



Department of Economics

# **Three Essays in Macroeconomics**

**Lenno Uusküla**

*Thesis submitted for assessment with a view to obtaining the degree of  
Doctor of Economics of the European University Institute*

Florence  
February 2011

EUROPEAN UNIVERSITY INSTITUTE  
**Department of Economics**

# **Three Essays in Macroeconomics**

**Lenno Uusküla**

Thesis submitted for assessment with a view to obtaining the degree of  
Doctor of Economics of the European University Institute

**Jury Members:**

Prof. Morten Ravn, University College London, Supervisor  
Prof. Giancarlo Corsetti, EUI and University of Cambridge  
Prof. Fabio Canova, Universitat Pompeu Fabra  
Dr. Luca Dedola, European Central Bank

© 2011, Lenno Uusküla

No part of this thesis may be copied, reproduced or transmitted  
without prior permission of the author

## Dedication

To my wife Mari and daughter Karolina

## Acknowledgements

I was very lucky to have Morten O. Ravn and Giancarlo Corsetti as supervisors. Morten O. Ravn was very patiently pushing me to write better papers. Giancarlo Corsetti was always cheerful and encouraging even at the times when models were not working.

The years in Florence would have been very lonely without many good friends. Mark Le Quement and Markus Kitzmüller helped to survive the first year and made the rest a pure pleasure. We spent together long evenings in VSP but happily not only in VSP. With the support of many more friends I found the strength not only to fight through, but also enjoy the study process. I hope that the future will make our friendship only stronger. I want to thank Jessica Spataro and Lucia Vigna for all the paperwork and Thomas Bourke for the help in getting firm turnover data.

Last but not least I grateful to my wife Mari who agreed to take the adventure in Florence and Karolina who has kept up the good mood during the last few months.

# Contents

<b>I</b>	<b>Introduction</b>	<b>v</b>
<b>II</b>	<b>Chapters</b>	<b>1</b>
<b>1</b>	<b>Monetary Transmission and Firm Turnover</b>	<b>2</b>
1.1	Introduction . . . . .	3
1.2	Empirical methodology . . . . .	5
1.3	Data . . . . .	9
1.4	Empirical results . . . . .	10
1.5	Robustness analysis . . . . .	11
1.6	Limited participation model . . . . .	13
1.6.1	Consumer problem . . . . .	13
1.6.2	Final goods firm . . . . .	14
1.6.3	Intermediate goods firms . . . . .	15
1.6.4	Financial intermediary . . . . .	16
1.6.5	Monetary authority . . . . .	16
1.6.6	Market clearing conditions and the equilibrium . . . . .	16
1.7	Model with pre-set prices . . . . .	17
1.7.1	Consumer problem . . . . .	17
1.7.2	Final goods firm . . . . .	18
1.7.3	Intermediate goods firms . . . . .	18
1.7.4	Monetary authority . . . . .	20
1.7.5	Market clearing conditions . . . . .	20
1.8	Calibration and results of the two models . . . . .	20
1.9	Conclusions . . . . .	22
	Bibliography . . . . .	23

<b>2</b>	<b>Deep Habits and the Dynamic Effects of Monetary Policy Shocks</b>	<b>37</b>
2.1	Introduction . . . . .	38
2.2	The Model . . . . .	41
2.2.1	Households . . . . .	42
2.2.2	Firms . . . . .	45
2.2.3	Monetary Policy . . . . .	48
2.2.4	Market Clearing . . . . .	48
2.2.5	Symmetric Equilibrium . . . . .	48
2.3	Estimation . . . . .	50
2.3.1	SVAR Estimates of the Impact of Monetary Policy Shocks . . . . .	50
2.3.2	Estimation of the Structural Parameters . . . . .	52
2.4	Results . . . . .	55
2.4.1	Constrained Markup . . . . .	58
2.4.2	Sub-Sample Stability . . . . .	59
2.5	Conclusions . . . . .	60
	Bibliography . . . . .	61
<b>3</b>	<b>Firm Turnover, Financial Friction and Inflation</b>	<b>77</b>
3.1	Introduction . . . . .	77
3.2	The model . . . . .	79
3.2.1	Household problem . . . . .	80
3.2.2	Final good firms . . . . .	81
3.2.3	Intermediate good firms . . . . .	82
3.2.4	Banks . . . . .	85
3.2.5	The Government and the Central Bank . . . . .	85
3.2.6	Aggregation and market clearing . . . . .	85
3.2.7	Equilibrium . . . . .	86
3.3	Data, Estimation and Priors . . . . .	86
3.4	Results . . . . .	88
3.5	Conclusions . . . . .	93
	Bibliography . . . . .	95

# Part I

## Introduction

## Introduction

Does the number of firms increase or decrease after a contractionary monetary shock? Do the predictions of a standard sticky price model match with the empirical evidence? How can we explain persistent and hump shaped effects of monetary policy? What explains inflation? These are the central questions in the thesis. Three papers have strong overlaps, but contain also major differences. The common element in the papers is a modified New Keynesian Phillips curve, but that was never an objective on its own. The macroeconomic models of the first and third chapter are similar as they include a financial friction and the number of firms dynamics. Second is based instead on a deep habits mechanism that changes the pricing behavior of firms. In terms of econometric method, the first two chapters are alike as they help to understand monetary shocks based on structural VAR evidence. Third paper explains inflation using full likelihood Bayesian estimation of a DSGE model.

In the first chapter I show that based on structural VAR evidence for the postwar U.S. economy, a contractionary monetary shock leads to a drop in the creation of new firms and increase in the number of failures. In the theoretical part of the paper I show that financial friction is important in understanding the firm creation and destruction for monetary shocks. The requirement of working capital in production helps to generate a decrease in the number of firms for a negative monetary shock. However a standard sticky price model predicts that the number of firms increases after a negative monetary shock. When firms do not adjust their prices immediately aggregate demand falls. This also lower labor demand. But when wages are low, it is cheap to create new firms. Therefore sticky prices cannot be the only and most important mechanism for monetary transmission.

Second chapter, written together with Morten O. Ravn, Stephanie Schmitt-Grohé and Martín Uribe introduces deep habits in a standard sticky price and sticky wage monetary model and demonstrates how the inclusion can explain two features of the monetary effect that are usually called puzzles in the literature. First the deep habits leads to a persistent decline in prices after a monetary shock. Second, the deep habits mechanism can reproduce the price puzzle often found in the papers - inflation tends to increase rather than decrease after a contractionary monetary shock. The deep habits work through two channels. First, intratemporally the prices increase after a contractionary shock because the elastic part of consumption has decreased compared to the non-elastic component, so that the optimal mark-up increases. Second, given the expected decline in consumption firms do not have



incentives to invest into demand, so that prices increase even further. The model impulse responses are matched with a monetary VAR evidence for the postwar U.S. economy.

In the third chapter I ask the question what explains inflation dynamics over the business cycle. I augment a medium scale New Keynesian DSGE model with two features. First, I allow the number of firms to vary over the business cycle. Second, firms need to borrow part of their wage bill in advance. Financial frictions and firm dynamics enter both the New Keynesian Phillips curve and uncouple marginal cost from the inflation rate. I show that the shocks to the cost of creating firms are important in explaining inflation dynamics. A drop in the entry costs leads to increase in inflation as many firms are created and costs are high. Inflation decreases only gradually as the number of firms in the economy increases. I find evidence that also shocks to the technology are important in generating volatility in inflation. Financial friction does not play a crucial role in explaining inflation. The results are obtained using full likelihood Bayesian estimation of a DSGE model for the U.S. economy.

# Part II

# Chapters

## Chapter 1

# Monetary Transmission and Firm Turnover

Lenno Uusküla<sup>1</sup>

### Abstract

Traditional models of monetary transmission such as sticky price and limited participation abstract from firm creation and destruction. Only a few papers look at the empirical effects of the monetary shock on the firm turnover measures. But what can we learn about monetary transmission by including measures for firm turnover into the theoretical and empirical models? Based on a large scale vector autoregressive (VAR) model for the U.S. economy I show that a contractionary monetary policy shock increases the number of business bankruptcy filings and failures, and decreases the creation of firms and net entry. According to the limited participation model, a contractionary monetary shock leads to a drop in the number of firms. On the contrary the same shock in the sticky price model increases the number of firms. Therefore the empirical findings support more the limited participation type of monetary transmission.

---

<sup>1</sup>I want to thank Morten O. Ravn, Giancarlo Corsetti, Saverio Simonelli, Jeff Campbell, Zeno Enders and Alan Sutherland for their valuable suggestions, Thomas Bourke for help in getting the data. I am also grateful to the seminar participants at the European University Institute, and Eesti Pank, and conference participants at MAREM Conference in Bonn, International Conference on Economic Modeling in Berlin, EEA/ESEM conference in Milan, and Money, Macro and Finance (MMF) conference in London.

**Keywords:** monetary transmission, limited participation, sticky prices, firm entry, firm bankruptcy, structural VAR

**JEL codes:** E32, C32

## 1.1 Introduction

Two popular approaches for understanding monetary transmission are limited participation and sticky price models. These models rarely include firm turnover: entry and exit of firms. What can we learn about monetary transmission by including the number of firm dynamics into these models? What are the empirical effects of monetary shocks on the firm turnover variables?

The empirical results of the paper show that a contractionary monetary shock leads to an increase in the number of business failures and to a decrease in the creation of firms. The sticky price and limited participation models give contradicting predictions about the firm turnover dynamics. According the sticky price model a contractionary monetary policy shock leads to an increase in the number of firms, whereas in the limited participation model the same shock leads to a decrease in the number of firms. Therefore the empirical evidence supports limited participation hypothesis of monetary transmission in comparison to the sticky prices.

I estimate an 11-variable vector autoregressive (VAR) model for the U.S. economy including labor productivity, total hours, GDP deflator, capacity utilization, real wages, consumption, investment, Federal Funds Rate, money velocity, and one-by-one alternative firm turnover measures: firm entry, net entry, business bankruptcy filings, and failures. I adopt the recursive approach in identifying monetary shocks which is based on contemporaneous restrictions. In addition I identify investment specific and neutral technology shocks with long run restrictions in order to minimize problems of mis-specification. The monetary policy results are robust to the use of non-borrowed reserves and the Federal Funds Rate (FFR) in order to identify the shock, inclusion and exclusion of the firm turnover measures from the central bank information set, difference and level stationarity of hours, reduction of the estimation period, etc.

My empirical findings are in line with the previous literature measuring the effects of the monetary policy on the creation of firms. Bergin and Corsetti (2008) use a relatively small scale VAR of monthly data and impose short run restrictions in order to identify the monetary shock. They find that net entry decreases after a contractionary monetary shock when either the FFR or non-borrowed reserves are

used in order to identify monetary policy shocks. The firm creation decreases only if non-borrowed reserves are used to identify the monetary shock. Lewis (forthcoming) adopts a sign restriction approach to estimate the effect of the monetary shock to net entry. She finds that net entry decreases only with a significant lag after a contractionary monetary policy shock.

In the theoretical part of the paper I augment two simple models of monetary transmission, a limited participation and a pre-set price model as a simple case of sticky prices, with the endogenous firm creation and exogenous firm destruction dynamics. I assume that creation and operating firms is labor intensive. According to the limited participation model, firms pay wages before production and have to borrow the wage bill from the financial intermediary. A contractionary monetary policy shock decreases the liquidity of the financial intermediaries: bank lending falls and the interest rate increases. The real wage and hours worked decrease because firms can borrow less money to pay for their workers. The marginal cost of production for the firm remains constant because the real wage declines and interest rate increases. Fall in the total production leads to a drop in the creation of firms. In a standard sticky price model, a contractionary monetary shock leads to a drop in demand for the consumer good and consequently to a drop in demand for labor. Therefore labor costs fall equally for production of goods, and for operating and creating firms. Increasing profits per firm lead to higher creation of firms up to the level where the free entry condition is satisfied. These results are the opposite of the predictions of the limited participation model and the empirical results. Some recent models of monetary transmission include the firm turnover dynamics.

In the Bilbiie, Ghironi, and Melitz (2007) model with quadratic adjustment cost of prices, a contractionary monetary policy shock leads to an increase in the number of firms (in their interpretation varieties) when creating firms is labor intensive. Instead, in order to get a decrease in the number of firms, Bilbiie, Ghironi, and Melitz (2007) and Bergin and Corsetti (2008) assume that for the entry cost, new firms buy goods from the existing firms, who sell at pre-set prices. Then monetary contractions decrease entry of firms because of the increase in the real entry cost. However, a decrease in the demand for the output leads to a drop in wages and to an increase in profits for the existing firms. Increasing profits should still lead to an increase in entry in the production sector.

In order to keep entry costs fixed Mancini-Griffoli and Elkhoury (2006) assume that in order to create a firm, entrepreneurs have to buy goods from a specific sector in the economy that which sets their prices in advance, whereas the rest of the

entrepreneurs set the prices of their goods freely. In such a set-up, a contractionary monetary shock raises the real cost of entry and consequently the creation of firms decreases. Lewis (forthcoming) shows that a contractionary monetary shock in the sticky wage model can also lead to a drop in the entry of firms.

## 1.2 Empirical methodology

I set up the VAR model in order to estimate the effects of the monetary policy shock to the firm turnover measures. I adopt the recursive approach in identifying the monetary shock. In order to reduce the problem of mis-specification, I identify in addition two technology shocks: investment specific and neutral technology shocks with the long-run restrictions.

The reduced form VAR is given as:

$$y_t = b_0 + \sum_{i=1}^p b_i y_{t-i} + u_t, \quad (1.1)$$

where  $y_t$  is the set of endogenous variables listed in Table 1.1 in the order as they appear in the model,  $b_0$  represents all the deterministic terms which are used in the estimation including constants, seasonal and impulse dummies,  $b_i$ -s are matrices of coefficients,  $p$  is the number of lags in the model, and  $u_t$  is the error term.

Table 1.1: Variables used in the benchmark VAR

Notation	Name of the variable
<i>ip</i>	change in logarithm of investment price
<i>lp</i>	change in logarithm of labor productivity
<i>GDPdef</i>	change in logarithm of GDP deflator
<i>capu</i>	level of capacity utilization
<i>h</i>	logarithm of per capita hours worked (level)
<i>w</i>	logarithm of real labor cost
<i>c</i>	logarithm of consumption share in GDP
<i>i</i>	logarithm of investment share in GDP
<i>ee</i>	change in logarithm of firm demographics measure
<i>FFR</i>	federal funds rate (level)
<i>vel</i>	logarithm of money velocity

I use the Federal Funds Rate (FFR) to measure monetary conditions and the

change in the log of the GDP (Gross Domestic Product) deflator as a proxy for inflation. I include the relative price of investment in order to identify an investment specific technology shock and a labor productivity variable in order to identify a neutral technology shock. I add a list of macroeconomic variables in order to reduce a possible omitted variable bias. The additional macroeconomic variables are capacity utilization, hours worked, real unit labor cost (real wages), consumption and investment shares in GDP, and money velocity. For a detailed description of the data see Table 1.2 in the Appendix.

Several other authors have estimated similar systems of VAR models. For example Altig, Christiano, Eichenbaum, and Linde (2005) use a 10-variable VAR including the relative price of investment, productivity, a GDP deflator, hours, consumption, investment, and several other variables, but do not include a measure of firm dynamics in their system. Ravn and Simonelli (2007) estimate a 12-dimensional VAR adding government expenditures and, specific to their paper, several labor market variables.

The structural VAR is given as:

$$A_0 y_t = B_0 + \sum_{i=1}^p B_i y_{t-i} + \epsilon_t \quad (1.2)$$

where  $B_i$ -s are matrices of the structural coefficients, related to  $b_i$ -s as follows:  $b_i = A_0^{-1} B_i$ ,  $\epsilon_t$  are the structural shocks, the variance-covariance matrix  $\Sigma_\epsilon = E(\epsilon_t \epsilon_t')$  is assumed to be diagonal and related to the reduced form shock variance-covariance matrix  $\Sigma_u = E(u_t' u_t)$  by the following formula  $\Sigma_u = A_0^{-1'} \Sigma_\epsilon A_0^{-1}$ .

The recursive approach of identifying the monetary policy shocks builds on a Taylor-rule type of argument. A central banker who takes into account the contemporaneous values of the variables in his information set ( $\Omega$ ), then decides on the shock ( $\zeta_t$ ) by setting the interest rate ( $R_t$ ),

$$R_t = F(\Omega) + \zeta_t. \quad (1.3)$$

In order to obtain identification, I impose short-run restrictions. The variables in the information set can have a contemporaneous effect on the interest rate, but not vice versa. I estimate the following equation:

$$\begin{aligned}
FFR_t &= b_0^f + \sum_{i=0}^p b_i^{f,ip} ip_{t-i} + \sum_{i=0}^p b_i^{f,lp} lp_{t-i} \\
&+ \sum_{i=0}^p b_i^{f,GDPdef} GDPdef_{t-i} + \sum_{i=0}^p b_i^{f,capu} capu_{t-i} + \sum_{i=0}^p b_i^{f,h} h_{t-i} \\
&+ \sum_{i=0}^p b_i^{f,w} w_{t-i} + \sum_{i=0}^p b_i^{f,c} c_{t-i} + \sum_{i=0}^p b_i^{f,i} i_{t-i} + \sum_{i=0}^p b_i^{f,ee} ee_{t-i} \\
&+ \sum_{i=1}^p b_i^{f,FFR} FFR_{t-i} + \sum_{i=1}^p b_i^{f,vel} vel_{t-i} + u_t^f.
\end{aligned} \tag{1.4}$$

All the variables placed before the interest rate can have contemporaneous effects on it, but are assumed not to be affected contemporaneously by it. For example, money velocity, which is the only variable after the interest rate, is contemporaneously influenced by the interest rate, but does not affect the FFR in the same period. I assume that the firm turnover variables enter into the central bank's information set ( $\Omega$ ). The explanatory variables for the interest rate are all the contemporaneous values and lags of the variables placed before it, plus the lags of the interest rate and money velocity.

The recursive identification scheme for the monetary policy is popular in empirical literature, for example it is adopted in the papers by Altig, Christiano, Eichenbaum, and Linde (2005), Boivin, Giannoni, and Mihov (2007), and Ravn and Simonelli (2007). The main alternative is a non-recursive approach proposed by Sims and Zha (2006), but it has been shown to result in very similar impulse responses to the recursive identification scheme. Uhlig (2005) proposes an identification scheme according to which sign restrictions are set on the impulse response functions. The sign restrictions approach challenges some of the empirical results obtained by the short-run restrictions. See Christiano, Eichenbaum, and Evans (1999) for an overview of the main results of the monetary shock and the comparison of various identification approaches.

Bergin and Corsetti (2008) exclude the firm turnover variable from the information set of the central bank. The reason might be the use of monthly data in their estimation. As shown in the robustness analysis section of this paper, the results are not sensitive to different timing.

I base the identification of the investment specific technology shock on the assumption that only the investment specific technology shocks can have a long-run



impact on the relative price of investment goods. Therefore, the explanatory variables for the estimated equation on the relative price of investment are the lags of the investment price itself and the lagged values of all other variables differenced once. The use of differenced data implements the zero long-run restrictions, see Shapiro and Watson (1988). The contemporaneous values of the FFR and velocity are not included because of the identification of the monetary shock.

For the permanent neutral technology shock, I assume that only the neutral and investment embodied technology shocks can lead to permanent changes in labor productivity. Therefore all the other variables are differenced once. Again, contemporaneous values of the FFR and money velocity are not included in the set of explanatory variables in order to identify the monetary policy shock.

The embodied technology equation cannot be estimated with the ordinary least squares technique because the contemporaneous value of productivity might be correlated with the residual. Therefore I estimate the equation by IV technique. The instruments are the lagged values of the explanatory variables. The equation neutral technology has the same problem, therefore the equation is estimated with the IV technique using the same instruments as for the equation on the investment price adding the residual from the investment price equation.

After estimating the two technology shocks, I proceed with the estimation of the equations in the order of the variables in Table 1.1. I estimate all the equations by the recursive IV technique. I include the contemporaneous values of the previous variables in the regression and exploit all the estimated residuals as instruments. Therefore for the estimation of the last equation on money velocity, I include all the other contemporaneous values of the variables in the regression and residuals in the set of instruments.

Many authors consider technology to be the key factors in the macroeconomic fluctuations, including Kydland and Prescott (1982), Altig, Christiano, Eichenbaum, and Linde (2005), Ravn and Simonelli (2007), etc. Several authors adopt the long-run restrictions approach in identifying neutral technology shocks, for example see Gali (1999), Altig, Christiano, Eichenbaum, and Linde (2005), Fisher (2006), and Ravn and Simonelli (2007). Recently Fischer (2006) showed that the neutral technology shock might be mis-specified if the investment technology shock is not identified. Campbell (1998) shows that technology shocks can be important for generating variance in the plant entry and exit dynamics, which is closely related to the business entry and failure variables.

### 1.3 Data

The creation of firms (number of new incorporations) and the number of business failures (number of firms failed) are available for the period 1959Q1–1998Q3, and the net entry index (net business formation) can be obtained for the period 1959Q1–1995Q4. This data are collected and calculated by Dun&Bradstreet Inc. available through various sources (see Table 1.2 in the Appendix). The number of business bankruptcy filings is from the U.S. Court of Bankruptcy. It is used in the estimations for the period 1960Q3–2005Q4. The firm turnover data are presented in log-levels in Figure 1.1 in the Appendix.

The Dun&Bradstreet database covers around 90% of the enterprises with at least one employee and some without employees. The registration of a company in the Dun&Bradstreet database is voluntary and the registration of the firm can take place some time after the actual start of the business. Therefore the entry data contain noise. The index of the net entry of firms is not available in its aggregate numbers because of the difficulties in counting the number of closing firms. In addition to the abovementioned problems, Armington (2004) discusses several other weaknesses of the firms created and net entry variables.

Up until the year 1984 the number of business failures included only commercial and industrial sectors. In 1984 Dun&Bradstreet extended the coverage and added banks, railroads, real estate, insurance, holding, financial companies, which made the new data directly incomparable. Naples and Arifau (1997) propose an adjustment which makes the post 1984 time-series comparable to the pre 1984 period. According to their results, the number of business failures increased on average about 31% because of the increase in the coverage. For the period 1984–1996, I use the adjusted data. There are no adjusted failure numbers available for the years 1997 and 1998. For these years I subtract the average increase in the coverage of 31%.

In 1978, a new bankruptcy law eased the bankruptcy procedure. The number of failures increased steadily and stabilized at a higher level around 1983. In order to capture the change in the law, a dummy variable is added to the equation of business failures. The number of bankruptcy filings increases at the beginning and decreases at the end of the period, however the inclusion of dummies for different periods does not change the results given the confidence intervals of the estimated results.

Table 1.3 in the Appendix presents the (augmented) Dickey-Fuller stationarity test results for the firm turnover measures. The variables are not stationary in log-

levels, but are stationary in first differences. The results are robust to the number of lags, and the inclusion and exclusion of the trend. The number of business failures has a statistically significant seasonal pattern. Hence for the equation on failures, I include seasonal dummies in the set of explanatory variables. Ravn and Simonelli (2007) show that statistical tests are not robust in determining whether the level of hours is stationary or not. Based on their results, in the robustness analysis I also allow for difference stationarity of hours. For all other series I assume stationarity.

## 1.4 Empirical results

This section presents the main empirical results. The benchmark SVAR model has 3 lags. The 68% confidence intervals are centered around the point estimates and based on 1000 bootstrap replications.

Figure 1.2 in the Appendix illustrates the dynamics of the firm turnover variables in response to a contractionary monetary policy shock — an increase in the interest rate by one standard deviation. The number of business bankruptcy filings and failures increase by 2% starting from the second quarter (see the two upper panels). The effect lasts for more than four years for both of the failure measures. The net entry index decreases by 0.5% after one quarter (see the third panel). The effect is statistically significant up to quarter ten. The entry of firms, presented in the lower panel, decreases by 0.6% and the impact is statistically significant for 11 quarters. The failure rate increases after the contractionary monetary shock, but the results are uninformative about the changes in the entry rate. The failure rate increases because a higher number of firms fail from a smaller number of total firms in the economy (net entry is negative, the entry of firms is lower and the number of failures is higher). Depending on the relative size of firm entry to net entry, the entry rate can either increase or decrease.

All the reactions of the firm turnover measures remain statistically significant also at the 95% confidence level, at least for some quarters. The estimated impulse response functions for the entry of firms and net entry are with a relatively lower confidence level compared to other economic data and to the number of failures. This can be explained by a high level of noise in these the entry variables as explained before.

The result about decrease in the net entry after the contractionary monetary shock is similar to the finding of Bergin and Corsetti (2008). In contrast to my findings, the creation of firms in their model does not react to a contractionary

monetary shock when FFR is used to identify monetary shock. In comparison to the results in Lewis (forthcoming), I find that after a contractionary monetary shock, net entry becomes statistically significantly different from zero after one quarter, not after 2 years.

In addition a contractionary monetary shock leads to a hump-shaped decrease in hours, output, consumption, investments, capacity utilization, and velocity of money. The results can be found in Figure 1.3 in the Appendix for the results of the VAR that includes bankruptcy filings as the firm turnover measure. The investment price, productivity, and inflation react very little. Inflation decreases after a lag of one year. The real wage declines after the contractionary shock. The results on the macroeconomic variables are similar to several previously estimated VAR models, such as Altig, Christiano, Eichenbaum, and Linde (2005), Christiano, Eichenbaum, and Evans (1999), and others.

## 1.5 Robustness analysis

In this section I show that the results are robust to various changes in the set-up. As in Bergin and Corsetti (2008), I replace the FFR with the ratio of non-borrowed reserves to total reserves (NBR/TR) in the VAR. A contractionary monetary policy shock is now described by a drop in the NBR/TR ratio. The impact of the shock is smaller for business bankruptcy filings and higher for the other three measures. A standard deviation-sized contractionary monetary shock in the NBR/TR ratio leads to an increase in bankruptcy filings by 2% and business failures by more than 3%. The entry of firms and net entry both decrease by more than 0.6%. The impulse response functions of the firm turnover measures are presented in Figure 1.4 and all other economic variables in Figure 1.5 in the Appendix.

