RE rule	0.09	0.84	0.00	0.72
Robust rule	0.12	1.28	0.00	0.61

Table 5: Losses with $\lambda_{\Delta i} = 1, \ \theta = 57.75, \ \ p(\theta) = 0.25$

RE equilibrium	Worst-case equilibrium	Approximating equilibrium	Insurance premium in %
5.58	9.89	8.23	61.63

Note: Differences due to rounding errors.

6 Conclusions

Financial distress challenges central banks with respect to at least two questions: First, should a central bank react to a shock in the financial sector and how? Second, given that the central bank faces model uncertainty, should its response to a shock to collateral be different from the appropriate response in the RE model?

Regarding the first question we corroborate the findings of Goodfriend and McCallum (2007) by letting monetary policy operate optimally under discretion. The central bank should reduce its policy rate substantially when faced with financial distress. A financial shock, modelled as a decline in the effectiveness of collateral, introduces a spread between the intertemporal interest rate and the policy rate. Ignoring this spread leads to poor stabilisation.

In this paper we focus on the second question and look for robust responses of the central bank to potential model misspecification using a New Keynesian model that is extended by a banking sector. We apply the robust control approach to derive the robust rules under optimal discretion. These robust rules turn out to be more aggressive than the rule under rational expectations both with respect to a cost-push shock and a shock to collateral. Thereby, we confirm those proponents that have argued in favour of a more aggressive policy in light of model uncertainty.

This basic insight does not critically depend on the specification of the loss function as an increase in the weight attached to interest rate smoothing does not change the results. Yet, although model uncertainty does induce a policymaker to cut interest rates more aggressively the responses of other macroeconomic variables do not show a notable deviation from the RE equilibrium.

Our findings are related to other extensions of the New Keynesian model (Leitemo and Söderström, 2008 and Dennis, Leitemo and Söderström, 2009). In that strand of the literature, the presence of the exchange rate leads to an additional trade-off and thereby an additional source for model misspecification. As we have assumed that society is reluctant to volatility of the policy rate, a shock to collateral gives rise to a trade-off between inflation and marginal costs on the one hand and interest rate smoothing on the other. Precisely because of this additional trade-off insuring against model uncertainty leads the policymaker to be more aggressive than in the RE equilibrium.

Appendix

Table 1a: Increases of aggressiveness in percent for different weights of $\lambda_{\Delta i}$

$\lambda_{\Delta i}$	0.10	0.25	0.50	0.75	1.00
Cost-push shock	27.65	35.67	44.19	49.73	53.63
Shock to collateral	10.18	17.98	26.26	31.89	35.93

Table 2a: Parameters of optimal instrument rules for different weights of $\lambda_{\Delta i}$

$\lambda_{\Delta i}$	θ	Policy rule	$a3_t$	u_t	P_{t-1}	R^{IB}_{t-1}
0.25	42.90	RE rule	0.18	1.62	0.00	0.64
		Robust rule	0.21	2.20	0.00	0.57
0.50	50.00	RE rule	0.13	1.18	0.00	0.68
		Robust rule	0.16	1.70	0.00	0.60
0.75	54.42	RE rule	0.10	0.97	0.00	0.71
		Robust rule	0.13	1.45	0.00	0.61
1.00	57.75	RE rule	0.09	0.84	0.00	0.72
		Robust rule	0.12	1.28	0.00	0.61

Table 3a: Losses for different weights of $\lambda_{\Delta i}$

$\lambda_{\Delta i}$	θ	RE equilibrium	Worst-case equilibrium	Approximating equilibrium	Insurance premium in %
0.25	42.90	4.33	6.76	5.79	60.31
0.50	50.00	4.94	8.23	6.96	61.36
0.75	54.42	5.31	9.20	7.70	61.58
1.00	57.75	5.58	9.89	8.23	61.63

Note: Differences due to rounding errors.

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