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Asymmetric Effects of Monetary Policy: Theory and Evidence

A Master's Thesis submitted for the degree of
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supervised by
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Affidavit

I, Elizaveta Lukmanova

hereby declare

that I am the sole author of the present Master's Thesis,

Asymmetric Effects of Monetary Policy: Theory and Evidence

53 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Contents

List of Figures

List of Tables

Abstract

Empirical studies have documented the presence of asymmetric effects of monetary policy. For example, some studies show that the magnitude of the response of output to different types of shocks depends on whether the economy is in recession or expansion or whether the shock is negative or positive (Garcia and Schaller, 1999). In this paper I use a theoretical model capable of capturing asymmetric effects of monetary policy found in real data. I use a standard New Keynesian model and impose the Zero Lower Bound (ZLB) constraint on the nominal interest rate. The presence of the ZLB constraint leads to a kink in the solution of the model. As a result the standard approximation technique in the literature (the projection method with the Chebyshev polynomials) is not reliable. To deal with the kink problem in the policy function of the nominal interest rate I employ the projection method with the spline polynomials. To preserve nonlinearities of the model and reveal possible asymmetries I obtain fully nonlinear solution. As a preliminary step there is an overview of the related literature as well as empirical analysis of the U.S. data using a Markov-switching model.

1 Introduction

Empirical studies have documented the presence of asymmetric effects of monetary policy. For example, some studies show that the magnitude of the response of output to different types of shocks depends on whether the economy is in recession or expansion or whether the shock is negative or positive (Garcia and Schaller, 1999).

In my thesis I study asymmetric responses of monetary policy in the standard New Keynesian model. I solve the model nonlinearly since the necessary condition to have asymmetric responses is the nonlinearity of the model.

In particular I consider two specifications of the model: with and without the zero lower bound constraint. The zero lower bound constraint is a constraint on nominal interest rate that insures its nonnegative value. The introduction of the zero lower bound constraint to the model is motivated by the fact that, in general, if the interest rate offered by some asset was negative then no one would like to hold that asset and would hold currency instead. That would, of course, create many problems for the banking sector. But this is only part of the problem with negative interest rates. Financial markets are designed to operate under positive interest rates and could encounter problems ones the latter became negative. In principle, of course, it is possible for the interest rates to become negative. However, in practice it rarely happens. For example, money market mutual funds operate under rules that make it almost impossible to pay their investors negative interest rate. Negative interest rates could lead to inefficient allocations in treasury auctions (given the current rules). Moreover, it is argued that it is the zero lower bound constraint that leads to asymmetric effects of monetary policy. Without the presence of the zero lower bound constraint the basic new Keynesian model does not seem to produce asymmetries (Sripinit, 2012).

To study asymmetric effects of monetary policy using the standard New Keynesian model with the zero lower bound constraint, first, one needs to obtain the nonlinear solution of the model. As there is no closed form solution numerical methods are employed for the approximation. The standard approach in the literature is to use the projection method with the Chebyshev polynomials (J.Fernandez-Villaverde et al, 2012). Unfortunately, this choice of polynomials for the projection method is not a satisfactory one. The Chebyshev polynomials are good in approximating smooth functions. However, the presence of the zero lower bound constraint creates a kink in the model solution leading to the situation in which the use of the Chebyshev polynomials is inappropriate.

My main contribution to the literature is that I employ the projection method with spline polynomials to approximate the solution of the model with the zero lower bound constraint. The spline polynomials are piecewise polynomials that offer superior approximation when a kink is present in the solution of the model (Miranda and Fachler, 2002). To best of my knowledge, there is no paper studying the asymmetric effects of monetary policy in the context of the basic New Keynesian model with the zero lower bound constraint that employs the projection method with the spline polynomials to approximate the model solution.

I detected asymmetric effects in the model. In particular I find that there are differences in how economy responds to a monetary policy shock depending on whether the economy is in expansion or recession. The effect of monetary policy in recession is stronger than that in expansion. However, the effects of expansionary and contractionary monetary policy shock are found to be symmetric. These results are consistent with the the literature (Garcia and Schaller, 1999). The findings also suggest that the nonlinear approach is essential in obtaining a correct solution of the model, in other words linear solution cannot be considered as a good approximation of the model behavior. Comparing my solution to the solutions from papers using Chebyshev polynomials (J.Fernandez-Villaverde et al, 2012), there are differences in behavior of policy functions (i.e. consumption): with spline polynomials policy functions look smoother. This serves as another cross-check of the validity of model's solution.

Additionally, I perform an empirical exercise of testing the US data for the presence of asymmetric effects of monetary policy. For this purpose I use a Markov-switching model (the most common model in the related literature). As the result of the model estimation I can identify two types of asymmetric effects of monetary policy: between periods of expansion and recession and between expansionary monetary policy shocks in recession and contractionary monetary policy shocks in expansion.

The paper is organized in the following way: Section 2 reports the empirical evidence about asymmetries of monetary policy from the literature, Section 3 presents the empirical model and tests for asymmetric effects of monetary policy in the data. In Section 4 I introduce the theoretical model. Section 5 presents the comparisons (in terms of simulations and impulse responses) of the nonlinear solutions of the model with and without the ZLB constraint.

2 Evidence in the literature

In this section I present the empirical findings regarding the asymmetries of monetary policy. Based on these empirical findings I make an attempt to develop a theoretical model that is able to exhibits the asymmetries.

The recent world economic crisis again increased the attention of economists towards questions of asymmetries of monetary policy: policymakers were required to make important decisions about the direction of monetary policy in order to help the economy to exit a crises stage. These decisions were meant to create an immediate positive effect on the economy. In order to be able to make a right decision a government needs to foresee the consequences of its actions in advance. Here economic theory comes into play: the recession stage is relatively less frequent and less studied than the expansion stage, what if the effects of monetary policy are not the same in the crises stage as in the boom stage? What are these effects? What is the most efficient monetary instrument during crisis? The last question is particularly important since most of the developed economics faced the problem of the binding Zero Lower Bound (ZLB) constraint on the nominal interest during the crisis which means that the most standard instrument of the monetary economy is not applicable anymore. The last observation by itself leads to the conclusion that that are important differences between boom and crisis.

Evidences of asymmetries in the behavior of economic variables can be found in relatively old papers (Hamilton (1989),Garcia and Schaller (1999), Weise (1999), Morgan (1993)). The paper by Morgan (1993) is motivated by the U.S. crises of 1980s and 1990s. The question of asymmetry of monetary policy is considered in the context of the effects of tight and easy monetary policy: is the tight policy more effective than the easy policy? Morgan presents three main reasons of the asymmetries. He calls the first one changing outlook and it is related to the observation that firms are more pessimistic during recessions that optimistic during booms. The second reason is due to credit constraints which augment only the tight policy. The last one concerns the fact that prices are less flexible downward since it is costly for a firm to change a price. This leads to the situation when tight policy can decrease output with little change in price while on the contrary easy policy has a small effect on output with a big rise in price level.

With the development of computational methods and economic theory economists can estimate parameters with a high precision. The idea of asymmetries makes apparent the fact that a linear model is not a good choice. The presence of different stages of the business cycle suggests that an economy can be found in one of two regimes: recession or expansion. This evidence made economists depart from the standard linear models to nonlinear multi stage models as a better approximation of the real economy with business cycles. Empirical data strongly supports the nonlinear model. Morley and Piger (2012) test if nonlinear model fits the data better than linear model. The results are promising: all the standard information criteria choose nonlinear model. Garcia and Schaller (1999) show that the linear model is rejected with a p-value of 0.0001.

While the majority of the papers use Markov regime -switching models to test for the presence for asymmetries of monetary policy, Weise (1999) was one of the first to use a smooth transition regime switching model (he used logistic smooth transition vector autoregressive model LSTVAR). The economic intuition of this paper relates to the fact that there are several regimes in the economy in which economic variable behave similarly but their behavior differs across the regimes and the change between these regimes happens rather slowly than by discrete shifts. Weise studies asymmetries between: expansionary and contractionary shocks, monetary shocks in recession and expansion and between shocks of different sizes. The growth rate of output is used as a proxy for the switching variable between different phases of business cycles which correspond to different regimes in this model. The results of the Lagrange multiplier test are in favor of the STVAR model, the linearity hypothesis is strongly rejected. Estimation of a LSTVAR model with output growth, money growth and inflation as regressors confirms the fact that there is nonenegligible evidence of asymmetries between monetary policy effects across business cycle and some evidence of asymmetries depending on the size of the monetary policy shock but the effects of positive and negative shocks are symmetric.

The Smooth transition VAR model is a special case of endogenous Markov-switching (MS) models. However there are several disadvantages of the Smooth Transition (ST) model. Using ST model one is forced to make assumption on the parameters of the transition function. The issue concerns the estimation of a smoothing parameter: it may be problematic since it requires a very high accuracy to give a precise information about the transition between regimes (Guidolin, 2012). The ST model requires to make a choice about the transition variable. In this respect the MS model represent the most widely applied and best studied model.

Garcia and Schaller (1999) use an extended Markov-switching model presented by Hamilton (1989) to investigate if there are asymmetric reactions of output during recessions and expansions. Switch between regimes occurs when the deviation of the output growth rate from its normal value is high enough. The model used in this paper differs from the previous literature in the way of modeling the transition between regimes: first, monetary policy can affect the growth rate of output and, second, probabilities of switching between the regimes also depend on the monetary policy. Again the data strongly rejects the linear model in favor of the MS model. Changes in Fed funds rate (used as a measure of monetary policy) have statistically significant effects on output on every stage of the business cycle. The conclusion is that output reacts more strongly to the changes in interest rate during recessions: this effect is two or three times larger during recessions than expansions.

Ravn and Sola (2004) also use a Markov-switching model which allows for changes in the mean and variance of the innovation process so that they can differentiate between big and small shocks. There are two possible regimes in the model: low-growth, low-variance regime (1947-1967) and high-growth, high-variance regime (1968-1987). Three different types of asymmetries are tested: between expansionary and contractionary shocks, between small and big shocks and between low-variance shocks and high-variance shocks. However the conclusion is that only small expansionary money-supply shocks have greater real effects. Interestingly, Ravn and Sola test the data using two measures of monetary policy: M1 and Fed funds rate. In the first case no conclusions are made since the the evidence is mixed. This suggests that there is an important choice of how to measure monetary policy.

The recent paper by Morley and Piger (2012) compare different measures of business cycle. The measure of the business cycle is important because its characteristics are highly dependent on the model specification. The paper stresses the fact that linear models imply symmetric fluctuations around trend and only nonlinear models can lead to asymmetric effects. Later arguing that the presence of structural breaks is important for the model's ability to replicate the postwar data the authors allow for a break in long-run growth in the first quarter of 1973 (due to the change in the average growth rate of U.S. real GDP) and a break in volatility in the second quarter of 1984 (due to co-called Great Moderation or reduction in volatility of a business cycle). The results support the choice of a nonlinear regime-switching model by Hamilton (1989) with strong asymmetries between expansions and recessions: there are large and negative comovements of economy's variables during recessions and small variations during expansions mainly caused by movements in trend.

Asymmetries of the monetary policy were documented not only with the U.S. data. Silva and Portugal (2009) used a Markov-switching model and data from Brazil. The novelty of their paper lies in the fact that authors included in the model lagged expansionary and contractionary monetary policy shocks as a measure of the change in monetary policy. As a proxi for the monetary policy instrument overnight interest rate (SELIC) was used. They found strong evidence of asymmetry of tight and easy monetary policy during expansion (or effect of increase in the interest rate during expansion is not the same of the effect of decrease in the interest rate). They also found that easy policy (or expansionary monetary policy shock) has asymmetric effects between expansion stage and recession stage.

There are papers that claim that exactly the opposite conclusions are correct. Tenreyro and Thwaites (2013) find on the contrary that the monetary policy shocks have greater effect during booms than recessions. They employ the smooth transition-local projection model following Auerbach and Gorodnichenko (2012) who find the same results. Tenreyro and Thwaites argue that previous approaches to estimation of asymmetries make inappropriate assumptions (e.g. to test asymmetric responses using a Markov switching model one assumes constant probabilities of regime switches) and this leads to wrong conclusions. They also look for asymmetries between expansionary and contractionary monetary policies and find that the latter ones are more powerful.

Given this empirical evidence from the literature it seems to be important to investigate the above mentioned facts. First of all it is important to test if the nonlinear model is indeed important for the analysis. Then I test the empirical data for the presence of asymmetric responses on different phases of the business cycle (during expansions and recessions) since the literature does not agree on the actual amplitude of these effects. Such analysis is very relevant due to the recent crisis experience that had a long-lasting worldwide negative consequences on the economies. For instance, the binding ZLB constraint is still a problem in many developed countries and the behavior of economic variables under this constraint is of particular interest.

3 Empirical Evidence of Asymmetric Responses of the Monetary policy

In this section I test the U.S. data for the presence of asymmetries of monetary policy.