Positioning the firm turnover measure after the interest rate, therefore excluding it from the central bank's information set, as it is done in the paper by Bergin and Corsetti (2008), does not change the results much. The contemporaneous effect of the monetary shock is insignificant for the new firms, net entry, and bankruptcy filings, but significant for the failures: a contractionary shock is associated with a small contemporaneous increase in the number of failures. Therefore for the variables Bergin and Corsetti (2008) were concerned with (the entry of firms and net entry), the results are similar.

When two firm turnover measures, the entry of firms and failures are added to the VAR simultaneously, the results again change very little. The entry of firms

still decreases by 0.6% and is statistically significant for 12 quarters. The number of failures increases by 2% and lasts for 18 quarters. Differencing hours instead of using it on levels leads to stronger effects for all variables: the entry of firms does not converge in 20 quarters.

Dropping the first 2 or 5 years from the sample does not change the reaction of the firm turnover measures much compared to the baseline: only the failure measure converges quicker than in the benchmark case. However, exclusion of the last 2 or 5 years leads to a stronger and more persistent effect on business bankruptcy filings and the entry of firms, but does not change the results on the business failures and net entry.

Using 8 variables instead of 11 (dropping consumption, investment and the real wage from the initial set-up) makes the effects of the monetary contraction to all firm turnover variables stronger and longer lasting. Using 4 lags instead of 3 leads to a weaker effect on the entry of firms and a stronger effect on bankruptcy filings, leaving the reaction of the other two variables unchanged.

It is impossible to carry out a structural break test related to the change in the bankruptcy law in 1983 because there are two additional important changes that took place around the same time. According to Bernanke and Mihov (1998), the period 1979–1982 is described as a change in the monetary policy regime in the U.S. In addition, around the year 1980, several banking regulations were changed, including the interest rate ceilings for deposits, which might have changed the transmission of shocks in the U.S. economy (Mertens, 2008). For the robustness analysis I drop 20 years of data from the beginning and from the end in order to make the degrees of freedom comparable. The variables are stationary in differences, as was the case for the full period (see Tables 1.4 and 1.5 in the Appendix).

Dropping 20 years from the beginning of the sample makes the impulse responses stronger and longer lasting for the case of new firms. Dropping the last 20 years makes the reactions of the business failures, net entry and the entry of firms short — the effect lasts up to 3 quarters. The impact of the shock on bankruptcy filings remains unchanged. As bankruptcy filings data includes the latest period, years from 1999 to 2005, the effects of monetary shocks to firm turnover measures have remained strong. The inclusion of the last 6 years of the data leads to much smoother and stronger impulse responses also for other economic variables.

The use of an unadjusted measure for failures, and the regression without a dummy for the period of high increase in failures does not change the results significantly. There is one more measure available for business failures. The Dun &

Bradstreet published a failure rate based on 10000 listed enterprises for the period 1959Q1–1983Q4. The failure rate is stationary only if it is differenced once (see Table 1.6 in the Appendix). A contractionary monetary shock leads to an increase in the failure rate by 1.5% with the effect lasting for 15 quarters.

## 1.6 Limited participation model

In this section I present a simple limited participation model for analyzing the effects of a monetary shock on the number of firms dynamics. In the next section I write down the sticky price model. I keep the two models separate because this allows to pronounce the basic mechanisms at work clearer and keep the models simple.

I adopt the model of Christiano, Eichenbaum, and Evans (1997) and add the endogenous creation and exogenous destruction of firms in the intermediate goods producing sector. The economy consists of a representative consumer, final and intermediate goods producers, financial sector, and a monetary authority.

### 1.6.1 Consumer problem

The representative consumer maximizes her lifetime utility derived from consumption and leisure:

$$E_t \sum_{t=0}^{\infty} \beta^t \left( \frac{c_t^{1-\sigma} - 1}{1-\sigma} - \psi_0 \ln(n_t) \right), \quad (1.5)$$

where  $c_t$  is real consumption at period  $t$ , and  $n_t$  denotes the hours spent working.  $E_t$  is the expectations operator,  $0 < \beta < 1$  is the discount factor, and the weight on the disutility of labor is given by  $\psi_0 > 0$ . The inverse of elasticity of substitution is denoted by  $\sigma > 1$ . Together with the logarithmic disutility of labor, it means that the Frisch elasticity of the labor supply is positive. Upper-case letters denote nominal and lower case letters real variables unless it is clear from the context.

She decides on consumption  $c_t$ , labor input  $n_t$ , money  $M_t$ , and deposits  $H_t$ . The predetermined variables are cash  $M_{t-1}$ , the deposits  $H_{t-1}$ , profits from the financial intermediaries  $R_t X_t$ , and profits from final and intermediate goods firms. The consumer faces following intertemporal budget constraint:

$$M_t - H_t \leq W_t n_t + M_{t-1} - H_{t-1} - P_t c_t + R_t H_{t-1} + R_t X_t + D_t + O_t, \quad (1.6)$$

where  $M_t$  is the nominal money decided at period  $t$  to be used for the purchases at  $t + 1$ ,  $H_t$  is the deposit decided at period  $t$  to be given to the financial intermediary in the next period,  $W_t$  is the nominal wage,  $P_t$  is the price level,  $R_t$  is the gross interest rate,  $R_t X_t$  are the nominal profits received from the financial intermediary, and the nominal profits from the intermediate and final goods production firms are denoted by  $D_t$  and  $O_t$  respectively.

In addition the consumer faces a cash-in-advance constraint. For consumption purchases, she can only use the cash left over from one period before ( $M_{t-1} - H_{t-1}$ ) and labor income, so the condition is:

$$P_t c_t \leq W_t n_t + M_{t-1} - H_{t-1}. \quad (1.7)$$

The optimality conditions are Euler Condition (Equation 1.8) and optimality condition for labor-leisure choice (Equation 1.9).

$$E_t \left( \frac{c_{t+2}}{c_{t+1}} \right)^\sigma = \beta E_t \frac{R_{t+1}}{\pi_{t+2}} \quad (1.8)$$

$$\psi_0 c_t^\sigma = w_t n_t \quad (1.9)$$

where  $\pi_t = P_t/P_{t-1}$  is one plus the inflation rate and the real wage  $w_t = \frac{W_t}{P_t}$ .

### 1.6.2 Final goods firm

The final goods sector produces consumption goods. It uses a constant elasticity of substitution (CES) aggregator to combine the goods from the intermediate sector:

$$y_t = \left( \int_0^{F_t} y_{i,t}^{1-1/\varepsilon} di \right)^{1/(1-1/\varepsilon)}, \quad (1.10)$$

where  $y_t$  is the output made from intermediate goods,  $y_{i,t}$  is the input from the intermediate good producer  $i$  at period  $t$ ,  $F_t$  is the number of the intermediate input firms, and  $\varepsilon > 1$  is the elasticity of substitution between the intermediate goods.

The final goods firm maximizes profits:

$$O_t = P_t y_t - \int_0^{F_t} P_{i,t} y_{i,t} di, \quad (1.11)$$

where  $O_t$  is the profit of the final goods firm from aggregating the intermediate goods. As there is perfect competition and no entry or exit, it is always equal to zero.

After some rearrangements the first order condition with respect to  $y_{it}$  gives the following demand for each of the intermediate goods:

$$y_{i,t} = \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} y_t, \quad (1.12)$$

where  $P_t = \left( \int_0^{F_t} P_{i,t}^{1-\varepsilon} di \right)^{1/(1-\varepsilon)}$  is the price index, with the empirical counterpart of  $P_t^{emp} = F_t^{\varepsilon/(1-\varepsilon)} \left( \int_0^{F_t} P_{i,t}^{1-\varepsilon} di \right)^{1/(1-\varepsilon)}$ , where  $F_t^{\varepsilon/(1-\varepsilon)}$  removes the effects of number of varieties from the price index.

### 1.6.3 Intermediate goods firms

The present value ( $V_{i,t}$ ) of an existing intermediate goods producing firm is defined by discounted flow of profits. Writing it in the value form for an existing firm gives the expression:

$$V_{i,t} = D_{i,t} + \beta(1 - \delta)E_t \left( \frac{c_{t+1}}{c_{t+2}} \right)^{-\sigma} V_{i,t+1} \quad (1.13)$$

where  $0 < \delta < 1$  is the probability of a death shock to a firm and the future value is discounted with the stochastic discount factor of the consumer.

In each period, a share of the existing firms is hit by a death shock. The death shock is realized before the entry decisions are made, so all new firms produce. The aggregate number of existing firms is described by the following equation:

$$F_t = (1 - \delta)F_{t-1} + F_t^N, \quad (1.14)$$

where  $F_t^N$  is the number of newly created firms.

The intermediate goods firms produce with the linear technology:

$$y_{i,t} = n_{i,t}. \quad (1.15)$$

The market structure is monopolistic competition. The firm takes the demand from the final goods sector as given. They pay wages in advance, and borrow the wage bill from a financial intermediary. The marginal cost of production is equal to the nominal wage times the gross interest rate ( $MC_t = R_t W_t$ ). The intermediate goods firms use a fixed quantity of labor ( $\xi^{op} \geq 0$ ) to operate. The profits are sales minus the costs:

$$D_{i,t} = (P_{i,t} - R_t W_t)y_{i,t} - \xi^{op} R_t W_t \quad (1.16)$$



In order to maximize profits, take the derivative with respect to the price  $P_{i,t}$  and get the pricing rule  $P_{i,t} = \frac{\varepsilon}{\varepsilon-1} R_t W_t$ . The firm set the price as a constant mark-up over marginal cost.

The free entry condition is written as follows:

$$V_{i,t} = \xi^{ent} R_t W_t. \quad (1.17)$$

The entry of the intermediate goods to the market is free, but every entrant has to pay a one-time fixed cost  $\xi^{ent} > 0$  in labor.

#### 1.6.4 Financial intermediary

In the limited participation model the intermediate goods firms borrow their wage bill from financial intermediaries:  $W_t N_t = H_{t-1} + X_t$ . For giving out loans financial intermediaries use deposits  $H_{t-1}$  and the money injection of the monetary authority  $X_t$ . At the end of each period, financial intermediary pays out its' profits to consumers  $R_t X_t = R_t(H_{t-1} + X_t) - R_t H_{t-1}$ . Bank gets income from giving out loans, and returns deposits to the consumers with gross interest rate  $R_t$ .

#### 1.6.5 Monetary authority

In the limited participation model, the monetary authority decides on the money injection to the financial intermediary  $X_t$ . It is a one-time shock with zero autocorrelation.

#### 1.6.6 Market clearing conditions and the equilibrium

The aggregate output (Equation 1.18) is consumed, including the production that is done for creating and operating the firms. Total labor equals total output (Equation 1.19). This assumption is necessary to avoid any effects from the number of firms to the aggregate consumption, and therefore there is no feedback from the number of firms to the economy. The total profits by firms consists of the aggregate operating profits minus the entry costs paid by the newly created firms (Equation 1.19).

$$c_t = F_t^{\varepsilon/(1-\varepsilon)} y_t + \int_0^{F_t} \xi^{op} di + \int_0^{F_t^N} \xi^{ent} di \quad (1.18)$$

$$n_t = c_t \quad (1.19)$$

$$D_t = \int_0^{F_t} D_{i,t} di - \int_0^{F_t^N} W_t R_t \xi^{ent} di \quad (1.20)$$

*Definition of equilibrium:* The equilibrium of the model is the sequence of quantities  $\{c_t, n_t, m_{t+1}, h_{t+1}, d_t, d_{i,t}, j_t, F_t, F_t^N\}_{t=0}^\infty$ , prices  $\{P_t, R_t\}_{t=0}^\infty$ , given the initial conditions  $\{m_0, h_0, F_{-1}\}$ , and the sequence of government monetary injections  $\{X_t\}_{t=0}^\infty$ , such that consumers maximize their lifetime utility, final and intermediate goods firms are maximizing their profits, financial intermediaries are maximizing their profit, the free entry condition is satisfied, and the markets clear.

## 1.7 Model with pre-set prices

In this section I present a simple pre-set prices model as an example of sticky prices. Again I augment the simple model with endogenous entry and exogenous exit of firms in the intermediate goods firms. Creation and destruction of firms in this sector takes place after the shock and the prices are fixed before the monetary shock is realized. The entry is determined by the free entry condition. Fully competitive final goods sector aggregates the goods from intermediate goods sector, there is no entry and exit. Differently from the limited participation model, there is no financial sector.

### 1.7.1 Consumer problem

The representative consumer maximizes lifetime utility derived from consumption, leisure, and money balances:

$$E_t \sum_{t=0}^{\infty} \beta^t \left( \frac{c_t^{1-\sigma} - 1}{1-\sigma} - \psi_0 \ln(n_t) + \frac{1}{1-\varphi} \left( \frac{M_{t+1}}{P_t} \right)^{1-\varphi} \right), \quad (1.21)$$

where  $M_{t+1}$  is the nominal money transferred to the next period and  $0 < \varphi < 1$  is the inverse of elasticity of substitution for money demand. The consumer decides on consumption and work today, and money left for tomorrow. For the pre-set prices model I adopt a money-in-utility approach which is standard in the literature. The utility function implies the neutrality of money, so the sole cause of the real effects is the imposed price stickiness.

Each period consumer faces the following budget constraint:

$$P_t c_t + B_{t+1} + M_{t+1} = W_t n_t + (1 + i_{t-1}) B_t + M_t + D_t + O_t, \quad (1.22)$$

where  $B_t$  are the bonds at period  $t$ . In order to buy consumption good, the consumer

can use all the profits received from the firms, money, and bonds: there is no cash-in-advance condition.

In order to maximize consumer utility, take first order conditions with respect to the bonds  $B_{t+1}$ , money  $M_{t+1}$ , consumption  $c_t$ , and labor  $n_t$ . There are three optimality conditions for the consumer:

$$E_t \left( \frac{c_{t+1}}{c_t} \right)^\sigma = \beta E_t \frac{1 + i_t}{\pi_{t+1}} \quad (1.23)$$

$$\psi_0 c_t^\sigma = w_t n_t \quad (1.24)$$

$$\left( \frac{M_{t+1}}{P_t} \right)^{-\varphi} = \frac{i_t}{1 + i_t} c_t^{-\sigma}. \quad (1.25)$$

The Euler Equation (no. 1.23) determines the optimal consumption path. It is different from the tradeoff in the limited participation model, where the decision was between tomorrow and the day after. Labor-leisure choice Equation 1.24 is identical to the one in the limited participation model. The money demand is given in Equation 1.25, which is again different from the limited participation approach, where the money demand was determined by the cash-in-advance constraint.

### 1.7.2 Final goods firm

The final goods sector is identical to the limited participation model. The demand for each of the intermediate goods is given by:

$$y_{i,t} = \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} y_t, \quad (1.26)$$

where  $P_t$  is the same as in the limited participation model.

### 1.7.3 Intermediate goods firms

In the intermediate goods sector there are three differences compared to the limited participation model. First, the wages are not paid out before production: labor costs do not include the interest rate. Second, the prices must be set one period in advance and the new firms set the same price as all the other firms. Third, according to the consumer problem, the stochastic part of the discount factor for firms includes trade-off between today and tomorrow.

The value of the firm in the intermediate goods sector is given by:

$$V_{i,t} = D_{i,t} + \beta(1 - \delta) E_t \left( \frac{c_t}{c_{t+1}} \right)^{-\sigma} V_{i,t+1}, \quad (1.27)$$

where the stochastic discount factor is taken from the consumer problem, and the profit is given by

$$D_{i,t} = E_{i,t-1} \left( (P_{i,t} - W_t) \left( \frac{P_{i,t}}{P_t} \right)^{-\varepsilon} y_t - \xi^{op} W_t \right) \quad (1.28)$$

The law of motion for the number of firms is described as before by:

$$F_t = (1 - \delta)F_{t-1} + F_t^N. \quad (1.29)$$

The production technology in the intermediate goods sector is again linear:

$$y_{i,t} = n_{i,t}. \quad (1.30)$$

The nominal marginal cost of production is given by the shadow price of producing an additional unit of output ( $MC_t = W_t$ ). Wages are paid out at the time when the final output is sold.

For maximizing the firms value, take the derivative with respect to  $P_{i,t}$  and solve for  $P_{i,t}$  to get the condition for optimal pricing, the mark-up over the expected marginal cost:

$$P_{i,t} = \frac{\varepsilon}{\varepsilon - 1} E_{t-1} W_t. \quad (1.31)$$

The entry to the market of intermediate goods is free, but every entrant has to pay a one-time fixed cost  $\xi^{ent} W_t$ . The free entry condition is written as follows:

$$V_{i,t} = \xi^{ent} W_t. \quad (1.32)$$

The crucial assumption in this model in order to have the effects of a monetary policy on the creation of firms is that the firm creation decisions are made during the period in which the nominal rigidities are still binding. Therefore the results also hold when I would assume longer price rigidities and let the firms to enter with a lag.

In the present version of the model, the new firms are not allowed to set different prices from the existing firms. Such a change would complicate the aggregation of the demand without affecting the results much, the extension is left for the future.

### 1.7.4 Monetary authority

The monetary authority decides on the injection of money into the economy. There is a one-time shock to money growth  $g_t^m$  with zero autocorrelation.

### 1.7.5 Market clearing conditions

Again, all the production (Equation 1.33) is consumed and the total labor equals to the total output (Equation 1.34). The aggregate profits by the firms are the sum of total operating profits from each firm minus the entry costs (Equation 1.35).

$$c_t = F_t^{\varepsilon/(1-\varepsilon)} y_t + \int_0^{F_t} \xi^{op} di + \int_0^{F_t^N} \xi^{ent} di \quad (1.33)$$

$$n_t = c_t \quad (1.34)$$

$$D_t = \int_0^{F_t} D_{i,t} di - \int_0^{F_t^N} W_t \xi^{ent} di \quad (1.35)$$

*Definition of equilibrium:* Equilibrium is defined by the sequence of quantities  $\{c_t, n_t, b_{t+1}, M_{t+1}, j_t, d_t, d_{i,t}, F_t, F_t^N\}_{t=0}^{\infty}$ , prices  $\{P_t\}_{t=1}^{\infty}$ , given the initial conditions  $\{m_0, F_{-1}, P_0\}$ , and government money injections, such that consumers maximize their utility, final and intermediate goods firms maximize their profit, the free entry conditions for firms is satisfied, and markets clear.

## 1.8 Calibration and results of the two models

I log-linearize the model around the steady state and solve it computationally by using the method of undetermined coefficients proposed by Uhlig (1999).

I follow traditional parameter values in the calibration of the two models for the quarterly frequency (see Table 1.7 in the Appendix). I set the inverse of the intertemporal elasticity substitution parameter  $\sigma = 2$ . The probability of the death of a firm is calibrated to 2.5%, which is 10.7% per annum, very close to the actual 11% exit rate per year in the U.S.. I assume that shocks to the economy are small so that there is always positive entry. The discount factor reflects a real interest rate of 4% per year, the elasticity of substitution ( $\varepsilon = 17$ ) gives a mark-up of 6%, which is standard in the literature, but its only role together with the death probability, operation and entry costs, is to determine the number of firms in the economy. The cost of entry is calibrated to be higher than the operation cost. Steady state yearly inflation in the limited participation model is 2%. The inverse of the elasticity of

substitution of money in the middle of the allowed range (between zero and one), and constant in front of the disutility of labor only determines the steady state share of hours worked and does not affect the impulse responses

Figure 1.6 in the Appendix presents the impulse response functions to a monetary contraction in a limited participation framework. The monetary shock leads to a drop in the funds which the financial intermediary can lend to the intermediate goods producers. This results in lower wages and hours. However, an accompanied increase in the gross interest rate leaves marginal costs for the intermediate goods producers unchanged. As output drops, profits per firm decrease. The lower value of a firm reduces the entry of firms in order to keep the free entry condition satisfied. In the simple limited participation model, a monetary contraction brings an economic expansion from the second period onwards. Nonetheless the number of new firms is decreasing in the first period. By making the limited participation model empirically more plausible for the second period onwards (see Christiano and Eichenbaum, 1992), the decrease in the number of created firms will be stronger. The prediction of the limited participation model is in line with the empirical results on the reaction of the number of firms.

In the pre-set price framework, a contractionary monetary policy shock leads to an increase in the number of firms. The results are presented in Figure 1.7 in the Appendix. Lower wages lead to an increase in profits and a decrease in the entry cost. The entry of firms increases to the level in which the free entry condition is satisfied. This stands in sharp contrast with the empirical findings about the creation and destruction of firms in the previous section.

The theoretical results depend on the assumption that inverse of the intertemporal elasticity of substitution ( $\sigma$ ) is greater than one. The value below one would mean negative Frisch elasticity of labor supply: decrease in wages leads to an increase in the hours worked. In this version of the model, the results are reversed. In the sticky price model, after a contractionary monetary shock wages decrease, hours increase, and number of firms increases. Under the limited participation hypothesis, the number of firms decreases. The empirical evidence in this paper does not find support for this assumption as a contractionary shock leads to a statistically and economically important decrease in the hours worked.

The models are very simple and stylized with the purpose of being clear about the mechanism that drives the results. Because of the simplicity, it also allows to discuss intuitively certain extensions. The results also hold for sticky information type of transmission. The sticky price model where only the firms with low markups

change their prices can help to reduce the counterintuitive results of the sticky price approach and lead to no effect of monetary shocks to firm turnover, but cannot deliver reversal of the impact. When one assumes very high menu costs for changing prices, firms could file a bankruptcy instead of lowering prices after a contractionary monetary shock, but then menu costs should also lead to more bankruptcies for expansionary monetary shocks. Therefore the mechanism that causes the firm turnover dynamics must be different from price stickiness.

My empirical results also show that prices do react very little to the shock within a one-year period, whereas output, and firm entry and failures react after two quarters. So if prices do not react, then in order to have increase in the profits at least for some firms, the cost of production has to decrease. When prices are exogenously assumed to be sticky, there is even more need for the costs to decrease.

The simple limited participation model predictions fit well the qualitative empirical results. Monetary contraction leads to an increase in the interest rate, drop in wages, no movement in prices, and increase in firm bankruptcies. The economic contraction that brings drop in the expected profits can explain an increase in failures and a decrease in the creation of firms.

## 1.9 Conclusions

Many authors add firm creation and destruction to the traditional dynamic stochastic general equilibrium models. Intuitively the extensive margin plays an important role in propagating shocks, but it is unclear if it constitutes a different propagation mechanism? What does firm turnover influence? These are the questions most of the firm turnover literature tries to answer. This paper takes a different route. Here the question is instead, What can we learn about modeling monetary transmission by introducing firm creation in the models? The answer is that the empirical results about firm creation and destruction reaction after a monetary shock are more in line with the predictions of the limited participation model than those of the sticky prices.

The paper offers extensive empirical evidence that a contractionary monetary policy shock increases failures and decreases entry of firms. This is a robust finding of a VAR model where the monetary shock is identified by using recursiveness assumption based on the Taylor rule type of argument. When the number of firms that file a bankruptcy after an unexpected monetary contraction increases, it is a sign that their expected future profit decreased and restructuring of activity costs more

than bankruptcy. This evidence does not necessarily say anything about amplification of shocks in the economy because existing firms could expand their production and possibly increase profits. But the evidence shows that some existing firms do suffer from the shock. The same is true for some of the new firms. Monetary contraction means that fewer firms are created: some of the business ideas are not realized because they are not profitable.

Although standard models of monetary transmission assume away firm creation and destruction, it is straightforward to augment them with firm turnover. I take two alternative approaches, limited participation and sticky price models and augment with endogenous creation and exogenous destruction of firms. The predictions of the two main models of monetary transmission are at odds with each other. According to the sticky price model the number of firms increases after a contractionary monetary policy shock. After the same shock, the limited participation model predicts a decrease in the number of firms in the economy. Therefore the empirical findings about firm turnover support more the limited participation type of monetary transmission compared to the sticky prices.

## Bibliography

Altig, D., Christiano, L. J., Eichenbaum, M., Linde, J., 2005. Firm-Specific Capital, Nominal Rigidities and the Business Cycle. NBER working paper, No. 11034.

Armington, C., 2004. Development of Business Data: Tracking Firm Counts, Growth and Turnover by Size of Firms. SBA, Office of Advocacy, Small Business Research.

Bergin, P., Corsetti, G., 2008. The Extensive Margin and Monetary Policy. *Journal of Monetary Economics*, No. 55(7).

Bernanke, B., Mihov, I., 1998. Measuring Monetary Policy. *The Quarterly Journal of Economics*, No. 113(3).

Bilbiie, F. O., Gironi, F., Melitz, M. J., 2007. Monetary Policy and Business Cycles with Endogenous Product Variety. NBER Macroeconomics Annual 2007.

Boivin, J., Giannoni, M., Mihov, I., 2007. Sticky Prices and Monetary Policy: Evidence from Disaggregated U.S. Data. NBER working paper, No. 12824.



- Campbell, J. R., 1998. Entry, Exit, Embodied Technology, and Business Cycles. *Review of Economic Dynamics*, No. 1(2).
- Christiano, L. J., Eichenbaum, M., 1992. Liquidity Effects and the Monetary Transmission Mechanism. *American Economic Review, Papers and Proceedings*, No. 82(2).
- Christiano, L. J., Eichenbaum, M., Evans, C. L., 1997. Sticky price and limited participation models of money: A comparison. *European Economic Review*, 41(6).
- Christiano, L. J., Eichenbaum, M., Evans, C. L., 1999. Monetary Policy Shocks: What Have We Learned and to What End? *Handbook of Macroeconomics, Handbooks in Economics Vol 1A*, Elsevier Science, North-Holland, 65-148.
- Fisher, J. D. M., 2006. The Dynamic Effects of Neutral and Investment-Specific Technology Shocks. *Journal of Political Economy*, No. 114(3).
- Gali, J., 1999. Technology, Employment and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations? *American Economic Review*, No. 89(1).
- Kydland, F., Prescott, E., 1982. Time to Build and Aggregate Fluctuations. *Econometrica*, No. 50(6).
- Lewis, V., forthcoming. Business Cycle Evidence on Firm Entry. *Macroeconomic Dynamics*.
- Mancini-Griffoli, T., Elkhoury, M., 2006. Monetary Policy with Endogenous Firm Entry. mimeo.
- Mertens, K., 2008. Deposit Rate Ceilings and Monetary Transmission in the US. *Journal of Monetary Economics*, No. 55(7).
- Naples, M. I., Arifau, A., 1997. The Rise in the US Business Failures: Correcting the 1984 Data Discontinuity. *Contributions in Political Economy*, No. 16.
- Ravn, M., Simonelli, S., 2007. Labor Market Dynamics and the Business Cycle: Structural Evidence for the United States. *Scandinavian Journal of Economics*, No. 109(4).
- Shapiro, M., Watson, M., 1988. Sources of Business Cycle Fluctuations. NBER Macroeconomics Annual 1988, MIT Press.

