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Business Cycle Analysis: Comparing DSGE models with Financial Frictions

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This thesis compares DSGE models with financial frictions in two ways. First, a theoretical comparison sets out the incorporation of financial frictions into standard DSGE models. The implications of these frictions for the transmission mechanism after an unexpected monetary tightening are then demonstrated by a quantitative comparison. DSGE models with financial frictions on the level of firms mainly differ from the standard DSGE models by the larger drop in investment caused by the rise in the external finance premium. On the level of financial intermediaries, the model with financial frictions implies substantial differences for the transmission mechanism as consumption barely drops while investments decline exponentially. Furthermore, investment or capital adjustment costs have substantial implications for the magnitude and duration of the fall in investment and output.

Key words: Financial frictions, DSGE models, Monetary policy

Content

List of Abbreviations:

BGG: Bernanke, Gertler and Gilchrist (1999)
CEE: Christiano, Eichenbaum and Evans (2005)
CEE-rule: Monetary policy rule as estimated in Christiano, Eichenbaum and Evans (2005)
CD: Christensen and Dib (2008)
DG: Degraeve (2008)
EFP: External finance premium
GK: Gertler and Karadi (2011)
GR-rule: Monetary policy rule as estimated in Gerdesmeier and Roffia (2004)
LWW-rule: Monetary policy rule as estimated in Levin, Wieland and Williams (2003)
SW: Smets and Wouters (2007)
SW-rule: Monetary policy rule as estimated in Smets and Wouters (2007)
TR-rule: Monetary policy rule as estimated in Taylor (1993a)

1. Introduction

[1]As the financial crisis unfolded, it became clear that financial markets are not working perfectly. Banks were overleveraged and had overvalued their assets. The financial sector was vulnerable and when the mortgage market crisis erupted, it quickly spilled over into a worldwide financial crisis. Suddenly, asset prices dropped sharply and banks were under severe pressure as their own equity quickly diminished. As the balance sheet worsened, banks tightened credit lending standards and raised the required interest rate on loans. As loans became scarcer and more expensive, firms invested less which led to a downturn in the real economy. Thus, the financial crisis was at the roots of what is now already known as the "the Great Recession".

As the reigning paradigm of perfectly working financial markets was severely criticized, researchers started to investigate how financial imperfections could be introduced into the existing macroeconomic models. One important strand of macroeconomic models are the dynamic stochastic general equilibrium (DSGE) models. These models have been used extensively to address multiple macroeconomic questions. In addition, the DSGE models have become part of the standard toolkit of central banks to evaluate policy changes. However, the baseline version of standard DSGE models, like the Smets and Wouters (2007) model, assumed that there are no frictions in the financial sector. Although there is no disagreement that the real and financial economies interact, the still rapidly expanding literature on financial frictions shows that there is still much debate about the precise nature and extent of this interaction. A comparison of the features of the existing financial frictions models can therefore lead to a better understanding of this interaction. This enhanced understanding can then lead to improved policy making, both from the government and central bank. In addition, these models can shed light upon the dynamics of the financial crisis and the ensuing developments.

As to the concrete way to incorporate financial frictions into macroeconomic models, there are three main approaches in the literature to do so. The first approach is to model financial frictions on the firm level, which is done in Bernanke, Gertler and Gilchrist (1999), Christensen and Dib (2008) and Degraeve (2008). The second approach is to model financial frictions on the level of the financial intermediary like in Kyotaki and Moore (2007), Gerali et al. (2010), Cúrdia and Woodford (2010) and Gertler and Karadi (2011). The third approach, is to model frictions on the level of households like in Iacoviello (2005). All these papers, however, only have an in-model comparison.

[1] I would first of all like to thank Professor Smets for giving me the opportunity to work on this intriguing topic. Furthermore, I would also like to thank Dr Villa for her advice and insightful remarks on the financial frictions models. My thanks also go to Joke Dujardin and Fleur Verbiest, whose comments were very valuable towards the creation of this thesis.

As policy makers face uncertainty about the nature of the economy and the transmission mechanism, they have an incentive to adopt policies that are robust across models. Therefore, researchers have done cross-model comparisons to analyze their implications for monetary policies. Examples of these comparisons and their implications for robust monetary policy rules can be found in Bryant et al. (1993), Levin, Wieland and Williams (2003), Taylor and Wieland (2012) and Cogley et al. (2011). However, a comparison across models with financial frictions has not been done before. So while the financial frictions papers only do an in-model comparison, the cross-model comparisons have not addressed the full range of financial frictions models.

Therefore, this thesis aims to compare financial frictions models along two dimensions. The first dimension is to compare how these models differ in their set-up. This theoretical comparison will consist of a broad overview of the most important features of the models. The focus, however, will lie on the modeling of financial frictions. The second dimension is to investigate how the models quantitatively differ in response to a monetary shock. This quantitative comparison will be done in the standardized framework of the Macroeconomic Model Database that was created by Wieland et al. (2012). While this database can be used for both model comparisons and policy robustness exercises, this thesis will focus on the comparison of models and their impact on the transmission mechanism. The models that were selected are available in the database, contain financial frictions and were estimated or calibrated on the US economy.

The quantitative comparison shows that the different financial frictions approaches have implications for the transmission mechanism following a monetary shock. While DSGE models with financial frictions on the firms' level mainly differ with the standard DSGE models in the investment dynamics, the model with financial frictions on the level of financial intermediaries implies substantial differences in the way a shock is propagated through the economy. Furthermore, the choice of capital or investment adjustment costs has significant implications for the intensity and duration of the drop in output.

The rest of the thesis is organized as follows. Section 2 gives an overview of DSGE models and discusses their basic framework. Section 3 discusses the two approaches to incorporate financial frictions into DSGE models. Section 4 analyzes the real effects of monetary policy and how these are incorporated into the database. Section 5 compares the reactions of the models to an unexpected monetary tightening. Section 6 concludes.

2. DSGE models

2.1. General overview of DSGE models

DSGE models are macro-economic models built upon micro-foundations. Their purpose is to investigate and explain macroeconomic topics like business cycles and the impact of policy shocks. These models are extensively used at central banks to analyze policy implications. They are entire, albeit simplified, economies derived from the rational optimizing behavior of agents. The basic agents in these models are households, firms and central banks. All these agents have an objective function that they try to maximize. Households maximize their utility with respect to income and leisure. Firms maximize their profits and central banks try to minimize the welfare costs from fluctuations. Furthermore, the agents take possible future developments into account. Some of these developments, however, are not fixed but have a certain expected probability of occurring, which is why these models are called stochastic. These are general equilibrium models because a change in one sector influences all the other sectors. If all markets are cleared and agents no longer have an incentive to deviate, the equilibrium has been reached.

DSGE models have three main advantages. A first advantage is that they bring theoretical rigor to the table, as modeling an entire economy from the ground up is quite comprehensive. A second advantage is that these models can be used for welfare analysis. Since they contain households with preferences, welfare gains and losses can be calculated and used as a benchmark for analyzing the impact of different policies. A third advantage is that, since they are micro-founded, DSGE models are not subject to the Lucas critique and can be used for policy analysis. Traditional macroeconomic models estimated the economy based on a certain economic structures. Once this structure was established, the impact of a shock was assessed. However, as Lucas (1976) pointed out, expectations are important in the optimizing behavior of agents. The changing policy affects the expectations of agents which causes changes in the originally estimated model. So the model that was used to evaluate the policy change no longer holds the moment the policy is introduced. DSGE models address this critique because they include micro-foundations and rational expectations. Therefore, these DSGE models can be used to investigate the effect of policy changes.

Although the DSGE models have advantages, they also have limitations. A first limitation is that these models assume that agents have full information and behave rationally and optimize over the course of their lifespan. However, efforts have been made to incorporate the limited information, habit formation and back-ward looking agents into these models, and thus to create more "realistic" models. A second limitation is that the models that will be compared in this thesis are all linearized DSGE models. Linearized DSGE models analyze the fluctuations of the economy around a steady state. Brunnermeier and Sannikov (2011) warn against this because these linearized models cannot fully capture the effects of shocks like the financial crisis that move the economy far away from its steady state.[2] To address this issue, they develop a non-linear system of equations. The disadvantage of this approach is that it is computationally quite demanding and requires very complex models. In addition, in non-linear models, the impact of a wrong equation/modeling can be quite large whereas linear models are more robust to modeling errors.

DSGE models can differ in what they model. For example, they can include an extensive financial or labor sector. In addition, they can differ in how they model these sectors. The estimation strategy also plays a role. Calibrated models set their parameters in part according to research that estimated these parameters, and in part to correspond to the data. Estimated models, while using priors, fully calculate their parameters to let the model match the data as best as possible. As the estimation and calibration depend on data, the specific data that are used will also play a role.

The benchmark for current DSGE models was set by Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2003, 2007) who incorporated new theoretical insights and estimation techniques. However, financial frictions were largely absent in these models. Therefore, efforts were made to incorporate financial frictions based on credit-constraints for firms into these models. This literature started with Bernanke and Gertler (1989) and led to a financial accelerator which was incorporated into a full macroeconomic model by Bernanke et al. (1999). Degraeve (2008) and Christensen and Dib (2008) build further on the BGG-framework as they integrate the same financial frictions in more comprehensive DSGE models. The financial crisis, however, highlighted that there were also financial frictions on the level of financial intermediaries. Resent research has focused on modeling financial intermediaries and possible sources for their imperfections like market power, credit spreads, liquidity risks.

2.2. Standard DSGE models

This section will analyze the Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007) models. These models have become standard DSGE models, and are also the models upon which the other papers build their financial frictions. Apart from discussing the Christiano et al. model, there will be a more substantial treatment of the key equations in the Smets and Wouters model for two reasons. The first reason is to provide some insight into the workings of their DSGE-model. The second reason is that it will aid in explaining the reactions to an unexpected monetary tightening later on.

Christiano, Eichenbaum and Evans (2005, henceforth CEE) build a DSGE-model to specifically investigate the reaction of the economy to a monetary shock. They incorporated advancements in research by introducing habit-formation in preferences for consumption, investment adjustment costs, variable capital utilization and an interest cost channel. This last feature is absent in Smets and Wouters (2007). CEE use a limited information strategy to estimate the model. They find that wage stickiness is an important factor for the

[2] In their paper they go into more detail about the limitations of linearized models

performance of the model. Furthermore, the model follows a hump-shaped pattern for output and its components, in line with the data. One drawback, however, is that they only include a monetary shock into the model.

Smets and Wouters (2007, henceforth SW) build a DSGE model that was estimated using Bayesian techniques. In contrast to the one monetary shock of CEE, they include seven shocks. They show that their model corresponds well to the empirical features of the US economy. Furthermore, they analyze which of the seven shocks are most important in the explanation of the business cycle. In addition, they address multiple macroeconomic questions using this Bayesian framework as it allows to easily test different microeconomic specifications.

The SW model has become a benchmark DSGE-model, as many DSGE models are based upon it. For example, the Degraeve (2008) and Gertler and Karadi (2011) models have a SW-"core" upon which they build their frictions. The model that will be presented here is the loglinearized version of the SW model. Therefore, all small letters are defined as the deviations of output from the flexible output gap. As the quantitative shock that will be analyzed later on is a demand shock, the main focus will be on the equations for the demand side of the economy. A full exposition and analysis of the model can be found in Smets and Wouters (2003).

The first equation is the one that determines consumption and is known as the *Euler equation*:

$$c_t = c_1 c_{t-1} + (1 - c_1) E_t c_{t+1} + c_2 (l_t - E_t l_{t+1}) - c_3 (r_t - E_t \pi_{t+1} + \varepsilon_t^b)$$

The Euler equation indicates that consumption depends on the expected future consumption $E_t c_{t+1}$. If you expect to consume more in the future, you will already increase your consumption in the present. In addition to this forward looking component, consumption also has a backward looking component c_{t-1}. This component arises because SW introduce habit formation. Habit formation implies that households wish to have a certain continuity of the consumption of the previous period. The parameter c_1 indicates how strong the backward looking component is in comparison with the forward looking component. Because SW have a non-separable utility function of consumption and labor, consumption also depends on the evolution of hours worked. More traditionally, consumption depends inversely upon the real interest rate $r_t - E_t \pi_{t+1}$. An increase in the real interest rate has two effects; one is that it decreases the current wealth of consumers, the other that it makes borrowing more expensive and saving more attractive. There is also a shock ε_t^b that completes this equation.