3.1 Empirical model

It is a well documented fact (Ravn and Sola, 2004) that the behavior of the economy changes over time. In other words over the business cycle one can more or less clearly distinguish between different stages: a stage of economic growth and high activity followed by the stage of contraction and decrease in economic activity. Sometimes one can even see breaks when an unexpected shift in the behavior occurs. Following the logic of this observation for the purpose of data analysis it is reasonable to have an econometric model which is able to distinguish between different stages or regimes: there are common characteristics within a given regime and different across the regimes. As a response to the demand for such a model, the Markov-switching (MS) model was developed by Hamilton (1989).

This model characterizes a nonlinear data generating process as piecewise linear by restricting the process to be linear in each regime where each regime depends only the information available in the previous regime. There is a discrete number of regimes. Consider a process whose behavior can be described by the following equation (Hamilton, 2005)

$$y_t = c_1 + \phi_1 y_{t-1} + \epsilon_{1,t}$$

where $\epsilon_{1,t} \sim i.i.d.\mathbb{N}(0, \sigma_1^2)$. The process performs well in describing the behavior of y_t until some time t_0 when a structural break occurs and the process changes the behavior substantially. From now on another equation describes y_t:

$$y_t = c_2 + \phi_2 y_{t-1} + \epsilon_{2,t}$$

where $\epsilon_{2,t} \sim i.i.d.\mathbb{N}(0, \sigma_2^2)$. This change allows the model to replicate the true behavior of the process. But this rule cannot be used as a probability law for generating the data because the structural break is not a perfectly predictable deterministic event. In order to model this change as a stochastic event one has to create a more general model. So the Markov-switching model was created:

$$y_t = c_{s_t} + \phi_{s_t} y_{t-1} + \epsilon_{s_t} \tag{1}$$

where $\epsilon_{s_t} \sim i.i.d.\mathbb{N}(0, \sigma^2_{s_t})$ and s_t is a random variable which represents different regimes (in the example above $s_t = \{1, 2\}$).

The general idea behind this model is that the parameters of the underlying data generating process of the observed time series vector y_t depend upon the unobservable regime variable s_t, which represents the probability of being in the different state of the world.

The main characteristic of the Markov-switching model is the assumption that the unobservable realization of the regime s_t follows a discrete state Markov chain process via changes in transition probabilities (Krolzig, 1997):

$$\mathbb{P}(s_t|\{s_{t-j}\}_{j=1}^{\infty}, \{y_{t-j}\}_{j=1}^{\infty}) = \mathbb{P}(s_t|s_{t-1}) \tag{2}$$

The MS model can be estimated by maximum likelihood or Bayesian inference. This work uses the first method.

The log likelihood of the model from equation (1) can be written as:

$$lnL = \sum_{t=1}^{T} ln\left((\frac{1}{\sqrt{2\pi\sigma^2_{s_t}}})exp(-\frac{y_t - c_{s_t} - \phi_{s_t} y_{t-1}}{2\sigma^2_{s_t}}) \right) \tag{3}$$

If all the states were known the procedure for the estimation of the parameters would be standard: maximize lnL from the equation (3) with respect to all the parameters. In the Markov-switching model the states are unobserved, that is why one has to implement some changes to the standard likelihood function. Considering all the possible states of the economy or conditioning on a particular state with some probability the log likelihood function for the MS model takes the following form:

$$lnL = \sum_{t=1}^{T} ln \sum_{j=1}^{2} f(y_t|s_t = j, \Theta)\mathbb{P}(s_t = j)\} \tag{4}$$

where Θ is the set of parameters of the model. Equation (4) represents a weighted average of the likelihood function of each state with weights given by the state's probability. If states are not observed (as is the case here) one can only make inferences about the probabilities based on the available information. This is the main idea of Hamilton's filter which is used to calculate the filtered probabilities of each state upon the arrival of new information.

Consider $\mathbb{I}_{t-1}$ as the matrix of all the available information at time $t-1$. Using Hamilton's filter the probabilities $\mathbb{P}(s_t = j)$ are calculated using the following iterative procedure [1] :

(i.) Make a guess for starting probabilities for each state: $\mathbb{P}(s_0 = j)$ for $j = \{1, 2\}$ (i.e. a naive guess would be 0.5 and 0.5).

(ii.) Move to $t = 1$ and calculate probabilities for each state conditional on information up to time $t - 1$:

$$\mathbb{P}(s_t = j|\mathbb{I}_{t-1}) = \sum_{i=1}^{2} p_{ji}\mathbb{P}(s_{t-1} = i|\mathbb{I}_{t-1}), \tag{5}$$

where p_{ji} are the transition probabilities from the Markov chain (equation (2)).

(iii.) The probability of each state is updated with new information available at time t. For this all the parameters from the model are used $(c_1, c_2, \phi_1, \phi_2, \sigma_1, \sigma_2)$ and the transition probabilities for the calculation of the likelihood function in each state for time t $(f(y_t|s_t = j, \mathbb{I}_{t-1}))$. Then the probability is updated using the following formula:

$$\mathbb{P}(s_t = j|\mathbb{I}_t) = \frac{f(y_t|s_t = j, \mathbb{I}_{t-1})\mathbb{P}(s_t = j|\mathbb{I}_{t-1})}{\sum_{j=1}^{2} f(y_t|s_t = j, \mathbb{I}_{t-1})\mathbb{P}(s_t = j|\mathbb{I}_{t-1})} \tag{6}$$

[1] the algorithm is taken from Perlin (2009) "A Matlab package for Markov regime Switching Models"

(iv.) Move one step forward (set $t = t + 1$) and repeat steps 2 and 3 until T.

Given the algorithm above the log likelihood function can be expressed as:

$$lnL = \sum_{t=1}^{T} ln \sum_{j=1}^{2} f(y_t|s_t = j, \Theta)\mathbb{P}(s_t = j|\mathbb{I}_t), \tag{7}$$

and the estimation of the model boils down to finding a set of parameters which maximizes equation (7).

3.2 Empirical Analysis

For the purpose of my empirical exercise I follow the methodology given in Silva and Portugal (2009) and define the Markov switching model by the following equation:

$$\triangle y_t = c_{s_t} + \phi_1 \triangle y_{t-1} + ... + \phi_p \triangle y_{t-p} + \gamma_{s_t}^{-} u_{t-1}^{-} + \gamma_{s_t}^{+} u_{t-1}^{+} + \epsilon_t \tag{8}$$

where c is a state dependent constant, $\epsilon_t \sim i.i.d.\mathbb{N}(0, \sigma^2)$, $\triangle y_t$ is the output growth, u_{t-1}^{-} is an expansionary monetary policy shock, u_{t-1}^{+} is a contractionary monetary policy shock and $\gamma_{s_t}^{-/+}$ is a state-dependent coefficient measuring the response of output growth to a expansionary/contractionary monetary policy shock. There are two regimes in the economy: expansion and recession.

As in a standard Markov-switching model the transition probabilities are assumed to be constant over time:

$$p = \mathbb{P}(s_t = 1|s_{t-1} = 1)$$

$$q = \mathbb{P}(s_t = 2|s_{t-1} = 2)$$

where p and q represent probabilities of staying in regime 0 and 1 respectively. The full transition probabilities matrix is given by:

$$P = \begin{pmatrix} p & 1-p \\ q & 1-q \end{pmatrix}$$

First I describe the data that I use for my empirical exercise. The data is downloaded from St.LouisFed (2014) website). I use U.S. quarterly data for real output (seasonally adjusted), inflation and federal funds rate. Inflation is computed using the consumer price index, also seasonally adjusted. The output and CPI are transformed using the following formula: $\triangle x_t = ln(\frac{x_t}{x_{t-1}})$ such that in the end I work with output and inflation quarterly growth rates. The values for the federal funds rate are in percent thus I only divide each observation by 100.

The federal funds rate is used as a measure of a monetary policy. It is the most natural measure of monetary policy because policymakers target exactly this rate when implementing monetary policy. As an alternative measure M1 is typically used but since M1 is an aggregate indicator it may be the case that it is affected not only by monetary policy but also by other changes in the economy. In this case it is hard to identify the role of monetary policy and conclusions can be misleading. An expansionary monetary policy is enacted to expand the money supply to encourage economic growth. On the other hand contractionary monetary policy is aimed to reduce the money supply and ultimately spending in the economy.

In the next step I define expansionary and contractionary monetary policy shocks in order to use them as indicators of tight and easy monetary policy respectively. By using expansionary and contractionary shocks separately I can test the symmetry of the effects of expansionary and contractionary monetary policy shocks, countercyclical monetary shocks and monetary policy between recessions and expansions conditional on the type of the shock. This can be done by testing the appropriate restrictions on coefficients of expansionary and contractionary shocks. As estimators for these shocks I use innovations corresponding to the monetary policy from vector autoregression of output growth, inflation growth and federal funds rate. According to the Akaike information criterion (AIC), VAR(5) is chosen (three out of four criteria choose 5 lags).

To identify shocks which corresponds only to the monetary policy the following assumption is made: output and inflation are not contemporaneously affected by the federal funds rate. This assumption can be justified by the fact that the data for output and inflation is available with some delay but on the other hand the government has access to some indicators of current inflation and output when setting the federal funds rate. Then using Cholesky decomposition I define the matrix of innovation terms such that the last row corresponds to the monetary policy shocks (the ordering of the VAR is the following: output, inflation, fed funds rate). Finally, expansionary and contractionary monetary policy shocks are defined as:

$$u_t^+ = max(0, u_t)$$

$$u_t^- = min(0, u_t)$$

where u_t is the vector of innovations define above.

In the next step I estimate equation (8) using the Markov-switching model. For this purpose I use a toolkit by Perlin (2009) (MSRegress). The toolkit is written for Matlab software and is available online. Following equation (8) I use as state dependent regressors lagged values of expansionary and contractionary monetary policy shocks and a constant. As state independent regressors I use lagged values of output growth. To determine the number of lags of output growth I use information criteria. The results are given in table (1): according to the AIC MS(2) is chosen and BIC chooses MS(0). Since BIC tends to chose the most parsimonious model and also due to the fact that there are reasons to believe that the output growth depends on its past values, MS(2) model is chosen.

For the sake of completeness I do some robustness checks. For example, I try to make output growth coefficients state-dependent. The model in this interpretation still produces similar results of the estimation and in particular similar coefficients for the monetary policy innovations. I also use different orders of lags of monetary innovation terms. Every time I use up to 8 lags of output growth and up to 4 lags of monetary innovations,

Table 1: Markov-switching model lag selection

Number of lags	AIC	BIC
8	-1495	-1437
7	-1502	-1448
6	-1504	-1453
5	-1494	-1447
4	-1502	-1458
3	-1502	-1461
2	**-1511**	-1473
1	-1509	-1475
0	-1510	**-1480**

both negative and positive. The results of the estimation are found to be robust to these changes.

I determine an expansion state as a state when an output growth is higher than in another state which is determined as a recession given there is no disturbances. From now on state 1 corresponds to recession and state 2 corresponds to expansion. The mean output growth in recession is estimated to be 0.0007, while in expansion it is 0.007 per period (per quarter). Expected duration of the first state is 4.64 quarters (about a year) and of the second state 22.25 quarters (about 5 years). These numbers seem to be plausible, expansion lasts for about 5 times longer that recession stage. Conditional probabilities matrix is presented in table (2) and standard errors are presented in parentheses. The probability of staying in recession, about 70%, is lower than staying in expansion which is about 95%.

Table 2: Conditional probabilities.

Regime	Recession	Expansion
Recession	0.7847 (0.37)	0.2153
Expansion	0.0449 (0.31)	0.9551

The intercept has a value of 0.0070 in expansion with standard deviation of 0.0015 and is significant (p-value is 0) while in recession it is 0.0007 and is indicated as insignificant (p-value is 0.85). The effect on the output growth from state dependent expansionary and contractionary monetary shocks is given in table(3), standard errors are in parentheses.

During recession output growth reacts much stronger to the expansionary monetary shock. During expansion the economy again reacts more strongly to the decrease of the interest rate but the reaction is countercyclical: given expansionary shock the output growth slows down but this effect is almost negligible. However the effect of the contractionary shock is significant only in recession (standard deviation is 0.015 and p-value is 0.02). The estimate of the effect of the expansionary shock on output growth is again only significant in case of recession (standard deviation is 0.0318 and p-value is 0.02). In general the model suggests that the effects during recession are stronger than during expansion for both types of shocks.

Contractionary monetary policy shock acts as an increase of the interest rate. One would guess that this type of shock leads to a decrease in the output growth. Expansionary monetary policy on the contrary acts as a decrease of the nominal interest rate in the economy and on the intuitive level leads to an increase in the output growth. To sum up one would expect of γ coefficients to be negative. However the Markov-switching model exhibits other results in case of recession. The most likely reason for this is hidden in the assumption made for identification of monetary policy shocks. To find out why the data behaves in such a counterintuitive way one would have to try to replicate the same exercise with other method of identification of monetary policy.