Sims, C. A., Zha, T., 2006. Does Monetary Policy Generate Recessions? *Macroeconomic Dynamics*, No. 10(02).

Uhlig, H., 1999. A Toolkit for Analyzing Nonlinear Dynamic Stochastic Models Easily. *Computational Methods for the Study of Dynamic Economies*.

Uhlig, H., 2005. What are the effects of monetary policy on output? Results from an agnostic identification procedure. *Journal of Monetary Economics*, No. 52(2).

## Appendix

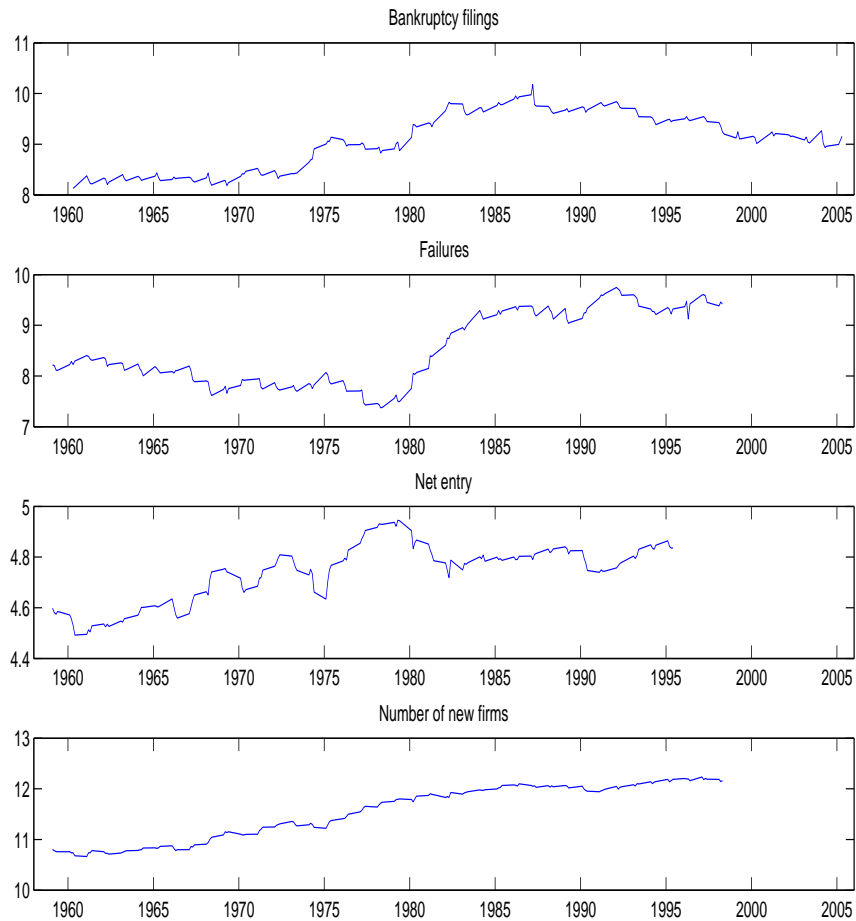


Figure 1.1: Business Bankruptcy Filings, Failures, Net Entry and New Firms Data in Log Levels

Table 1.2: Data Description and Sources

Name	Explanation	Source
Consumption	Consumption of non-durables, services and government expenditures	BEA
Investment	Nominal investment in household consumption of durables and gross private domestic investment	BEA
Investment price	Price of investment relative to consumer prices	For period 1959-1990 from Ravn and Simonelli (2007)
Price of investment	Nominal divided with real investments	BEA
Price of consumption	Nominal divided with real consumption	BEA
Nominal output	Nominal Gross Domestic Product (GDP)	BEA
Real output	Real Gross Domestic Product (GDP)	BEA
GDP deflator	GDP deflator, nominal GDP/ real GDP	BEA
Hours	Gross non-farm business hours (HOANBS)	BEA from Fed. St. Louis
Population	Total population over the age of 16	CPS
Capacity utilization	Index of capacity utilisation in manufacturing	Board of Governors
Nominal wages	Nominal hourly non-farm business compensation	BLS
New incorporations	Number of new enterprises created, mostly employee firms	Dun&Bradstreet, Economagic
Net entry	Index composed by Dun&Bradstreet	Dun&Bradstreet, BEA
Firm failures	Number of firms failed in a quarter	Dun&Bradstreet, Economic Report of the President
Failure rate	Firm failures / listed companies	Dun&Bradstreet, Economic Report of the President
No. of bankruptcies	Number of bankruptcy failings by companies	U.S. Courts of Bankruptcy
FFR	MZM	Fed. St. Louis
NBR/TR	Non- borrowed reserves / Total reserves	Fed. St. Louis
Money stock	Monetary aggregate MZM	Fed. St. Louis

Table 1.3: Stationarity Analysis of Business Bankruptcy Filings, Failures, Entry of New Firms and Net Entry

	Bankr. Filings		Failures		Net entry		New firms	
Level/Diff	Level	Diff	Level	Diff	Level	Diff	Level	Diff
Trend	y	n	y	n	n	n	n	n
Seas dum	y	n	y	y	n	n	n	n
0	-1.48	-12.00	-1.48	-12.04	-1.33	-9.91	-0.75	-12.65
1	-1.45	-7.98	-1.49	-6.76	-1.65	-7.71	-0.86	-7.41
2	-1.25	-5.70	-1.71	-5.68	-1.66	-6.41	-1.01	-7.17
3	-1.42	-5.22	-1.76	-4.62	-1.62	-5.11	-1.00	-5.72
4	-1.43	-5.01	-1.92	-3.57	-1.86	-4.48	-1.05	-4.99

Note: Constant is included in every regression. The asymptotic critical values for rejecting the hypothesis of unit root on the level of the lagged dependent variable in an (augmented) Dickey-Fuller regressions case without trend are -3.43, -2.86 and -2.58 and with trend -3.96, -3.41 and -3.12 respectively for 1, 5 and 10% critical levels.

Table 1.4: Stationarity Analysis for Period of First 20 Years Omitted

	Bankr. filings	Failures	Net entry	New firms
Level/Diff	Diff	Diff	Diff	Diff
trend	n	n	n	n
seas dum	y	y	n	y
0	-8.95	-8.49	-5.48	-6.06
1	-4.88	-4.62	-5.44	-4.97
2	-3.78	-3.99	-4.24	-4.57
3	-3.94	-3.82	-3.63	-3.97
4	-3.82	-3.36	-3.25	-2.88

Note: A constant is included in every regression. The asymptotic critical values for the level of the lagged dependent variable in an (augmented) Dickey-Fuller regressions case without trend are -3.43, -2.86 and -2.58 and with trend -3.96, -3.41 and -3.12 respectively for 1, 5 and 10% critical levels.

Table 1.5: Stationarity Analysis for Period of Last 20 Years Omitted

	Bankr. filings	Failures	Net entry	New firms
Level/Diff	Diff	Diff	Diff	Diff
trend	n	n	n	n
seas dum	y	y	y	n
0	-8.22	-8.77	-8.44	-12.62
1	-6.96	-4.97	-5.13	-6.23
2	-4.94	-4.15	-3.94	-5.65
3	-4.53	-3.23	-3.18	-4.18
4	-4.48	-2.66	-3.03	-3.86

Note: A constant is included in every regression. The asymptotic critical values for the level of the lagged dependent variable in an (augmented) Dickey-Fuller regressions case without trend are -3.43, -2.86 and -2.58 and with trend -3.96, -3.41 and -3.12 respectively for 1, 5 and 10% critical levels.

Table 1.6: Stationarity Analysis for Failure Rate

	Failure rate	
Level/Diff	Level	Diff
trend	y	y
seas dum	y	y
0	-0.14	-12.70
1	0.76	-7.53
2	0.79	-5.63
3	0.70	-4.00
4	0.06	-2.92

Note: A constant is included in every regression. The asymptotic critical values for the level of the lagged dependent variable in an (augmented) Dickey-Fuller regressions case without trend are -3.43, -2.86 and -2.58 and with trend -3.96, -3.41 and -3.12 respectively for 1, 5 and 10% critical levels.

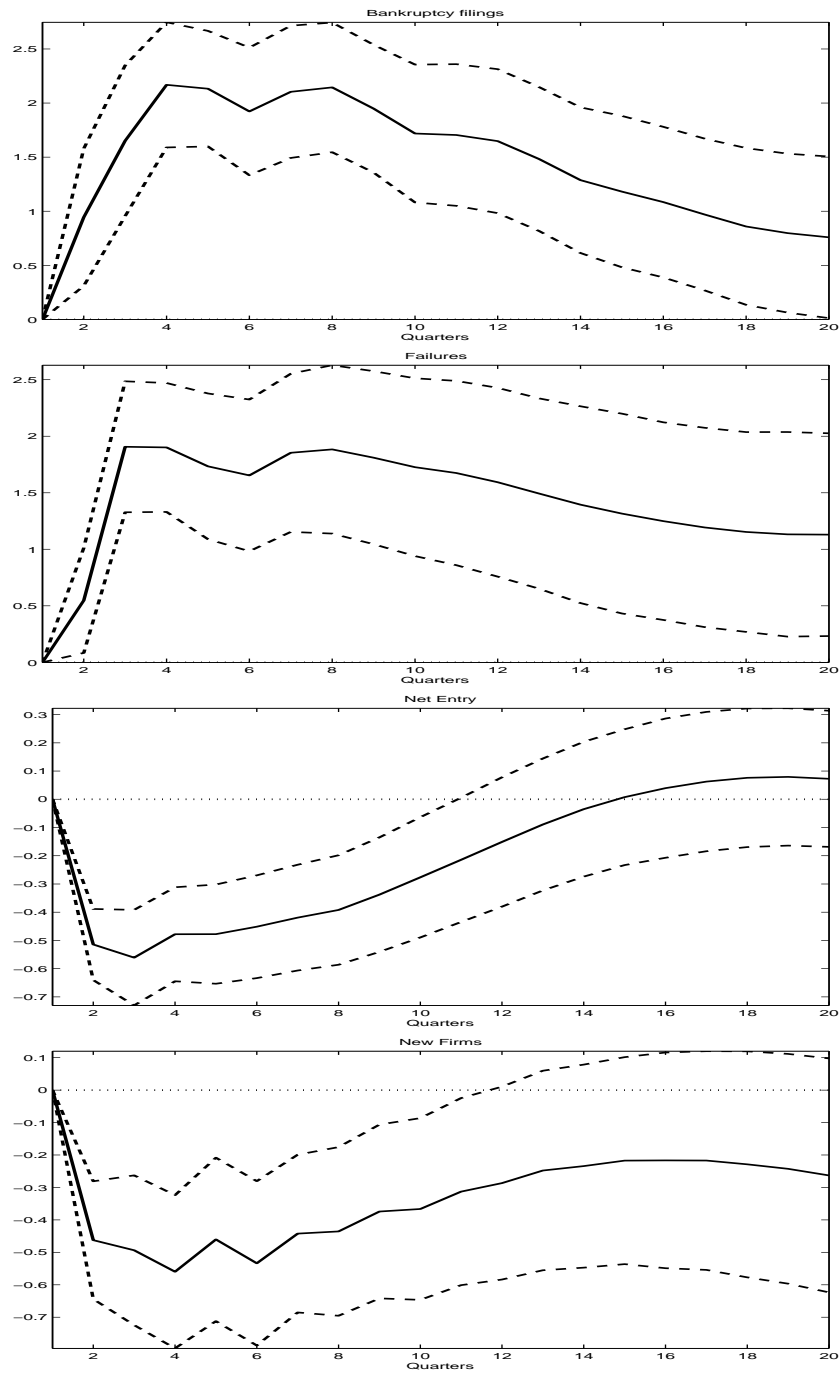


Figure 1.2: Impulse Response Functions of **Business Bankruptcy Filings, Failures, Net Entry and New Firms** to a Contractionary Monetary Shock, 68% Confidence Intervals around the Point Estimates

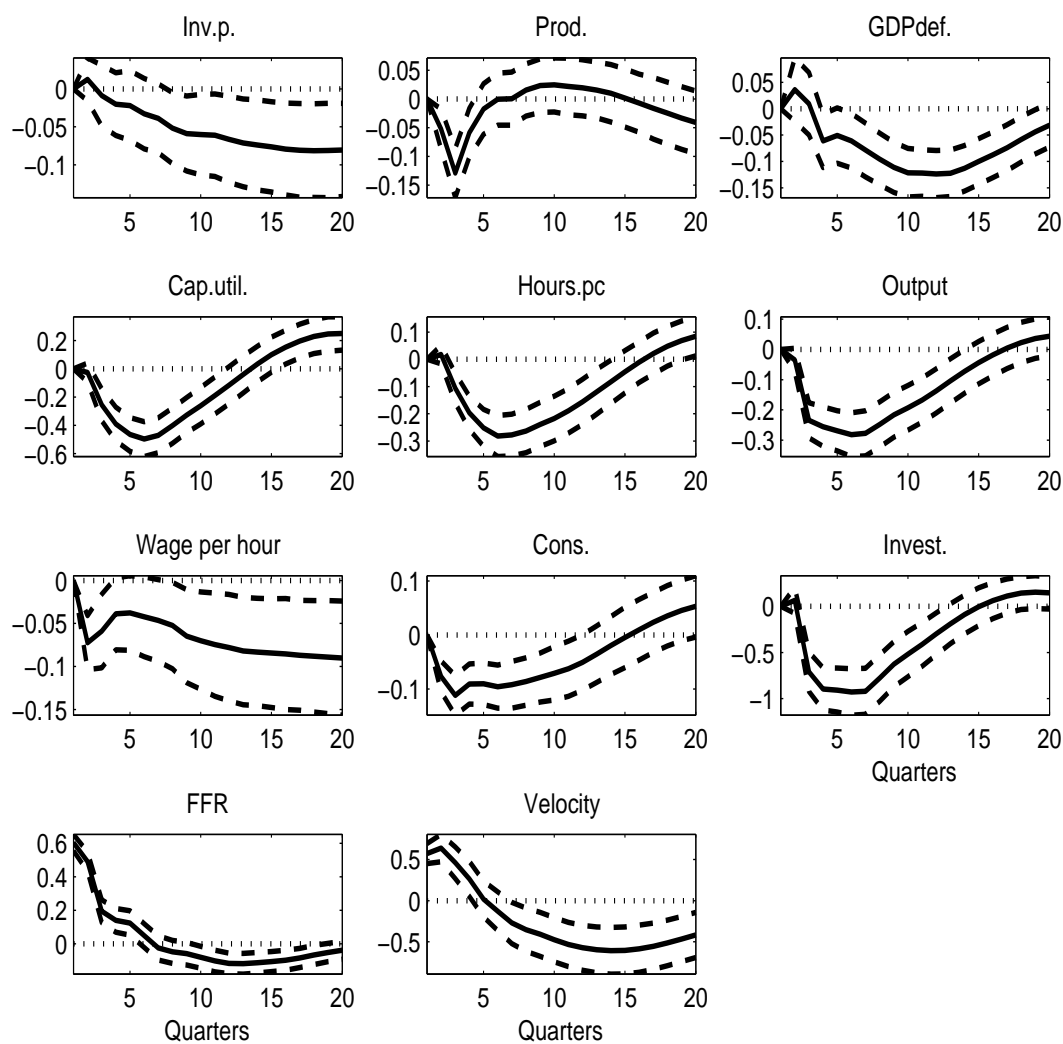


Figure 1.3: Impulse Response Functions of Macroeconomic Variables to a Contractionary Monetary Shock, SVAR with **Business Bankruptcy Filings** Included, 68% Confidence Intervals around the Point Estimates



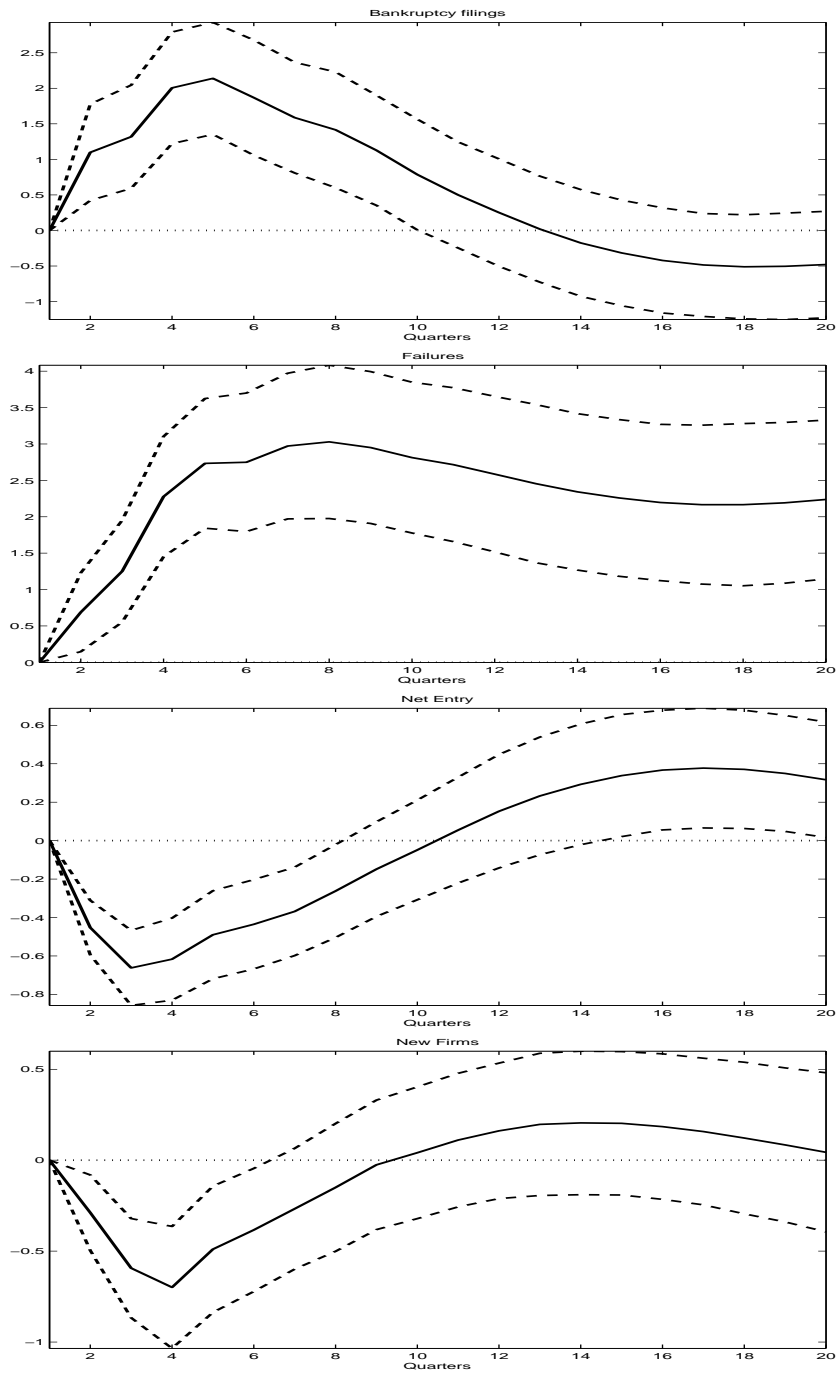


Figure 1.4: Impulse Response Functions of Business Bankruptcy Filings, Firm Failures, Net Entry and New Firms to a Contractionary Monetary Shock Defined by Change in the NBR/TR ratio, 68% Confidence Intervals around the Point Estimates

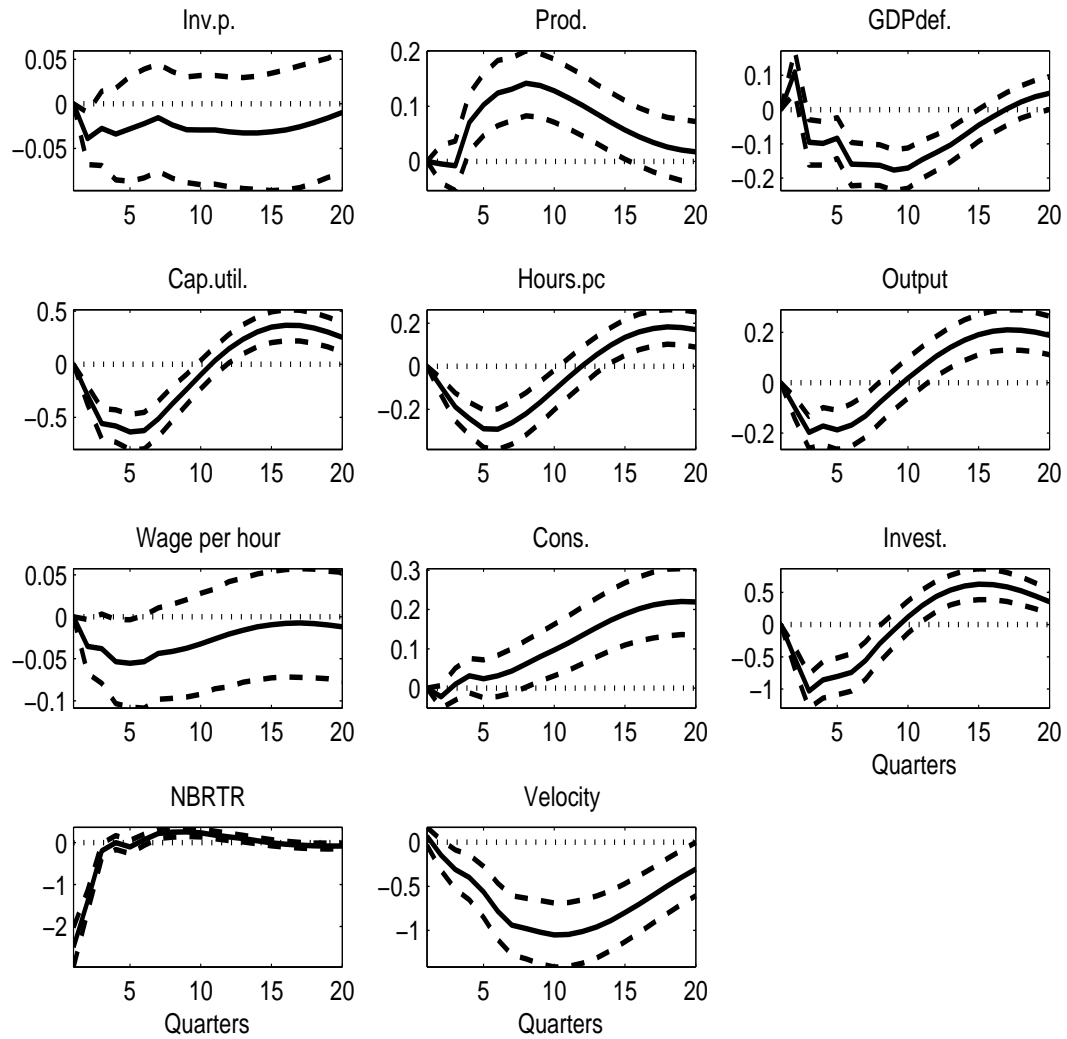


Figure 1.5: Impulse Response Functions of the Macroeconomic Variables to a Contractionary Monetary Shock Defined by a Drop in the NBR/TR ratio, When Business Bankruptcy Filings are Included, 68% Confidence Intervals around the Point Estimates

Table 1.7: Parameter values

Notation	Value	Name
$\sigma$	2	Inverse of intertemporal elasticity of substitution
$\beta$	0.99	Discount factor
$\psi_0$	2	Disutility of labor
$\varepsilon$	17	Elasticity of substitution
$\delta$	0.025	Share of firms hit with death shock
$\xi^{ent}$	$10^{-5}$	Units of labor for entry
$\xi^{op}$	$10^{-10}$	Units of labor for operation
Specific to the sticky price model		
$g_m$	1	Size of a shock
$\varphi$	.5	Inverse of elasticity of substitution of money
$\pi$	1	Inflation in the steady state
Specific to the limited participation model		
$\pi$	1.005	Inflation in the steady state