The next equation is the *investment equation*:

$$i_t = i_1 i_{t-1} + (1 - i_1) E_t i_{t+1} + i_2 q_t + \varepsilon_t^i$$

The investment equation says that current investment is influenced by investment of the previous period i_{t-1}, expected investment of the next period $E_t \mathrm{i}_{t+1}$, and the value of installed capital q_t. SW derive this equation by assuming investment adjustment costs rather than the traditional capital adjustment costs. The advantage of investment adjustment costs

is that it introduces more dynamic behavior of investments. This dynamic behavior arises because, as it is costly to have large changes in the level of investments, firms have an incentive to set their investment levels not too far off from past and future optimal investments. Furthermore, investment traditionally depends upon the current value of capital, reflected by Tobin's q. If this value increases, investment becomes more profitable and firms will increase their investments.
The arbitrage equation of capital is given by:

$$q_t = q_1 E_t q_{t+1} + q_1 E_t r_{t+1}^k - (r_t - E_t \pi_{t+1} + \varepsilon_t^b)$$

The current value of capital q_t is a function of the expected future value q_{t+1}, the real rental rate of capital r_{t+1}^k, and the real interest rate $r_t - E_t \pi_{t+1}$. As the expected future value increases, the current value will increase as well due to the arbitrage. Furthermore, as capital becomes more productive, reflected by a rise in the expected real rental rate, capital becomes more valuable and its price will rise. However, if the real interest rate rises, this will negatively affect asset prices as the future payoffs decline in real worth. Furthermore, this equation contains the same shock as in the consumption equation. This risk premium shock represents the wedge between the interest rate of the central bank and the rate households earn on their assets. SW show that this shock creates the same effect as a net worth shock in the BGG model, which will be addressed later. As such, SW can create similar dynamics as models with financial frictions on the firm level that have a net worth shock. However, it does not have endogenous balance sheet constraints.
The capital accumulation equation is given by:

$$k_t = k_1 k_{t-1} + (1 - k_1) i_t + k_2 e_t^i$$

Where capital depends upon the previous capital $k_{t-1}$and current investments i_t.
The inflation equation is:

$$\pi_t = \pi_1 \pi_{t-1} + \pi_2 E_t \pi_{t+1} - \pi_3 \mu_t^p + e_t^p$$

Current inflation π_t, depends upon expected inflation $E_t \pi_{t+1}$, past inflation π_{t-1} and negatively upon a price mark-up shock μ_t^p. As SW introduce indexation to past prices, past inflation influences current inflation. If there would be no indexation, SW show that this equation reverts back to a purely forward looking inflation equation. The price mark-up is the difference between the marginal product of labor and the real wage. This mark-up enters the equation because of staggered wage setting. Wage stickiness prevents mark-ups from remaining constant as wages are not fully flexible. Thus, a positive mark-up shock will decrease inflation because firms can produce more efficiently and will therefore set their prices lower as a result.

3. Financial frictions models

3.1. Financial frictions on the firm level

There are essentially three approaches to financial frictions. The first approach models the frictions on the level of firms. In this approach, firms are constrained in their borrowing by their own net worth. The second approach is to focus on the financial intermediary level. Frictions arise on this level because financial intermediaries are constraint in their lending to firms. The third approach is to model frictions on the household level, like in Iacoviello (2005). However, these frictions will not be discussed in this thesis.

This section will go into more detail on how the financial frictions on the firms' level are incorporated into DSGE models. First, Bernanke et al. (1999) will be discussed in-depth as this paper provided the basic framework for credit-constrained firms. Second is a discussion of the Degraeve (2008) and Christensen and Dib (2008) model and how they incorporated the Bernanke et al. framework into more comprehensive DSGE models. The next section then goes deeper into the frictions for financial intermediaries as modeled by Gertler and Karadi (2011).

3.1.1. Bernanke, Gertler and Gilchrist (1999)

The aim of Bernanke, Gertler and Gilchrist (1999, henceforth BGG) was to incorporate credit-market imperfections into a full macro-economic model. They model these imperfections to assess their impact in the event of a serious downturn of the economy. Their model encompasses two concepts, the external finance premium and credit-constraint entrepreneurs. The external finance premium is the difference between the cost of internal and external funds. The opportunity cost of internal funds is the alternative investment in deposits that yield the risk-free interest rate. However, firms cannot borrow funds at this rate from financial intermediaries because they have to pay a premium. Credit-constraint entrepreneurs arise because they are constrained in their borrowing by their own net worth. As firms want to borrow more relative to their own net worth, the more risk the bank takes. More concretely, the higher the leverage ratio of a firm, the higher the probability will be that the firm will default. The bank wants to be compensated for this higher default probability by demanding a higher premium on the risk-free interest rate. For a certain investment, this premium will be higher the lower the own net worth of the firm. This higher premium increases the cost of borrowing and will dampen investments.

To concretely model this imperfection, BGG use the Costly State Verification (CSV) framework which was developed by Townsend (1979). In this framework, the premium is the result of asymmetric information because only the borrowers directly observe the rate of return on the investments. It is assumed that entrepreneurs always pay the required amount back if they are able to do so. However, if the entrepreneurs are not able to do so, they default and go bankrupt. In this case, the bank has to pay an auditing cost to observe what is left. The bank gets this amount while the firm receives nothing. The auditing cost is a constant fraction of the loans.

As an entrepreneur can never fully support his own desired investments, he must finance the difference between his investments $Q_t K_{t+1}^j$ and his net worth N_{t+1}^j.

$$B_{t+1}^j = Q_t K_{t+1}^j - N_{t+1}^j$$

In the case where there is no aggregate risk, the only source of fluctuations in a project's return is the idiosyncratic shock to the firm. BGG define a threshold value below which the firm is unable to pay back the required amount. This threshold value depends upon the other parameters in the model and is endogenously determined.

BGG do include aggregate risk but assume that households are risk-averse while entrepreneurs are risk-neutral. Therefore, entrepreneurs are willing to take on the aggregate risk, as they only care about the mean value of the payoff. After several steps, they then come to the next equation

$$E\left\{R_{t+1}^k\right\} = s\left(\frac{N_{t+1}^j}{Q_t K_{t+1}^j}\right) R_{t+1}$$

This equation indicates that the expected return on capital will equal the marginal external financing cost in equilibrium. As the stake of a firm in the own investment increases, the lower the premium will be. Therefore, investment costs are inversely depending on the own leverage ratio. The key variable in this framework is the external finance premium elasticity. Loglinearizing the previous equation gives:

$$E_t r_{t+1}^k - r_{t+1} = \varepsilon_f (n_t - q_t - k_t)$$

$E_t \mathrm{r}_{\mathrm{t+1}}^{\mathrm{k}} - r_{t+1}$ is the deviation of the external finance premium from its steady state. The external finance premium elasticity ε_{f} is the key financial variable in this model that represents how strong the premium increases when there is a change in the net worth of a firm. Estimated values of this elasticity are 0.05 by BGG, 0.042 by Christensen and Dib (2008), 0.044 by Villa (2011) and 0.1 by Degraeve (2008).

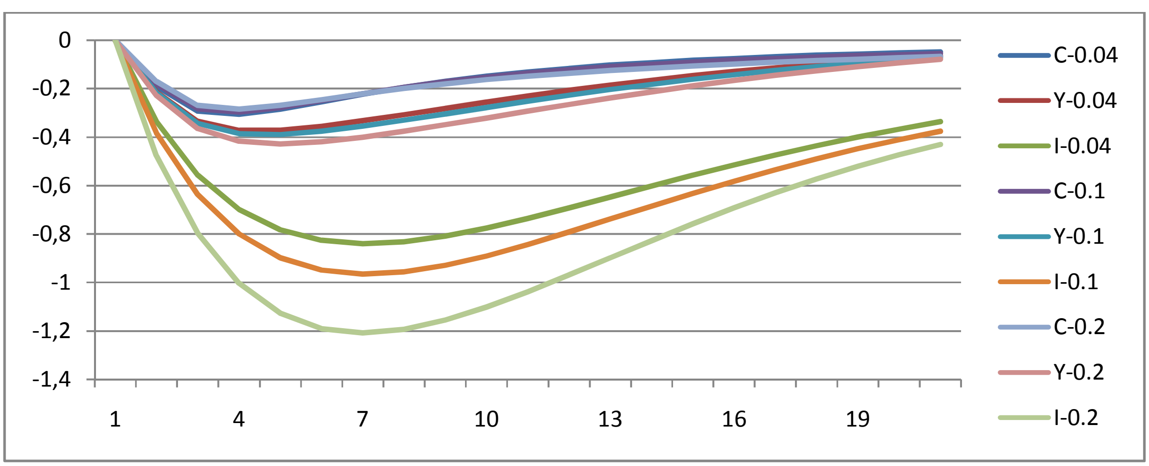

Figure 1: Effect of different external finance premium elasticities in the Degraeve model on consumption (C), output (Y) and investment (I) after a monetary shock of 100 basis points.

Figure 1 illustrates the impact of changes in this elasticity after an unexpected monetary tightening in the Degraeve model. The Degraeve model, who incorporates BGG frictions, was chosen because it demonstrates the dynamics clearer because of the gradual fall in output and investment. As figure 1 illustrates, the drop in consumption after an unexpected monetary tightening remains constant for the different elasticities, which is intuitive as the risk free real interest rate does not change. However, as net worth decreases after an unexpected increase in the interest rate, the different values of the elasticity do affect investment. A higher elasticity makes borrowing relatively more expensive for firms as they will have to pay a higher interest rate for the same investment which will decrease investments.

Furthermore, in this set-up, a firm can only acquire net worth through its own profits. In order to prevent firms from being able to finance the total amount themselves, a constant fraction of intermediaries exit the market each period. Moreover, a constant fraction of new firms enters the market to keep the total amount of firms constant.

To conclude, the friction in the credit-market is modeled by the interaction between the net worth of the firm and the external finance premium. This friction creates a "financial accelerator". This accelerator arises if there is a shock that affects the net worth of a company. If a shock negatively impacts the net worth, an entrepreneur will need to lend a higher fraction for a given investment. However, since this higher leverage implies a higher risk for the intermediaries, they will require a higher premium. This increased cost of lending will lead to less investment and a drop in asset prices. And this drop in asset prices once again decreases the own net worth of firms which causes a rise in the external finance premium. These second-round effects thus amplify the original contraction in the economy. This effect remains absent if the risk premium would remain unchanged. And it is also this accelerator that is at the center of the following models.

3.1.2. Christensen and Dib (2008)

Christensen and Dib (2008) examine the role of the financial accelerator in the amplification and propagation of shocks. They show that a model with an accelerator fits the data better because a maximum likelihood test rejects the model without in favor of the model with an accelerator. They use a closed-economy model, based upon Ireland (2003) and BGG (1999). Distinct from Ireland is that they introduce sticky prices by staggered price setting behavior based on Calvo (1983) instead of using quadratic price adjustment costs. Furthermore, Christensen and Dib introduce capital adjustment costs and nominal debt contracts. This latter feature is absent in BGG. These nominal contracts allow for debt-deflation dynamics, as already brought forward by Fisher (1933). With these contracts, a nominal rate is set at the start of the period. With unanticipated inflation however, the real payments vary. For example, if there is an unexpected decrease in inflation, the firms have to pay a higher real interest rate which negatively influences their net worth.

For monetary policy, they use a Taylor rule that contains output, inflation and money growth. They can model money growth because they have a non-separable utility function for consumption and real balances.

They find, just like Iacoviello (2005), that the financial accelerator mechanism only applies to demand shocks, as these shocks drive output and inflation in the same direction. This is because the drop in output is reinforced by the fall in inflation. This drop in inflation, due to the nominal debt contracts, decreases the net worth of the firm creating a rise in the risk premium. However, if the shock drives output and inflation in a separate direction the financial frictions can become a financial 'decelerator' because the inflation dynamics create an opposite effect on net worth, softening the shocks. Angelini et al. (2010) mention that supply-side shocks were dominant before the crisis, but that demand shocks have once again become central during and after the financial crisis. As demand shocks become central, the financial accelerator amplifies shocks and will lead to larger declines in output gap and inflation.