Table 3: Estimated coefficients, Markov-switching model

Type of shock/Regime	Recession	Expansion
Intercept	0.0007 0.0035	0.0070 0.0015
Contractionary monetary shock	0.0343 0.0150	−0.0144 0.0445
Expansionary monetary shock	0.0747 0.0318	−0.0221 0.0198

Figure(1) presents the dynamic of the conditional probabilities over time. As one can see the majority of time economy spends in expansion. The model predicts crises more or less in line with the historical data. It can be also helpful to look on the graph of the transition probabilities and the output growth together: when output grows a lot the probability of crisis is negligible while the probability of expansion if almost one (figure (2)). The transition from one regime to another is accompanied by a substantial change in the output growth.

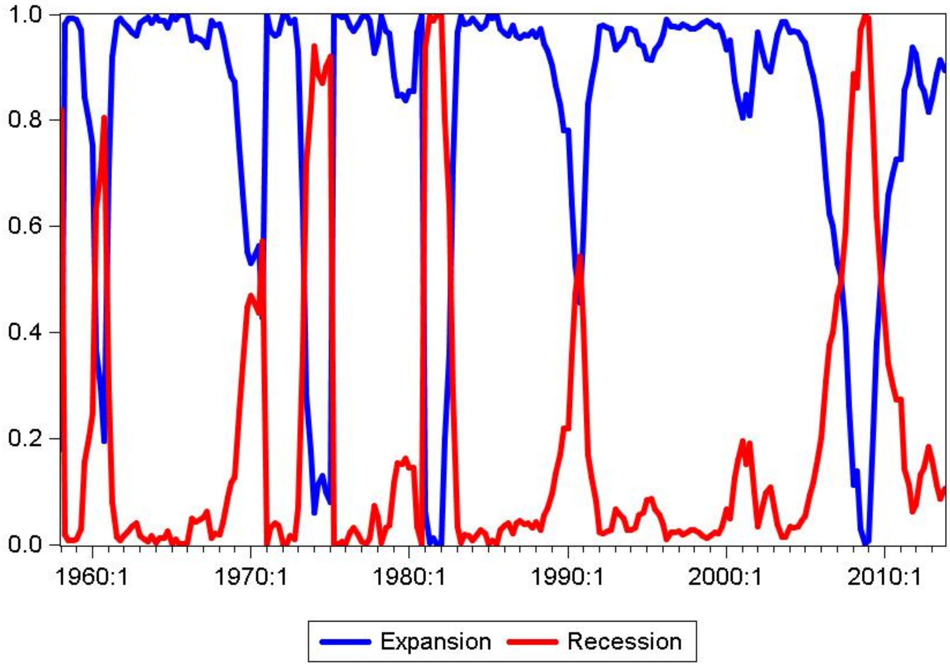


Figure 1: Smooth transition probabilities

To explore the asymmetries in the model caused by the monetary policy I test the following restrictions on the coefficients of positive and negative monetary policy shocks:

- to test the asymmetries of expansionary and contractionary monetary policy shocks:

$$\mathbb{H}_0 : \gamma_1^- = \gamma_1^+ \tag{9}$$

$$\mathbb{H}_0 : \gamma_2^- = \gamma_2^+ \tag{10}$$

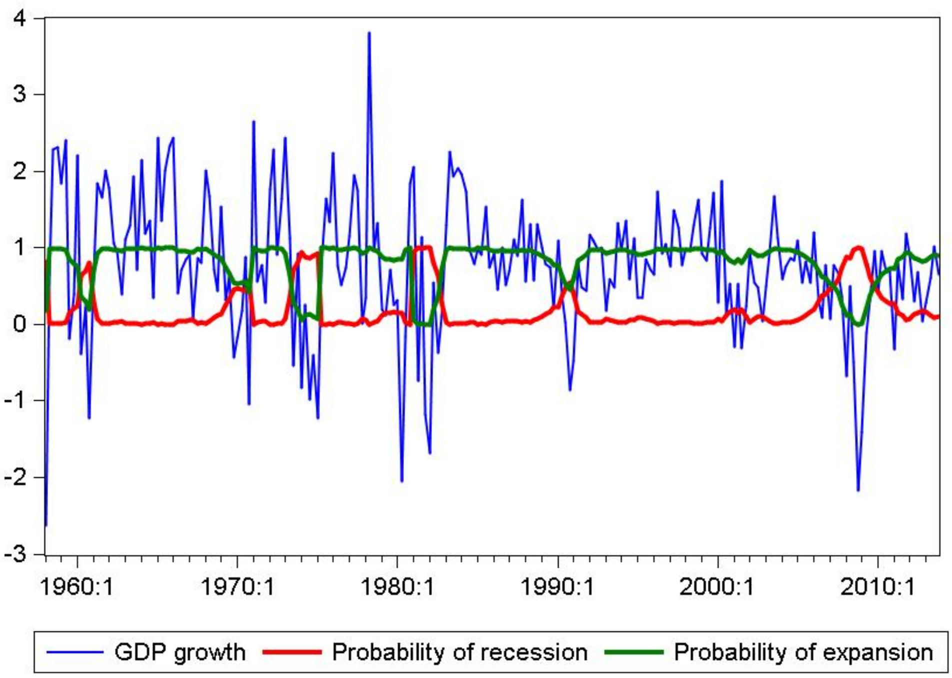


Figure 2: Smooth transition probabilities and GDP

- to test if contractionary shocks in the recession are symmetric to expansionary shocks in expansion:

$$\mathbb{H}_0 : \gamma_1^+ = \gamma_2^- \tag{11}$$

- to test if expansionary shocks in the recession are symmetric to contractionary shocks in expansion:

$$\mathbb{H}_0 : \gamma_1^- = \gamma_2^+ \tag{12}$$

- to test if monetary policy effects in recession are symmetric to those in expansion:

$$\mathbb{H}_0 : \gamma_1^- = \gamma_2^- \tag{13}$$

$$\mathbb{H}_0 : \gamma_1^+ = \gamma_2^+ \tag{14}$$

These hypothesis are tested using the Wald test (W), the test statistic under null hypothesis is chi-square distributed with degrees of freedom equal to the number of restrictions

$$W = (R\hat{\gamma} - r)'(Var(R\hat{\gamma} - r))^{-1}(R\hat{\gamma} - r) \sim \chi_1^2,$$

where $\mathbb{H}_0 : R\gamma = r$ is the restriction and $\hat{\gamma}$ is the vector of estimated coefficients. The Wald test is convenient here since the test only requires estimation of the unrestricted model (Greene, 2008).

The value of the test statistic is presented in table (4). A critical value for Chi-squared distribution with one degree of freedom for a significance level of 10% is 2.706, while for the significance level of 5% it is 3.841. Only two tests show strong evidences of asymmetry: between expansionary monetary policy shocks in contraction and contractionary monetary policy shocks in expansion, also between expansionary monetary policy shock in expansion and recession. This means that decreasing the nominal interest rate in recession has lower effect than increasing nominal interest rate in expansion. Also a decrease in the nominal interest rate has much bigger effect in recession than in expansion. But in recession the possibility of decreasing the nominal interest rate is limited by the presence of the Zero Lower Bound constraint (even though the estimation suggests that this instrument is very powerful).

One can see that the hypothesis of symmetry of expansionary and contractionary monetary policy shocks is not rejected (both test statistics are less than 1). Data also suggests that contractionary shocks have similar effects in expansions and recessions and that contractioanary monetary shocks in expansions affect output growth with the same amplitude as expansionary shocks in recessions.

Even though the MS model is widely used one can claim that the model produces counterintuitive results, in particular it predicts that no matter what government does in recession the effect on output growth is negative (since all γ coefficients are positive in the recession). If we assume that the identification of monetary policy shocks is correct there is a possible explanation for the obtained results which is concerned with the data: if

Table 4: Hypothesis testing: Wald test statistic values

Null hypothesis	Test statistic value
Symmetry of expansionary and contractionary shocks in recession(eq(9))	0.9856
Symmetry of expansionary and contractionary shocks in expansion(eq(10))	0.0179
Symmetry of contractionary shock in expansion and expansionary shocks in recession(eq(11))	**4.9710**
Symmetry of expansionary shock in expansion and contractionary shocks in expansion (eq(12))	2.0215
Symmetry of expansionary shock in expansion and recession(eq(13))	**7.3984**
Symmetry of contractionary shock in expansion and recession(eq(14))	1.2378

the changes in the output are performed very slow then it can be hard to distinguish between recession and expansion and the intervals of recession and expansion are very wide, a part of expansionary monetary policy in expansion can be evaluated as a contractionary policy in recession and the other way around. Then a contractionary monetary shock in recession has positive effect on output growth and expansionary monetary policy shock has a negative effect on output.

In this respect it seems natural to estimate these coefficients using a less sophisticated model: a model with observed switching variable and then compare the results. The type of model used for the last exercise is called threshold regression model and can be represented by the following process:

$$\triangle y_t = \begin{cases} c_1 + \phi_1 \triangle y_{t-1} + \phi_2 \triangle y_{t-2} + \gamma^-_{1,t} u^-_{t-1} + \gamma^+_{1,t} u^+_{t-1} + \epsilon_{1,t}, & \text{if } \triangle y_t > 0.001 \\ \triangle y_t = c_2 + \phi_1 \triangle y_{t-1} + \phi_2 \triangle y_{t-2} + \gamma^-_{2,t} u^-_{t-1} + \gamma^+_{2,t} u^+_{t-1} + \epsilon_{2,t} & \text{otherwise} \end{cases}$$

The difference with the MS model is the assumption that the switch between two regimes is perfectly observable and is treated as a deterministic event every period. The difference with the MS model is that the regime switches only when it reaches a given threshold value.

I divide the economy between two regimes using the level of output growth as a switching variable: as long as output growth falls below 0.001 the economy jumps from expansion to recession. This number for the threshold is chosen given that the mean of output growth is 0.007 and economy spends around 4-5 quarters in the recession out of 57 years that are considered here. The results of the estimation are presented in the table 5 (standard errors are presented in parentheses).

Table 5: Estimated coefficients, threshold regression model

Type of shock/Regime	Recession	Expansion
Intercept	-0.0029 0.0013	0.0085 0.0008
Contractionary monetary shock	-0.0306 0.0173	0.0205 0.0096
Expansionary monetary shock	0.0415 0.0150	-0.0072 0.0178

Intercepts are state dependent and significant for each model: the output growth is negative in recession ans positive in expansion given that everything else is unchanged. As for the coefficients of expansionary and contarctionary monetary policy only two of them are estimated with a high precision: the effect of contractionary monetary policy in expansion and the effect of expansionary monetary policy in recession.

This simple model predicts that in expansion an increase in the interest rate creates a positive effect on the output growth. The second prediction is that a decrease in the interest rate during recession makes a negative impact on the output growth. However in recession the effect of contractionary monetary policy is negative and in expansion the effect of expansionary monetary policy is positive.

In general one can see that even this simple model with endogenous switching parameter produces counterintuitive results. This suggests that again either there is a problem with identification or with the data (using more frequent data could produce other results; as a proxy for output growth which is not available monthly one can use industrial production index).

The only solid conclusion that can be made is that estimation of the effects of monetary policy can be very tricky. One should be careful with the choice of the model and its specification. Nevertheless asymmetries of the effects of monetary policy are identified. For the rest of the thesis I will refer to the asymmetric effects both from the literature and the empirical exercise which was performed in this chapter.

4 Theoretical model

4.1 Theoretical Models with Asymmetric Responses of the Monetary Policy

I use a basic new Keynesian model to study asymmetric effects of monetary policy. The choice of the model is supported by recent research of Smets and Wouters (2007): this model has a good fit and allows for rich structure and nonlinear dynamics. The possibility of switching between regimes and the presence of difference shocks make New Keynesian model a perfect instrument to explore the asymmetries of monetary policy in every detail.

Nonlinear dynamics of the model is an essential feature to study asymmetric effects of monetary policy. The linear solution looses important interactions between variables and exhibits symmetric responses to shocks. Since the linearity is not supported by the data (Morley and Piger (2012), Garcia and Schaller (1999)) the nonlinear model is crucial for the analysis of asymmetries. Structural analysis of the New Keynesian model also rejects linearity in favor of nonlinear specification of the model (Smets and Wouters, 2007).

However, Sripinit (2012) argues that the basic New Keynesian model by itself exhibits only negligible asymmetries: the model's responses to shocks are numerically symmetric. Allowing for the more realistic structure of the model by adding relevant frictions leads to the asymmetric effects of monetary policy: Sripinit (2012) introduces financial frictions (financial accelerator model. However using financial frictions as a possible source of asymmetries for New Keynesian model (Sripinit, 2012) produces a model with very mild asymmetries.

Eggertsson and Woodford (2003) introduces a zero lower bound constraint on the nominal interest rate. Woodford argues that a standard result of a high marginal government multiplier effect in recession holds in New Keynesian model only after introducing the ZLB constraint otherwise the model produces symmetric results which are not supported by the data.