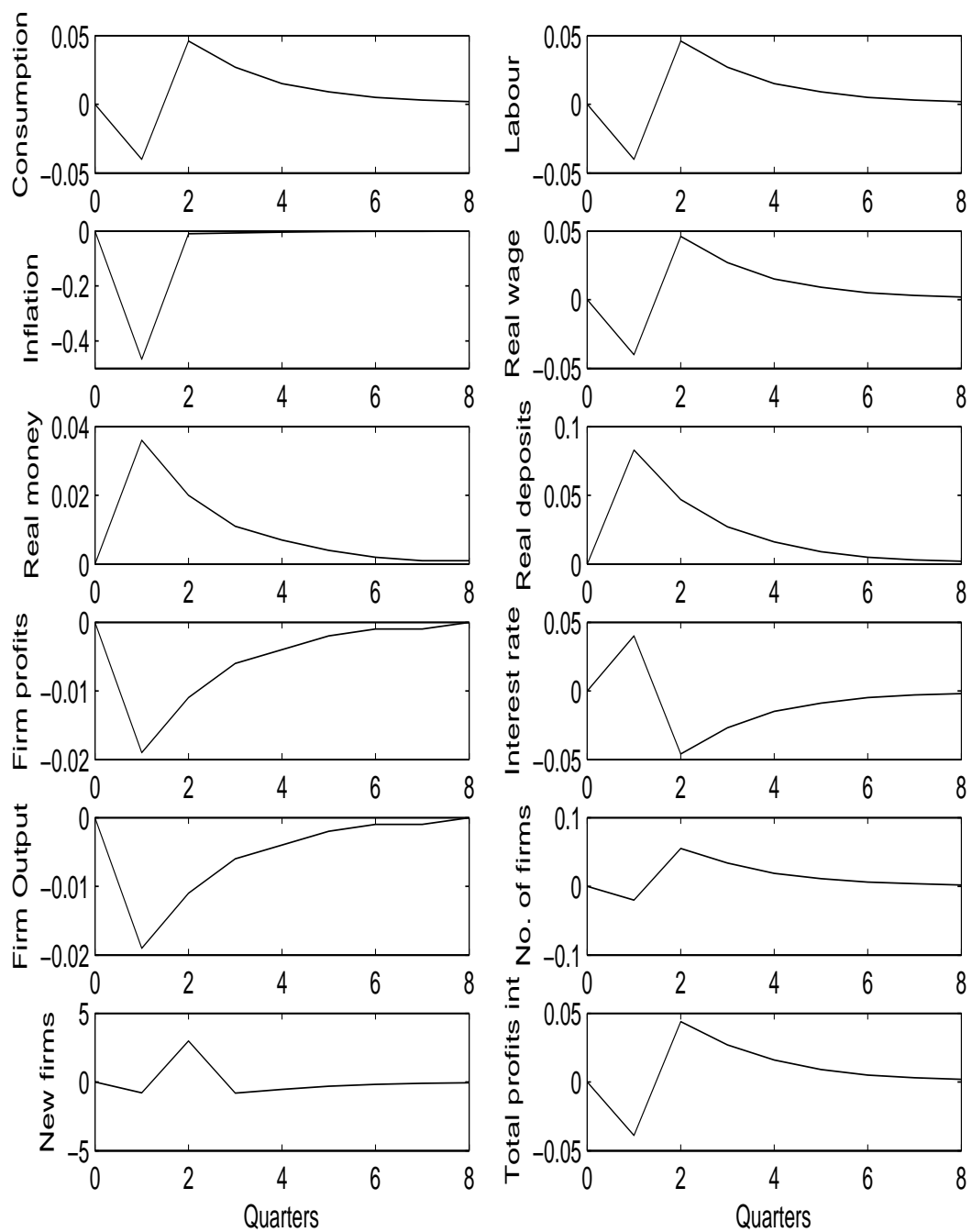


Figure 1.6: Impulse Response Functions of Economic Variables to a Contractionary Monetary Shock in a Limited Participation Model

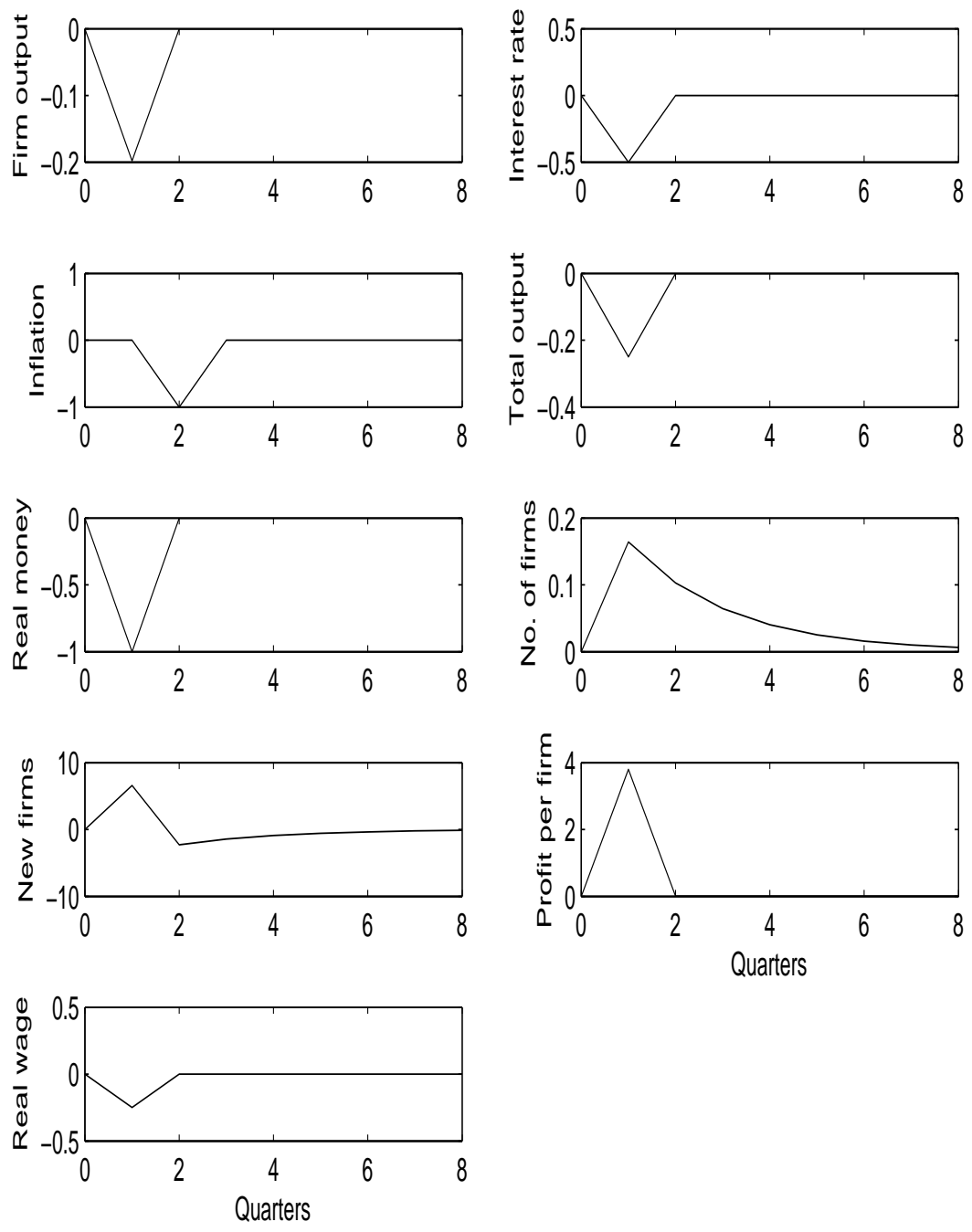


Figure 1.7: Impulse Response Functions of Economic Variables to a Contractionary Monetary Shock in a Pre-set Price Model

## Chapter 2

# Deep Habits and the Dynamic Effects of Monetary Policy Shocks

Morten O. Ravn<sup>a,d,1</sup>, Stephanie Schmitt-Grohé<sup>b,d,e</sup>, Martín Uribe<sup>b,e</sup>, and Lenno Uusküla<sup>c</sup>  
University College London<sup>a</sup>, Columbia University<sup>b</sup>, European University Institute<sup>c</sup>,  
CEPR<sup>d</sup>, NBER<sup>e</sup>

### Abstract

We introduce deep habits into a sticky-price sticky-wage economy and examine the resulting model's ability to account for the impact of monetary policy shocks. The deep habits mechanism gives rise to countercyclical markup movements even when prices are flexible and interacts with nominal rigidities in interesting ways. Key parameters are estimated using a limited information approach. The deep habits model can account very precisely for the persistent impact of monetary policy shocks on aggregate consumption and for both the price puzzle and inflation persistence. A key insight is that the deep habits mechanism and nominal rigidities are complementary: The deep habits model can account for the dynamic effects of monetary policy shock at low to moderate levels of nominal rigidities. The results are shown to be stable over time and not caused by monetary policy changes.

---

<sup>1</sup>This paper was prepared for the 2008 CEPR/NBER/TRIO conference in Tokyo. We are grateful for comments from Alexander Kriwoluzky, and from seminar participants at the TRIO conference and the European University Institute.

**Keywords:** deep habits, monetary policy, price puzzle, inflation persistence, countercyclical markups

**JEL classifications:** E21, E31, E32, E52

## 2.1 Introduction

A substantial body of research has studied the dynamic impact of monetary policy shocks using vector autoregression based methods. This literature has demonstrated that monetary policy shocks identified with timing assumptions give rise to persistent effects on output and its components but also that the dynamic effects on prices are associated with two puzzles: The “inflation persistence puzzle” (a slow and delayed rise in inflation in response to an expansionary monetary policy shock) and the “price puzzle” (a temporary drop in the price level after an expansionary monetary policy shock). These two findings are termed puzzles because they appear contrary to conventional monetary wisdom. This paper examines whether a model of countercyclical markups is helpful for understanding these and other features of the impact of monetary policy shocks. We extend a standard sticky-price sticky-wage model with goods-specific (“deep”) habits which gives rise to a theory of time-varying markups even in the absence of nominal rigidities. We demonstrate that this mechanism gives rise to a model that can provide a very precise account of the dynamic effects of monetary policy shocks and which can address both of price puzzle and the inflation persistence puzzle.

According to the standard “New Keynesian Phillips curve” inflation is determined by current marginal costs and by expected future inflation. The purely forward looking feature of this relationship implies a lack inflation persistence.<sup>2</sup> A large number of papers have addressed this issue by studying mechanisms that either give rise to persistent movements in marginal costs or that introduce backward looking features into the New Keynesian Phillips curve. Galí and Gertler (1999) allow for the coexistence of forward looking and backward looking price setters. The presence of backward looking price setters introduces a lagged inflation term in the Phillips curve and therefore helps explaining the sluggish adjustment of inflation to monetary policy shocks. Fuhrer and Moore (1995) study a relative contracting model in which workers care about other workers’ past real wages and they show that this feature

---

<sup>2</sup>This result holds in Calvo style sticky price models and in models where there are costs of changing prices. Chari, Kehoe and McGrattan, 2000, show that it also holds in Taylor type staggered contracts models.

may help explain sluggish inflation adjustments to monetary policy shocks.<sup>3</sup> Erceg, Henderson and Levin (2000) assume that nominal wages as well as prices adjust sluggishly. Christiano, Eichenbaum and Evans (2005), Rabanal and Rubio-Ramirez (2003), and Smets and Wouters (2003) have shown that the combination of sticky prices and sticky wages is helpful for accounting for inflation persistence. There has been less theoretical work on the price puzzle an exception being Castelnuovo and Surico (2008) who study a model in which passive policy gives rise to indeterminacy. When the equilibrium is indeterminate, inflation expectations become very persistent and this has the consequence that a structural VAR can erroneously lead one to conclude that expansionary monetary policy shocks give rise to a drop in the price level.

We focus instead upon goods market features. We study a monetary model in which it is costly for producers to change prices and for labor unions to change nominal wages. We introduce into this environment the deep habit mechanism proposed in Ravn, Schmitt-Grohe and Uribe (2006). The deep habits model assumes that households are subject to keeping up with the Joneses effects at the level of *individual* goods varieties. This feature implies that the demand function facing individual producers depends not only on relative prices and on the level of aggregate demand but also on the firm's past sales. The impact of past sales on current demand, often referred to as state dependence, captures empirically relevant aspects of goods demand functions. Houthakker and Taylor (1970) studied goods level demand functions and found that past sales are key for determining current consumption of goods. Guadagni and Little's (1983) seminal scanner data study of ground coffee purchases documented a large predictive power of past brand choices on current brand choices, a finding reproduced by many researchers when studying brand demand functions, see Chintagunta, Kyriazidou and Perktold (2001) for a recent discussion and survey. Browning and Collado (2007) study goods level consumption demand functions controlling for unobserved consumer heterogeneity and for goods-level habits at the household level and find significant habit effects for a substantial number of goods.

According to the deep habits model, markups are time varying even when prices are flexible. The non-constancy of the optimal markup derives from an elasticity effect and an intertemporal effect. The elasticity effect is induced by variations in

---

<sup>3</sup>Holden and Driscoll, 2003, challenge the results of Fuhrer and Moore, 1995, on the grounds that the relative contracting model assumes that workers care about past not current relative real wages. They show that when workers care about other workers' current real wages, the model has no inflation persistence in the sense that the Phillips curve is entirely forward looking.



aggregate demand that affect the price elasticity of demand facing producers. In our model, an increase in current aggregate demand increases the price elasticity and therefore leads producers to lower markups. The intertemporal effect arises because a producer who expects high future demand will have an incentive to lower the current markup in order to attract more future demand. Ravn, Schmitt-Grohe and Uribe (2006, 2007) have shown that these mechanisms are helpful for understanding the impact of technology shocks and of government spending shocks. In the current paper we argue that deep habits is also an interesting mechanism when accounting for the impact of monetary policy shocks and that it interacts in an intriguing manner with nominal rigidities to produce a model that leads to substantial price inertia even when nominal rigidities are moderate.

We first estimate a VAR on post-war U.S. data and derive the impact of a timing-based identified monetary policy shock. We study a small scale VAR that consists of aggregate consumption, the CPI inflation rate, the federal funds rate, and the commodity price index. We include the commodity price index in the VAR in order not to bias our results towards the existence of a price puzzle.<sup>4</sup> The VAR measurements of the dynamic effects of a monetary policy shock conform with the conventional wisdom regarding inflation persistence and the price puzzle: The price level drops for 2 quarters after an expansionary monetary policy shock and the maximum increase in inflation appears as late as 3 years after the initial expansion of monetary policy. We also find that aggregate consumption increases persistently in a hump-shaped manner in response to an expansionary monetary policy shock.

We estimate key parameters of the model using a limited information approach and compare the deep habits model with the predictions of a standard New Keynesian model and a New Keynesian model that allows for habits in aggregate consumption. This latter economy differs from the deep habits model in that aggregate habits do not lead to time-variation in markups when prices are flexible. We find that the model with deep habits provides a superior fit to the identified dynamic effects of monetary policy shocks. In particular, this model can account simultaneously for the persistent impact of monetary policy shocks on consumption, for the price puzzle, and for inflation persistence. Moreover, the estimates of the extent of nominal rigidities are significantly lower in the deep habits economy than in the economy with aggregate habits.

---

<sup>4</sup>A common argument is that the price puzzle reflects misspecification of VAR models in the sense that it is important to include variables that are forward looking. Following Sims (1992) much of the literature has addressed this point by augmenting VARs with the commodity price index.

We show that the model implies a complementarity between nominal rigidities and deep habits. In response to an expansionary monetary policy shock, the presence of nominal rigidities implies that aggregate consumption increases. In the deep habits economy the increase in consumption gives producers an incentive to lower the markup. This by itself gives rise to a smaller inflation impact of an expansionary monetary policy shock in the deep habits economy than in models that assume either no habits or habits that operate at the level of aggregate consumption. When the deep habit effect is sufficiently strong, the deep habits model generates a fall in inflation on impact after an expansionary monetary policy shock. As the consumption boom dies out, producers slowly increase prices and this implies that the model also can account for inflation persistence.

Parts of the literature has pursued the idea that the inflation persistence puzzle is not “structural” but caused by changes over time in monetary policy and by instability of the inflation process. It has been pointed out that inflation persistence appears to be sensitive to the monetary policy regime (see e.g. Benati, 2008), and that there appears to have been breaks in the inflation process which renders inflation less persistent when controlled for (see e.g. Levin and Piger, 2003). We repeat our analysis for two sub-samples breaking the data in the third quarter of 1979 when Volcker became the chairman of the Fed. We find that the early sub-sample is associated with more pronounced price and inflation puzzles than the late sample. We reestimate the structural parameters and find that monetary policy has become less accommodating over time, that price rigidity has increased while wage rigidity has declined, but the extent and importance of deep habits have remained roughly constant.

The remainder of the paper is structured as follows. Section 2 describes the model. Section 3 contains the details of the structural estimation approach and also applies a structural VAR estimator to U.S. quarterly data. Section 4 analyses the results. Finally, Section 5 concludes.

## 2.2 The Model

We consider an economy with monopolistically competitive firms and households that act as monopolistically competitive suppliers of labor. Firms and households face costs of changing nominal prices and wages, respectively. The key contribution of the paper is the introduction of the deep habits model of Ravn, Schmitt-Grohe and Uribe (2006) into the monetary economy.

### 2.2.1 Households

There is a continuum of identical, infinitely lived households indexed by  $j \in [0, 1]$ . Households maximize the expected present discounted value of their utility stream. They derive utility from consumption of a continuum of differentiated goods and suffer disutility of supplying labor. As in Erceg, Henderson and Levin (2000), households supply a differentiated labor input and act as monopolistically competitive labor unions in the labor market. They face costs of changing nominal wages. Households own the firms and receive dividend payments on their equity shares.

Households are subject to good-specific habits as in the external deep habits model of Ravn, Schmitt-Grohe and Uribe (2006). Specifically, the marginal utility of the consumption of *individual* goods varieties is subject to a consumption externality specified as catching up with the Joneses. Household  $j$  consumes a basket of goods,  $c_{it}^j$ ,  $i \in [0, 1]$  and supplies labor to the firms. Preferences are given as:<sup>5</sup>

$$V_0^j = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{1}{1-\sigma} (x_t^j)^{1-\sigma} - \frac{\gamma}{1+\kappa} (h_t^j)^{1+\kappa} \right] \quad (2.1)$$

$$x_t^j = \left[ \int_0^1 (c_{it}^j - \theta^d c_{it-1}^j)^{1-1/\eta} di \right]^{1/(1-1/\eta)} \quad (2.2)$$

$$c_{it} = \int_0^1 c_{it}^j dj \quad (2.3)$$

where  $\mathbb{E}_t$  denotes the mathematical expectations operator contingent on all information available at date  $t$ ,  $\beta \in (0, 1)$  is the subjective discount factor,  $\sigma$  is a curvature parameter,  $1/\kappa > 0$  is the Frisch elasticity of labor supply,  $\gamma > 0$  is a preference weight, and  $h_t^j$  denotes the household  $j$ 's labor supply in period  $t$ .

$x_t^j$  is the consumption basket from which the household derives utility. According to equation (2.2), the consumption basket is a CES-aggregate of “habit adjusted” consumption levels of a continuum of differentiated goods. We model the habit relating to the consumption of *variety*  $i$  as the past *aggregate* consumption of this *variety*. The household take  $c_{it}$ , as given. The parameter  $0 \leq \theta^d < 1$  measures the importance of the habit. When  $\theta^d = 0$ , preferences are separable over time and the consumption aggregator is a standard CES function. In this case,  $\eta > 0$  denotes the standard intratemporal elasticity of substitution between goods. When  $\theta^d > 0$ , preferences display “catching up with the Joneses” at the goods level.<sup>6</sup>

<sup>5</sup>Implicitly, households also derive utility from real money balances and we assume that the utility function is separable in money and its other arguments.

<sup>6</sup>Ravn, Schmitt-Grohe and Uribe, 2006, also deal with the case of internal habits in which

The goods demand functions are found as the solutions to the following expenditure minimization problem:

$$\min_{c_{it}^j} X_t^j = \int_0^1 P_{it} c_{it}^j di$$

subject to:

$$\left[ \int_0^1 (c_{it}^j - \theta^d c_{it-1})^{1-1/\eta} di \right]^{1/(1-1/\eta)} = x_t^j$$

where  $P_{it}$  denotes the nominal price of variety  $i$ . The demand functions that solve this problem are given as:

$$c_{it}^j = \left( \frac{P_{it}}{P_t} \right)^{-\eta} x_t^j + \theta^d c_{it-1} \quad (2.4)$$

where  $P_t$  is an aggregate price index defined as:

$$P_t = \left[ \int_0^1 P_{it}^{1-\eta} di \right]^{1/(1-\eta)} \quad (2.5)$$

According to the demand function in equation (2.4), the household's demand for each goods variety depends negatively on its relative price,  $P_{it}/P_t$ , and when  $\theta^d > 0$  current demand also depends positively past aggregate demand for the good.

Households act as monopolistically competitive labor unions in the labor market. In return for their market power, they must stand ready to satisfy any demand for their labor services at the quoted wage. The demand for household  $j$ 's labor (see the next section) is given by:

$$h_t^j = \left( \frac{W_t^j}{W_t} \right)^{-\psi} h_t \quad (2.6)$$

where  $W_t^j$  denotes the nominal wage demand of household  $j$ ,  $W_t$  is an aggregate wage,  $\psi > 1$  is the labor demand price elasticity, and  $h_t$  is a measure of aggregate labor demand. Individual households take  $W_t$  and  $h_t$  for given.

The household makes its choices subject to the following sequence of budget

---

the household's current marginal utility of consumption of variety  $i$  depends on its *own* past consumption of that variety. Nakamura and Steinsson, 2008, examine pricing implications of this specification.

constraints:

$$P_t x_t^j + \varkappa_t + B_t^j = R_{t-1} B_{t-1}^j + W_t^j h_t^j + \Phi_t^j - P_t \frac{\zeta_w}{2} \left( \frac{W_t^j}{W_{t-1}^j} - \tilde{\pi}_{wt} \right)^2 \quad (2.7)$$

$$\varkappa_t = \theta^d \int_0^1 P_{it} c_{it-1} di$$

and subject to a no-Ponzi game restriction.

The household budget constraint assumes that the household has access to a nominal risk free bond which allows it to smooth consumption expenditure (and labor supply) over time.  $B_t^j$  denotes the household's purchases of one-period nominal bonds,  $R_t$  denotes the gross nominal interest rate and  $\Phi_t^j$  is the household's receipts of dividend payments on its equity portfolio.<sup>7</sup>

The last term on the right hand side of the budget constraint denotes nominal costs of adjusting nominal wages.  $\zeta_w \geq 0$  parametrizes the extent of nominal wage rigidity. When  $\zeta_w = 0$ , nominal wages are flexible while  $\zeta_w > 0$  implies that households incur a nominal cost of changing wages which is quadratic in the deviation of nominal wage growth from an indexation factor  $\tilde{\pi}_{wt}$  given as:

$$\tilde{\pi}_{wt} = \vartheta_w \pi_w^* + (1 - \vartheta_w) \pi_{wt-1}$$

where  $\vartheta_w \in [0, 1)$  is a measure the degree of wage indexation. When  $\vartheta_w = 1$  households can costlessly adjust wages with the steady-state wage inflation rate ( $\pi_w^*$ ) while  $\vartheta_w = 0$  implies that wages are fully indexed to the realized past inflation rate of aggregate nominal wages,  $\pi_{wt-1} = W_{t-1}/W_{t-2}$ .

The household's labor supply, the nominal wage, and its intertemporal allocation of  $x_t^j$  can be found as the solutions to the maximization of (2.1) subject to (2.6)–(2.7) taking as given  $P_t$ ,  $\vartheta_t$ ,  $W_0^j$ ,  $R_t$ , and  $\Phi_t^j$ . The first-order conditions are:

$$\gamma (h_t^j)^\kappa = (x_t^j)^{-\sigma} \frac{W_t^j}{P_t} - \lambda_{j,t}^h \quad (2.8)$$

$$\begin{aligned} \psi \lambda_{j,t}^h h_t^j (x_t^j)^\sigma &= h_t^j \frac{W_t^j}{P_t} - \zeta_w \frac{W_t^j}{W_{t-1}^j} \left( \frac{W_t^j}{W_{t-1}^j} - \tilde{\pi}_{wt} \right) \\ &\quad + \beta \zeta_w \mathbb{E}_t \frac{W_{t+1}^j}{W_t^j} \left( \frac{W_{t+1}^j}{W_t^j} - \tilde{\pi}_{wt+1} \right) \left( \frac{x_{t+1}^j}{x_t^j} \right)^{-\sigma} \end{aligned} \quad (2.9)$$

$$(x_t^j)^{-\sigma} = \beta R_t \mathbb{E}_t \frac{P_t}{P_{t+1}} (x_{t+1}^j)^{-\sigma} \quad (2.10)$$

<sup>7</sup>The formulation of the budget constraint uses the fact that  $P_t x_t^j = \int_0^1 P_{it} (c_{it}^j - \theta^d c_{it-1}^j) di$ .

where  $\lambda_{j,t}^h$  is the multiplier on the labor demand function in equation (2.6).

We note from (2.8) – (2.10) that the labor supply decision and the intertemporal consumption allocation are affected by the presence of habits in the consumption aggregator. Equation (2.9) is a forward looking “wage setting curve”. When wages are flexible ( $\xi_w = 0$ ), equations (2.8) – (2.9) imply that the household sets the real wage as a fixed markup over the marginal rate of substitution between labor and consumption. The markup is given as  $\psi/(\psi - 1) \geq 1$ .<sup>8</sup> Equation (2.10) is the intertemporal Euler equation.

### 2.2.2 Firms

Firms produce differentiated goods and are monopolistically competitive. They produce output using inputs of labor and we assume that the production function is linear:

$$y_{it} = h_{it} \quad (2.11)$$

where  $y_{it}$  denotes firm  $i$ 's output and  $h_{it}$  is firm  $i$ 's input of labor. The labor input is defined as:

$$h_{it} = \left( \int_0^1 (h_{it}^j)^{1-1/\psi} dj \right)^{1/(1-1/\psi)}$$

where  $h_{it}^j$  is firm  $i$ 's input of labor variety  $j$  at date  $t$ . The firm purchases the labor varieties at the nominal price  $W_t^j$ . It follows that the labor demand functions are given as:

$$h_{it}^j = \left( \frac{W_t^j}{W_t} \right)^{-\psi} h_{it} \quad (2.12)$$

where  $W_t$  is defined as:

$$W_t = \left[ \int_0^1 W_{jt}^{1-\psi} dj \right]^{1/(1-\psi)}$$

Aggregating (2.12) across firms gives (2.6).