3.1.3. Degraeve (2008)

Degraeve (2008) investigates the movements of the external finance premium for the US. As this important financial variable is essentially unobservable, he uses a DSGE-model to analyze its dynamics and response to different shocks. He bases his model on a version of CEE and SW. In addition, he uses the standard framework of households, final and intermediate goods producers and a central bank. Furthermore, following BGG, he incorporates financial intermediaries, capital goods producers and entrepreneurs. He prefers to use the BGG-framework over the Carlstrom and Fuerst (1997)-framework because the mechanism of asset price movements that influence credit market imperfections is absent in the latter model.[3] Degraeve does not include nominal debt contracts like Christensen and Dib. Furthermore, he differs from Bernanke et al. in that Degraeve rewrites certain equations in order to avoid certain computational difficulties. As for the estimation, he uses US data ranging from 1954 to 2008 and estimates his model with Bayesian methods.

Degraeve finds that a model with financial frictions fits the data better than a model without frictions or a reduced form VAR, based on a marginal likelihood evaluation. Further indications of the usefulness of financial frictions to produce a better fit with the data are Queijo (2005) and Gelain (2010). Gelain makes use of a Bayes factor to favor the model with frictions as a better fit for the data. In contrast to this, Meier and Müller (2005) find that, using distance metric tests, their model with financial frictions contributes only marginally to the fit and is rejected statistically.

Despite the better fit of the model with frictions, the model with and without often produce comparable results. The largest difference is that the frictions model better captures the investments dynamics. The cost of including financial frictions is that for this model "the correlation of consumption with wages and labour becomes borderline".

A crucial difference with the BGG and CD model is that Degraeve uses investment adjustment costs instead of capital adjustment costs. These investment adjustment costs lead to the typically observed gradual hump-shaped dynamics of output. Capital adjustment

[3] Faia and Monacelli (2005) and Walentin (2005) give a comprehensive analysis of these frameworks.

costs are the more traditional way of modeling. Groth et al. (2006) give an extensive discussion about the differences, in addition, they show that a loglinearized equation of capital adjustment costs amounts to:

$$i_t = k_t + \frac{1}{\varepsilon\delta^2}q_t$$

In this investment equation, the changes in investment are only a function of the level of capital and the current value of capital. If capital is in its steady state, the changes in investment will only depend upon the value of capital. Therefore, after a monetary shock, investments will quickly change to their optimal levels for profit maximizing firms. Groth et al. (2006) find that a disaggregated analysis of industry data shows evidence in favour of capital adjustment costs. Furthermore, recalling the investment equation of SW, who have investment adjustment costs is:

$$i_t = i_1 i_{t-1} + (1 - i_1)E_t i_{t+1} + i_2 q_t + \varepsilon_t^i$$

In this equation, investment still depends on the current value of capital, but because it is costly to change levels of investment instead of levels of capital, the previous and future investments come into play. This introduces more dynamic behaviour in the investments. Furthermore, on an aggregate level, investment adjustment costs lead to more gradual adjustments that are in line with the observed data as is documented by CEE and SW.

3.2. Financial frictions on the financial intermediaries level

The previous models constructed financial frictions for firms. However, the financial crisis has shown that also financial intermediaries are subject to frictions. Therefore, new research has investigated why and how these frictions of intermediaries can be modeled into the standard DSGE models. In the first part of this section, there will be a discussion of how Gertler and Karadi (2011) model these frictions. In the second part, other approaches to this problem will be discussed.

3.2.1. Gertler and Karadi (2011)

In contrast with the previous approach, were firms were constrained in their borrowing, in the Gertler and Karadi (2011, henceforth GK) model, it are the banks that are constrained in their lending. They assume that intermediaries have perfect information about the firms' returns so that the previous Costly State Verification problem no longer holds. GK model frictions for banks to investigate how unconventional monetary policy can help to stabilize the economy in periods of financial distress, where this distress is represented by credit spreads.

To investigate this, GK create an endogenous capital constraint on financial intermediaries' ability to acquire assets. This endogenous constraint is based on its own net worth because the own net worth determines how much deposits the intermediary can collect. One reason for this is that a larger net worth leads to a larger buffer that can better counter unexpected losses. As in the BGG-framework, financial intermediaries' net worth can only grow through their own profits. The constraint is endogenous because in good times, asset prices and profits will increase leading to an automatic increase in the own equity, whereas it will automatically decline in bad times.

More concretely, they introduce an agency problem by assuming that banks have an incentive to “divert” assets away to their respective stakeholders/households. This divertment does come at a cost. Financial intermediaries are only capable to divert a fraction of their total assets away, the rest is retaken by the depositors. Intermediaries thus lose the other fraction of their assets and the possible interest payments. Depositors will therefore only lend to the as long as the expected utility on the return on lending for intermediaries are greater or equal to the utility of divertment.

There are five types of agents in the model: Households, financial intermediaries, non-financial goods producers, capital producers, and monopolistically competitive retailers. The latter are in the model to create nominal price rigidities. Each household consumes, saves and supplies labor. They save by lending to financial intermediaries. Within each household there are two types of members: workers and bankers. The fraction of workers is f and bankers 1-f. A banker has a (1-θ) chance of switching occupations which leads to a fraction of (1-θ) f workers exiting each period. Although there is switching, the parameters are set to keep the relative ratio of workers and bankers constant. A leaving banker gives his entire assets to his household. A worker switching to banking gets a "start up" fund. This fund is a fraction of the assets the household gets from the exiting bankers.

Financial intermediaries lend funds from households to non-financial firms. The intermediaries’ balance sheet is thus given by:

$$Q_t S_{jt} = N_{jt} + B_{jt}$$

Where N_{jt} is the equity of the bank, B_{jt} the amount of deposits,S_{jt} the amount of claims a financial intermediary has on firms, and Q_t the value of these claims. The amount of lending is equal to the own assets of the bank plus the deposits. Furthermore, intermediate goods firms have to fully finance their capital by borrowing from the financial intermediary which leads to the following equation.

$$Q_t K_{t+1} = Q_t S_{jt}$$

The total value of the value of capital $Q_t K_{t+1}$ will be equal to the total value of claims$Q_t S_{jt}$ that the intermediaries have on the firms.

As the financial intermediaries’ objective is to maximize their revenue, as long as they have a positive risk adjustment premium, they would go on borrowing from households to increase their lending. Gertler and Karadi therefore introduce an agency problem through a moral hazard problem: At the beginning of each period the banker can choose to give a fraction λ of his available funds to his respective household. The gain is that this household can immediately consume these assets. The cost is that the household loses the other fraction of the assets and the interest payments. Therefore, there is an incentive constraint for lenders

$$V_{jt} \geq \lambda Q_t S_{jt}$$

They will only make deposits as long as the intermediaries' utility of the payoff of the investment on loans, V_{jt}, is larger than the direct utility gain of embezzling, $\lambda Q_t S_{jt}$. By several other equations, and assuming the incentive constraint is binding, they show that the assets the intermediaries can obtain from depositors, and therefore its lending capacity to firms, will depend only on their own net worth:

$$Q_t S_{It} = \phi_t N_t$$

Total lending to the private sector is a multiple ϕ_t of the own equity of the intermediary. The lower the fraction an intermediary can divert to its household, the higher will be the leverage ratio ϕ_t. If there is an exogenous shock to net worth of the financial intermediary, this will have an amplified effect on lending. Although they use a different set-up, GK also have a financial accelerator because a shock to net worth will be amplified.

For the concrete values of the parameters, GK use estimates from CEE (2005) for certain parameters and calibrate the rest in line with standard findings. GK do not model wage rigidity, which they compensate by setting a high labor supply elasticity. They calibrate their three financial parameters to correspond to three targets "a steady state interest rate spread of one hundred basis points; a steady state leverage ratio of four; and an average horizon of bankers of a decade. The choice of the leverage ratio is a rough guess of a reasonable economy-wide mortgage."

GK frictions are also reflected in the data. Villa (2012) incorporates both the frictions of BGG and Gertler and Karadi into a SW model and estimates them on the Euro Area. Using a Bayes factor, she finds that the frictions of Gertler and Karadi give a better fit of the data than the frictions of BGG.

3.2.2. Other modeling approaches

The approach of GK for financial frictions for financial intermediaries is not the only possibility. This section will give an overview of other models and their key set-ups. Gertler and Kyotaki (2009), for example, use the same approach for constraints on the lending, but they add liquidity constraints based on Kyotaki and Moore (1997). They model these liquidity constraints by randomly arriving investment opportunities to firms on separated islands. In addition, they create a parameter indicating how strong the interbank market faces the same risk as households to model spreads in the interbank markets. Gertler and Kyotaki (2009) use this set-up to evaluate and to assess the impact of three forms of intervention: direct lending by the Central Bank to households, indirect lending through increased lending in the interbank market and government acquisition of private banks. Cúrdia and Woodford (2010) use a DSGE-model with credit frictions to assess how an inclusion of risk spreads in a monetary policy rule affects the economy. They find that, just like GK, an adjusted Taylor rule can improve the stability of the economy. The optimal weight on the credit spreads component, however, depends upon which shocks drive the variation in credit spreads.

Gerali et al. (2010) take a different approach by introducing two distinguishing features. They assume imperfect competition in the banking sector and sticky interest rates. They provide theoretical and empirical reasons for these two assumptions. The sticky interest rates are introduced through quadratic adjustment costs for retail interest rates and the constraints on lending by an optimal exogenous capital to assets-ratio. In contrast with GK, they thus have an exogenous leverage ratio. The only model in the database that incorporates frictions on the financial level is the GK-model, which will be taken as the representative of these models.

In addition to using financial frictions on the intermediaries' level to analyze unconventional monetary policy, these models are also used to study the effect of macro-prudential policies. These are policies to insure the stability of the financial system and prevent financial imbalances from building up. Bean et al. (2010) use the GK-framework to investigate how macroprudential and monetary policy interact. Angelini et al. (2010) take the Gerali modeling approach to investigate if macro-prudential policy provides substantial benefits in addition to monetary policy.

4. Modeling of Monetary Policy

There are two strands among micro-founded macroeconomic models, RBC models and DSGE models. RBC-models assume that prices are fully flexible and can be optimally reset each period. Although monetary policy has no effect in these models, the results are used to provide a benchmark case. For monetary policy to have real effects, there is a need for nominal rigidities. If prices are fully flexible, companies can always set their prices optimally as a function of the mark-up over marginal costs. For example, if there is a rise in the money supply, firms will just increase their prices to offset this increase in inflation. However, if there are nominal rigidities, prices can only gradually adjust over time, creating real implications of monetary policy.

Within the DSGE models, there are a number of ways to model nominal rigidities. Romer (2012) discusses seven approaches and shows that these can have quite distinct implications for price-adjustment. One of the popular approaches is Calvo-price setting. The Calvo model is a time-dependent model because the opportunities to change prices follow a Poisson process. As only a fraction of the firms can reset their prices each period, there is only a gradual adjustment to nominal shocks which implies that changes in nominal variables have real effects. The disadvantage of this approach is that it is a reduced form approach, it does not provide a clear explanation for where the opportunities to change the price come from. The advantages are that it can generate any kind of inflation quite easily and is relatively easy to work with. The popularity of Calvo price setting is reflected in these models as they practically all use a variant of it. However, the concrete modeling can differ. For example, SW include partial indexation of those prices that cannot be adjusted to lagged inflation. They also model wage stickiness based on this mechanism. An in-depth discussion of the different approaches and their implications can be found in Romer (2012).