Eggertsson and Woodford (2003) demonstrates that the presence of the zero lower bound constraint on the nominal interest rate leads to the presence of the asymmetric effects. The constraint creates a kink which leads to a high frictions given that the constraint is binding (J.Fernandez-Villaverde et al, 2012). Without the none negativity constraint model's nominal interest rate tends to be a lot below zero during a serious recession. With the presence of inequality constraint on the nominal interest rate different shocks have different amplitudes of their effects: positive shocks are more powerful than negative shocks, durations at the zero lower bound are highly nonlinear. However for an appropriate solution it is important to apply a correct solution technique to overcome a kink problem generated by the zero lower bound constraint. The right way is to employ splines polynomials. Such solution was not found in the literature while the present paper uses splines.

4.2 The model

I consider two specification of a standard New Keynesian model: the model with the zero lower bound (ZLB) inequality constraint on the nominal interest rate which prevents interest rate to be lower than zero and a model without this constraint.

The general structure of the economy is the following: a representative household supplies labor to the market and spends his income on consumption and savings. On the production side there are final good producers and intermediate good producers. Finally, there is a government which is responsible for the monetary policy: it sets a nominal interest rate according to the Taylor rule.

Households

There is a representative household in the model. He derives utility separably from consumption c_t and labor(leisure) l_t. Overall, the representative household maximizes:

$$\mathbb{E}\sum_{t=0}^{\infty}(\prod_{i=0}^{t}\beta_i)\{\log c_t - \psi\frac{l_t^{1+\nu}}{1+\nu}\}, \tag{15}$$

where ν is the inverse of the Frisch elasticity of labor which measures a substitution effect of a change in the wage rate on the labor supply, and β is a discount factor, β is time-dependent such that every period there is a possibility of change in the discount factor by means exogenously driven shock, ϵ_b. The law of motion of the discount factor is given by:

$$\beta_{t+1} = \beta^{1-\rho_b}\beta_t^{\rho_b}exp(\sigma_b\epsilon_{b,t+1}) \text{ where } \epsilon \sim \mathbb{N}(0,1) \tag{16}$$

The household can save by investing in government bonds b_t which earn a return R_t and he can consume. On the other hand he receives a wage from the labor market w_t and profits from the firms that he owns F_t. According the above description the household's budget constraint is:

$$c_t + \frac{b_{t+1}}{p_t} = w_t l_t + R_{t-1}\frac{b_t}{p_t} + F_t, \tag{17}$$

Solving the maximization problem 15 subject to 17 the household selects the optimal labor supply and consumption level by following the first-order conditions:

$$\frac{1}{c_t} = \mathbb{E}_t\{\beta_{t+1}\frac{1}{c_{t+1}}\frac{R_t}{\Pi_{t+1}}\}, \tag{18}$$

where Π_{t+1} is the inflation rate in period $t+1$ and

$$\psi {l_t}^{\nu} c_t = w_t \tag{19}$$

The first equation relates the optimal rate of consumption with inflation, nominal interest rate and discount factor. The second equation expresses the optimal amount of labor supply as a function of a wage rate and consumption.

Now let us consider the firm side.

Firms

There are two sectors of production: intermediate sector and final sector. Final sector good producers use inputs from the intermediate sector to produce a consumption good.

Final good producers.

The sector of final good producers is perfectly competitive, firms take prices for the intermediate goods and for the final good as given and produce only one final good y_t each period using a continuum of intermediate goods y_{it} and the following technology:

$$y_t = (\int_0^1 {y_{it}}^{\frac{\epsilon-1}{\epsilon}} di)^{\frac{\epsilon}{\epsilon-1}}, \tag{20}$$

where ϵ is an elasticity of substitution between different inputs. Firms maximize their profits:

$$max\{p_t y_t\} \text{ s.t. } 20,$$

where p_t is a price which a producer charges for his good.

In the end final good producers solve for the optimal input demand and the optimal price level:

$$y_{it} = (\frac{p_{it}}{p_t})^{-\epsilon} y_t \tag{21}$$

$$p_t = (\int_0^1 {p_{it}}^{1-\epsilon} di)^{\frac{1}{1-\epsilon}} \tag{22}$$

Intermediate good producers

This model model has a nominal price rigidities as is standard for New Keynesian models. The price rigidities are implemented through the assumption that not all the intermediate good producers can reoptimize their prices freely every period. There is a distribution over firms and with a certain probability a firm can change its price or it has to keep the old price until the next period. Such mechanism results in a situation when a constant fraction of firms resets prices every period on the aggregate level. This type of pricing is called Calvo price setting. It is widely used in the related literature due to the simplicity of its implementation but the results on aggregate close to reality.

For the production of an intermediate good a producer needs only labor input. Intermediate good producers are effected by exogenously driven productivity A_t with the following law of motion:

$$A_t = A^{(1-\rho_a)} A_{t-1}^{\rho_a} exp(\sigma_a \epsilon_{a,t}) \text{ where } \epsilon_a \sim \mathbb{N}(0,1) \tag{23}$$

As a result of Calvo price setting each period intermediate good producer has the following problem to solve:

$$max \mathbb{E} \sum_{\tau=0}^{\infty} \theta^{\tau} (\prod_{i=0}^{\tau} \beta_{t+i}) \frac{\lambda_{t+\tau}}{\lambda_{\tau}} (\frac{p_{it}}{p_{t+\tau}} - mc_{t+\tau}) \text{ s.t.}$$

$$y_{it} = (\frac{p_{it}}{p_t})^{-\epsilon} y_t, \tag{24}$$

where λ is the Lagrange multiplier from the household's maximization problem and θ is the fraction of firms which their prices constant.

The solution for this problem can be expressed in terms of auxiliary variables, x_1 and x_2, where:

$$x_{1t} = \frac{1}{c_t} mc_t y_t + \theta \mathbb{E} \beta_{t+1} \Pi_{t+1}^{\epsilon} x_{1,t+1} \tag{25}$$

$$x_{2t} = \frac{1}{c_t} \Pi_t^{\star} y_t + \theta \mathbb{E} \beta_{t+1} \Pi_{t+1}^{\epsilon-1} \frac{\Pi_t^{\star}}{\Pi_{t+1}^{\star}} x_{2,t+1}, \tag{26}$$

with $\Pi^{\star} = \frac{p_t^{\star}}{p_t}$ being a ratio between the optimal new price and the price of the final good.

From the properties of Calvo price setting the inflation evolution is:

$$1 = \theta \Pi_t^{\epsilon-1} + (1-\theta)(\Pi_t^{\star})^{1-\epsilon} \tag{27}$$

Government

The government implements a monetary policy by setting a nominal interest rate R_t. It uses the Taylor rule, which relates output, inflation and the nominal interest rate:

$$R_t = R^{1-\rho_r} R_{t-1}^{\rho_r} [(\frac{\Pi_t}{\Pi})^{\phi_\pi} (\frac{y_t}{y})^{\phi_y}]^{1-\rho_r} m_t, \tag{28}$$

where R is the steady state nominal interest rate, Π is the steady state target level of inflation, y is the steady state output and m_t is a monetary policy shock s.t.:

$$m_t = exp(\sigma_m \epsilon_{m,t}), \text{ where } \epsilon_m \sim \mathbb{N}(0,1) \tag{29}$$

For the model with the ZLB I impose an additional constraint on the nominal interest rate Z_t:

$$Z_t = max[1, R_t]$$

To sum up: in the constrained model the government uses Z_t as a nominal interest rate for the whole economy and in the unconstrained model the government uses R_t.

5 Results

In this section I present the results of the model's simulations. I compare a model with a Zero Lower Bound constraint on the nominal interest rate and a model without it. I apply different types of shocks to these models and compare the impulse responses of the key variables. To be consistent with the literature I also compare my solution with the solution from the linear model (linear approximation).

5.1 Solution of the model

For a nonlinear approximation of the model with the ZLB I use splines of order 17, for the model without the ZLB I use polynomials of order 10. The order of approximation is chosen in such a way that increasing an order does not influence the results. The model is calibrated such that steady state

Table 6: Parameters of the model

Variable	Name in the model	Value
Inverse of Frisch elasticity of labor	ν	1
Calvo parameter	θ	0.75
Discount factor	β	0.99
Elasticity of substitution among goods	ϵ	6
Labor elasticity	ψ	1
Steady state inflation	Π	1
Steady state output	Y	0.7940
Taylor rule parameters:		
	ψ_π	1.5
	ψ_y	0.25
Productivity shock:		
	A	1
	ρ_a	0.9
	σ_a	0.0025
Preference shock:		
	ρ_b	0.8
	σ_b	0.0025
Monetary policy shock:		
	ρ_m	0
	σ_m	0.0025

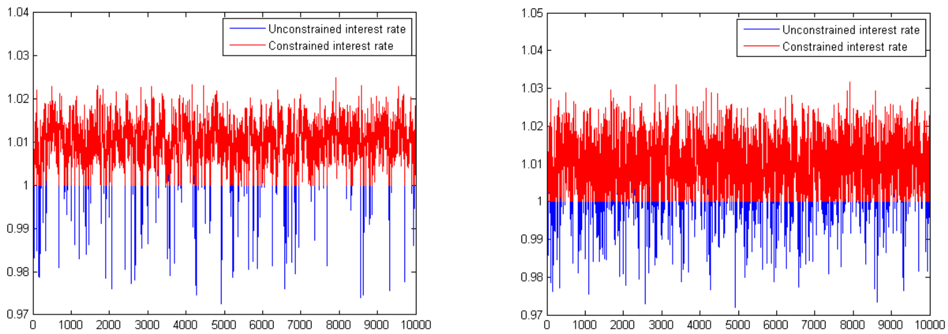
interest rate is 1% quarterly (discount factor is 0.99), steady state markup is 20% (elasticity of substitution among goods is 6) and average duration of the price is 4 quarters (Calvo parameter is 0.75). All the parameters of the model are standard in the literature and are presented in the table below (6). With these parameters productivity shock leads to the ZLB bindig for 5% out of all time, preference shock - 12% at the ZLB.

With the same variance as productivity and preference shock above the shock to the monetary policy does not lead to the event of binding ZLB. Once I increase the variance of shock by a substantial amount the constraint binds for 0.01 % of time. Due to such a small probability of the hitting of the bound I do not use this type of monetary policy shock for the analisys of the model: one can guess that in this case there are not many differences between a model with and without the ZLB. This observation is common in the literature (J.Fernandez-Villaverde et al, 2012). But I use monetary policy shock later to compare the performance of the theoretical model with the empirical model from chapter 2.

The general conclusion in the literature is that with a preference shock a simulated economy hits the ZLB often, with a shock to monetary policy the economy hits the ZLB very rarely and productivity shock is in between. However some papers (J.Fernandez-Villaverde et al, 2012) find that productivity shock leads to the highest frequency of the constraint binding event, preference shock (with almost the same number of periods) is on the second place and shock to monetary policy is far behind. Here however I can clearly identify between the frequency of binding ZLB caused by different types of shocks: preference shock, productivity shock and shock to monetary policy (ZLB does not bind).

Simulated interest rates for the cases of productivity shock and preference shock are presented in figures 3a and 3b, respectively. Blue lines stand for unrestricted interest rate and red lined represent the interest rate with imposed ZLB constraint. Unrestricted interest rate in case of productivity shock varies more over the life cycle than in case of preference shock. The difference becomes even more visible when the unrestricted interest rate is low. In case of productivity shock the interest rates tend to go much lower than in case of shock to the discount factor. This can be due to the fact that interest rate is the main instrument of monetary policy in the model and it is used to stimulate the economy in periods of low economic activity. A shock to productivity affects the interest rate directly through the output while shock to discount factor only affects interest rate and output through preferences of households and their demand.

To prove the point it is useful to look at the path of output (fig 4). In case of productivity shock output and consumption vary more than in case of discount factor shock. Even though discount factor shock makes the ZLB constraint hit more often, productivity shock creates more fluctuations in the economy.