The demand for firm  $i$ 's product is found by aggregating equation (2.4) across

---

<sup>8</sup>Given that our focus is not upon optimal monetary policy issues, we choose not to neutralize the steady-state monopoly power by a labor supply subsidy. This does not affect our results.

consumers:

$$\begin{aligned}
c_{it} &= \left(\frac{P_{it}}{P_t}\right)^{-\eta} x_t + \theta^d c_{it-1} & (2.13) \\
c_{it} &= \int_0^1 c_{it}^j dj \\
x_t &= \int_0^1 x_t^j dj
\end{aligned}$$

The demand function facing firm  $i$  at date  $t$  depends on the firm's past sales of its product whenever  $\theta^d > 0$ . This feature of the demand function implies that firms will set non-constant mark-ups even in the absence of nominal rigidities.<sup>9</sup> An increase in current demand,  $x_t$ , over habitual demand ( $c_{it-1}$ ), increases the price elasticity of the demand facing the firm and this gives firms an incentive to lower the mark-up. Moreover, firms will lower markups when they anticipate high value of future market share.

Firm  $i$  sets the price of its product,  $P_{it}$ , by maximizing profits subject to the household demand functions taking as given all aggregate quantities and prices. In return for having market power, firms must stand ready to serve any demand at the announced prices, i.e.  $c_{it} \geq y_{it}$ . Following Rotemberg (1982), we assume that there are quadratic adjustment costs associated with changing nominal prices. Firms face the following profit maximization problem:

$$\max_{P_{it}} \mathbb{E}_0 \sum_{t=0}^{\infty} q_t \Phi_{it} \tag{2.14}$$

$$\Phi_{it} = P_{it} c_{it} - W_t h_{it} - \frac{\zeta_p}{2} P_t \left( \frac{P_{it}}{P_{it-1}} - \tilde{\pi}_t \right)^2 \tag{2.15}$$

subject to (2.13) taking as given  $q_t$ ,  $P_{i0}$ ,  $P_t$ ,  $W_t$ ,  $x_t$  and  $\tilde{\pi}_t$ .  $\Phi_{it}$  denotes the nominal profits of firm  $i$  in period  $t$  and  $q_t$  is the rate at which the firm's owners (the households) discount the stream of nominal profits. This discount factor is given as:<sup>10</sup>

$$q_t = \beta^t x_t^{-\sigma} \frac{1}{P_t}$$

---

<sup>9</sup>Notice from the demand function that there is a price insensitive term that derives from past sales. One might be tempted to conclude that the firm can set a price of infinity making infinite profits due to this term. However, in equilibrium such a policy will not be consistent with household budget constraints and can therefore be ruled out.

<sup>10</sup>This equation imposes homogeneity across households, an assumption that we impose below.

$\zeta_p \geq 0$  parametrizes the extent of nominal rigidities. When  $\zeta \rightarrow 0$  prices are flexible while positive values of  $\zeta$  implies that firms have an incentive to smooth price changes over time. The term  $\tilde{\pi}_t$  is assumed to be given as:

$$\tilde{\pi}_t = \vartheta_p \pi^* + (1 - \vartheta_p) \pi_{t-1}$$

where  $\pi^*$  is the steady state inflation rate and  $\pi_{t-1} = P_{t-1}/P_{t-2}$  is the lagged realized aggregate inflation rate. When  $\vartheta_p = 1$  this specification implies that there are no adjustment costs along a balanced growth path with constant inflation. When  $\vartheta_p = 0$ , there is full indexation.

The first order conditions for  $h_{it}$ ,  $c_{it}$ , and  $P_{it}$ , in that order, are given as:

$$W_t = P_t \lambda_t^y \quad (2.16)$$

$$P_t \lambda_t^c + P_t \lambda_t^y - P_{it} = \theta^d \mathbb{E}_t \frac{q_{t+1}}{q_t} P_{t+1} \lambda_{t+1}^c \quad (2.17)$$

$$\begin{aligned} \mathbb{E}_t \frac{q_{t+1}}{q_t} \zeta_p P_{t+1} \frac{P_{it+1}}{P_{it}^2} \left( \frac{P_{it+1}}{P_{it}} - \tilde{\pi}_{t+1} \right) &= \zeta_p \frac{P_t}{P_{it-1}} \left( \frac{P_{it}}{P_{it-1}} - \tilde{\pi}_t \right) \\ &+ \eta P_t \lambda_t^c \frac{c_{it} - \theta^d c_{it-1}}{P_{it}} - c_{it} \quad (2.18) \end{aligned}$$

where  $\lambda_t^y$  is the multiplier on the production function (2.11), i.e. marginal costs, and  $\lambda_t^c$  is the multiplier on the demand function in (2.13).

When there are no habits ( $\theta^d = 0$ ) and prices are flexible ( $\zeta_p = 0$ ), equations (2.17) – (2.18), imply that prices are set as fixed mark-up over nominal marginal costs. When there are nominal rigidities and/or preferences display deep habits, the markup will be time-varying in response to shocks to the economy. Consider the two special cases when either prices are flexible or there are no deep habits. In these special cases, equations (2.17) – (2.18) can be expressed as:

$$\begin{aligned} \zeta_p &= 0 : P_{it} \left( 1 - \frac{1}{\eta} \frac{c_{it}/c_{it-1}}{c_{it}/c_{it-1} - \theta^d} \right) = P_t \lambda_t^y - \theta^d \mathbb{E}_t \frac{q_{t+1}}{q_t} P_{t+1} \frac{1}{\eta} \frac{c_{it+1}/c_{it}}{c_{it+1}/c_{it} - \theta^d} \\ \theta &= 0 : c_{it} \left( 1 - \eta \left( 1 - \lambda_t^y \frac{P_t}{P_{it}} \right) \right) \\ &= \zeta_p \frac{P_t}{P_{it-1}} \left( \frac{P_{it}}{P_{it-1}} - \tilde{\pi}_t \right) - \zeta_p \mathbb{E}_t \frac{q_{t+1}}{q_t} P_{t+1} \frac{P_{it+1}}{P_{it}^2} \left( \frac{P_{it+1}}{P_{it}} - \tilde{\pi}_{t+1} \right) \end{aligned}$$

When there are deep habits but prices are flexible, firms will vary the markup in response to changes in current aggregate demand and in response to expected changes in future consumption growth. When prices are sticky but there are no deep



habits, firms smooth price increases over time in response to changes in marginal costs or in aggregate demand. When these two mechanisms are combined, firms will vary markups in order to smooth price increases but taking into account that the optimal (flexible price) markup is affected by changes in aggregate demand and in expected future consumption growth.

### 2.2.3 Monetary Policy

We assume that the monetary policy authority sets the monetary stance according to a simple interest rate rule:

$$R_t = R^* + \rho_R (R_{t-1} - R^*) + (1 - \rho_R) \left[ \alpha_\pi (\pi_t - \pi^*) + \alpha_y \left( \frac{y_t - y^*}{y^*} \right) \right] + \varepsilon_t \quad (2.19)$$

where  $\varepsilon_t$  is a stochastic “monetary policy shock” with variance  $v^2$ .  $R^*$ ,  $\pi^*$  and  $y^*$  are positive constants which denote the steady state levels of the nominal interest rate, inflation and output, respectively. The parameter  $\rho_R \in [0, 1)$  denotes the extent of interest rate smoothing.

### 2.2.4 Market Clearing

We close the model by the market clearing conditions. The labor market clearing conditions are:

$$\begin{aligned} h_t^j &= \int_0^1 h_{it}^j di \\ h_{it} &= \int_0^1 h_{it}^j dj \end{aligned}$$

### 2.2.5 Symmetric Equilibrium

We concentrate upon a symmetric equilibrium in which all consumers make the same choice over consumption and set the same wage, and in which all firms set the same

prices. The symmetric equilibrium is summarized by the following set of equations:

$$x_t = c_t - \theta^d c_{t-1} \quad (2.20)$$

$$\gamma h_t^k = x_t^{-\sigma} w_t - \lambda_t^h \quad (2.21)$$

$$\begin{aligned} \psi \lambda_t^h h_t x_t^\sigma + \zeta_w \pi_{wt} (\pi_{wt} - \tilde{\pi}_{wt}) &= h_t w_t \\ &+ \beta \zeta_w \mathbb{E}_t \pi_{wt+1} (\pi_{wt+1} - \tilde{\pi}_{wt+1}) \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \end{aligned} \quad (2.22)$$

$$x_t^{-\sigma} = \beta R_t \mathbb{E}_t x_{t+1}^{-\sigma} \frac{1}{\pi_{t+1}} \quad (2.23)$$

$$c_t = h_t - \frac{\zeta_p}{2} (\pi_t - \tilde{\pi}_t)^2 - \frac{\zeta_w}{2} (\pi_{wt} - \tilde{\pi}_{wt})^2 \quad (2.24)$$

$$\lambda_t^y = w_t \quad (2.25)$$

$$\lambda_t^y + \lambda_t^c = 1 + \theta^d \beta \mathbb{E}_t \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \lambda_{t+1}^c \quad (2.26)$$

$$\eta \lambda_t^c x_t + \zeta_p \pi_t (\pi_t - \tilde{\pi}_t) = c_t + \beta \zeta_p \mathbb{E}_t \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \pi_{t+1} (\pi_{t+1} - \tilde{\pi}_{t+1}) \quad (2.27)$$

$$\begin{aligned} R_t - R^* &= \rho_R (R_{t-1} - R^*) + (1 - \rho_R) [\alpha_\pi (\pi_t - \pi^*) \\ &+ \alpha_y \left( \frac{y_t - y^*}{y^*} \right)] + \varepsilon_t \end{aligned} \quad (2.28)$$

$$\tilde{\pi}_t = \vartheta_p \pi^* + (1 - \vartheta_p) \pi_{t-1} \quad (2.29)$$

$$\tilde{\pi}_{wt} = \vartheta_w \pi_w^* + (1 - \vartheta_w) \pi_{wt-1} \quad (2.30)$$

$$w_t = w_{t-1} + \pi_{wt} - \pi_t \quad (2.31)$$

where  $w_t$  denotes the real wage,  $\pi_{wt}$  is the wage inflation rate, and  $\pi_t$  is the price inflation rate. We solve for the equilibrium by log-linearizing this system of equations around the steady-state.

It is instructive to consider the implications for inflation dynamics on the basis of the log-linearized version of equation (2.27). The log-linearized version of this equation can be expressed as:

$$\begin{aligned} \hat{\pi}_t &= \frac{(1 - \vartheta_p)}{1 + \beta(1 - \vartheta_p)} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta(1 - \vartheta_p)} \mathbb{E}_t \hat{\pi}_{t+1} \\ &+ \psi_1 \widehat{m} \hat{c}_t + \psi_2 (\mathbb{E}_t \hat{c}_{t+1} - \hat{c}_t) - \psi_3 (\hat{c}_t - \hat{c}_{t-1}) - \psi_4 \mathbb{E}_t \hat{\lambda}_{t+1}^c \end{aligned} \quad (2.32)$$

where we let  $\hat{x}_t$  denote the percentage deviation of  $x_t$  from its steady-state value,

and  $mc_t = \lambda_t^y$  denotes marginal costs. The coefficients are given as:

$$\begin{aligned}\psi_1 &= \left( \eta(1 - \theta^d) - (1 - \theta^d \beta) \right) / \left( \zeta_p \frac{\bar{\pi}^2}{\bar{c}} (1 + \beta(1 - \vartheta_p)) \right) \\ \psi_2 &= \sigma \beta \frac{\theta^d}{1 - \theta^d} / \left( \zeta_p \frac{\bar{\pi}^2}{\bar{c}} (1 + \beta(1 - \vartheta_p)) \right) \\ \psi_3 &= (1 + \sigma \beta \theta^d) \frac{\theta^d}{(1 - \theta^d)} / \left( \zeta_p \frac{\bar{\pi}^2}{\bar{c}} (1 + \beta(1 - \vartheta_p)) \right) \\ \psi_4 &= \theta^d \beta / \left( \zeta_p \frac{\bar{\pi}^2}{\bar{c}} (1 + \beta(1 - \vartheta_p)) \right)\end{aligned}$$

where  $\bar{x}$  denotes the steady-state value of  $x$ .

In the absence of deep habits and when prices are not indexed ( $\theta^d = 1 - \vartheta_p = 0$ ), equation (2.32) generates the standard new Keynesian Phillips curve. Indexation introduces a backward looking inflation term which implies a more persistent response to shocks to marginal costs. The presence of deep habits moderates the Phillips curve in three important ways. First, the habit moderates the impact of marginal cost changes on inflation. Secondly, the deep habit introduces a backward looking term in the Phillips curve even in the absence of indexation through the impact of the habit stock on this period's demand. Third, the presence of habits introduces an additional forward looking term through  $\mathbb{E}_t \hat{\lambda}_{t+1}^c$  and  $(\mathbb{E}_t \hat{c}_{t+1} - \hat{c}_t)$ . Particularly interesting is the implication that an increasing in the expected marginal value of future demand ( $\mathbb{E}_t \hat{\lambda}_{t+1}^c$ ) has a negative impact on current inflation as it gives firms an incentive to lower the markup in order to capture a higher future market share.

## 2.3 Estimation

In this section we provide empirical evidence on the dynamic effects of a monetary policy shock and we discuss our approach to estimating the key parameters of the model presented in the preceding section.

### 2.3.1 SVAR Estimates of the Impact of Monetary Policy Shocks

We study U.S. quarterly data for the sample period 1954:2 - 2008:2. The dynamic effects of monetary policy shocks are estimated using a structural VAR estimator. Consider the following reduced form VAR:

$$x_t = B(L)x_{t-1} + e_t \tag{2.33}$$

where  $x_t$  is a vector of observables,  $B(L)$  is a lag-polynomial, and  $e_t$  is a vector of reduced form errors. We specify the vector of observables as:

$$x_t = [c_t, \pi_t, p_t^s, r_t]$$

where  $c_t$  denotes the logarithm of per capita consumption,  $\pi_t$  is the inflation rate,  $p_t^s$  is the logarithm of the commodity price index divided by the CPI, and  $r_t$  is the federal funds rate. We measure consumption as personal consumption expenditure in chained year 2000 prices divided by the civilian non-institutional population. Inflation is measured as the change in CPI (of all urban consumers). The commodity price index is the PPI of commodities. All variables are deseasonalized.

We include consumption rather than output in the VAR because our model excludes investment, and, for the same reason, we measure inflation on the basis of the CPI rather than the GDP deflator. The commodity price index is included in order to partially address the price puzzle. The small dimension of the VAR relative to other recent papers, see e.g. Christiano, Eichenbaum, and Evans (2005), is due to the fact that our model is focused entirely on the impact of monetary policy shocks on consumption and inflation.

The monetary policy shock is identified using standard timing assumptions. We assume that the interest rate is affected contemporaneously by shocks to the first three components of the VAR but that none of these variables respond contemporaneously to the monetary policy shock. Consider the structural VAR:

$$A_0 x_t = \sum_{i=1}^p A_i x_{t-i} + \varepsilon_t \tag{2.34}$$

where  $A_i$ ,  $i = 0, \dots, p$ , are square matrices and  $\varepsilon_t$  is the vector structural innovations with the restriction that its covariance matrix is diagonal. The last component of this vector is the monetary policy shock and it is identified by assuming that the last column of  $A_0$  consists of zeros apart from its last element (which is normalized to unity). We allow for constant terms and trends when estimating the VAR and we assume that  $p = 8$  (but shorter lag structures give almost identical results).

The impulse responses to the identified monetary policy shock are illustrated in Figure 2.1. We show the impact of a one standard error decline in the federal funds rate (i.e. an expansionary monetary policy shock) along with 95 percent (bootstrapped, non-centered) confidence intervals for a forecast horizon of 20 quarters. According to our estimates, an expansionary monetary policy shock corresponds to

a decline in the nominal interest rate which remains low for around 6 quarters before eventually returning to its long-run value.

We find that a monetary policy loosening gives rise to a bell shaped persistent increase in aggregate consumption which peaks at 4 percent above trend around 6 quarters after the initial one standard error expansionary monetary policy shock. The increase in consumption persists until approximately 3.5 years after the initial decline in the interest rate. The response of inflation confirms conventional wisdom. We find that the inflation rate declines for the first 2 quarters after the expansionary monetary policy shock (recall that the impact response is by definition equal to zero). Inflation starts increasing around a year and a half after the decline in the interest rate and it then rises very persistently. The peak response occurs about 3 years after monetary policy shock. Thus, the small-scale VAR confirms the presence of the price puzzle and the inflation persistence puzzle.

The impact of monetary policy shocks on the vector of observables is very similar to the estimates that derive from much larger scale VARs, see e.g. Christiano, Eichenbaum and Evans (2005). This is reassuring since omitted variables bias could potentially be important for both the price puzzle and the inflation persistence puzzle. Indeed, excluding the commodity price index from the VAR leads to much more significant price puzzle indicating the relevance of introducing forward looking indicators in the VAR. Nonetheless, even after controlling for the informational content of the commodity price index, we find that there is a small price puzzle and that inflation persistence is abundant. Moreover, as we will discuss later, these results are robust in a qualitative sense to allow for a structural change in 1979 when Volcker took over as the chairman of the Fed. For that reason, we will interpret the inflation and price puzzles as empirical regularities.

### 2.3.2 Estimation of the Structural Parameters

The model introduces quite a large number of parameters some of which we do not have strong priors about realistic values. Let the vector of parameters be given by  $\Theta$ . We partition this vector into two subsets,  $\Theta_1$  and  $\Theta_2$ .  $\Theta_1$  consists of parameters that we calibrate while the parameters in  $\Theta_2$  are estimated by matching the identified impulse responses discussed above. We make this distinction between the structural parameters because not all of them are easily identifiable from our estimation approach as they have little impact on the dynamics of the model but instead matter for the model's steady state. The vector of parameters that we calibrate consists of  $\Theta_1 = [\beta, \pi^*, \gamma, \kappa, \sigma, \psi]$  while the parameters that are estimated

formally are  $\Theta_2 = [\eta, \zeta_p, \vartheta_p, \zeta_w, \vartheta_w, \theta^d, \rho_R, \alpha_y, \alpha_\pi, \nu]$ .

### Calibration of $\Theta_1$

The calibration of the parameters in  $\Theta_1$  is summarized in Table 2.1. We calibrate  $\beta$  so that it implies a 4 percent annual real interest rate in the non-stochastic steady-state.  $\pi^*$  is normalized to 1 while  $\gamma$  is calibrated so that it is consistent with a steady-state level of hours work equal to thirty percent.

Ideally, we would like to estimate the parameters  $\kappa$ ,  $\sigma$ , and  $\psi$ . However, we found that these parameters are not well-identified from the data. Following Erceg et al (2000), we set  $\psi = 4$ . This implies that the real wage is set as a 33 percent markup over the marginal rate of substitution between consumption and leisure. We set  $\kappa = 0.5$ . This is a custom value in the macro literature. Finally, we set  $\sigma = 3$  which implies an intertemporal elasticity of substitution of consumption of 1/3 which is in the range of values that is viewed as “reasonable”.

### Estimation of $\Theta_2$

We estimate  $\Theta_2$  using a limited information approach. The idea is to derive estimates of  $\Theta_2$  by matching as closely the theoretical impact of a monetary policy shock with the empirical VAR estimates. We do this the following way. Collect the empirical estimates of the responses of consumption, inflation, and the nominal interest rate to a one standard error monetary policy shock in the  $(3R - 2) \times 1$  vector  $\hat{\Phi}^{data}$  and let  $W$  be a  $(3R - 2)$  square diagonal matrix with the inverses of the standard errors of  $\hat{\Phi}^{data}$  along its diagonal ( $R$  denotes the forecast horizon)<sup>11</sup>. The structural parameters are then estimated from the following minimization problem:

$$\hat{\Theta}_2 = \arg \min_{\Theta_2} \left( \hat{\Phi}^{data} - \hat{\Phi}(\Theta_2 | \Theta_1)^{theory} \right) W \left( \hat{\Phi}^{data} - \hat{\Phi}(\Theta_2 | \Theta_1)^{theory} \right)' \quad (2.35)$$

where  $\hat{\Phi}(\Theta_2 | \Theta_1)^{theory}$  denotes the impulse response of the observables in the model economy given  $\Theta_2$ , conditional upon the calibration of  $\Theta_1$ .

When estimating  $\Theta_2$  we need to take into account one subtle issue. Recall that  $\hat{\Phi}^{data}$  is estimated assuming that consumption and inflation do not respond within a quarter to a monetary policy shock. In our model this identifying assumption is not satisfied. To address this issue we introduce a simulation step in which we measure

<sup>11</sup>This vector is of dimension  $(3R - 2)$  because the impact responses of consumption and inflation to the monetary policy shock are constrained to be zero.

the model's impulse responses subject to the empirical identification strategy.<sup>12,13</sup> Thus,  $\widehat{\Phi}(\Theta_2|\Theta_1)^{theory}$  does not correspond directly to the “true” responses of the observables to the monetary policy in the model economy, but instead to the impact of a **measured** monetary policy shock on the model equivalents of the observables. That is, we derive the measure  $\widehat{\Phi}(\Theta_2|\Theta_1)^{theory}$  using the following strategy:

**Step 1:** Solve the model for a given value of  $\Theta_2$  and for the assumed value of  $\Theta_1$ .

**Step 2:** Simulate  $N$  time series of length  $T$  of the observables given  $\Theta$ . Let the observables be consumption, inflation and the nominal interest rate. Add a small amount of measurement error to each of the artificial time series.

**Step 3:** Estimate a VAR for each of the  $N$  artificial time series and calculate  $\widehat{\Phi}_i(\Theta_2|\Theta_1)^{theory}$  of the  $i$ 'th simulation from the impulse responses assuming that consumption and inflation do not respond contemporaneously to the monetary policy shock.

**Step 4:** Calculate  $\widehat{\Phi}(\Theta_2|\Theta_1)^{theory}$  as the mean of  $\widehat{\Phi}_i(\Theta_2|\Theta_1)^{theory}$  for  $i = 1, 2, \dots, N$ .

The measurement errors are added in step 2 in order to address the stochastic singularity of the VAR using the artificial data given that there is a single source of variation in the time series. This procedure is then continued until we find the solution to the minimization problem in equation (2.35). We calculate the standard errors of  $\widehat{\Theta}_2$  following Hall et al (2007) as:

$$\begin{aligned}\Omega_{\Theta_2} &= \Gamma(\Theta_2|\Theta_1)^{theory} \frac{\partial \widehat{\Phi}(\Theta_2|\Theta_1)^{theory'}}{\partial \Theta_2} W \Sigma_N W \frac{\partial \widehat{\Phi}(\Theta_2|\Theta_1)^{theory'}}{\partial \Theta_2} \Gamma(\Theta_2|\Theta_1)^{theory} \\ \Gamma(\Theta_2|\Theta_1)^{theory} &= \left[ \frac{\partial \widehat{\Phi}(\Theta_2|\Theta_1)^{theory'}}{\partial \Theta_2} W \frac{\partial \widehat{\Phi}(\Theta_2|\Theta_1)^{theory'}}{\partial \Theta_2} \right]^{-1} \\ \Sigma_N &= \Sigma + \frac{1}{N^2} \sum_{i=1}^N \Sigma_i\end{aligned}$$

where  $\Sigma_i$  is the covariance matrix of  $\widehat{\Phi}_i(\Theta_2|\Theta_1)^{theory}$  and  $\Sigma$  is the covariance matrix of the impulse responses in the data.

<sup>12</sup>Christiano, Eichenbaum and Evans (2005) address this issue instead by introducing timing assumptions in the model economy that renders it consistent with the identifying assumption in the data.

<sup>13</sup>Strictly speaking, there is another difference between the empirical VAR and the model since the empirical VAR includes the commodity price index. If this variable is excluded from the empirical VAR we find a much more pronounced price puzzle, see Sims (1993). In principle the model can be extended to include commodities but we believe that this would not generate many more insights but would certainly complicate the analysis very significantly.

This estimator is applied subject to various parameter restrictions. We assume that  $\xi_p, \xi_w, \alpha_y, v \geq 0$ ,  $0 \leq \vartheta_p, \vartheta_w \leq 1$ ,  $\eta, \alpha_\pi > 1$ ,  $0 \leq \theta^d < 1$ , and  $-1 < \rho_R < 1$ . We use 100 simulations in step 3 and the (vector of) measurement error added in step 2 is assumed to be normally distributed with mean 0 and variance 0.0001.

## 2.4 Results

In order to examine the impact of the deep habits mechanism we compare the results with the estimation results for two alternative models. The first alternative model is a standard “aggregate” habit new Keynesian model. In this model preferences are given by:

$$V_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{1}{1-\sigma} \left( c_t^j - \theta^a c_{t-1} \right)^{1-\sigma} - \frac{\gamma}{1+\kappa} \left( h_t^j \right)^{1+\kappa} \right] \quad (2.36)$$

$$c_t^j = \left[ \int_0^1 \left( c_{it}^j \right)^{1-1/\eta} di \right]^{1/(1-1/\eta)} \quad (2.37)$$

$$c_t = \int_0^1 c_t^j dj$$

which is the aggregate habit model studied in much of the literature.  $\theta^a$  here denotes the importance of the aggregate (external) habit. A crucial difference between this model and the deep habits model is that the aggregate habit does not impact directly on firms’ pricing policies and leaves markups constant unless there are impediments to changing prices. The second alternative model is the standard new Keynesian model with *no* habits which corresponds to our baseline model with the restriction that  $\theta^d = 0$ . The estimates of the parameters and their standard errors of the deep habits model and the parameters of the two alternative models are reported in Table 2.2.

It is instructive first to consult Figures 2.2-2.4 which illustrate the VAR based impulse responses of the observables to a monetary policy shock for the three alternative models along with their empirical counterparts. The deep habits model clearly provides a superior fit to the empirical estimates of the impact of a monetary policy shock. The deep habits model captures very precisely the bell shaped response of aggregate consumption and the interest rate path is also matched extremely well. Importantly, the model can account simultaneously for the price puzzle and for inflation persistence. Note that the model not only is consistent with an outdrawn increase in inflation but it also correctly identifies the period of maximum impact



on the inflation rate.