Because monetary policy has real effects, it has important implication as formalized by Orphanides (2007): "A perennial question in monetary economics has been how the monetary authority should formulate and implement its policy decisions so as to best foster ultimate policy objectives such as price stability and full employment over time." While monetary policy has real effects due to the nominal rigidities, the concrete transmission mechanism will depend upon the selected model. The transmission mechanism is the way in which a monetary shock propagates itself through the economy and how the several components of output are affected. And because a good understanding of this mechanism is essential to know the possibilities and limitation of monetary policy, the transmission mechanism for monetary policy has been investigated quite thoroughly.[4]

Once, however, the model is specified through its assumptions, an optimal monetary policy rule can be calculated based on welfare losses. These optimal rules are calculated in two steps. The first step is that there is a welfare loss function. This loss function often includes the output and inflation volatility which the central bank wants to minimize. In the second step, the "optimal" monetary rule is determined by analyzing which coefficients for the terms minimize the loss. For example, Cogley et al. (2011) calculate optimal monetary policy rules for the SW and BGG model. They find that the BGG optimal rule is a Taylor rule that responds aggressively to inflation with a small interest rate smoothing and output gap component. The SW optimal rule, however, has a high interest rate smoothing component and reacts more strongly to output gap movements.

In addition to calculating such an optimal rule for one model, several papers calculate "robust" optimal monetary policy rules because rules that are optimal in one model can lead to large losses in another. As these models capture different features of the economy, making a monetary policy rule robust addresses the issue of uncertainty and "one-model dependency". As an illustration, Cogley et al. (2011) find that the optimal BGG-rule leads to large losses in the SW-model. The optimal SW-rule fares quite well in the BGG-model and is also close to the optimal robust monetary policy when two other models are included. Taylor and Wieland (2012) investigate the robustness of optimal policy rules in the SW, CEE and Taylor model (1993a). They find that model-averaging of the optimal policy rules can improve the robustness of a policy rule across models. Orphanides and Wieland (forthcoming) compare how alternative policy rules affect the performance of Euro area models. Their analysis confirms the Cogley et al. study in that the robust interest rate rule has a near unity coefficient on the interest rate smoothing component.

Taking into account this variability of monetary policy rules across models, Wieland et al. (2012) introduce five different policy rule possibilities into their model. The rules will depend on the included terms and the specific data upon which they are estimated. The basis monetary policy rule is the Taylor-rule, as was proposed by Taylor him in 1993. The other rules are modifications that place emphasis on different aspects. The five models and their equations are given by

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[4]See the "The role of banks in the monetary policy transmission mechanism", ECB Monthly Bulletin. August 2008", for a comprehensive overview of the transmission mechanism in the Eurozone

$$\text{Taylor (1993a)}: i_t^z = \sum_{j=0}^{3} 0,38 p_{t-j}^z + 0,50 q_t^z + n_t^i$$

$$\text{Levin et al. (2003)}: i_t^z = 0,76 i_{t-1}^z + \sum_{j=0}^{3} 0,15 p_{t-j}^z + 1,18 q_t^z - 0,97 q_{t-1}^z + n_t^i$$

$$\text{Gerdesmeier and Rofia (2004)}: i_t^z = 0,66 i_{t-1}^z + \sum_{j=0}^{3} 0,17 p_{t-j}^z + 0,1 q_t^z + n_t^i$$

$$\text{Smets and Wouters (2007)}: i_t^z = 0,81 i_{t-1}^z + 0,39 p_t^z + 0,97 q_t^z - 0,90 q_{t-1}^z + n_t^i$$

$$\text{Christiano et al. (2005)}: i_t^z = 0,8 i_{t-1}^z + 0,3 E_t p_{t+1}^z + 0,08 q_t^z + n_t^i$$

The basic Taylor-rule only responds to inflation and the current output gap. The Levin, Wieland and Williams-rule (2003) is based on a study of Orphanides and Wieland (1998). Orphanides and Wieland added an interest-rate smoothing component and a lag of the output gap. They then estimated the rule with U.S data. Levin, Wieland and Williams continued with this rule and simulated it in five models of the U.S economy. Gerdersmeier and Roffia (2004) use a similar rule but only include the current output gap. They estimate their rule based on Euro-Area data. The Smets and Wouters-rule keeps the output gap lag of Levin et al. (2003), but only incorporates current inflation into their model. They estimate this rule using Bayesian techniques. The Christiano, Eichenbaum and Evans-rule differs from the previous rules in that they include expectations of future inflation instead of current inflation. They estimate the coefficients using a VAR–approach.

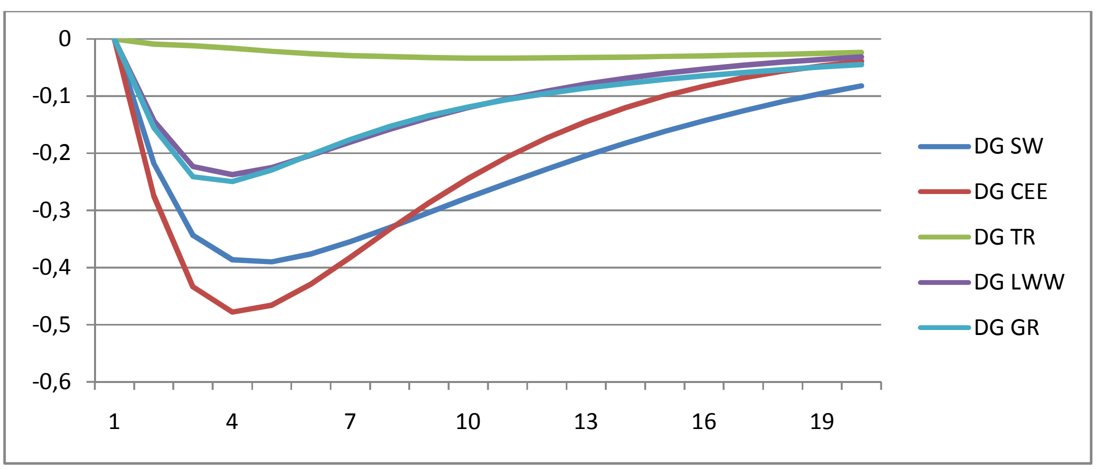

Figure 2: Output effect of a monetary shock in the Degraeve model under the different interest rate setting rules.

As rational agents also incorporate the interest setting rules of the central bank into their maximizing behaviour, different interest rate rules will also affect output. To compare the impact of the interest rate rules, the Degraeve model will be used as it is representative for the output dynamics in the other models. As the Taylor rule has no smoothing component, the interest rate drops to approximately zero after the monetary shock. Agents know this and will therefore only make a small adjustment in their investments and consumption, as can be seen in figure 2. The other four models do have smoothing components which makes the monetary shock last longer. The LWW-rule and the GR-rule have the same weight for the smoothing component and cause the same drop in output. This also is the case for the larger drops under the SW- and CEE-rule. The SW-rule and the CEE-rule have a higher interest rate smoothing component of 0.8 which causes the interest rates to remain high for longer. Therefore, rational agents will forecast these higher interest rates and decrease investment and consumption even more. Furthermore, the CEE-rule has a lower weight on the current output gap. This will lead to relatively higher interest rates compared to the SW-rule, explaining the larger drop in output in the CEE-model.

The reason why four of the five rules include a lagged interest rate term is because, as Orphanides (2007) notes, “good performance is associated with policy rules that exhibit considerable inertia”. This holds especially true in models with strong forward looking agents (Woodford, 2003). This lagged interest rate also prevents strong deviations in the monetary policy. One of Orphanides’ conclusions is that overreaction to mismeasured output gaps can be more damaging than beneficial for stability. Therefore, a lagged interest rates smoothes the interest-setting behaviour of central banks and prevents the bank from overreacting to new information.

5. Quantitative comparisons of the models

5.1. Macroeconomic Model Database

Because all models capture different aspects of the economy, a comparison is required to avoid overreliance on one specific model. However, such comparative exercises between models are not easy. As Wieland et al. (2012) note "Yet, systematic comparisons of the empirical implications of a large variety of available models are rare. Evaluating the performance of different policies across many models typically is work intensive and costly". Wieland et al. (2012) point out the insulation of models for this costliness. Often, only the authors involved have the knowledge of the concrete code and it is not an easy task to recreate the models solely based on the information about the parameters or calibration in the papers. Therefore, comparison of models required large groups of peoples and modelers. Wieland et al. wanted to construct a way to easily compare models at low cost of time and effort. To put this comparative perspective of models in a more concrete format, they constructed a macroeconomic model database. Their software uses DYNARE and operates in Matlab.[5]

The models in this database have been constructed on the basis of the equations in their respective papers. In addition, a number of authors have provided their Matlab-codes. To get to a standard framework, however, some challenges arise. A first challenge is that every model defines variables in their own way. Wieland et al. address this by defining a limited set of variables that are common among all models. They redefine the original variables in terms of these common variables, which gives a standardized output and leaves the original model unmodified. A second challenge is that every paper uses its own monetary policy rule. These monetary rules can differ in the use of elements and their weights. They tackle this problem by taking the original monetary policy rule out of the model and replacing it with a standard monetary policy rule that is available in the model. This monetary rule is defined in terms of the common variables. There are five monetary policy rules available, which have been analyzed in the previous section. Furthermore, Wieland et al. have a section on their website about the replicability of results.

A last remark is that DSGE models differ in the way they define the output gap. For example, SW define it as "the difference between the actual and potential output". Where the potential output is the output that would occur in the model with fully flexible prices. Other models define it as the difference between the actual and the steady state output. The advantage of a monetary shock is that these two approaches coincide as the output under the flexible prices does not change after this shock. This is also the reason why the output gap and output fluctuations in the next section are the same.

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[5]The software can be downloaded at www.macromodeldatabase.com. For more information about DYNARE see Juillard (1996).

The selected models were all estimated or calibrated for US data. For the standard DSGE models without explicit financial frictions, there are the Christiano, Eichenbaum and Evans (2005) and the Smets and Wouters (2007) models. Models with financial frictions on the firm level are the Bernanke et al. (1999), Christensen and Dib (2008) and the Degraeve (2008) models. Gertler and Karadi (2011) represent models with frictions on the financial intermediaries' level.

5.2. General overview

There are two steps in the quantitative approach. The first step is a general comparison of the dynamics in output, inflation and the interest rates across models. These dynamics give a good overview of how the models react to the monetary shock and allow to identify substantial differences. The second step is a more in-depth comparison for the different financial frictions, which will be done in section 5.3.

While it is a comparison between models, a comparison of these models under different interest rate rules might point out which models are more sensitive to changes in the interest rate. The two monetary policy rules that will be used for this are the SW- and CEE-rule. Their features were already discussed in section 4. Every monetary shock in the following sections is an interest rate increase of 100 basis points. After this shock, the interest rate is set according to the selected monetary policy rule. The time period on the horizontal axis is always measured in quarters.

5.2.1. Smets and Wouters monetary policy rule

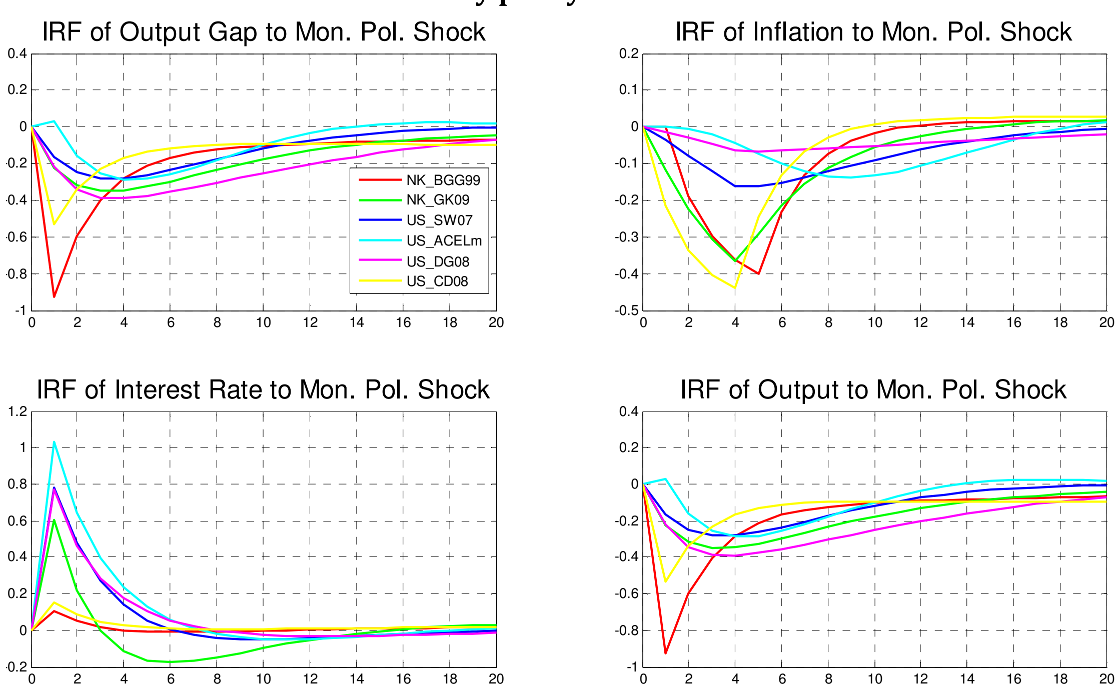

Figure 3: The reaction in output, inflation and interest rate in the Bernanke et al. (NK_BGG99), Gertler and Karadi (NK_GK09), Smets and Wouters (US_SW07), Christiano et al. (US_ACELm),

Degraeve (US_DG08) and Christensen and Dib (US_CD08) models to a monetary shock under the SW-rule.