(a) Productivity shock (b) Preference shock

Figure 3: Simulated paths of interest rate

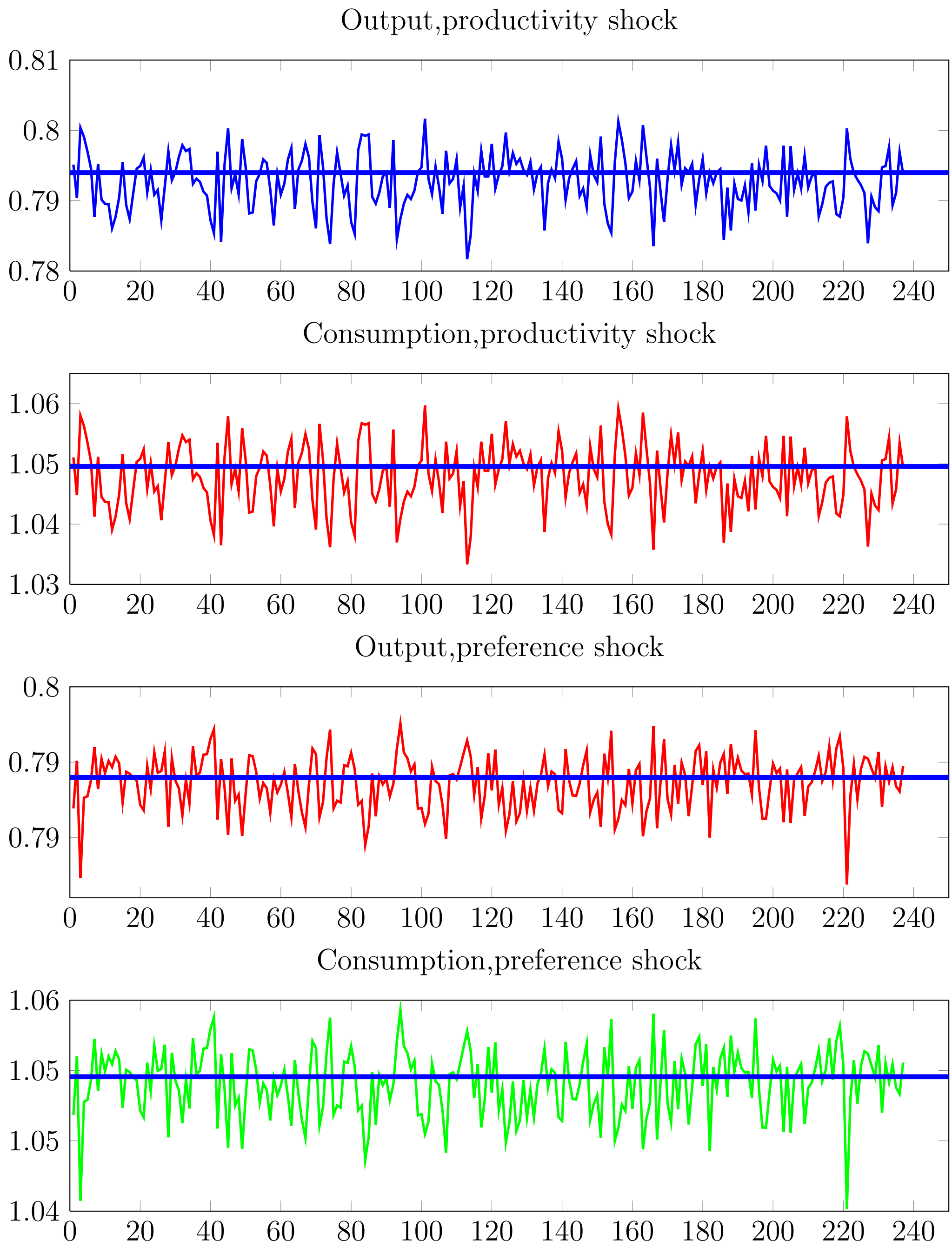


Figure 4: Simulated paths of output and consumption, blue line-steady state value

It is also important to check if nonlinear solution of model differers from the linear one. Figure 5 demonstrates the response of the nominal interest rate, consumption and output for linear and nonlinear solution given a small productivity shock. Figure 6 does the same for the preference shock. One can see that there are indeed differences between linear and nonlinear solution in both cases although these differences are not very big. This suggests that linear solution gives a relatively poor approximation of the model's behavior and there are nonlinear relationships between variables. The fact that nonlinearity is an essential feature of the model gives a room for possible asymmetries. In the remaining chapters I consider only nonlinear solution of the model.

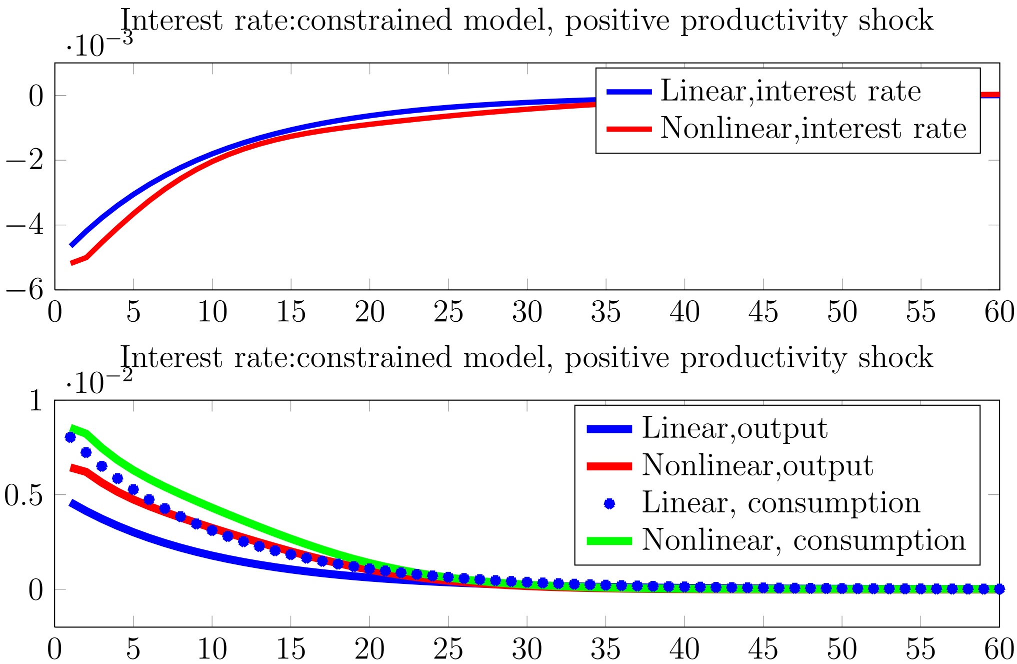


Figure 5: Linear vs Nonlinear solution of the model, productivity shock

5.2 Nonlinearities in the model

The reason for choosing New Keynesian model was that the model is able to exhibit nonlinearities. It is important to look at the performance of the model and measure these nonlinearities. In this work I consider different nature of shocks (productivity shocks, preference shock and monetary policy shock) and also divide each of them between small shock and big shock.

The effects of small and big shocks are presented in the appendix A and B. The first table corresponds to the model with the ZLB constraint and the second one to the model without this constraint.

As one can see the effects of the small shocks are absolutely symmetric for both models. In case of big shocks the model with the ZLB constraint seems to have larger differences in responses to positive and negative

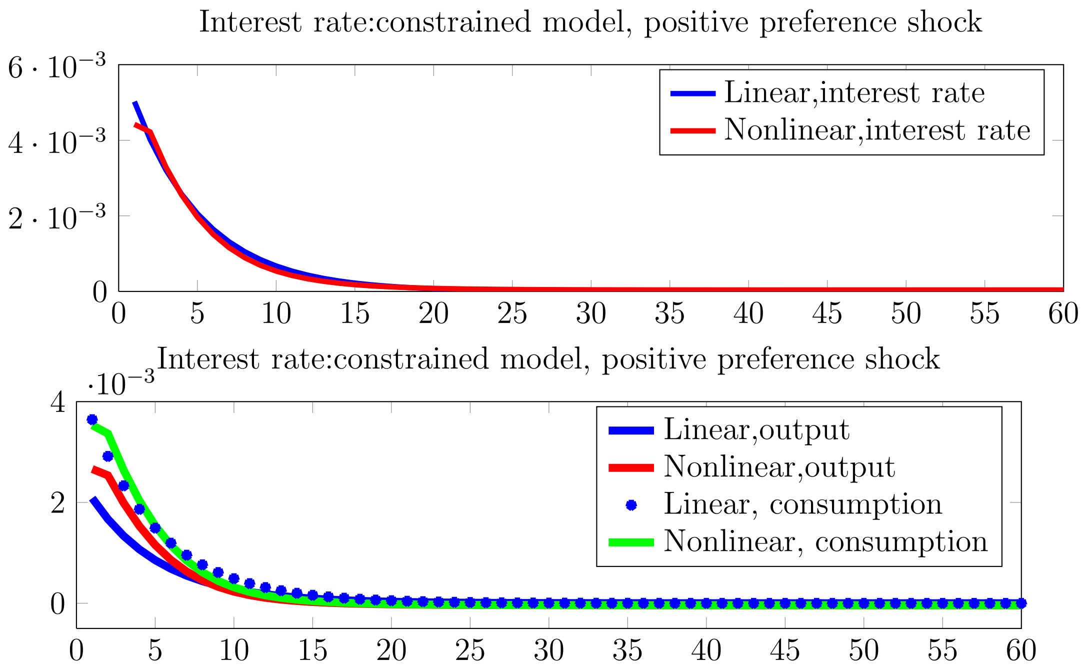


Figure 6: Linear vs Nonlinear solution of the model, preference shock

shocks. A big shock to the preferences of households seems to produce more asymmetries between positive and negative shocks than a big shock to the productivity. When talking about big and small shocks it is important to note that the agents in the economy assign 10% probability to event of big shock happening and 25% probability to the event of small shock happening. Also there is a 30% chance that there will be no changes.

The impulse response functions of interest rate, output and consumption are presented (fig. 7, fig. 8). I present only the impulse responses of the variables to the big shocks due to the fact that the tables mentioned above (A, B) suggest that the small shocks only cause the symmetric reaction of the variables from the model. Using the same logic I only present the impulse response function for a model with a ZLB constraint.

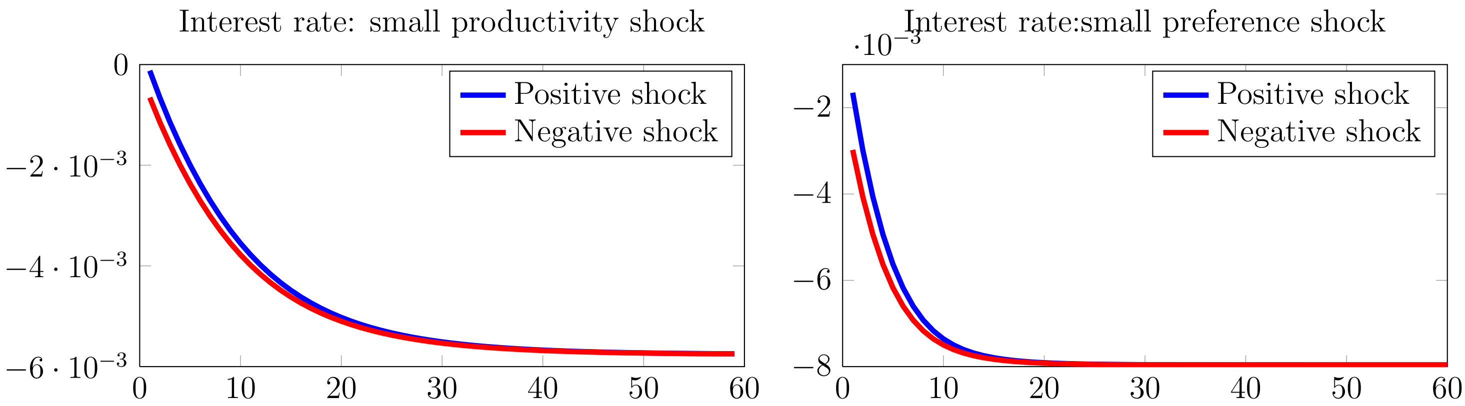


Figure 7: The impulse response function of the nominal interest rate on impact of a small shock in the model with the ZLB

The differences between positive and negative shocks to the interest rate are small but are visible. Both types of shocks, the shock to productivity and the preference shock, lead to almost the same differences between positive and negative shocks. This is also true for the consumption and output: there are some differences on impact but they are negligible (fig. 8).