The aggregate habit model gives rise to a consumption response to the monetary policy shock that is very similar to the deep habits model. However, the aggregate habits model provides a worse fit to both the interest rate path and, in particular, to the inflation response. As far as the interest rate path is concerned, the initial size of the shock appears to be under-estimated. In terms of the inflation response, the aggregate habits model can account neither for the price puzzle nor for the extent of the inflation persistence since the maximum impact on inflation occurs around a year earlier in the model than in the US data.

By far the worst fit occurs in the standard new Keynesian model in which the interest rate path is rather odd, and the consumption response is very different from what is observed in the data. The model does appear to be consistent with the main features of the inflation response but this is due to the rather odd interest rate path and comes at the cost of the poor fit to the consumption dynamics.

The impression of the superior fit of the deep habits model is confirmed by the minimized value of the quadratic form reported in the last row of Table 2.2. The deep habits model attains a minimum of the quadratic form that is 40 percent lower than the aggregate habits model and 70 percent lower than the standard new Keynesian model. The parameters estimated with the standard new Keynesian model are rather absurd. In particular, this model implies an extremely high cost of changing nominal prices while the estimate of the nominal wage rigidity is moderate. The former of these findings echoes results in Ireland (2001). For that reason, we concentrate the discussion on two habit formation models.

The point estimate of the key deep habits parameter,  $\theta^d$ , is 0.852. Interestingly, when we instead assume a standard aggregate habit model, we find a very similar point estimate of the aggregate habit parameter,  $\theta^a = 0.826$ . The associated standard errors are in both cases very small. Thus, for a given real interest rate, the two models have very similar implications for how habits affect the intertemporal allocation of consumption but as we have seen lead to very different implications for the dynamics of inflation.

The most interesting parameters apart from those relating to habits, are those that relate to the extent of nominal rigidities. The estimates of  $\zeta_p$  and  $\zeta_w$  are much lower in the deep habits economy relative to the aggregate habit model. When we allow for deep habits we find that  $\zeta_p = 14.5$  and that  $\zeta_w = 41$ . In the aggregate habits economy instead we find more than twice as high estimates of both parameters,  $\zeta_p = 31$  and  $\zeta_w = 103$ . Thus, not only does the deep habits model account better

for the dynamic adjustment of prices in response to a monetary policy shock, but it does so relying on much smaller impediments to price and wage adjustment. Notice also that both of the habit models gives estimates of  $\vartheta_p$  that imply full indexation of prices while the models disagree on the extent of wage indexation.

The monetary policy function parameter estimates imply a great deal of interest rate smoothing with a point estimate of  $\rho_R$  of 0.74 in the deep habits economy and 0.85 when assuming aggregate habits. However, the relative weight on inflation varies quite substantially across the two models with the deep habits model being consistent with a more hard nosed anti-inflationary central bank reaction function.

Recall that the impulse responses illustrated in Figures 2.2-2.4 do not correspond directly to the impact of a monetary policy shock in the model since they are measured subject to the VAR filter. In order better to understand the results, we now examine the *exact* impulse responses of the two habits models. These are illustrated in Figure 2.5 and 2.6. The exact impulse responses for the aggregate habits model confirm the lack of a good fit to the inflation process. In fact, this model implies that the inflation rate rises slightly upon impact and reaches its peak two years after the cut in the interest rate. Moreover, the consumption response is much more muted according to the exact impulse responses than the VAR-based impulse responses. The deep habits model instead paints a different picture. For this model the consumption and interest rate paths according to the VAR-based measurement are as good as identical to the exact impulse responses. The exact impulse responses of the inflation dynamics instead indicate an even larger price puzzle than the VAR based results. This is interesting since it implies that the price puzzle does not seem to be caused by measurement.

The adjustment of markups is the key difference between the two habit models. Figure 2.7 illustrates the paths of the markup in response to a monetary policy shock for three different economies. The first economy is the deep habits economy using the parameter estimates listed in the “Deep Habits” column of Table 2.2. The second economy is the aggregate habits model using the parameter estimates of the “Aggregate Habits” column of Table 2.2. The third economy is the aggregate habits economy but using the parameter estimates for the deep habits economy setting  $\theta^a = \hat{\theta}^d$ .

Comparing paths of the markup for the first and third of these economies reveals the impact of allowing for deep habits rather than the standard aggregate habit assuming that all other parameters are unchanged. The markup declines much more significantly in response to the monetary policy shock in the deep habits economy

than the standard aggregate habit model. The intuition for this result is that producers in the deep habit economy find it optimal to lower the markup in response to the increase in current demand (which increases the price elasticity of demand) and the expectation of high values of future market shares. In the deep habits economy, this leads to a period of declining inflation despite the monetary injection. As time passes, current consumption and habitual consumption become aligned and future consumption growth declines. This reverses producers' incentive to lower the markup in the deep habits economy and at this point prices start rising rather fast. This mechanism brings about a persistent increase in the inflation rate which matches the response of inflation observed in the US data.

Finally, an important insight is that the deep habits mechanism and nominal rigidities are complementary. Recall that our estimates of the costs of changing prices and wages are lower when we allow for deep habits than in the standard aggregate habit economy (see Table 2.2). Despite this, the markup declines more in the deep habits economy than in the aggregate habit economy when we allow for differences in parameter values. In other words, the movements in markups that arise optimally in the deep habits economy imply a persistent rise in inflation following a monetary policy expansion without relying on extreme degrees of impediments to the adjustment of prices and wages.

#### 2.4.1 Constrained Markup

The steady-state markup in the deep habits model is given as:

$$\mu = \left[ \frac{\eta - 1}{\eta} - \frac{1 - \beta}{\eta} \frac{\theta^d}{(1 - \theta^d)} \right]^{-1} > \frac{\eta}{\eta - 1}$$

while the steady-state markup is  $\frac{\eta}{\eta - 1}$  in the two alternative economies. Thus, given the point estimates in Table 2.2, the steady-state markup in the standard new Keynesian model is approximately 0, 24 percent in the standard habit model, but as high as 74 percent in the deep habits model. We now investigate the consequences of constraining the markup during the estimation procedure.

Table 2.3 reports the parameter estimates when we constrain the markup to be 50 percent. In the deep habits economy we introduce this restriction by allowing  $\theta^d$  to be estimated and then imposing the value of  $\eta$  that is consistent with a 50 percent markup. In the other two economies we instead impose  $\eta = 3$  directly.

Introducing this restriction leads to much more reasonable estimates of the degree

of nominal rigidities for the standard new Keynesian model but its fit is still much worse than any of the two alternative models. The parameters of the two habit economies are to a large extent unchanged. In particular, the estimates of  $\theta^d$  and  $\theta^a$  are very similar to those reported in Table 2.2 and still indicate significant habit effects. We find a slight drop in the estimate of the extent of nominal rigidities in the deep habits economy but the parameters now appear more precisely estimated. In the aggregate habits economy instead, the estimate of  $\zeta_p$  falls but we obtain an even higher estimate of  $\zeta_w$ . Most importantly, according to the quadratic form, the deep habits model still provides a much better fit to the data than the standard habit model.

Figure 2.8 illustrates the VAR based impulse responses for the constrained version of the deep habits model. We note that the results are approximately unchanged relative to those shown in Figure 2.3. Thus, our results do not derive from unreasonable assumptions regarding the markup.<sup>14</sup>

## 2.4.2 Sub-Sample Stability

During the sample period US monetary policy has undergone fundamental changes. These changes have elsewhere been shown to have given rise to important changes in the monetary reaction function and it has been claimed that these structural changes are partially responsible for price puzzle and for the extent of the inflation puzzle. Therefore, it is potentially an important issue to take into account as far as the current exercise is concerned.

Perhaps the most fundamental change in US monetary policy took place in August 1979 when Volcker took office at the Federal Reserve. His chairmanship marked the beginning of a less accommodating US monetary policy regime which has been associated with a decline in the US inflation rate. For this reason we now examine the consequences of allowing for a structural change that takes place in the third quarter of 1979. We reestimate the empirical VAR splitting the sample into a pre-1979:3 sample and a post-1979:2 sample. With the subsample estimates of the impact of monetary policy shocks at hand, we reestimate the structural parameters and investigate the extent to which the change in monetary policy affects our results.

The parameter estimates relating to the sub-samples are reported in Table 2.4. The key message from this table is that although we find changes in some parameters,

---

<sup>14</sup>We repeated this experiment setting the steady-state markup equal to 25 percent. We found that the deep habits model still fits the data better than the two alternative models. This restriction leads to higher estimates of the degrees of price and wage inflexibility.

the estimates of the deep habits parameter are constant across sub-samples and very similar to the full sample results.

Parameter instability relates instead mainly to (a) the parameters of the monetary policy reaction function, and (b) the parameters that determine the extent of nominal rigidities. As far as the interest rate rule is concerned, the late sub-sample is associated with a hard nosed interest rate rule which depends on inflation only while the early sample was characterized by accommodating monetary policy with a large weight associated with fluctuations in output. We also find some decline in the extent of interest rate smoothing. In terms of nominal rigidities we find that the extent of rigidity of prices has increased over time while wages have become more flexible. These results square well with conventional wisdom.

Figure 2.9 shows the impact of a monetary policy shock in the late sub-sample. We find a smaller price puzzle and a less persistent impact of monetary policy shocks on the inflation rate in recent sub-sample relative to the full sample. However, the post-1979:3 sub-sample still implies a negative impact response of an expansionary monetary policy shock on the inflation rate, and the peak response of inflation still occurs as late as 10 quarters after the monetary loosening. Importantly, the deep habits model provides a good fit even in the late sub-sample. We conclude from this that although the extent of the price puzzle and the inflation persistence puzzle are related to structural changes, the deep habits mechanism is key for understanding the dynamic impact of monetary policy shocks.

## 2.5 Conclusions

In this paper we have asked whether a parsimonious sticky-price sticky wage model extended with deep habits can account for the dynamic effects of monetary policy shocks. We find that this is indeed the case. In particular, when allowing for customer market effects modeled through deep habits, one can simultaneously account for the persistent effects of monetary policy shocks on aggregate consumption and for the impact on inflation. One important aspect of our results is that the introduction of deep habits allows one to account for the price puzzle and for inflation persistence without relying on unreasonable extents of nominal rigidities. The reason for this is that nominal rigidities in the form of impediments to price and wage adjustments and deep habits are complementary. The existence of nominal rigidities introduces a role for deep habits in accounting for the impact of monetary policy shocks and the countercyclical nature of markups that derive from deep habits decreases the

need for nominal rigidities when accounting for the sluggish adjustment of inflation to monetary policy shocks. We have also shown that while inflation persistence and the price puzzle were more pronounced pre-Volcker, the importance of the deep habit mechanism has remained constant over time. In that sense, our paper points towards structural reasons for the impact of monetary policy shocks on inflation.

Our results indicate that more attention should be directed towards goods market features when examining the impact of monetary policy shocks. The previous literature has examined in great detail how marginal cost persistence, backward looking price setting, and labor market frictions impact on monetary policy, but much less attention has been paid to goods market features which we here have shown to be key. We think that this may also have important implications for issues relating to optimal monetary policy design but we leave this issue for future research.

## Bibliography

Benati, Luca, 2008, “Investigating Inflation Persistence Across Monetary Regimes”, **Quarterly Journal of Economics** 123(3), 1005-60.

Brissimis, Sophocles N., and Nicolas S. Magginas, 2006, “Forward-looking Information in VAR Models and the Price Puzzle”, **Journal of Monetary Economics** 53(6), 1225-34.

Browning, Martin J., and Collado, Lola, 2007, “Habits and Heterogeneity in Demand: A Panel Data Analysis”, **Journal of Applied Econometrics** 22, 625-640.

Castelnuovo, Efrem, and Paolo Surico, 2006, “The Price Puzzle: Fact or Artefact”, Bank of England Working Paper no. 288.

Chari, Varadarajan V., Ellen McGrattan and Patrick J. Kehoe, 2000, “Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem?”, **Econometrica** 68(5), 1151-80.

Chintagunta, Pradeep, Kyriazidou, Ekatarina, and Perktold, Josef, 2001, “Panel Data Analysis of Household Brand Choices”, **Journal of Econometrics** 103, 111-153.

Christiano, Lawrence J, Martin Eichenbaum and Charles Evans, 2005, “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy”, **Journal of Political Economy** 113, 1-45.

- Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin, 2000, “Optimal Monetary Policy with Staggered Wage and Price Contracts”, **Journal of Monetary Economics** 46(2), 281-313.
- Fuhrer, Jeffrey and Gerald Moore, 1995, “Inflation Persistence”, **Quarterly Journal of Economics** 110, 127-160.
- Gali, Jordi and Mark Gertler, 1999, “Inflation Dynamics: A Structural Econometric Analysis”, **Journal of Monetary Economics** 44, 195-222.
- Guadagni, Peter M., and John D. C. Little, 1983, “A Logit Model of Brand Choice Calibrated On Scanner Data”, **Marketing Science** 1, 203-234.
- Hall, Alastair, Atsushi Inoue, James N. Nason, and Barbara Rossi, 2007, “Information Criteria for Impulse Response Function Matching Estimation of DSGE Models”, manuscript, Duke University.
- Hanson, Michael S., 2004, “The “Price Puzzle” Reconsidered”, **Journal of Monetary Economics** 51(7), 1385-1413.
- Holden, Steinar, and John C. Driscoll, 2003, “Inflation Persistence and Relative Contracting”, **American Economic Review** 93(4), 1369-72.
- Houthakker, Hendrik S., and Taylor, Lester D., 1970, **Consumer Demand in the United States: Analysis and Projections**, Cambridge: Harvard University Press.
- Ireland, Peter N., 2001, “Money’s Role in the Monetary Transmission Mechanism”, NBER working paper no. 8115.
- Levin, Andrew T., and Jeremy Piger, 2003, “Is Inflation Persistence Intrinsic in Industrial Economies?”, working paper no.2002-023, Federal Reserve Bank of St. Louis.
- Rabanal, Pau, and Juan F. Rubio-Ramirez, 2003, “Inflation Persistence: How Much Can We Explain?”, **Federal Reserve Bank of Atlanta Economic Review**, Second Quarter, 43-55.
- Ravn, Morten, Stephanie Schmitt-Grohe and Martin Uribe, 2006, “Deep Habits”, **Review of Economic Studies** 73(1), 195-218.

Ravn, Morten O., Stephanie Schmitt-Grohe and Martin Uribe, 2007, “Explaining the Effects of Government Spending on Consumption and the Real Exchange Rate”, NBER working paper no. 13328.

Rotemberg, Julio J., 1982, “Sticky Prices in the United States”, **Journal of Political Economy** 90(6), 1187-1211.

Sims, Christopher A., 1992, “Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy”, **European Economic Review** 36, 2-16.

Smets, Frank, and Raf Wouters, 2003, “An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area”, **Journal of the European Economic Association** 1(5), 1123-1175.

Steinsson, Jon, and Emi Nakamura, 2008, “Price Setting in Forward Looking Customer Markets”, manuscript, Columbia University.



Table 2.1: Calibrated Parameters

Parameter	Meaning	Calibration
$\gamma$	Weight on disutility of work	Calibrated to imply $\bar{h} = 0.3$
$\beta$	subjective discount factor	Calibrated to imply quarterly real interest rate of 1 percent
$\pi^*$	Steady-state gross inflation rate	1
$\psi$	Labor demand elasticity	4
$\kappa$	Inverse of labor supply elasticity	0.5
$\sigma$	Inverse of intertemporal elasticity of substitution	3

Table 2.2: Estimated Parameters

Parameter	Model					
	(1) Deep Habits		(2) Aggr. Habit		(3) No Habit	
	Estimate	s.e.	Estimate	s.e.	Estimate	s.e.
$\eta$	2.48	0.27	5.18	0.03	10134	281.22
$\zeta_p$	14.47	1.82	31.00	0.003	476040	378.33
$\vartheta_p$	0*	-	0*	-	0*	-
$\zeta_w$	40.89	81.83	102.94	0.001	2.25	0.12
$\vartheta_w$	0.96	1.72	0*	-	0.14	0.01
$\theta^d$	0.85	0.002	-	-	-	-
$\theta^a$	-	-	0.83	0.001	-	-
$\rho_R$	0.74	0.01	0.85	0.002	0.86	0.02
$\alpha_y$	0.04	0.01	0.48	0.02	1	0.34
$\alpha_\pi$	1.26	0.02	1.01*	-	1.01*	-
$v$	0.96	0.09	0.51	0.05	0.40	0.04
Value of quad. form	79.16	-	127.81	-	249.04	-

\*This parameter was up against the boundary condition.

Table 2.3: Estimated Parameters with Constrained Markup

Parameter	Model					
	Deep Habits		Aggregate Habit		No Habit	
	Estimate	s.e.	Estimate	s.e.	Estimate	s.e.
$\eta$	3.19		3		3	
$\zeta_p$	10.18	0.30	24.23	0.28	33.72	135.5
$\vartheta_p$	0*	-	0*	-	0*	-
$\zeta_w$	31.29	8.65	188.3	0.04	34.20	137.25
$\vartheta_w$	0.99	0.25	0*	-	0*	-
$\theta^d$	0.86	0.001	-		-	
$\theta^a$	-		0.88	0.001	-	
$\rho_R$	0.74	0.004	0.77	0.004	0.76	0.02
$\alpha_y$	0*	-	0*	-	0*	-
$\alpha_\pi$	1.49	0.02	1.01*	-	1.01*	-
$v$	0.90	0.09	0.93	0.09	0.61	0.06
Value of quad. form	81.95		158.32		261.83	

\*This parameter was up against the boundary condition.

Table 2.4: Sub-Sample Stability

Parameter	Sample			
	1954:2-1979:2		1979:3-2008:2	
	Estimate	s.e.	Estimate	s.e.
$\eta$	3.91	0.84	5.76	1.42
$\zeta_p$	6.36	4.99	10.53	14.06
$\vartheta_p$	0.00*	-	0.00*	-
$\zeta_w$	7.73	75.08	3.47	9.15
$\vartheta_w$	1.00*	-	0.95	1.77
$\theta^d$	0.89	0.003	0.90	0.003
$\rho_R$	0.74	0.02	0.66	0.01
$\alpha_y$	1.00	0.12	0*	-
$\alpha_\pi$	1.01*	-	2.14	0.11
$v$	0.74	0.07	0.93	0.09

\*This parameter was up against the boundary condition.

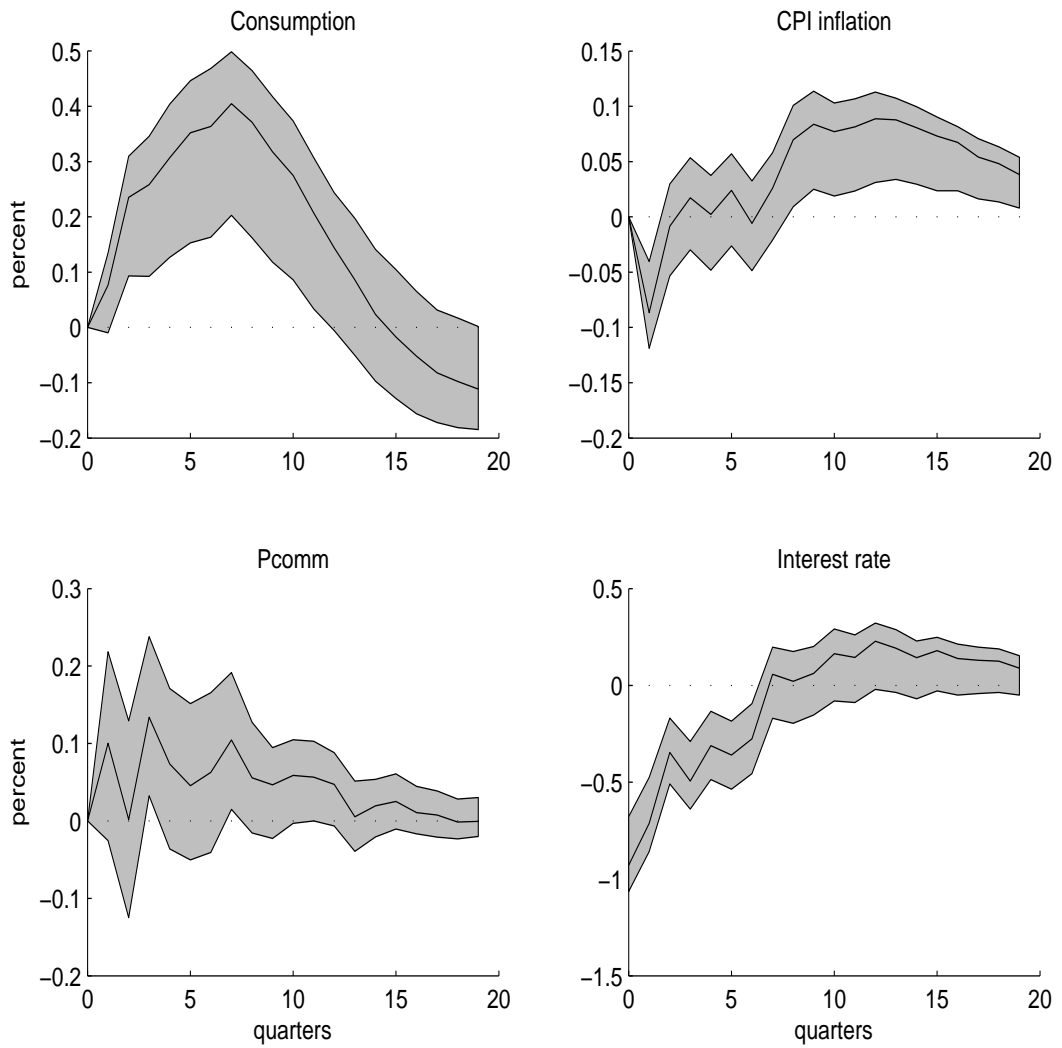


Figure 2.1: The Impact of an Identified Monetary Policy Shock.  
 Notes: The figure illustrates the impact of a 1 standard error decline in the federal funds rate in the U.S. Grey areas show the 95 percent confidence intervals.

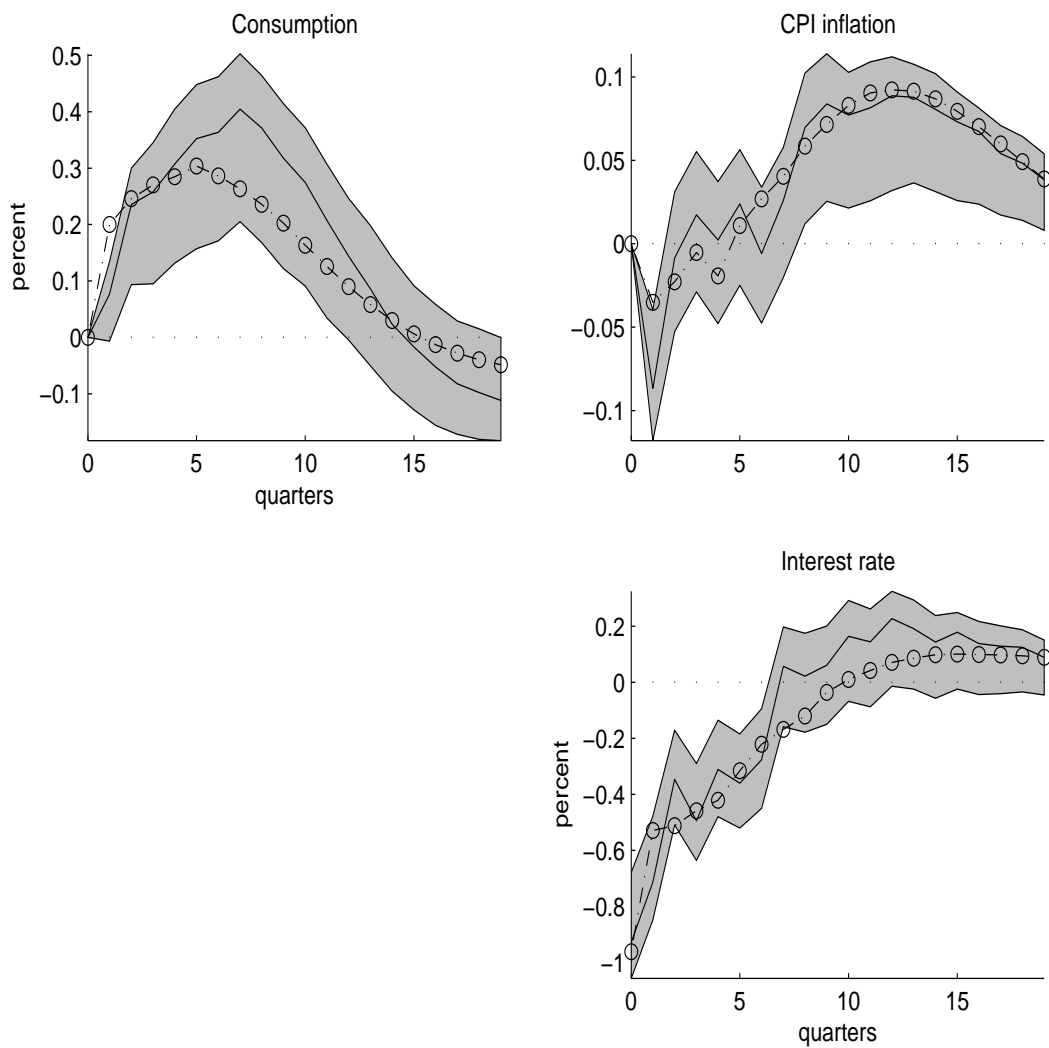


Figure 2.2: The VAR-based Impact of a Monetary Policy Shock in the Deep Habits Economy.

Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1 percentage point decrease in the interest rate in the deep habits. economy when measured with a VAR filter

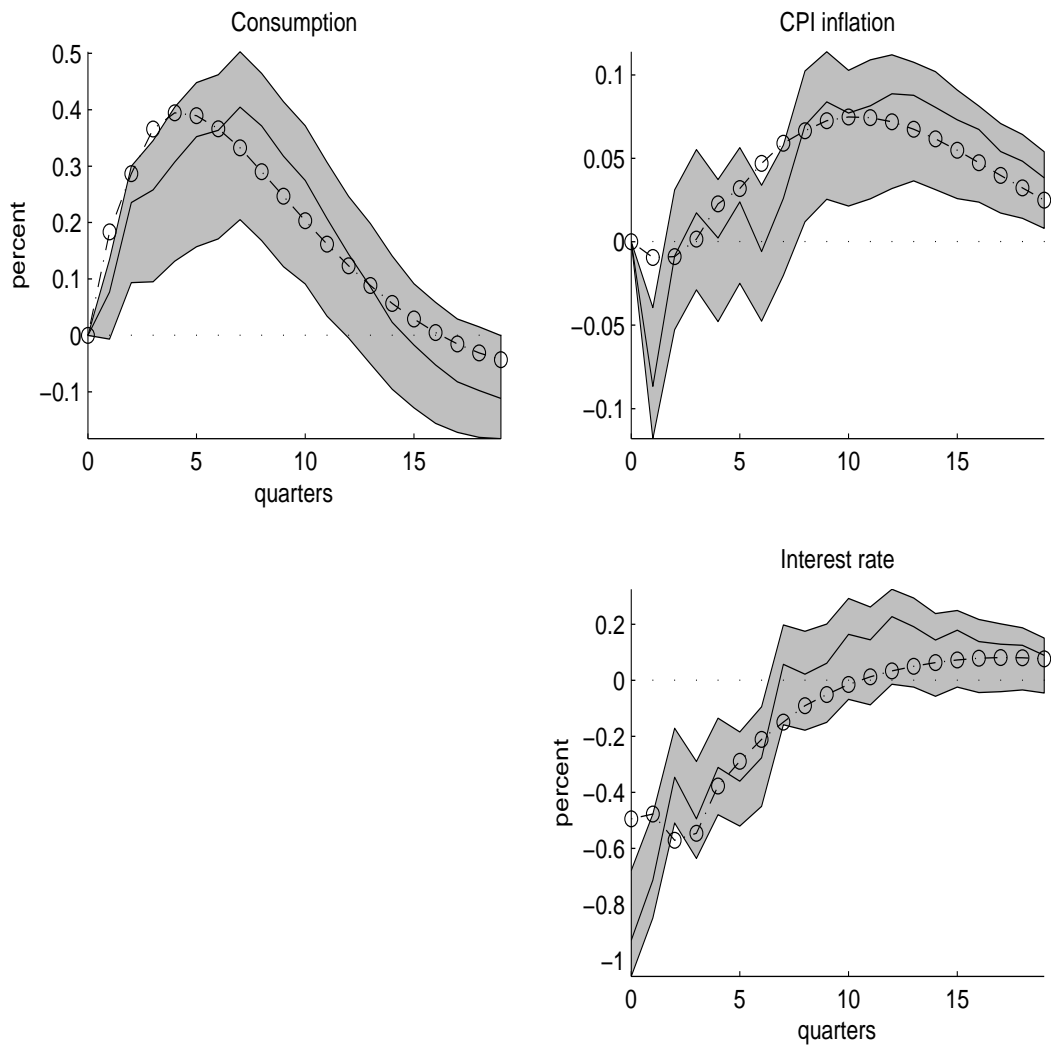


Figure 2.3: The VAR-based Impact of a Monetary Policy Shock in the Aggregate Habits Economy.

Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1 percentage point decrease in the interest rate in the aggregate habits economy when measured with a VAR filter

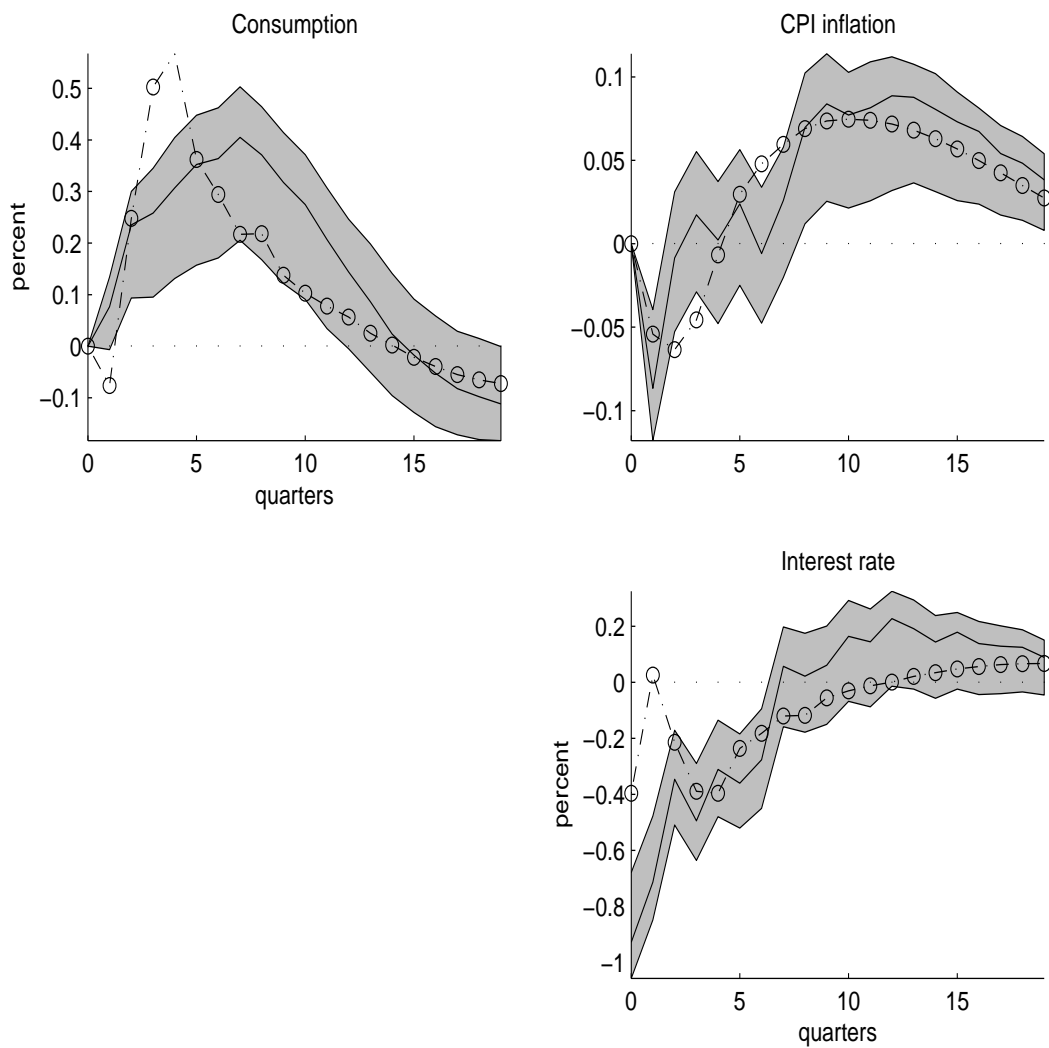


Figure 2.4: The VAR-based Impact of a Monetary Policy Shock in the Economy with No Habits.

Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1 percentage point decrease in the interest rate in the economy with no habits economy when measured with a VAR filter



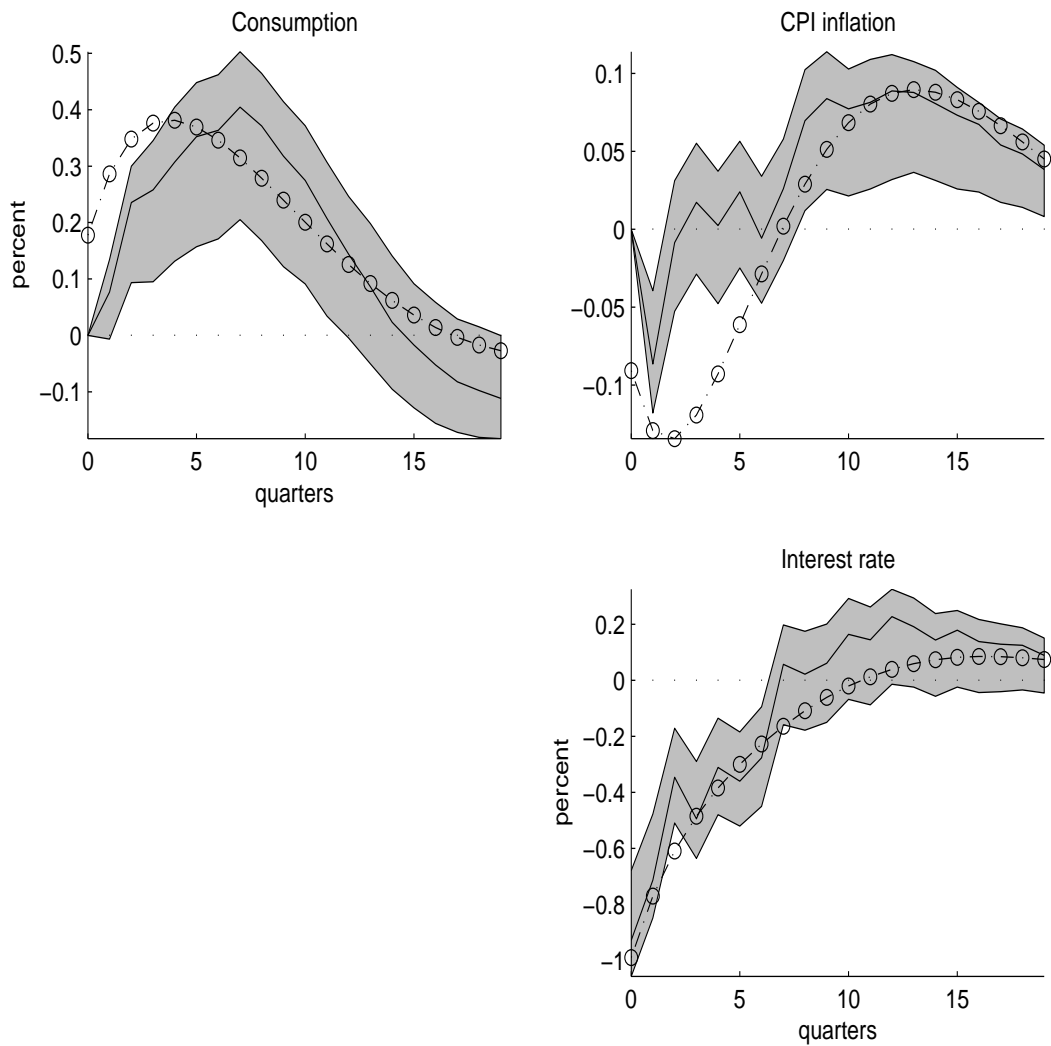


Figure 2.5: The Exact Response to a Monetary Policy Shock in the Deep Habits Economy.

Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1 percentage point decrease in the interest rate in the deep habits economy.

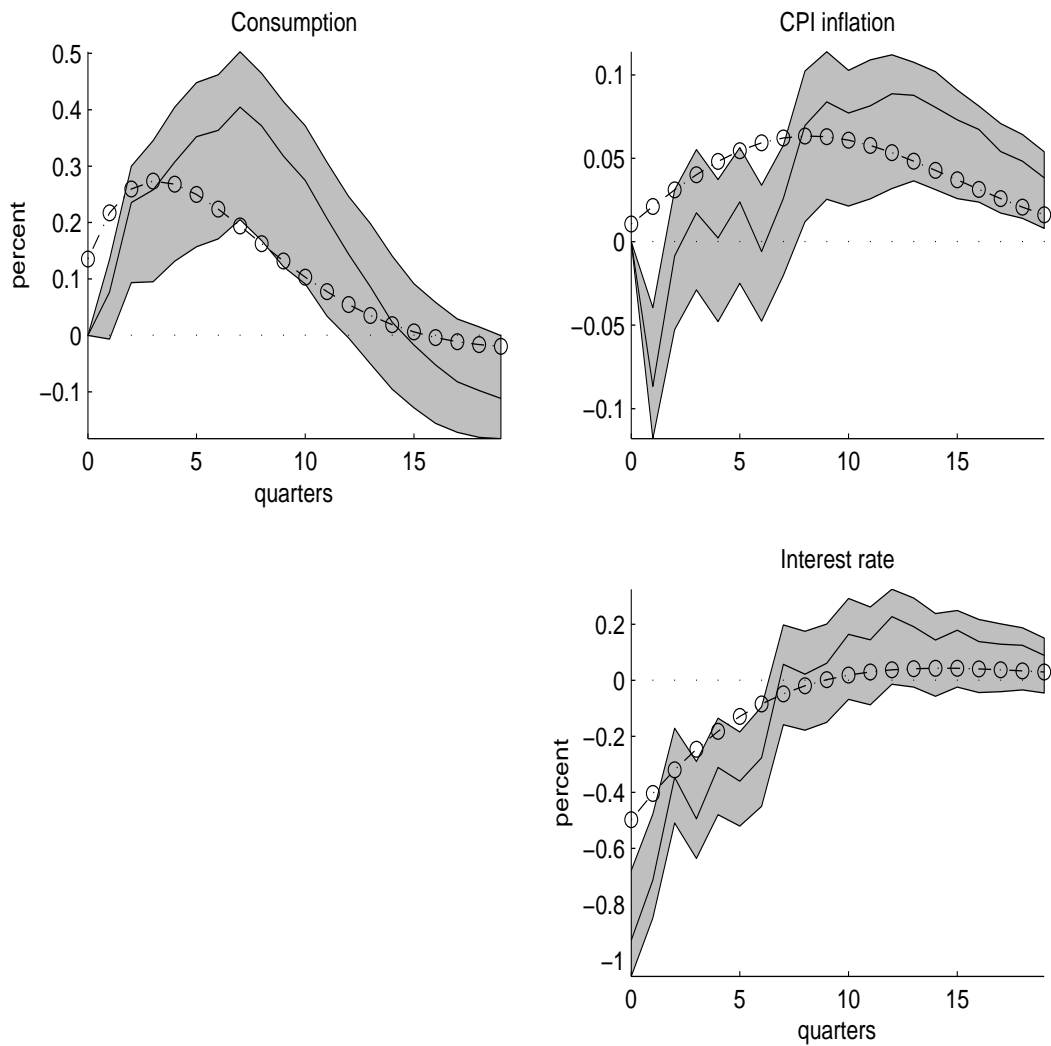


Figure 2.6: The Exact Response to a Monetary Policy Shock in the Aggregate Habits Economy.

Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1 percentage point decrease in the interest rate in the aggregate habits economy.

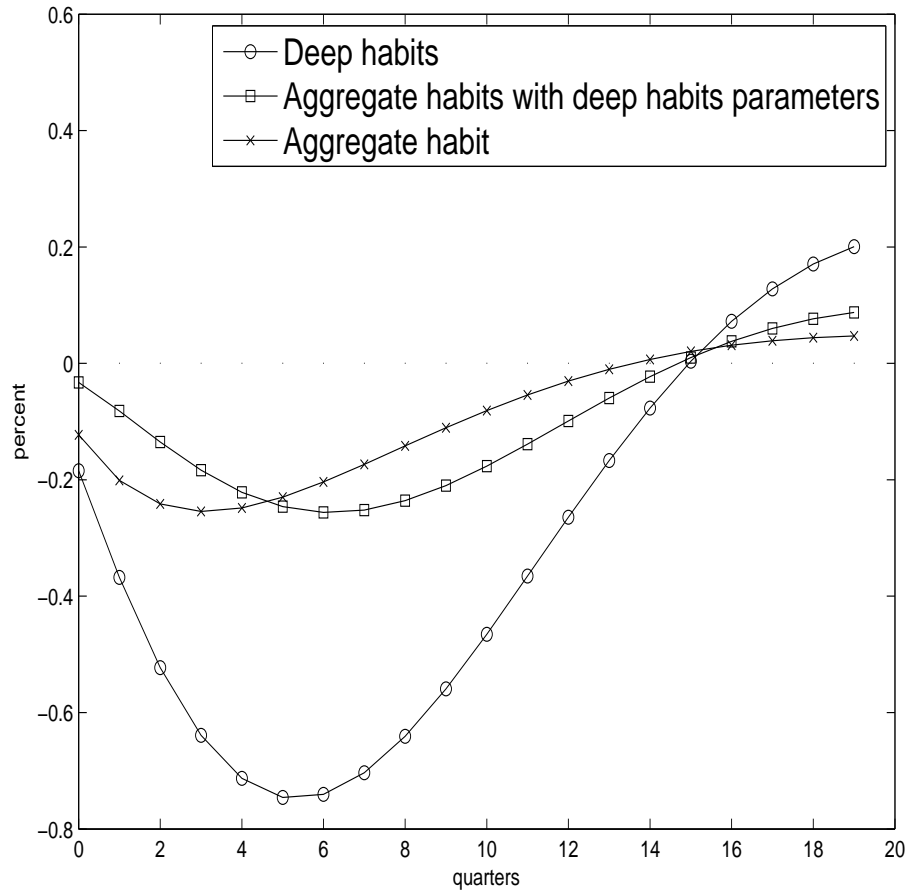


Figure 2.7: Markup Dynamics in Theoretical Economies.

Notes: The figure shows the dynamics of markups after a 1 percent drop in the interest rate in three different economies. The line with circles corresponds to the deep habits economy listed in Table 12., column (1). The line with crosses corresponds to the aggregate habit economy using the parameter values listed in Table 2.1, column (2). The line with boxes corresponds to the aggregate habit economy assuming the parameter values estimated in the deep habits specification listed in Table 2.1, column (1).

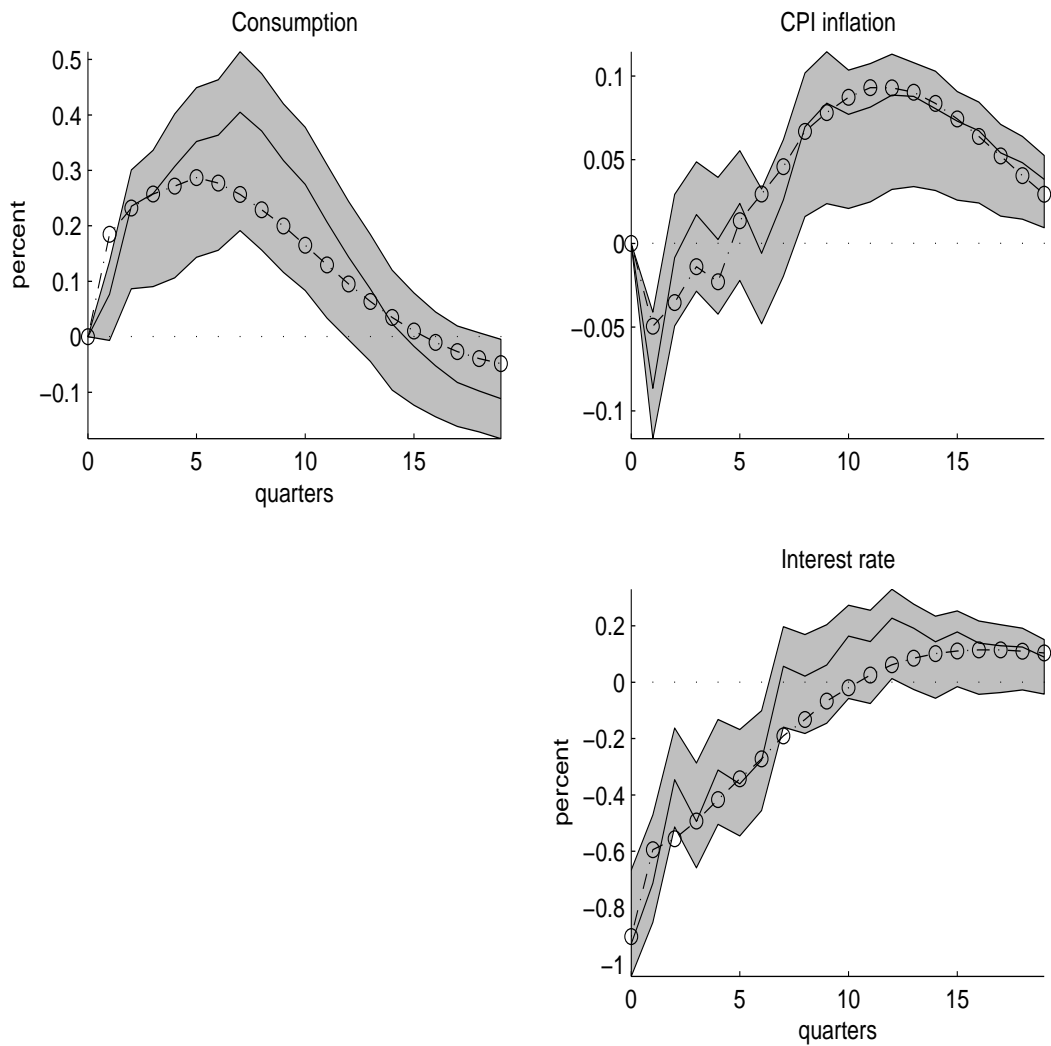


Figure 2.8: The Impact of a Monetary Policy Shock in the Deep Habits Economy with a Constrained Markup.

Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show the VAR-based theoretical impact of a 1 percentage point decrease in the interest rate in the deep habits economy when constraining the steady-state markup.

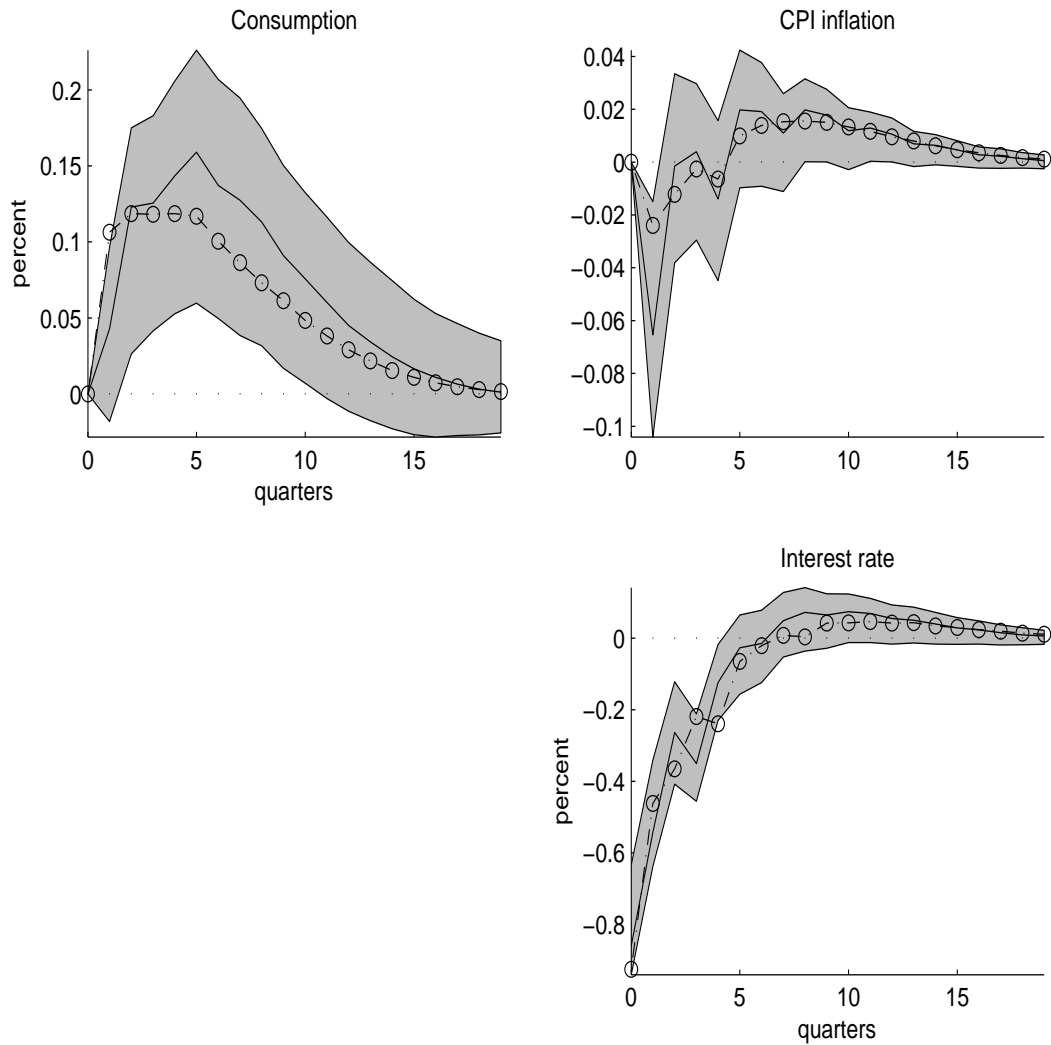


Figure 2.9: The VAR-based Impact of a Monetary Policy Shock in the Deep Habits Economy: Post 1979:2 sample.

Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate when estimated for the post 1979:2 sample. Lines with circles show theoretical impact of a 1 percentage point decrease in the interest rate in the deep habits economy when measured with a VAR filter.

## Chapter 3

# Firm Turnover, Financial Friction and Inflation

Lenno Uusküla<sup>1</sup>

### Abstract

In a standard New-Keynesian DSGE model exogenous price markup and cost-push shocks generate most of the volatility in inflation. The key equation determining inflation is the New Keynesian Phillips curve. Several authors have proposed modifications to the forward looking Phillips curve. In this paper I concentrate on the effects of endogenous markups due to firm turnover and the importance of financial friction. My findings show that entry cost shocks are important in explaining the dynamics of inflation at the business cycle frequency. Financial friction does not change the relative importance of the structural shocks in explaining inflation.