As the Euler equation indicates, an interest rate rise raises the cost of borrowing for households so there will be less consumption and more saving. In addition, the cost of borrowing for firms has increased which will lead to lower investments, as is visible from the investment equation. An interest rate rise also decreases asset prices and the net worth of firms because asset prices are a reflection of the discounted expected value of capital. This creates wealth effects for firms and collateral effects for household. Furthermore, this interest rate increase also creates expectations about a slowdown to which firms respond by investing less. All these factors lead to a drop in the output in the economy.

Just as in Taylor and Wieland (2012), figure 3 shows that the SW and CEE models have about the same output dynamics. In the CEE model, the interest rate affects output with a lag of one period, therefore leading to the drop starting a period later. After the initial decline, there is also more output gap persistence in the SW-model than in the CEE–model. All the financial frictions models know a small but substantial drop in output in comparison with the SW and CEE models. Although this could be due to modeling assumptions, the fact that the drop in output is consistent across models does indicate that this is partially due to the financial accelerator. As for the financial frictions models themselves, a substantial difference comes from the modeling assumptions of capital and investing adjustment costs. Both CD and BGG, who have capital adjustment costs, have a much sharper drop in the first period to quickly converge back as the interest rates adjust. The models with investment adjustment costs have a smoother drop and a prolonged minimum. This assumption does have quite an impact, as it determines whether there is a steep drop and quick convergence or a more gradual fall and adjustment.

As the economy slows down due to the interest rate shock, prices will be negatively affected as aggregate demand falls. The minimum of the drop in inflation in the CEE model lies after the minimum of the drop in its output. This is because it takes longer in this model for output to affect inflation. As for the DG model, its inflation drop is quite limited, and lies above that of the standard DSGE models. However, it does converge back more slowly, indicating a high persistence of inflation in the DG model. While DG has a small drop in inflation, the other financial frictions models have a larger drop in inflation. As such, there is no uniform difference in inflation between the standard models and the financial frictions models. While the output gap dynamics of GK mirror DG, its inflation dynamics follow the BGG and CD line. The larger drop of inflation in the GK model could be due to the absence of nominal wage rigidity in these models. The BGG and CD models have a sharp drop in inflation after which they quickly come back to the steady state inflation. The BGG inflation dynamics only start from period 2 onwards, because BGG include a one period lag of output on inflation.

Apart from the output and inflation dynamics, the interest rates are also shown in figure 3. After the unexpected monetary shock, the interest rates in the CD and BGG models rise only minor relative to the others because the current output gap has a high weight in the SW-rule. Therefore, the larger drop in output in these models induces the central bank to set lower interest rates. In addition, as output falls more in the BGG model, it is consistent that the interest rate in the BGG-case is lower than for the CD-model. The standard models and the DG model have about the same interest rate dynamics and stay in range of one another. GK partly follows the BGG-story, albeit more moderate. While the drop in the output of GK is similar to DG, inflation drops more sharply. This higher inflation drop moderates the interest rate rise in the GK model. As for the CEE-model, the reason why the interest rate is so high is that interest rate changes only affect output with a lag, thus the moderation affect of a negative output gap on the interest rate only comes into play into the next period.

5.2.2. Christiano, Eichenbaum and Evans monetary policy rule

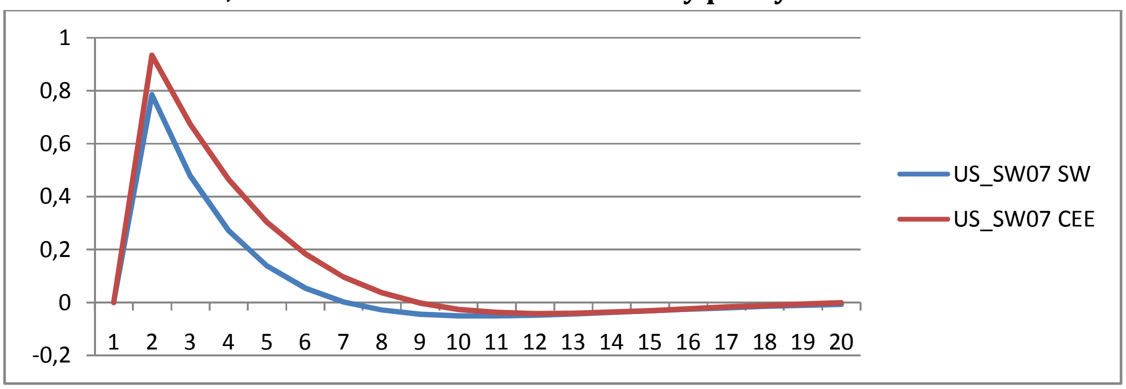

Figure 4: Different interest rates in the Smets and Wouters (US_SW07) model under the SW- and CEE-rule.

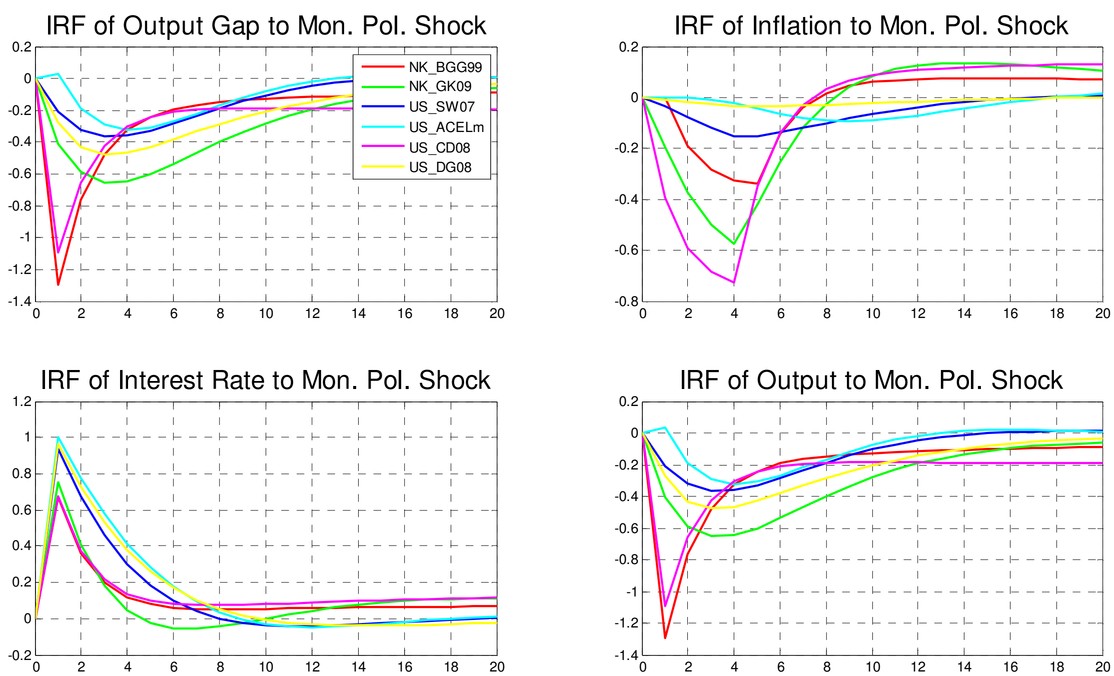

Figure 5: The reaction in output, inflation and interest rate in the Bernanke et al. (NK_BGG99), Gertler and Karadi (NK_GK09), Smets and Wouters (US_SW07), Christiano et al. (US_ACELm),

Degraeve (US_DG08) and Christensen and Dib (US_CD08) models to a monetary shock under the CEE-rule.

The CEE-rule has the same interest rate smoothing component as the SW-rule, but only has a small weight attached to the current output gap. Therefore, the moderating effect of the output drop on the interest rates is largely absent under this rule. And because of the high smoothing component, this higher rise will lead to higher future interest rates as figure 4 illustrates. Furthermore, agents' expectations will incorporate these higher interest rates which will lead to immediate stronger adjustments to the monetary shock. Therefore, it is not surprising that the declines in output are stronger than under the SW-rule.

Nevertheless, the results under the CEE-rule, shown in figure 5, are mainly in line with the results under the SW-rule. The largest differences are that the drops in output of the GK and CD models lie substantially lower than under the SW-rule. As the higher interest rate-setting holds true across models, this indicates that these two models are more sensitive to interest rate changes, which will be discussed later on.

The inflation dynamics have similar features as under the SW-rule. The main differences in magnitude are again for the CD and GK-models, as their larger output drop is reflected in their inflation dynamics.

5.3. Comparisons

5.3.1. Standard DSGE models and financial frictions on the firm level

While the aggregate movements in the economy are important, to obtain a better understanding how they come about, it is useful to see how the components behave. This section compares the effects of financial frictions on the firm level with the standard DSGE model of SW.

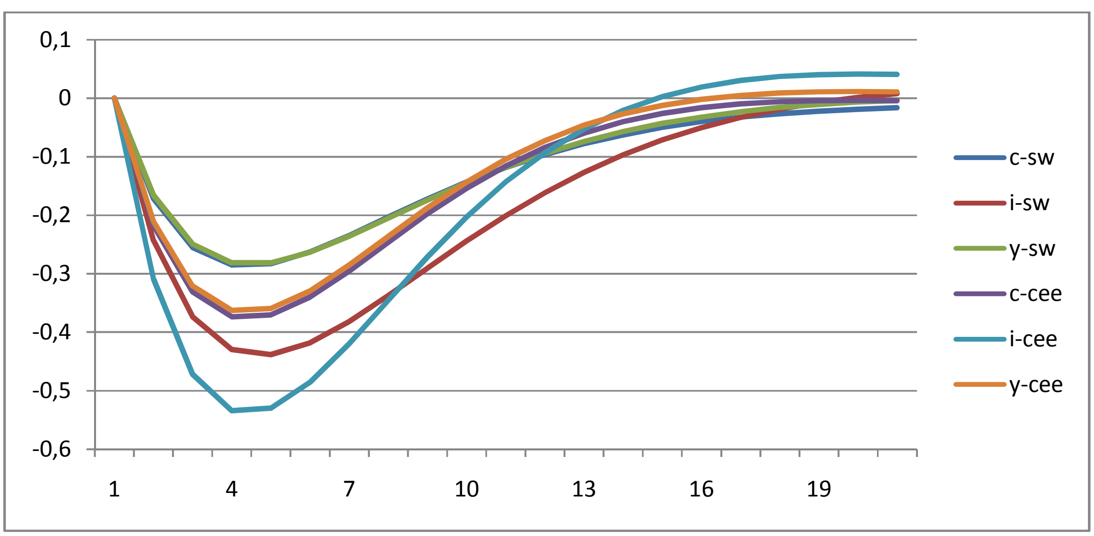

Figure 6: Monetary shock in Smets and Wouters-model: Drop in output (y), consumption (c), investment (i) under the SW (sw) and CEE (cee)-rule

In the Smets-Wouters model, the drop in output is mainly influenced by the drop in consumption and investment. The movement of output is influenced more by consumption as it has a larger share in output than investment. Also, investment drops twice as much as output, which is in line with the stylized fact that investment is twice as volatile as output (Romer 2012). In addition, the drop in output reaches its minimum after a year. Because of the higher interest rates remain under the CEE-rule, there are larger drops in output and investment when the central bank follows this rule.