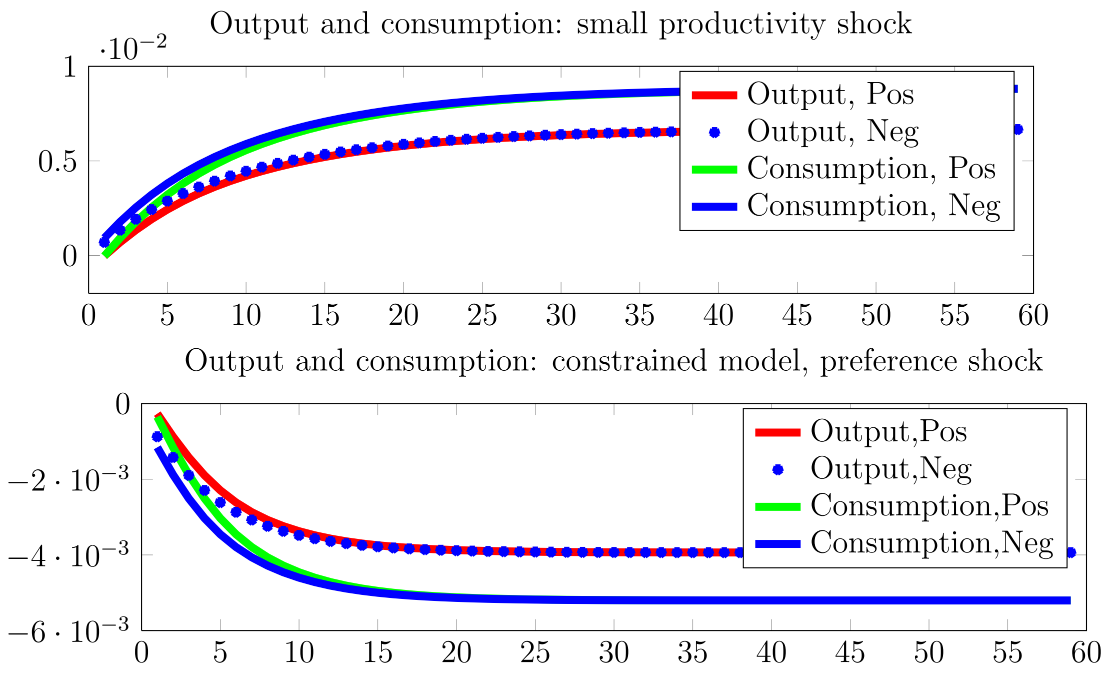


Figure 8: The impulse response function of consumption and output on impact of a small shock in the model with the ZLB

Note that even for the big shocks the ZLB is not binding. An interesting exercise would be to look at the impulse responses in the event when the economy hits the ZLB constraint (fig. 10 and fig. 9). Agents in the economy assign zero probability to this event, the shock given to the economy is so big that it can be interpreted as crisis or a rare disaster. However in this particular case the model with the ZLB constraint exhibits asymmetries in the responses to the positive and negative shocks in case of productivity shock and preference shock.

As one can see the ZLB binds longer on impact of the preference shock. The behavior of the output and consumption also differs a lot between two types of shock. The leads to the conclusion that the nominal interest rate plays a big role for the consumption decisions and output production. When the economy hits the ZLB constraint for a long time the consumption and output behavior is under stress (fig. 10).

To test if the ZLB constraint is the cause if asymmetries in case of a very big shock in the economy one has to look at the behavior of the unconstrained model under the same shock (fig. 11). The unrestricted model produces some asymmetries but they are not compatible with the constrained model. This suggests that the presence of the ZLB constraint is essential for the model and it makes a lot of changes in the economy once the shock is big enough or there are several big shocks in a row (for example the economy is in a deep crisis). However with a standard reasonable parameters of the model the probability of such a crisis is very low.

Overall there are large difference between the responses of the nominal interest rate in constrained and unconstrained models once the model hits the bound. This observation suggests that previous papers which argue that it is enough to approximate the economy first without ZLB constraint and impose it afterwards (Eggertsson and Woodford, 2003) lost an important interactions between variables in the economy and their approximation cannot be considered as plausible. In the remaining chapter I consider only the constrained model.

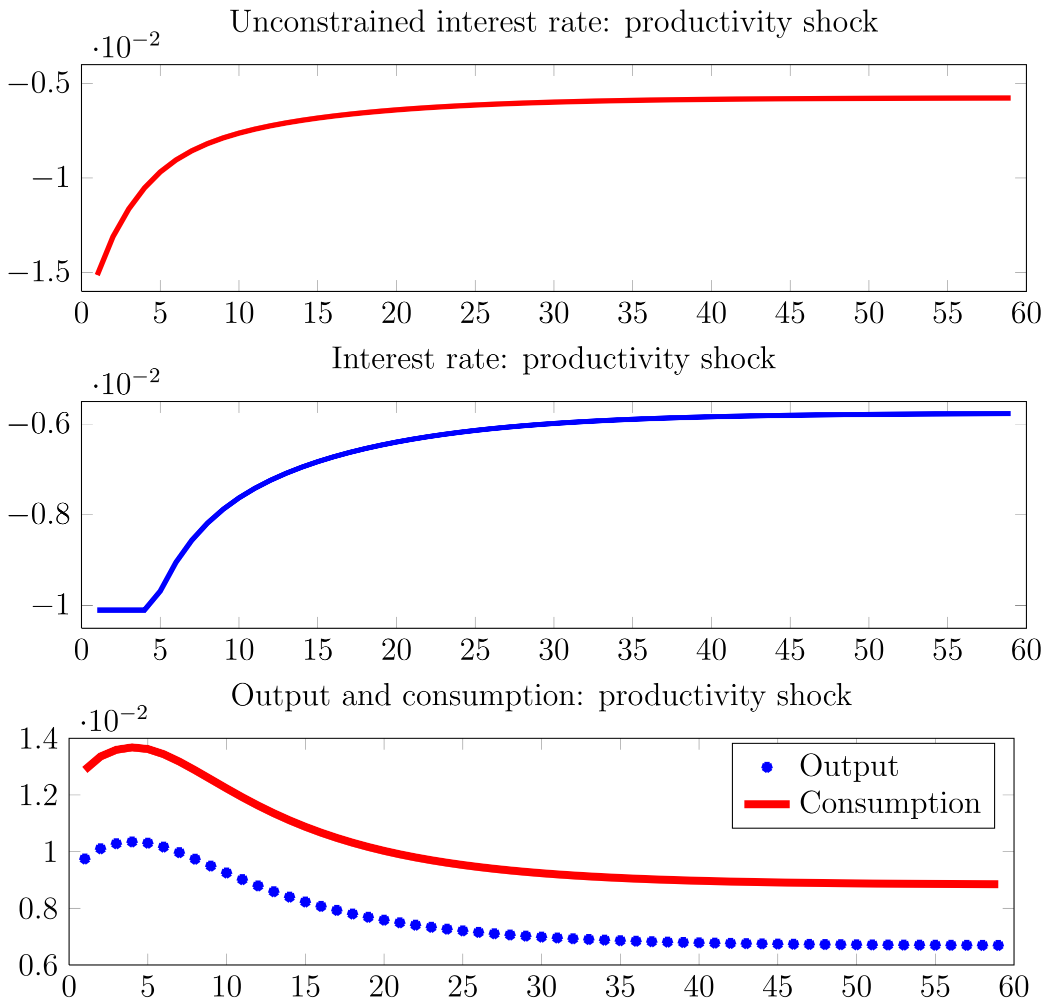


Figure 9: The behavior of interest rate, consumption and output during rare events (Productivity shock)

5.3 Asymmetric effects

In this section I compare the performance of the theoretical model with the empirical model from chapter 2. Since in the empirical model shocks to the federal funds rate were used as a measure of the monetary policy here I also use shocks to the monetary policy which directly hit the nominal interest rate in the model.

I look for for three types of asymmetries: between expansionary and contractionary shocks, between countercyclical shocks and between shocks on the different phases of the business cycle. To distinguish between the effects of the different shocks I plot the impulse response functions and compare them. To ease the comparison of the impulse responses I revert expansionary shocks and shocks in recession so the responses appear on

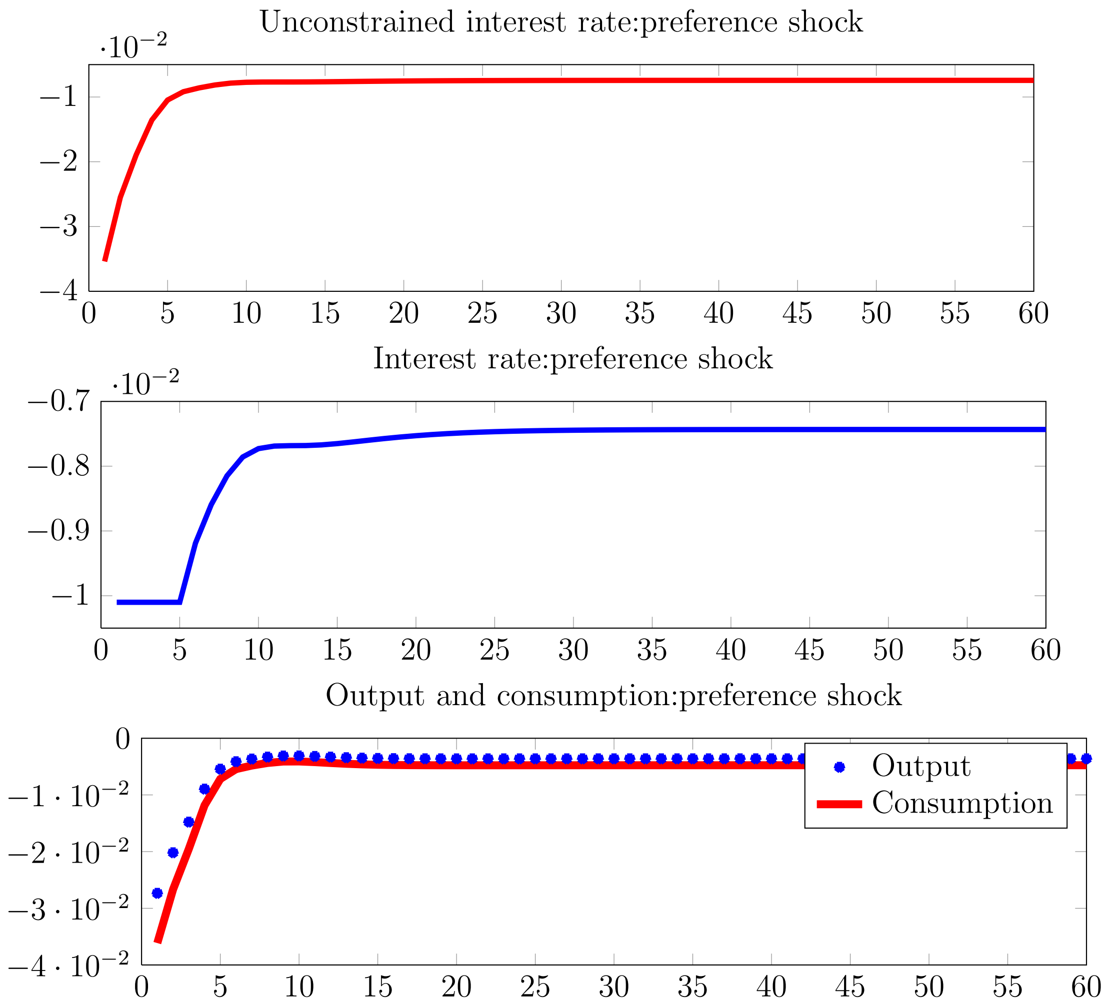
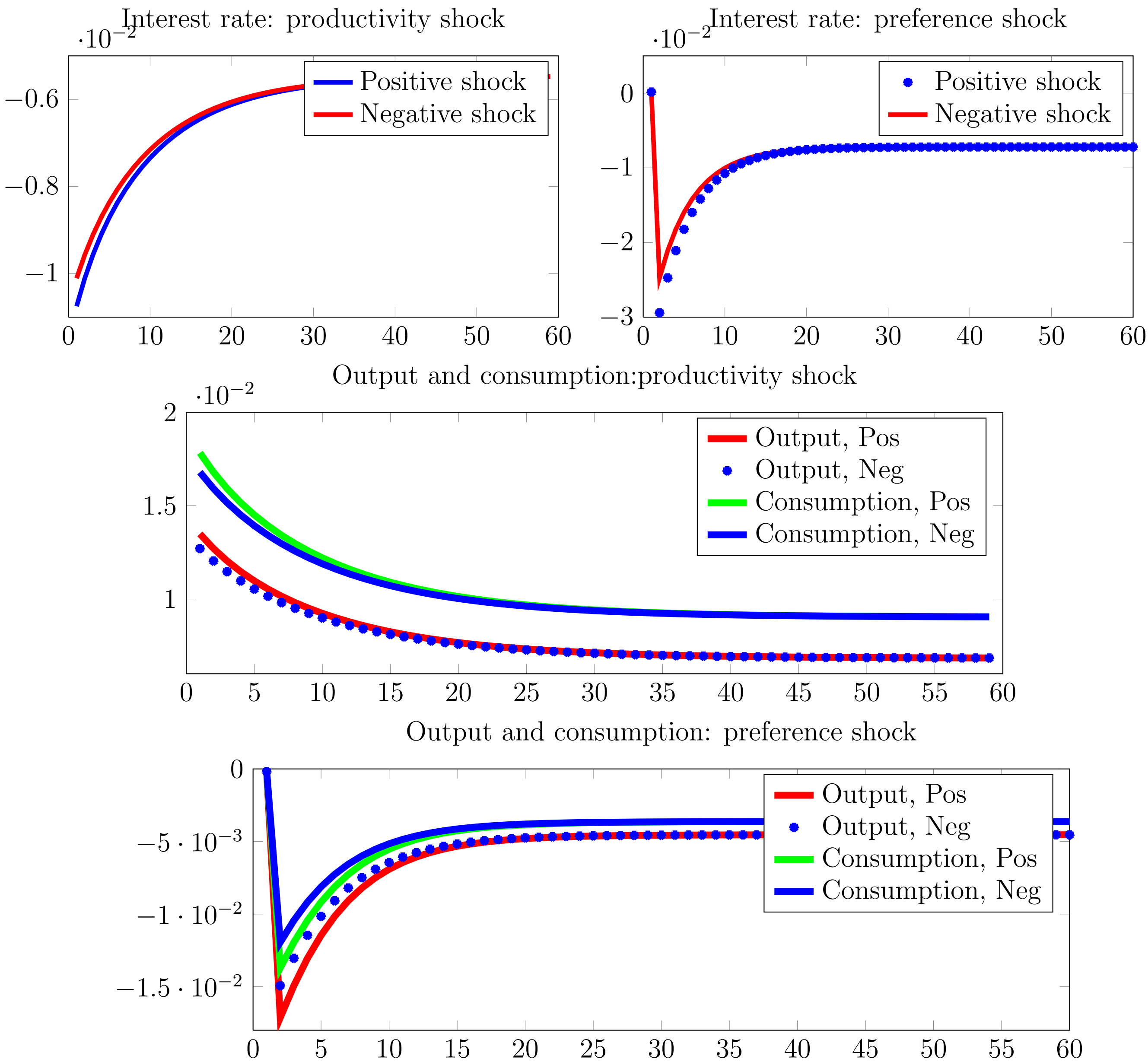


Figure 10: The behavior of interest rate, consumption and output during rare events (Preference shock)

the same side. If shocks perfectly coincide then the hypothesis of the symmetry cannot be rejected. Note that in the second chapter tests indicated the presence of two kinds of asymmetries: between contractionary shocks in expansions and recessions and between contractionary shocks in expansions and expansionary shocks in recessions, so there are asymmetries of monetary policy over the business cycle and between the countercyclical shocks.