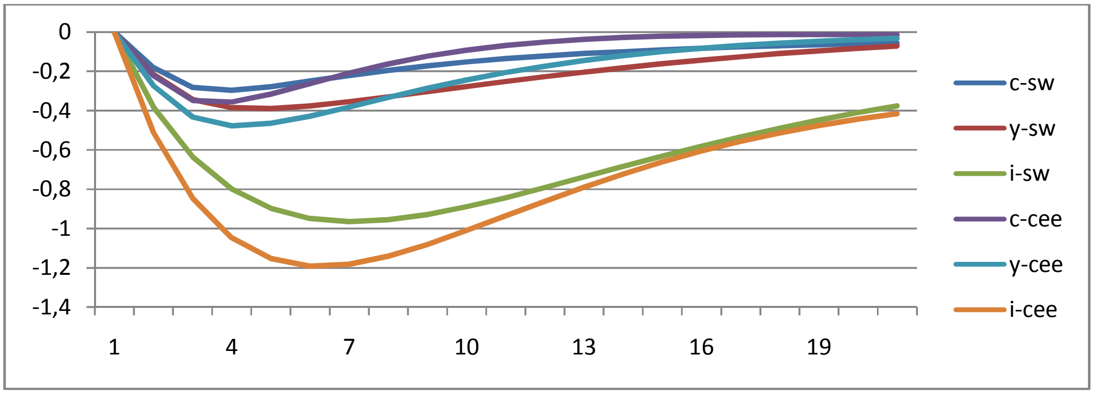

Figure 7: Drop in output (y), consumption (c), investment (i) in the Degraeve model under the SW-(sw) and CEE (cee)-rule.

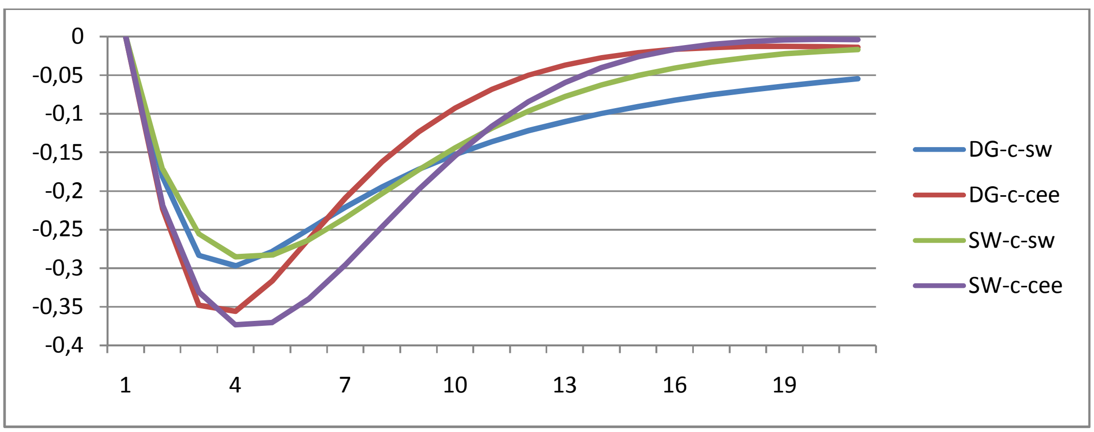

Figure 8: Drop in consumption in the Degraeve (DG) and Smets and Wouters (SW) models under the SW-(sw) and CEE (cee)-rule.

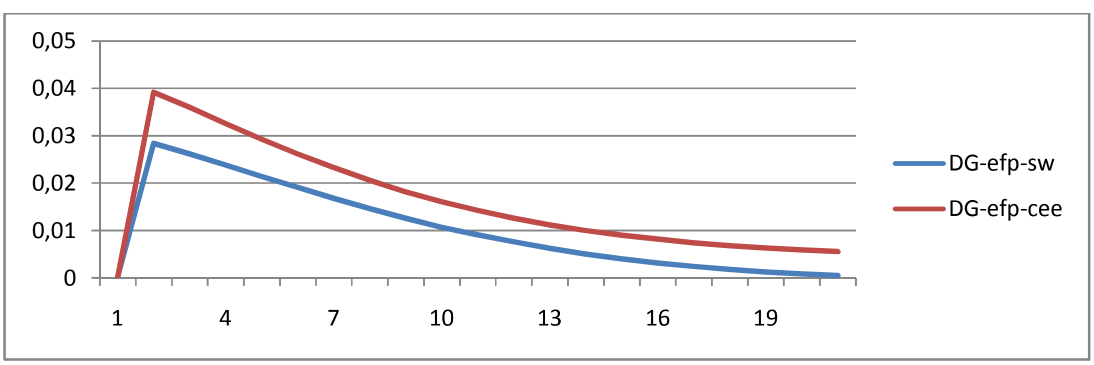

Figure 9: Rise in the external finance premium in the Degraeve model under the SW-(sw) and CEE (cee)-rule.

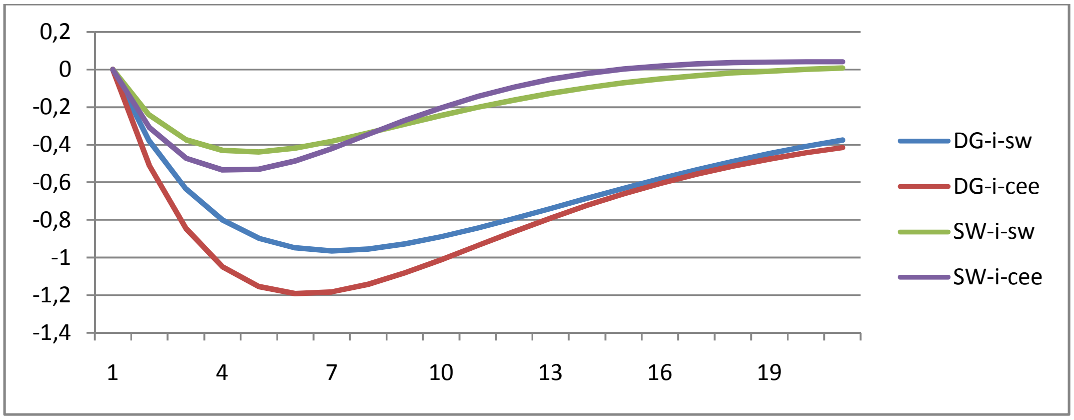

Figure 10:Drop in investments in the Degraeve (DG) and Smets and Wouters (SW) models under the SW-(sw) and CEE (cee)-rule.

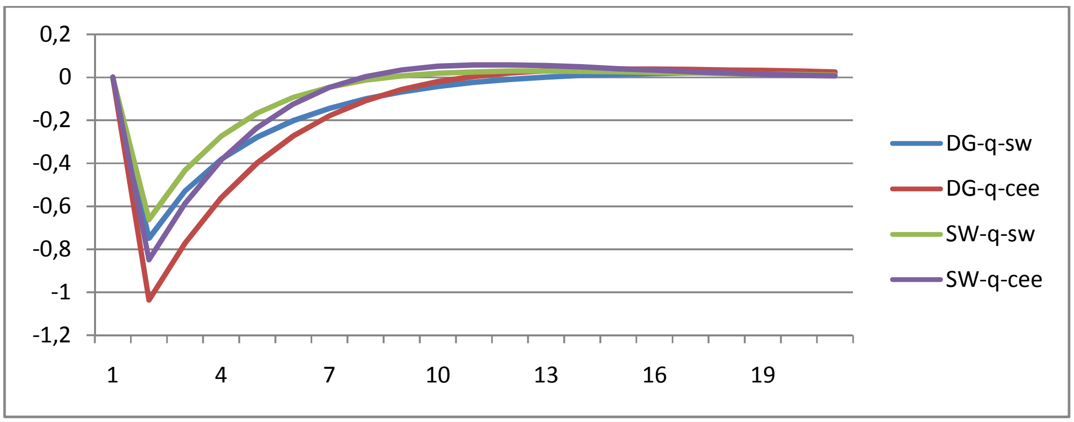

Figure 11: Drop in asset prices in the Degraeve (DG) and Smets and Wouters (SW) models under the SW-(sw) and CEE (cee)-rule.

After the standard SW model has been analyzed, the question remains how the financial frictions on the firm level influence the transmission mechanism. Degraeve starts from a standard DSGE model based upon SW and then incorporates the financial frictions on the firm level. As, after a monetary shock, the real interest rate for household deposits is not affected by these frictions, consumption in both models should be approximately the same. This is confirmed in figure 8. With financial frictions, however, the main difference should lie in the credit spreads and investments. This is because, when asset prices fall, the net worth of firms also declines which increases the external finance premium (EFP). As borrowing becomes more expensive, firms will invest less which leads to a further drop in asset prices. Figure 11 shows that asset prices indeed fall more in the Degraeve model. The EFP, visible in figure 9, clearly increases, which explains why investments, in figure 10, drop much more.

Another illustration of the financial accelerator is by comparing the extra drop of investments in the two models under the CEE-rule. The higher interest rates show that investments in the Degraeve decrease more than in the SW-rule. This follows from an additional increase in the EFP, as is visible in figure 9.

Taylor and Wieland (2012) find that adding the Degraeve model to a robust monetary policy exercise that includes the SW and CEE-model does not substantially change the robust optimal monetary policy rule.

5.3.2. Financial frictions on the firm and financial intermediary level

While Degraeve models financial frictions on the firm level, Gertler and Karadi introduce frictions on the financial intermediaries by constraining their lending based on their balance sheets. The financial intermediaries' set-up has quite substantial effects on the modeling approach and equations as was visible in the theoretical comparison.

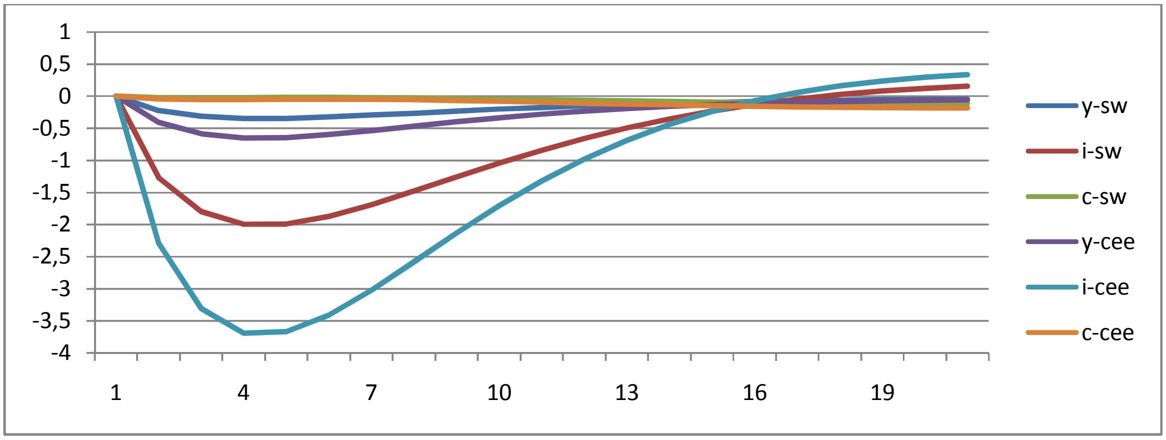

Figure 12: Drop in output (y), consumption (c), investment (i) in the Gertler and Karadi model under the monetary policy rule of SW (sw) and CEE (cee).

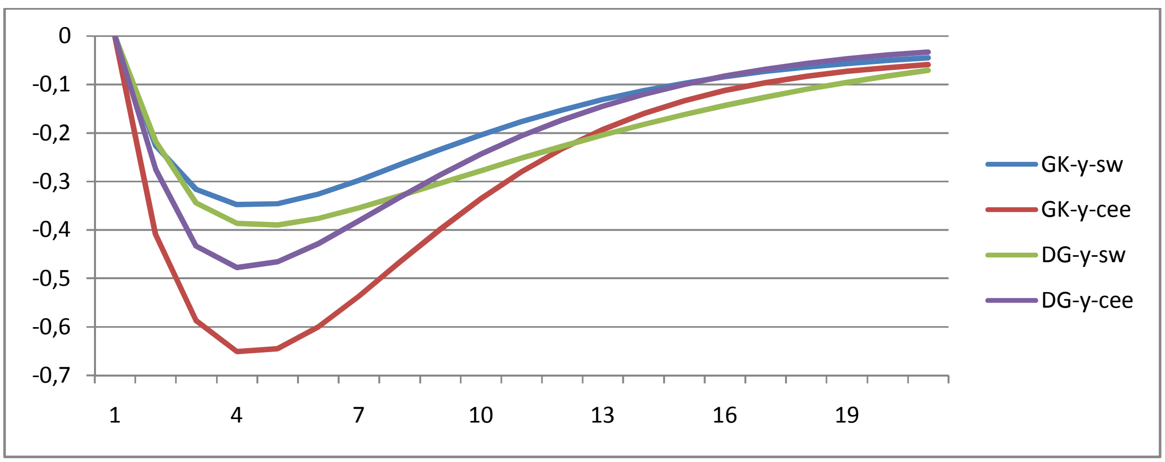

Figure 13: Drop in output in the Degraeve (DG) and Gertler and Karadi (GK) model under the SW-(sw) and CEE (cee)-rule.

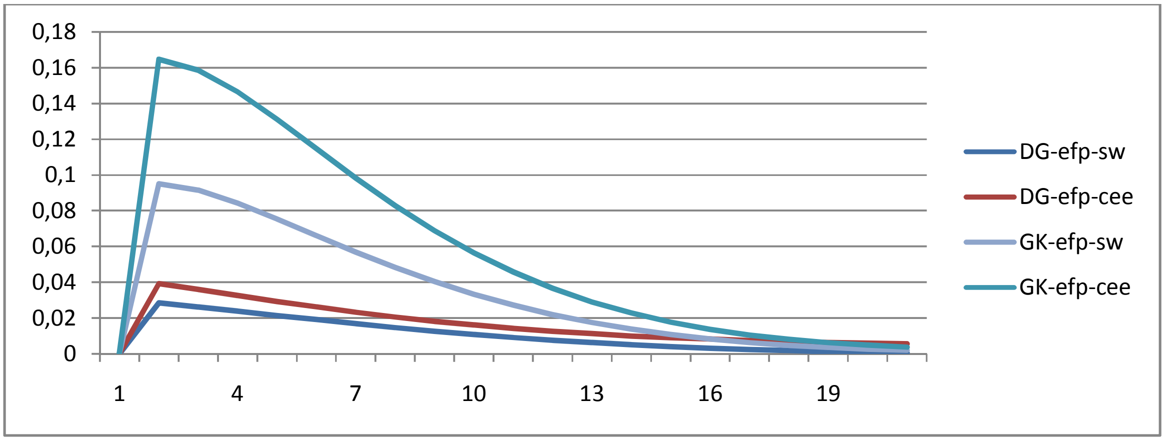

Figure 14: Rise in the external finance premium in the Degraeve (DG) and Gertler and Karadi (GK) models under the SW-(sw) and CEE (cee)-rule.

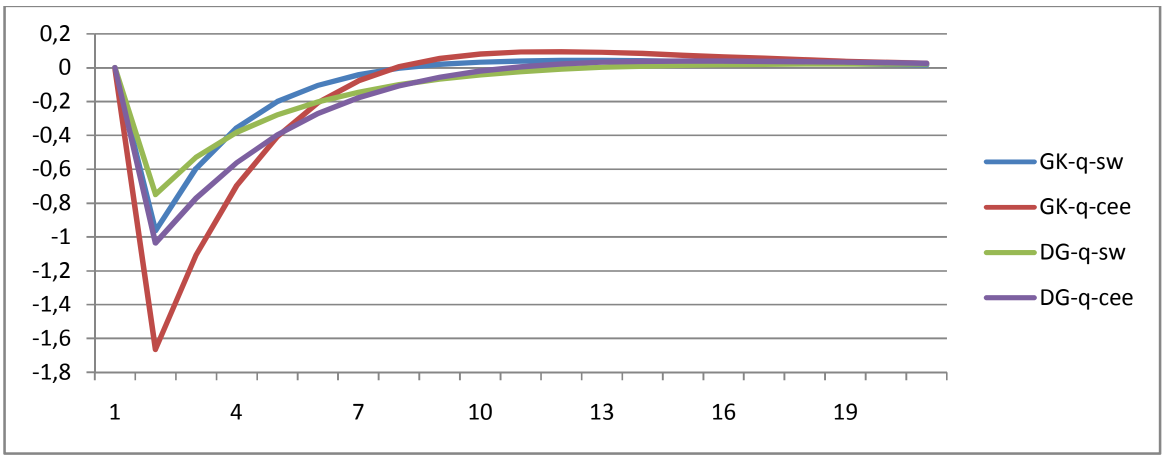

Figure 15: Drop in asset prices in the Degraeve (DG) and Gertler and Karadi (GK) models under the SW-(sw) and CEE (cee)-rule.

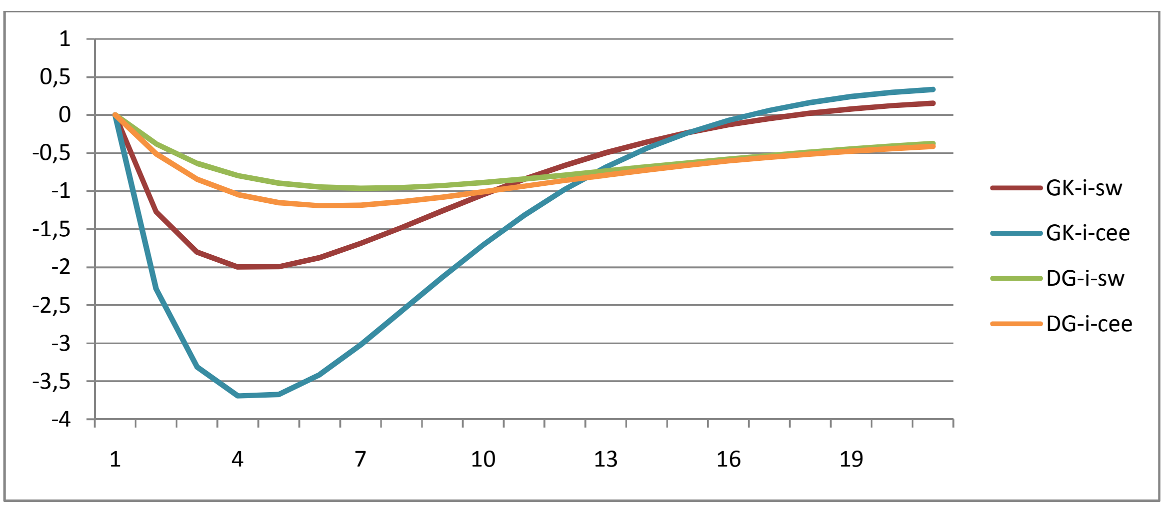

Figure 16: Drop in investments in the Degraeve (DG) and Gertler and Karadi (GK) models under the SW-(sw) and CEE (cee)-rule.

Figure 12 shows substantial differences for the transmission mechanism in the GK model. The first difference with the SW and Degraeve model is that consumption hardly drops. An explanation for this low consumption drop is that the real interest rate comes indirectly into the Euler equation of GK with a low coefficient.

$$E_t(\acute{\Lambda}_t + \acute{R}_t) = 0 \quad (1)$$

$$\acute{\Lambda}_t = \acute{m}u_{t+1} - \acute{m}u_t \quad (2)$$

$$c_t = c_1 c_{t-1} + (1 - c_1)E_t(c_{t+1}) - c_2 \acute{m}u_t \ (3)$$

$$\text{with } c_2 = \frac{(1-h)(1-\beta h)}{(1+\beta h)}$$

In the GK-model, if the real interest rate R_t increases, through equation (1), this will decrease Λ_{t+1}. This decrease will be reflected in equation (2) where the marginal utility of consumption, mu_t, must increase. This increase in the marginal utility is achieved by reducing current consumption in equation (3), which is in line with the expectations following a monetary shock. With the following parameters $\beta = 0.99$ and $h = 0.815$, that are given in the database, this leads to c_2 being 0.0198.
In the SW model, consumption is directly affected by the real interest rate. Recalling the SW Euler equation.

$$c_t = c_1 c_{t-1} + (1 - c_1)E_t(c_{t+1}) - c_2(l_t - E_t l_{t+1}) - c_3(r_t - E_t \pi_{t+1} + \varepsilon_t^b)$$

$$\text{with } c_3 = (1 - \frac{\lambda}{\gamma})/(\left(1 + \frac{\lambda}{\gamma}\right) * \sigma_c$$

The parameter settings in the database are $\lambda = 1.0043$, $\gamma = 0.7193$ and $\sigma_c = 1.38$. These parameters lead to a coefficient c_3 of 0.1185, which is substantially higher than in the GK model. In addition, as the interest rate rise has a larger effect, expected future consumption will be lower which causes an even larger drop in current consumption.

The second main difference between the GK and Degraeve model are the investment dynamics. The unexpected monetary shock will reduce the value of asset prices which negatively affects the net worth of financial intermediaries. When this net worth decreases, financial intermediaries can attract fewer deposits due to the balance sheet constraint and will have to cut back lending. In order to retain their profits, financial intermediaries will have to raise the interest rates for firms causing an increase in the EFP. However, as borrowing gets more expensive, firms invest less and asset prices will decline further. This additional drop in asset prices decreases the net worth of financial intermediaries even further, causing an even larger rise in the EFP.

These dynamics are reflected in the variables. Figure 15 shows the decline in asset prices. The asset prices in GK clearly drop more than in DG. Figure 14 shows that as a result of the balance sheet constraints, the effect on the EFP is much higher than in the Degraeve model. As the EFP is essentially a credit spread, and credit spreads are a measure of financial distress (Cúrdia and Woodford, 2010), this shows that a monetary shock causes more distress in the financial sector than in the Degraeve model. With lower asset prices and substantially higher EFP, firms reduce their investments much more. These large drops in investment occur despite the fact that firms face investment adjustment costs.

With regard to the financial crisis, Gertler and Karadi say, “As many observers argue, the deterioration in the financial positions of these institutions has had the effect of disrupting the flow of funds between lenders and borrowers. Symptomatic of this disruption has been a sharp rise in various key credit spreads as well as a significant tightening of ending standards. This tightening of credit, in turn, has raised the cost of borrowing and thus enhanced the downturn”. The dynamics in this statement, which they aim to model, are clearly reflected by the strong increase in the EFP and drop in investment. It is therefore also not surprising that GK include a term that reacts to credit spreads in the interest rate rule of the central bank.

Furthermore, GK is also more sensitive to different monetary policy rules. The CEE-rule, that has higher interest rates, causes a much larger drop in asset prices as can be seen in figure 16. And as financial intermediaries react to this, the EFP rises substantially as well. Moreover, these two changes explain why the fall in investment, under the CEE-rule, becomes four times as large as in the Degraeve model. It is also this substantial drop in investment that causes the drop output of the GK model to go below the Degraeve output, as was witnessed in figure 5.

In the previous section, it was mentioned that Taylor and Wieland (2012) do not find a substantial difference in the robust monetary policy rule if they add the Degraeve model. However, seeing the high interest rate sensitivity of the GK model, it could well be that an optimal monetary rule in the GK has substantial implications for such a robust rule. For example, a higher reaction to the output gap and a lower interest smoothing component could lead to less output fluctuations in the GK model.

To conclude, in the Gertler and Karadi model, the transmission mechanism is clearly different from the Degraeve and SW model. While consumption hardly drops in the GK model, investment falls twice as much as in the Degraeve model. This larger fall is reflected by the larger drop in asset prices and larger increase in the EFP.

5.3.3. Capital and investment adjustment costs

Apart from the financial frictions differences, the general overview showed that there was a clear distinction of the models with capital adjustment costs compared with the models with investment adjustment costs. The models with capital adjustment costs are the Bernanke et al. (1999) and Christensen and Dib (2008) model. The comparison will be with the Degraeve model because this model has the same financial frictions.