I use only a model with the ZLB constraint. Due to the evidence from the previous section the constraint leads to the presence of the asymmetric responses between different types of shocks while the model without the constraint is numerically symmetric.

Asymmetries between expansionary and contractionary shocks



Pos - positive shock, Neg - negative shock

Figure 11: The behavior of interest rate during rare events (Unconstrained model, productivity shock)

Figure 12 and figure 13 present the impulse response functions of the nominal interest rate, output and consumption in expansion and in recession. On each graph the response of the expansionary and contractionary shock is presented. The model exhibits no visible asymmetric effects of monetary policy between expansionary and contractionary monetary policy shocks both in expansions and in recessions. This results goes in line with the prediction from the Markov-switching model (see table 4).

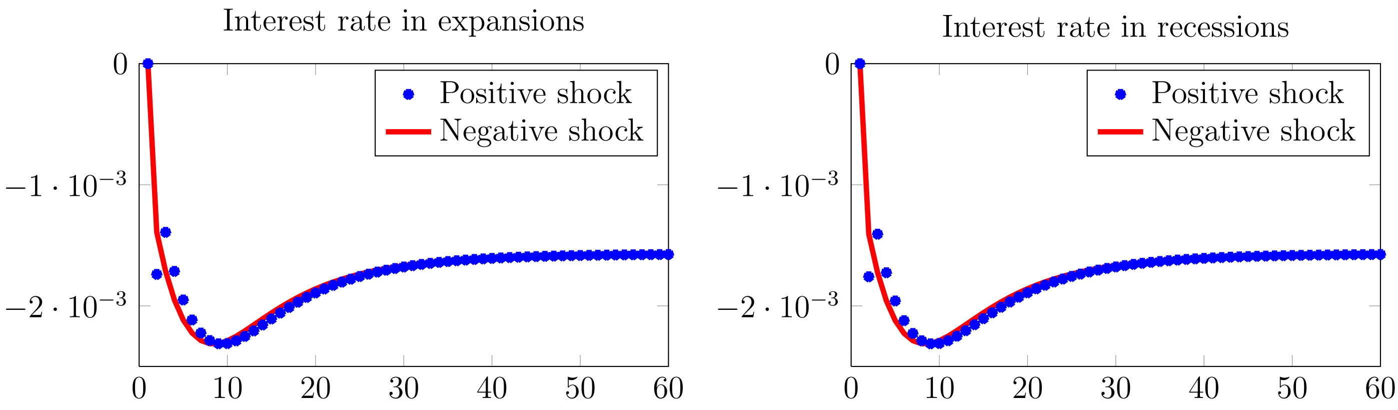


Figure 12: The behavior of interest rate under expansionary and contractionary monetary policy shocks

Consumption and output in expansion and recession are presented on figure 13. There is some difference between expansionary and contractionary monetary policy shock to consumption (green and blue lines on the graph). But this difference is very small. The difference between the response of output to expansionary and contractionary monetary policy shock is even smaller than for a case of consumption. From the difference that are visible on the graph one can conclude that consumption and output react more strongly to expansionary monetary policy shocks shocks.

Asymmetries between countercyclical shocks

By countercyclical shocks I understand two groups of shocks:

- contractionary shocks in recession and expansionary shocks in expansion;
- contractionary shocks in expansion and expansionary shocks in recession.

The reaction of the nominal interest rate under the second type of countercyclical shocks is symmetric (fig. 14). However there are some difference in the response of the nominal interest rate between contractionary shocks in recession and expansionary shocks in expansion. On impact of the expansionary shock in expansion the interest rate changes more and the effect on the interest rate is higher overall. This result suggests that

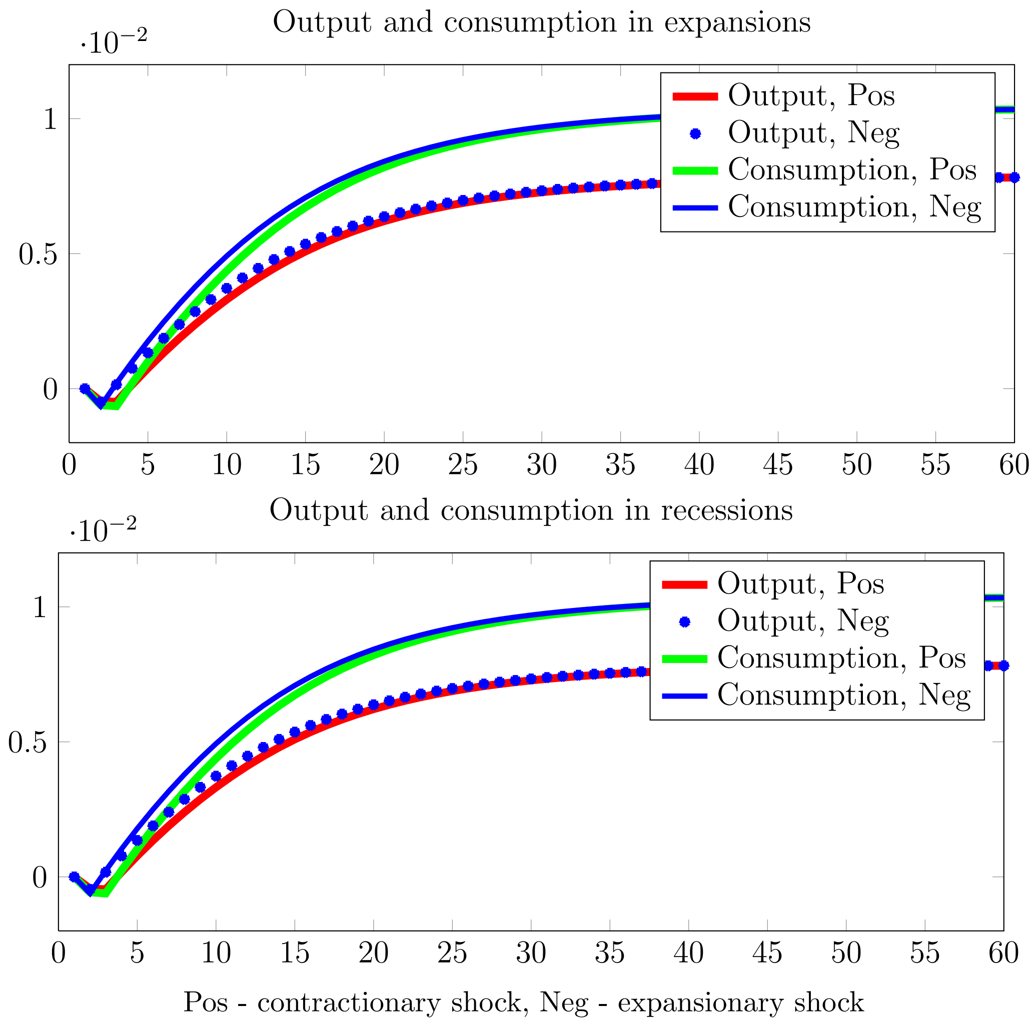


Figure 13: The behavior of output and consumption under expansionary and contractionary monetary policy shocks

the economy is more sensitive during expansions than during recessions. It is important to see what are the consequences of such asymmetries in the behavior of the interest rate on the behavior of output and consumption (fig. 15).

The reaction of consumption and output on countercyclical monetary policy shocks is presented on figure 15. As on can notice that there are again some difference in the responses of output and consumption but they are not very big. For example the model predicts that consumption reacts more strongly to a expansionary shock in expansion than to a contractionary shock in recession. Also it shows that the amplitude of the reaction of consumption to a expansionary shock in recession is higher than to a contractionary shock in expansion. These observations suggest that over-

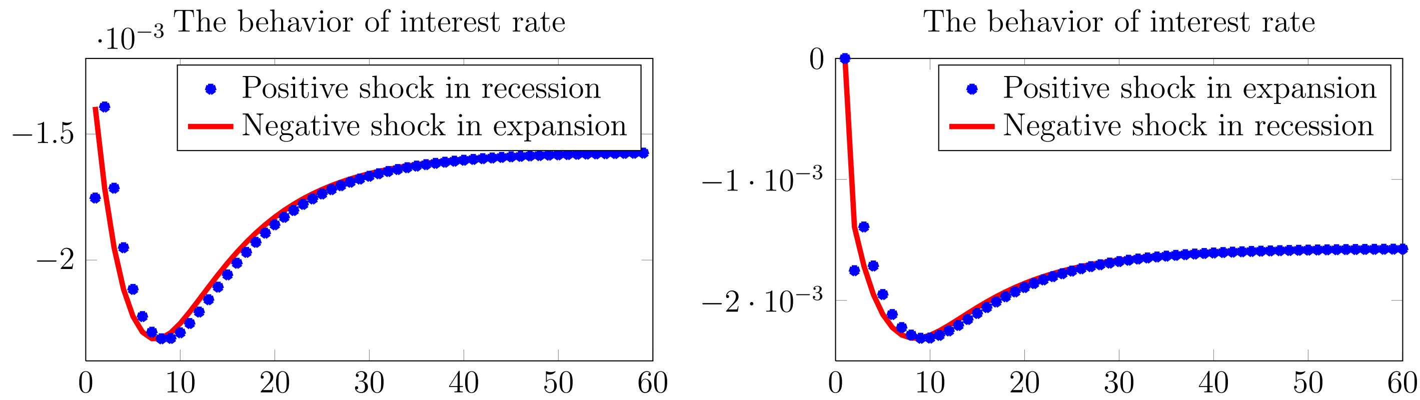


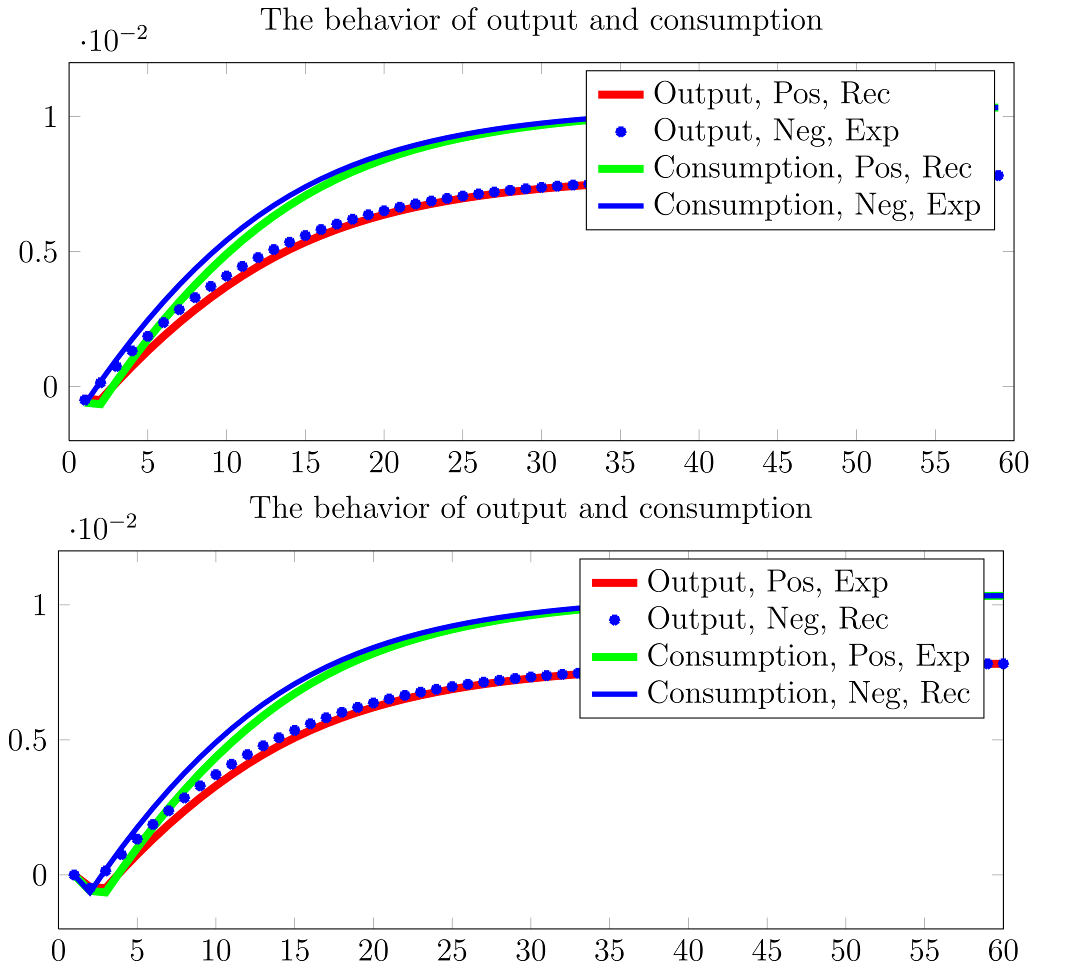
Figure 14: The behavior of interest rate under countercyclical monetary policy shocks

all consumption reaction more strongly to expansionary monetary policy shocks. The result goes in line with the result from testing the asymmetries between expansionary and contractionary shocks above.

The reaction of output exhibits smaller differences between different countercyclical shocks. However in both graphs a red line which represents the reaction of output to contractionary shocks in case of expansion and recession respectively lies below the blue dotted line which corresponds to the response of output to contractionary monetary shocks. From this one can conclude that the output is more sensible towards easy monetary policy shocks. This result also does not confront the results about asymmetries between expansionary and contractionary shocks in general in the model.

The MS model estimated in chapter 2 indicated that there is asymmetry in a response of output growth between expansionary shocks in expansion and contractionary shocks in recession (the first graph in figure 15). Theoretical model shows very poor evidence for this type of asymmetry. If one compares two graphs from the figure 15 it is hard to find differences. However the MS predicts that there should be differences between responses of output towards countercyclical shocks from the first figure. This leads to the fact that the theoretical model does not account for asymmetry between expansionary shocks in expansion and contractionary shocks in recession very well.

Asymmetries between shocks over the business cycle



Pos - contractionary shock, Neg - expansionary shock, Exp - expansion, Rec- recession

Figure 15: The behavior of output and consumption under countercyclical monetary policy shocks

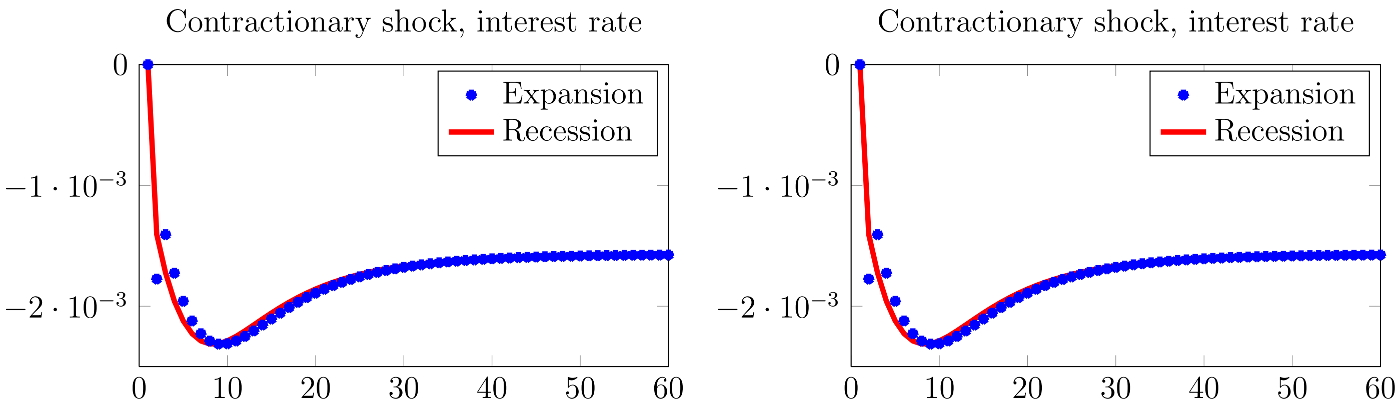


Figure 16: The behavior of interest rate over the business cycle (Productivity shock and preference shock)

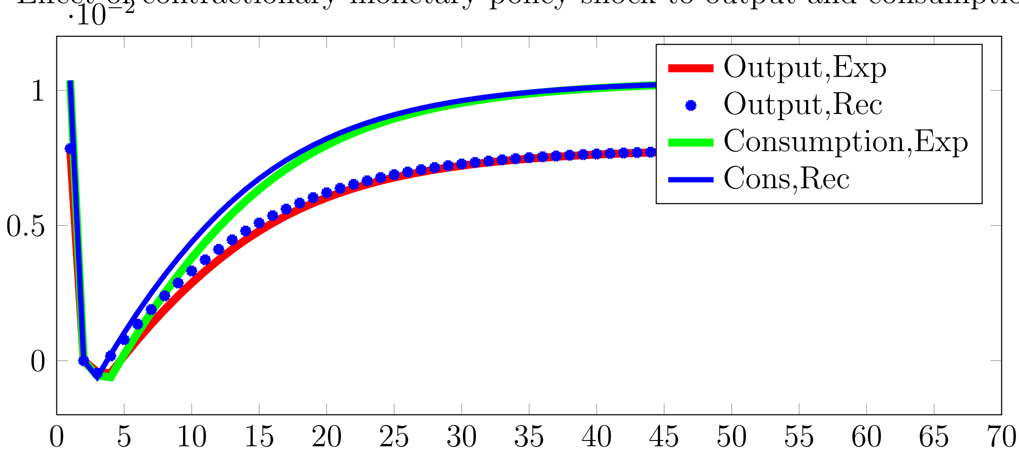
the behavior of the nominal interest rate in different phases of the business cycle is presented on figure 16. There are no visible difference in the effects of different shock on the nominal interest rate between expansion and recession. However one should look at eh behavior of the output and consumption (fig. 17).

Contractionary monetary policy shocks do not create a lot of asymmetries in the behavior of output and consumption. Consumption and output in expansion react more strongly to changes in monetary policy than in recessions. This result is intuitive: when economy is in expansion it is very sensitive to the changes since it is in the development stage. If the government decides to tight the economy in expansion or in recession the amplitude of the effect of consumption and output will be almost the same in both cases.

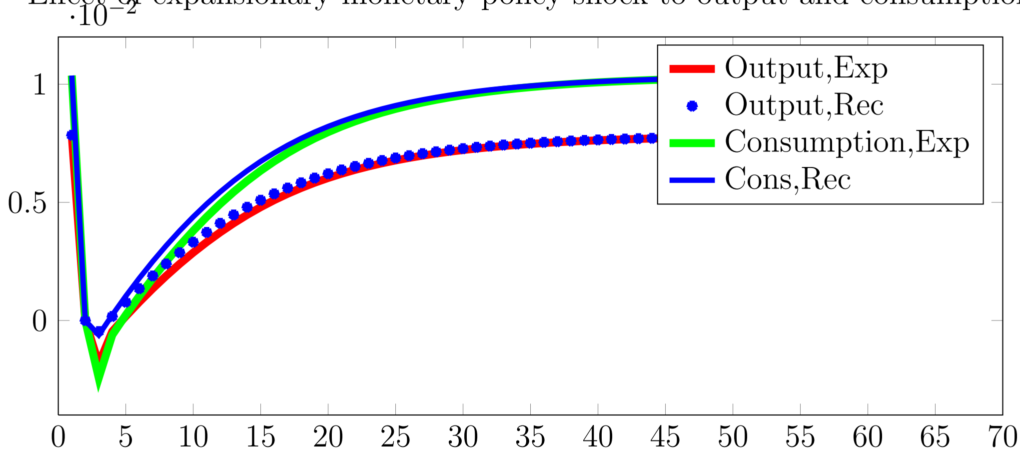
However expansionary shocks seem to cause more asymmetries than contractionary shocks. Expansionary shock translates into the decrease of the nominal interest rate . From figure 17 it is clear that consumption react more strongly to the contractionary monetary policy shocks in recession than in expansion. This can be due to the fact when the economy is in recession households have less income than in expansion and they have to contract their spendings and consequently consumption. This means that the consumption is very sensitive to any shocks. When expansionary monetary shock hits the nominal interest rate in the economy decreases and households experience positive effect on their consumption. The same process happens in expansions but the output growth is high and households already consume a lot. A decrease in the nominal interest rate during expansions leads to smaller marginal positive effect on the consumption of households than that in the recession.

The Markov-switching model predicts that there are asymmetries of monetary policy between expansionary monetary policy shocks in expansion and recession. The theoretical model also shows that there is substantial asymmetry between expansionary monetary policy shocks. In fact this type of asymmetry is the only one that one can easily identify looking at the impulse response functions.

Effect of contractionary monetary policy shock to output and consumption



Effect of expansionary monetary policy shock to output and consumption



Pos - contractionary shock, Neg - expansionary shock, Exp - expansion, Rec- recession

Figure 17: The behavior of output and consumption over the business cycle

6 Conclusion

In this work I consider the asymmetric effects of monetary policy. The general conclusion in the related literature is that there are asymmetric effects of the monetary policy between different phases of the business cycle while the effects of expansionary and contractionary monetary policy shocks are symmetric. However there is no agreement if the monetary policy is more powerful during recessions or expansions.

The chosen topic is of great importance after the last world economic crisis. In particular it is important to know if the economy reacts in the same way to the changes in monetary policy in recessions as in expansions or what is the most effective monetary policy instrument during crisis. The last question is indeed relevant since the most standard monetary policy instrument nowadays is a nominal interest rate and modern economies are faced with a non-negativity constraint on it (or the Zero Lower Bound constraint) which prevents Central Banks from lowering the interest rate to boost the economy during crisis.

To shed some light on this issue I use a theoretical model which is able to produce asymmetries found in the data. For these purposes I use a standard New Keynesian model with the Zero Lower Bound constraint on the nominal interest rate. The model is approximated using splines polynomials to account for a kink in the behavior of the nominal interest rate. The model is simulated using three types of shocks: productivity, preference and monetary policy shock. The simulated path of the nominal interest rate shows that in each case the economy hits the ZLB constraint (for 5% of all time in case of productivity shock and for 10% of all time in case of preference shock). Later comparing different scenarios the asymmetries generated by the model are considered.

The impulse response functions demonstrate only one type of asymmetry: the asymmetry of monetary policy during different phases of the business cycle. In particular the model predicts that consumption and output have differences in the responses to a expansionary monetary policy shock between periods of recession and expansion. Also the model predicts that there are no asymmetries between expansionary and contractionary monetary policy shocks both in expansions and recessions. These results are compatible with the estimation of data from the U.S. from 1959 to 2013.

Given the evidence from the literature the theoretical model can be considered as an appropriate approximation of the reality. But there is still a room for future research. For example one can employ other programming software (C++ instead of Matlab) to obtain a solution with even higher precision and compare the robustness of results. Another aspect is that the effects on the variables of different shocks are very small. The reason can be due to the choice of parameters of the model. One can apply a recent micro evidence about price rigidities and compare the results.

A Appendix

Table 7: The effect on the variables on the impact of a small shock in a model with the ZLB constraint ($*10^{-4}$)

	Small shock				**Big shock**			
	Productivity shock		*Shock to preferences*		*Productivity shock*		*Shock to preferences*	
	Positive	Negative	*Positive*	Negative	*Positive*	Negative	*Positive*	Negative
Unconstrained interest rate	-2	2	5	-5	**-2**	**3**	**1.9**	**-2.3**
Interest rate	-2	2	5	-5	-2	3	1.9	-2.3
Consumption	4	-4	-1	1	**3**	**-5**	**-5**	**4**
Output	3	-3	-1	1	**4**	**-6**	**-4**	**3**

B Appendix

Table 8: The effect on the variables on the impact of a small shock in a model without the ZLB constraint ($*10^{-4}$)

	Small shock				**Big shock**			
	Productivity shock		*Shock to preferences*		*Productivity shock*		*Shock to preferences*	
	Positive	Negative	*Positive*	Negative	*Positive*	Negative	*Positive*	Negative
Interest rate	-2	2	2	-2	**- 2**	**4**	2	-2
Consumption	5	-5	-1	1	5	-5	-1	1
Output	4	-4	-2	2	4	-4	-2	2

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