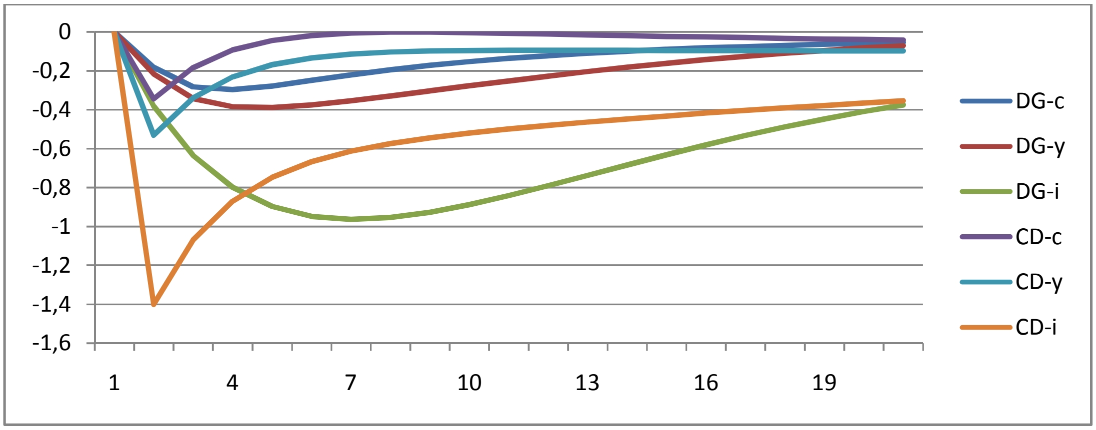

Figure 17: Drop in output (y), consumption (c), investment (i) in the Christensen and Dib (CD) and Degraeve (DG) models under the SW-rule.

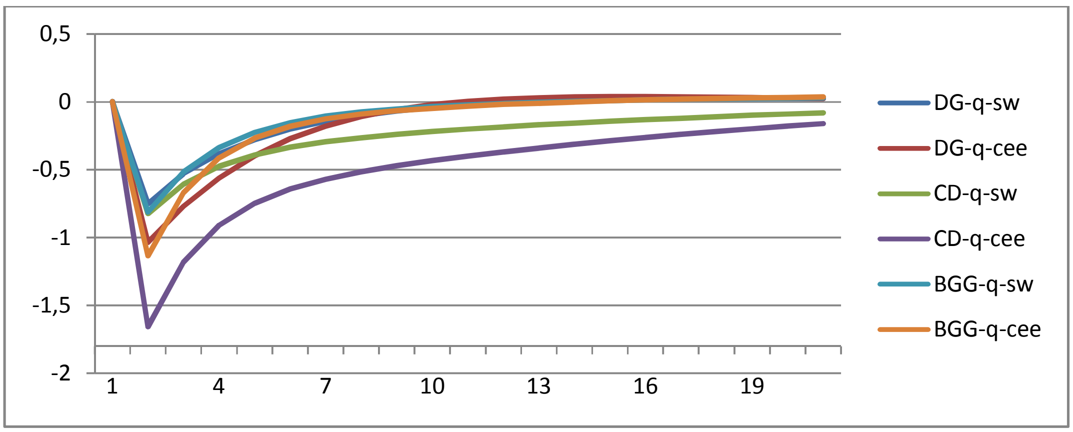

Figure 18: Drop in asset prices in the Degraeve (DG), Christensen and Dib (CD) and Bernanke et al. (BGG) models under the SW-(sw) and CEE (cee)-rule.

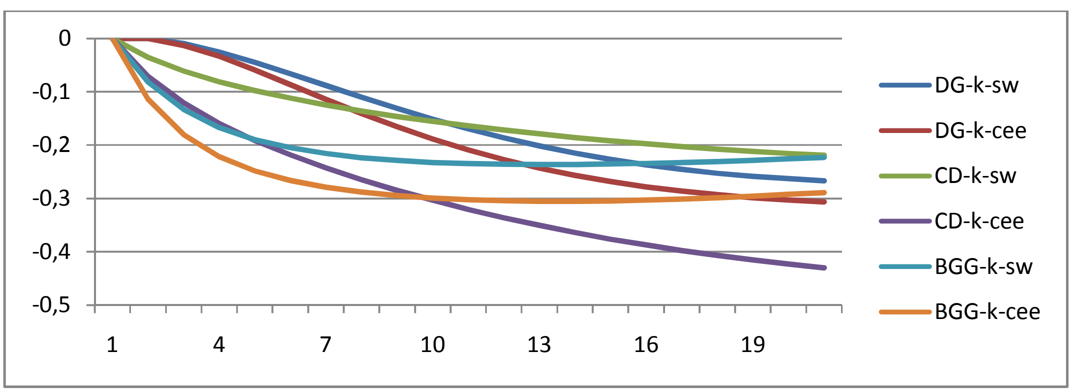

Figure 19: Drop in capital in the Degraeve (DG), Christensen and Dib (CD) and Bernanke et al. (BGG) models under the SW-(sw) and CEE (cee)-rule.

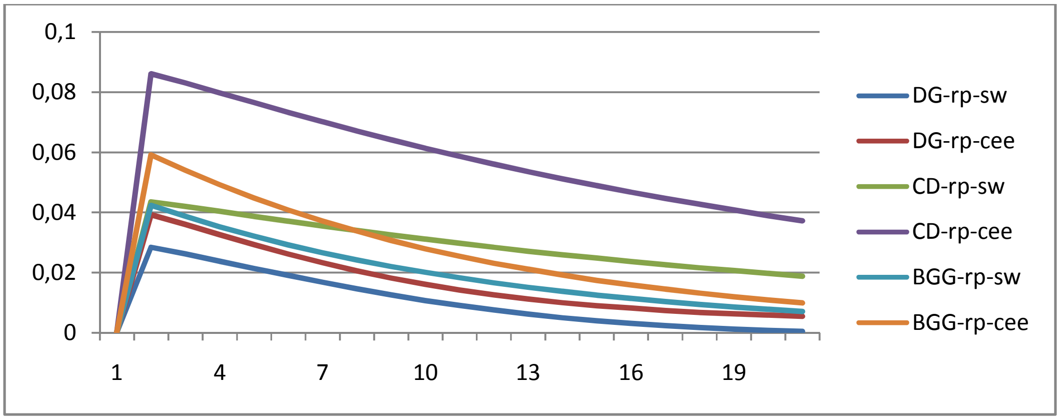

Figure 20: Rise in the external finance premium in the Degraeve (DG), Christensen and Dib (CD) and Bernanke et al. (BGG) models under the SW-(sw) and CEE (cee)-rule.

Figure 18 shows that the drop in the value of asset prices is about equal across the three models. However, in the capital adjustment costs models, this drop in value leads to larger and more immediate decreases in investments as can be seen in figure 17. And as investment drops more, this will lead to faster decline of capital as illustrated by figure 19. Moreover, after five years, capital is starting to rise again in the BGG and Christensen and Dib model, while it is still going downwards in the Degraeve model. Figure 20 shows that the EFP under capital adjustment costs are higher than for the investment adjustment costs. Furthermore, under the CEE-rule, it is especially the CD-premium that increases quite substantially, thereby contributing to the larger output fall as was evident before in figure 5. Groth et al. (2006) find evidence that, on a disaggregated level, there is more evidence in favour of capital adjustment costs. However, investment adjustment costs do seem better at capturing the gradual and prolonged fall that is witnessed on an aggregated level.

5.3. Limitations

This thesis aimed to compare financial frictions models. However, there were some limitations to this comparison. First, all the models were linearized DSGE models. Therefore, the introduction of non-linearized models into the comparison could have a profound impact on the transmission mechanism. Second, the quantitative comparison only considered monetary shocks. SW find that monetary shocks are only a minor driver of output and inflation dynamics. However, Degraeve finds that monetary shocks can explain up to one fifth of the fluctuations in the USA in the external finance premium in the short run. Gelain (2010), who does the same exercise for the Euro area, even finds that monetary shocks explain up to 38%. An advantage of the monetary shock was that the output gap is easily comparable across models. While it is worthwhile to investigate the impact of other shocks across these models, this is not an easy task as not all the models have the same shocks available. Third, while the financial frictions play an important role, there remain differences in assumptions and parameters which affect the dynamics of the economy. One way to address this has been done by Villa (2012), who models both the BGG and GK frictions into one DSGE model to compare them. This approach furthermore allows to compare the impact of different shocks. A last limitation is that there are different ways to incorporate financial frictions on the financial intermediaries' level, so the question remains if the Gertler and Karadi (2011) model is representative for these models.

6. Conclusion

In the light of the uncertainty and the continuing debate on the incorporation of imperfections into macroeconomic models, this thesis aimed to compare how existing DSGE models with financial frictions differ from each other in two ways. The first way was to theoretically compare their different set-ups. The second way was to investigate how these models affect the transmission mechanism after an unexpected monetary tightening of the central bank.

The theoretical comparison focused on two integrated parts. One part was to compare the general set-up of the models and how they specifically model features like price stickiness and adjustment costs. The second part was to compare three kinds of DSGE models. First, the standard DSGE models who do not explicitly model financial frictions like the Smets and Wouters (2007) and Christiano, Eichenbaum and Evans (2005). These models were analyzed to give a basic framework about DSGE models. Secondly, the models of Bernanke et al. (1999), Christensen and Dib (2008) and Degraeve (2008) who incorporate financial frictions on the firm level. These frictions arise because firms are constrained in their borrowing by their own net worth as this net worth determines the external finance premium. This constraint gives rise to a financial accelerator that amplifies monetary shocks. These models mainly investigate the external finance premium, a central variable in the finance literature. The third kind of models, represented by Gertler and Karadi (2011), introduce imperfections for financial intermediaries. Through an agency problem between intermediaries and depositors, Gertler and Karadi introduce endogenous balance sheet constraints. These constraints arise because intermediaries are limited in their lending by their own equity. These models investigate how monetary policy can help stabilize the economy in times of financial distress.

Apart from the theoretical comparison, there was a quantitative comparison to analyze how the different modeling assumptions influence the transmission mechanism after an unexpected monetary shock. This comparison was done in the standardized framework of the Macroeconomic Model Database, with the interest rate rule of Smets and Wouters (2007) being the standard rule for the different models. As is expected after an unexpected rise in the interest rate, both output and inflation fall in all the models. However, there were three distinctions that impacted the transmission mechanism.

A first distinction for the transmission mechanism was that the models of Bernanke et al. (1999) and Christensen and Dib (2008), which use the more traditional capital adjustment costs, had a sharper drop and faster recovery of output than the other models. This phenomenon relates to capital adjustment costs, as investment can more freely adjust to the shadow value of capital. On the other hand, investment adjustment costs introduce more investment dynamics as it is costly to change the level of investments. Therefore, investments and output fall more gradually and recover slower.

The second distinction that influenced the transmission of a monetary shock was the inclusion of financial frictions on the level of firms, like in the Degraeve (2008) model. While the consumption drop in this model was the same as in the standard DSGE models, investment dropped twice as much in the Degraeve model. This larger investment drop was reflected in the larger decreases in the value of capital and the increases in the external finance premium.

The last distinction was the implications by the financial frictions on the financial intermediaries' level, which was represented by the model of Gertler and Karadi (2011). This model had a much larger increase in the external finance premium than the Degraeve model, which contributed to the greater fall in investment. Consumption hardly decreased in this model, but the fall in investment was large enough to create approximately the same drop in output as in the Degraeve model. In addition, the Gertler and Karadi model was much more sensitive to a higher interest rate setting rule. These higher interest rates led to a further, much more pronounced drop in investment and output than in the Degraeve model.

An area for further research is to include other models with financial frictions on the intermediaries' level like Gerali et al. (2010) and Kyotaki and Moore (2007) and to research if they imply the same dynamics for the transmission mechanism as the Gertler and Karadi model.

A second avenue would be to study what the effect of these financial frictions models are on optimal robust monetary policy rules, especially when the Gertler and Karadi model is involved. This could allow central banks to make their monetary policy robust to the uncertainty and fluctuations caused by financial frictions.

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