**Keywords:** firm turnover, financial frictions, inflation, DSGE

**JEL codes:** E32, C11, E23

### 3.1 Introduction

In a standard New-Keynesian Dynamic Stochastic General Equilibrium model inflation volatility is mostly explained by the exogenous price markup and cost-push

---

<sup>1</sup>Department of Economics, European University Institute (e-mail: lenno.uuskula@eui.eu). I want to thank Morten O. Ravn and Giancarlo Corsetti for guidance, and Marco del Negro and Ricardo Reis for helpful discussions at early stage of the project.

shocks. For example in Smets and Wouters (1998) exogenous price markup shocks explain more than half of the variance in inflation during first years after the shock. Several authors have proposed modifications to the forward looking New Keynesian Phillips curve which determines inflation. First, the mark-up is not exogenous but depends on the level of competition, which is determined by the number of firms in the economy (see Bergin and Corsetti (2008), Bilbiie et al. (2007)). Second, Ravenna and Walsh (2003) find evidence for a financial friction - firms borrow a share of the wage bill from the banks. I ask what is the role of firm turnover and financial friction in explaining the dynamics of inflation over the business cycle?

I augment a standard medium scale sticky price and sticky wage New Keynesian model such as Smets and Wouters (1998) with two features. First I assume that the creation of firms is labor intensive, a fixed cost to start a business. I allow the death rate of firms to be stochastic. The number of firms is determined by free entry condition and the number of firms determines the level of markup in the economy. The law of motion for the number of firms is based on Bilbiie et al. (2007). Second I allow for a financial friction in the economy. Firms borrow resources from banks to pay for a share of production costs in advance. This way changes in the interest rate have an impact on the costs of production. The financial friction is proposed by Christiano et al. (1997) and recently employed by Rabanal (2006) and Uhlig (2007).

The economy is described by the following 5 structural shocks: monetary policy, labor productivity, wage cost-push shocks, a shock to the fixed cost of starting a business, and a shock to the firm survival probability. I match the model with 5 U.S. data series: consumption, hours, inflation, the interest rate, and the creation of firms for the period 1983Q1-1998Q3. I estimate the parameters of the model with the Bayesian likelihood approach and use the variance decomposition at the business cycle frequency and the forecast error variance decomposition to discuss the main results.

My results show that the shocks to the creation of firms explain 67% of the variance in inflation at the business cycle frequency. The channel between the number of firms and inflation is not trivial. A drop in the cost of entry leads to an increase in the demand in labor and therefore also to an increase in marginal costs and inflation. As more firms are created and the number of firms is increasing the markup effect becomes stronger and inflation drops again. To the knowledge of the author this is the first attempt to quantify the effect of entry cost shocks to the inflation rate in a DSGE framework.

I find that 80% of the production costs are borrowed from the banks. However I

find little evidence that the cost channel is important in explaining the volatility of inflation at the business cycle frequency. The results are in line with the findings of Ravenna and Walsh (2003) who find evidence for the cost channel. But compared to Rabanal (2006) my estimate for the financial friction is relatively high. He also estimates a DSGE model using Bayesian techniques and finds that 15% of the costs are borrowed from the banks. Also Uhlig (2007) calibrates the share of costs borrowed from the banks to 10%. But similarly to these papers I find that the financial friction has little to explain in inflation dynamics.

My results assign very little importance to the wage cost-push shocks. This is in sharp contrast with the findings of Smets and Wouters (1998). Technology shocks explain 17% of the variance in inflation at over the business cycle. This is in accordance with the DSGE and VAR evidence where the role of technology shocks is around 20% (see Smets and Wouters (1998) for the DSGE and Altig et al. (2005) for the VAR literature). Finally, monetary shocks and firm survival shocks explain around 6% of the variance in inflation at the business cycle frequency.

The rest of the paper is organized as follows. Second chapter introduces the model with financial frictions and firm turnover. Third chapter gives a short overview of the data and the estimation approach. Basic results are presented in chapter four and chapter five concludes.

## 3.2 The model

In the first section I present a New Keynesian dynamic stochastic general equilibrium model with financial friction and the creation and destruction of firms. There are five types of agents in the economy: final goods producers, intermediate goods producers, households, banks and a government.

Households maximize their utility from consumption and leisure, firms maximize profits. In the final goods sector, firms operate under full competition and aggregate inputs from the intermediate firms into consumption good. In the intermediate goods production sector firms operate under monopolistic competition structure. The firms are subject to stochastic death shocks and the creation of firms is labor intensive. The number of firms in the intermediate goods sector is determined by the free entry condition.

The economy has a financial sector. It takes deposits from the households and receives monetary injections from the government. Banks give loans to the intermediate firms as the firms are assumed to borrow a share  $\xi$  of their wage bill from the



banks. Finally, monetary policy authority decides about the monetary injections to commercial banks by targeting the interest rate.

### 3.2.1 Household problem

The representative household maximizes discounted lifetime utility from consumption  $c_t$  and dislikes time spent at work  $n_t$ .

$$U_t = E_t \left[ \sum_{t=0}^{\infty} \beta^t \left( \frac{(c_t - \chi c_{t-1})^{1-\frac{1}{\sigma}}}{1 - \frac{1}{\sigma}} - \frac{A}{1 + \frac{1}{\kappa}} n_t^{1+\frac{1}{\kappa}} \right) \right] \quad (3.1)$$

where  $\beta$  is the discount factor,  $\chi$  is the consumption habit parameter,  $\sigma$  is the intertemporal elasticity of substitution,  $\kappa$  is the Frisch elasticity of labor supply,  $A$  is scaling parameter, and  $E_t$  is the conditional expectations operator.

Households need cash at hand to buy a fraction  $\eta$  of the consumption ( $C_t$ ). The cash in advance constraint is  $H_{t,res} + \eta C_t = H_{t-1}$  where  $H_{t,res}$  is the residual cash holding, which in equilibrium equals zero, and  $H_{t-1}$  is cash at hand in period  $t$ . Divide the equation by  $P_t$  to get the real budget constraint

$$h_{t,res} + \eta c_t = \frac{h_{t-1}}{\pi_t^C}, \quad (3.2)$$

where  $c_t = \frac{C_t}{P_t}$ ,  $h_{t,res} = \frac{H_{t,res}}{P_t}$ , and  $h_{t-1} = \frac{H_{t-1}}{P_t}$ .

Households face a sequence of budget constraints. The available funds in period  $t$  consist of the income from working, deposits, bonds, profits, transfers and residual cash.

$$H_t + D_t + q_t B_t + (1 - \eta) C_t = W_t n_t + (1 + i_t) D_{t-1} + B_{t-1} + H_{t,res} + V_t + G_t \quad (3.3)$$

where  $D_t$  is deposit with banks,  $q_t$  is the discount price for the government bonds  $B_t$ ,  $1 + i_t$  is the gross return on deposits made the previous period,  $G_t$  are the government transfers, and  $V_t$  are the profits received from the household's ownership of intermediate goods firms. The money is spent on non-cash consumption, or saved in bonds, and kept in cash or deposits.

In real terms, the equation is given by

$$h_t + d_t + q_t b_t + (1 - \eta) c_t = w_t n_t + (1 + i_t) \frac{d_{t-1}}{\pi_t^C} + \frac{b_{t-1}}{\pi_t^C} + h_{t,res} + v_t + g_t \quad (3.4)$$

where  $d_t = \frac{D_t}{P_t}$ ,  $b_t = \frac{B_t}{P_t}$ ,  $w_t = \frac{W_t}{P_t}$ ,  $g_t = \frac{G_t}{P_t}$ ,  $v_t = \frac{V_t}{P_t}$ , and  $\pi_t^C$  is consumer inflation

defined specifically later.

Labor market is characterized by a sluggish adjustment of the nominal wage.

$$w_t = \left( (1 - \omega)w_{t-1} + \omega\Upsilon w_t^f \right) (1 + u_{t,w}) \quad (3.5)$$

Where  $w_t^f$  is the market clearing wage,  $\Upsilon$  shows bargaining power of households, and  $u_{t,w}$  is the wage cost-push shock following an  $ARMA(1, 1)$ ,  $u_{t,w} = \rho_w u_{t-1,w} + \varepsilon_{t,w}$  and  $\varepsilon_{t,w} = \rho_w^{ma} \varepsilon_{t-1,w} + \epsilon_{t,w}$ .

Households choose consumption, bonds, cash at hand, deposits, and work hours. The Lagrange multiplier on the cash in advance equation is  $\varrho_t$  and budget constraint  $\lambda_t$ . The first order conditions are:

$$\eta \varrho_t = -(1 - \eta)\lambda_t + (c_t - \chi c_{t-1})^{-\frac{1}{\sigma}} - \beta \chi (c_{t+1} - \chi c_t)^{-\frac{1}{\sigma}} \quad (3.6)$$

$$\lambda_t \varrho_t = \beta E_t \left[ \frac{\lambda_{t+1}}{\pi_{t+1}^C} \right] \quad (3.7)$$

$$\lambda_t = \beta E_t \left[ \frac{\varrho_{t+1}}{\pi_{t+1}^C} \right] \quad (3.8)$$

$$\lambda_t = \beta E_t \left[ \lambda_{t+1} \frac{1 + i_{t+1}}{\pi_{t+1}^C} \right] \quad (3.9)$$

$$\lambda_t w_t^f = A n_t^{\frac{1}{\kappa}} \quad (3.10)$$

The optimality condition for the labor-leisure choice gives the market clearing wage  $w_t^f$ .

### 3.2.2 Final good firms

Final good firms maximize profits

$$P_t y_t - \int_0^{N_t} p_{t,j} y_{t,j} dj \quad (3.11)$$

where  $y_t$  is the final output,  $N_t$  is the number of intermediate inputs indexed by  $j$  with prices  $p_{t,j}$  and quantities  $y_{t,j}$ . Firms use a CES aggregator for production

$$y_t = \left( \int_0^{N_t} y_{t,j}^{\frac{1}{1+\mu}} \right)^{1+\mu} \quad (3.12)$$

where  $\mu = \frac{1}{\sigma-1}$  and  $\sigma$  is the intertemporal elasticity of substitution between intermediate goods. After some algebra, the demand for the intermediate inputs is following:

$$y_{t,j} = \left( \frac{P_t}{p_{t,j}} \right)^{\frac{1+\mu}{\mu}} y_t \quad (3.13)$$

where the price index is given by  $P_t = \left( \int_0^{N_t} p_{t,j}^{-\frac{1}{\mu}} \right)^{-\mu}$ . The relative price is given by  $\rho_t = \frac{p_{t,j}}{P_t} = N^\mu$ .

In the equilibrium all firms are the same so  $p_{t,j} = p_t$ . Inflation  $\pi_t = \frac{p_t}{p_{t-1}}$  is described in terms of intermediate goods prices and therefore the consumer inflation index  $\pi_t^C$  is given by  $\frac{\pi_t^C}{\pi_t} = \frac{\rho_t}{\rho_{t-1}} = \left( \frac{N_t}{N_{t-1}} \right)^\mu$ . A rise in the number of firms leads to a drop in the consumer inflation relative to the intermediate goods inflation rate. When  $\mu$  approaches zero, the elasticity of substitution approaches infinity, and the variety effect on consumer inflation disappears.

### 3.2.3 Intermediate good firms

Intermediate sector firms produce goods for the final goods sector. The market structure is monopolistic competition and the number of firms is determined by a free entry condition.

Intermediate firms use a production technology which is linear in labor.

$$y_{t,j} = \gamma_t n_{t,j} \quad (3.14)$$

where  $\gamma_t$  is a productivity shock that is assumed to follow an ARMA process  $\gamma_t = \rho_\gamma \gamma_{t-1} + \varepsilon_{t,\gamma}$  and  $\varepsilon_{t,\gamma} = \rho_\gamma^{ma} \varepsilon_{t-1,\gamma} + \epsilon_{t,\gamma}$ .

Firms have to pay part of the labor input in advance. They borrow funds for this purpose from commercial banks. This gives rise to the loan condition for the representative firm  $L_{t,j} = \xi W_t n_{t,j}$ .

In order to change prices, firms face a price adjustment cost as in Rotemberg (1982) with the cost parameter  $\phi$ . The profits are given by  $V_{t,j} = (p_{t,j} \gamma_t - (1 + \xi i_t) MC_t) n_{t,j} - \frac{P_t \phi}{2} \left( \frac{p_{t,j}}{p_{t-1,j} \pi} - 1 \right)^2$ , and in real terms:

$$v_{t,j} = \left( \frac{p_{t,j}}{P_t} - (1 + \xi i_t) mc_t \right) y_{t,j} - \frac{\phi}{2} \left( \frac{p_{t,j}}{p_{t-1,j} \pi} - 1 \right)^2 \quad (3.15)$$

where the real variables are  $v_{t,j} = \frac{V_{t,j}}{P_t}$ , and  $mc_t = \frac{MC_t}{P_t}$ .

The firm  $j$  chooses labor  $n_{t,j}$  and price  $p_{t,j}$ . The cost minimization problem gives marginal cost net of interest rate payments

$$mc_t = \frac{w_t}{\gamma_t}. \quad (3.16)$$

The net present value of the firm  $NPV$  today is defined as the discounted profits of all future periods. The net present value is defined at the time when production has already taken place, but firms do not yet know if they survive until the next period. In this way the net present value is the same for the incumbents and new firms. In nominal terms the net present value is defined as  $NPV_{t,j} = (1 - \delta)E_t \left[ (1 + u_{t+1,surv}) \frac{\lambda_{t+1}}{\lambda_t} (V_{t+1,j} + NPV_{t+1,j}) \right]$  and in the real terms after dividing with the price level:

$$npv_{t,j} = (1 - \delta)E_t (1 + u_{t+1,surv}) \left[ \frac{\lambda_{t+1}}{\lambda_t} (v_{t+1,j} + npv_{t+1,j}) \right], \quad (3.17)$$

where the  $\frac{\lambda_{t+1}}{\lambda_t}$  is the stochastic discount factor of the consumer,  $\delta$  is the exogenous death probability of the firm, and  $u_{t,surv}$  is the exogenous survival shock of the firm. The shock follows an  $ARMA(1,1)$ ,  $u_{t,surv} = \rho_{surv}u_{t-1,surv} + \varepsilon_{t,surv}$  and  $\varepsilon_{t,surv} = \rho_{surv}^{ma}\varepsilon_{t-1,surv} + \epsilon_{t,surv}$ . Previously Vilmi (2009) has a model with a stochastic rate of firm survival. In this paper I the survival probability is modelled as an exogenous process for the reason of simplicity. However the survival probability could also be modeled as an endogenous factor in the model. In fact Jacobson et al. (2008) show that macroeconomic factors are important for the the firm bankruptcy rates.

In order to enter, firms have to pay a sunk entry cost in labor. The free entry condition is given in real terms:

$$npv_{t,j} = \xi^{ent} \frac{w_t}{\gamma_t} (1 + \xi i_t) (1 + u_{t,ent}), \quad (3.18)$$

where the entry cost shock  $u_{t,ent}$  is ARMA(1,1) process  $u_{t,ent} = \rho_{ent}u_{t-1,ent} + \varepsilon_{t,ent}$  and  $\varepsilon_{t,ent} = \rho_{ent}^{ma}\varepsilon_{t-1,ent} + \epsilon_{t,ent}$

New firms can only produce the following period and a fraction of firms dies at the end of the period, so some of the new firms never produce. The law of motion of the firms is

$$N_t = (1 - \delta)(1 + u_{t,surv})(N_{t-1} + N_{t-1}^E) \quad (3.19)$$

There are two issues writing the number of firms dynamics in this way. First, there is

no guarantee that the number of firms created is not negative. However this problem is addressed by assuming that the variance of the entry shock is small. Secondly, there is nothing that stops from the number of firms to increase between two periods if the positive survival shock exceeds the natural death rate of firms, so that firms can be generated from nothing overnight. The interpretation of it would be that some of the firms split in two but they are not accounted among the entrants.

Because of the price adjustment cost, the model is characterized by a forward looking Phillips curve:

$$\rho_{t,j} = \frac{p_{t,j}}{P_t} = mu_{t,j} mc_t \quad (3.20)$$

where  $\rho_{t,j} = \frac{p_{t,j}}{P_t}$  is the relative price, and the markup ( $mu_{t,j}$ ) is given by following equation

$$mu_{t,j} = \frac{(1 + \mu)}{\mu} \frac{1}{(1 + \xi_{i_t})} \dots \left( -\frac{1}{\mu} - \frac{\phi}{y_{t,j}} \left( \frac{\pi_t}{\pi} - 1 \right) \frac{\pi_t}{\rho_t \pi} + \frac{\phi}{y_{t,j}} (1 - \delta) E_t \left[ (1 + u_{t+1, surv}) \frac{\lambda_{t+1}}{\lambda_t} \left( \frac{\pi_{t+1}}{\pi} - 1 \right) \frac{\pi_{t+1}}{\rho_t \pi} \right] \right)^{-1} \quad (3.21)$$

As this is one the key equation that is changed compared to the standard model, I present here the log-linearized version.

$$\hat{\pi}_t = \frac{y_i}{\phi \mu} \left( -\hat{\rho}_t + \frac{\xi}{1 + \xi_i} \hat{i}_t + \hat{m}c_t \right) + \beta(1 - \delta) \hat{\pi}_{t+1} \quad (3.22)$$

where the variables without time subscript denote their steady-state levels, the variables with hats denote percentage change from the steady state with the exception of inflation and interest rate where it is percentage point change from the steady state, and the firm level subscript  $j$  are dropped as all firms are the same.

The equation states that the inflation rate today depends on the expected inflation and marginal cost as in the standard Phillips curve. However the two new elements, financial frictions and the firm turnover, uncouple marginal cost (the wage rate) from the inflation rate by making markups endogenous. In short, **the financial friction** modifies the effect of marginal cost on inflation. Decreasing marginal cost leads to a drop in inflation. Decreasing inflation reduces the interest rate, and thus the cost of production, magnifying the effect on the inflation rate. Any shock that results in **an increase in the number of firms** pushes down markups and

reduces inflation.

### 3.2.4 Banks

Banks lend money to the intermediate good sector firms, who pay share  $\xi$  of the wages in advance. The funds the banks can use are the deposits from the households  $d_{t-1}$  and central bank money injections  $\psi_t$ . By aggregating get the following condition:

$$\frac{d_{t-1}}{\pi_t^C} + \psi_t = \xi w_t n_t = l_t \quad (3.23)$$

### 3.2.5 The Government and the Central Bank

Central bank uses money injections to the commercial banks

$$m_t = \frac{m_{t-1}}{\pi_t^C} + \nu \psi_t \quad (3.24)$$

where  $\psi_t$  is the money injection and  $\nu$  determines what is the share of money taken out from the economy in the end of the period.

Monetary policy is described by an interest rate rule:

$$i_t = \bar{i} + \rho_i i_{t-1} + (1 - \rho_i) \left[ \zeta_\pi \left( \frac{\pi_t^C}{\bar{\pi}^C} - 1 \right) + \zeta_x \left( \frac{m_t^C}{\bar{m}^C} - 1 \right) + \epsilon_{t,i} \right] \quad (3.25)$$

where  $\epsilon_{t,i}$  is an idiosyncratic shock to the interest rate.

The budget is balanced every period:

$$g_t = (\nu + i_t) \psi_t \quad (3.26)$$

### 3.2.6 Aggregation and market clearing

Money in this model is the sum of cash ad hand and deposits

$$m_t = d_t + h_t \quad (3.27)$$

The hours worked by the household are divided between creating new firms and producing output.

$$n_t = N_t n_{t,j} + N_t^E \frac{\xi^{ent} (1 + u_t^{ent})}{\gamma_t} \quad (3.28)$$

Aggregate profits  $v_t$  include the individual profits of the firm minus the cost of starting new businesses.

$$v_t = N_t v_{t,j} - N_t^E w_t \xi^{ent} (1 + \xi_{i_t}) \frac{(1 + u_t^{ent})}{\gamma_t} \quad (3.29)$$

In the total consumption I take out the effect of the number of firms on the consumption in order to keep the productivity of the economy independent from the number of firms,

$$c_t = N_t^{\iota - (1 + \mu)} y_t, \quad (3.30)$$

where  $\iota = 1$ , so the model departs from the standard Dixit-Stiglitz aggregator. The reason is that I focus on looking at the transmission through the Phillips curve. Without this transformation the increasing number of firms would lead to production technology that is not linear in labor. The issue should be dealt in a separate paper.

### 3.2.7 Equilibrium

The system is described by 33 variables, out of which 28 are endogenous,  $b_t, g_t, c_t, n_{t,j}, n_t, v_{t,j}, v_t, y_{t,j}, y_t, mc_t, d_t, h_t, m_t, l_t, \psi_t, i_t, q_t, w_t, w_t^f, \pi_t, \pi_t^C, NPV_t, N_t, N_t^E, P_{t,j}, P_t, \rho_t$ , and two Lagrange multipliers:  $\varrho_t, \lambda_t$ .

There are 5 exogenous i.i.d shocks:  $\epsilon_{t,\gamma}, \epsilon_{t,w}, \epsilon_{t,ent}, \epsilon_{t,i}, \epsilon_{t,surv}$ . I allow ARMA(1,1) structure for the processes of technology  $\gamma_t$ , labor cost  $u_{t,w}$  and entry costs  $u_{t,ent}$  shocks. The equilibrium is symmetric, in which consumers maximize utility, firms and banks maximize profits, and all markets clear.

## 3.3 Data, Estimation and Priors

I estimate the model using quarterly US data for the sample period 1983Q1-1998Q3. This sample period reflects a compromise between availability of data and institutional features of the U.S. economy. Firm creation data is not available for the period after 1998Q3. In the year 1983 a major change in the bankruptcy law was launched. I use the following 5 series for the US economy:

- consumption - log of real non-durable consumption divided by 16 years and older civilian population, demeaned and detrended,
- hours - log of non-agricultural sector hours worked, divided by 16 years and older civilian population, demeaned and detrended,

- inflation, CPI inflation, demeaned,
- the Federal Funds Rate, demeaned,
- the number of new firms, log of firm creation, demeaned and detrended,

The data is presented in the Figure 3.1. There is a strong positive correlation between hours, consumption and the creation of firms. The inflation rate and the short-term interest rate are also strongly comoving. The contemporaneous correlation between hours and inflation is close to zero for the full sample. Consumption and hours have similar variances. The variance of firm creation clearly exceeds that of the hours.

The firm creation in the model and data are not calculated in the identical way. The model with endogenous entry and exogenous exit is a measure for net entry. However, in the data I prefer to use the number of new firms as a proxy for net entry because of problems with the available quarterly net entry measure. The main difficulty in getting a good series for net entry is to account for the closing firms (for a more detailed discussion see Uuskula (2007)).

Some of the parameters are known to be difficult to estimate, especially because of the short sample period and will instead be calibrated using results from previous studies for quarterly frequency in order to concentrate on the main parameters of interest relating to firm turnover. The calibrated parameters are presented in Table 3.1. The discount rate  $\beta = .99$  is set to match a 4% annual real interest rate. The exogenous rate of firm death is set to  $\delta = 0.025$  in order to match 10.7% annual firm closing rate in the U.S. The number of firms is set to 1 without the loss of generality and I solve for the steady state entry cost. Steady state markup is 25% ( $\mu = .25$ ), which is higher than standard in the data, but lower than often calibrated in the entry literature (Bilbiie et al. (2007) assume steady state markup equal to 36%.) The number of firms and the markup determine the entry cost to satisfy the free entry condition. Steady state inflation is 1.005 to match 2% annual inflation. In solving the model I assume that people work one third of their time  $\hat{n} = \frac{1}{3}$  and I solve for the value of  $A$  that satisfies this constraint.

In addition I calibrate the parameters on consumption habit  $\chi = .7$ . Frisch elasticity of labor supply  $\kappa = 1$ , both often used in the DSGE literature. In addition there are a few parameters for which there was very little information in the current set of observables. The share of cash on hand goods and the share of government money left in the economy in the end of the period are both equal to  $\eta = \nu = 0.5$



and the wage markup equal to 10% ( $\Upsilon = 1.1$ ). Robustness analysis is carried out about the importance of the fixed parameters in the estimation.

I use the Bayesian likelihood approach to estimate the model using the Metropolis-Hastings sampler as described in Canova (2006). All calculations are done in Matlab, the model is log-linearized around the stochastic steady state and solved with the method of undetermined coefficient of Uhlig (1999). The priors of the parameters are selected so that they represent the theoretical restrictions and with very low information content (see Table 3.2). The autoregressive parameters are set to be between 0 and 1 with the mean 0.5 and variance 0.29<sup>2</sup>. For the intertemporal elasticity of substitution and price stickiness I assume normal distributions. For the intertemporal elasticity of substitution I use the mean of 1 and for the Rotemberg price adjustment cost with the mean of 17 and variance equal to 16. The prior value for the price stickiness is taken from Ireland (2001) and adjusted for the value of calibrated markup and units of account in the price adjustment cost.

I take 250000 draws in two chains. The initial values are chosen based on posterior maximization and only the last 50% of the draws are used in calculating the moments of the data to allow for a burn-in period. The convergence is difficult to achieve in some the parameters, such as the ARMA processes of the shocks. The confidence intervals for the impulse responses and variance decompositions are based on 1000 independent non-parametric draws from the posterior.

### 3.4 Results

Before explaining the main results I discuss some of the parameter estimates that are crucial for the dynamics of inflation. The posteriors of the model parameters are presented in Table 3.3.

First, the results show the importance of the financial friction in the model. The parameter estimate for the financial friction - the share of wages paid in advance - is 0.8 with a relatively wide confidence interval. The results support the findings of Ravenna and Walsh (2003) who use single equation approach in the estimation of the cost channel. The share of costs borrowed from the banks is much higher than the estimate of Rabanal (2006). He finds that only a small share (0.15) of costs are borrowed from the banks. Also Uhlig (2007) calibrates the parameter to a low value as 0.1.

Second, the price and wage stickiness parameters are lower compared to the previous estimates. The parameter estimate for the Rotemberg price adjustment

cost is 11. The posterior is much lower than the prior value 17, the transformed value to make price adjustment cost comparable with the paper by Ireland (2001) as discussed in the section on priors. The price stickiness parameter value cannot be directly translated to the Calvo probability of re-setting prices since the Phillips curve contains financial friction and the relative price.

The parameter estimate for the wage flexibility is very close to one (wage rigidity is close to zero), leaving very little importance for the wage stickiness. The parameters for the nominal rigidities are well identified and do not depend very strongly on the prior distribution as previously found by Del Negro and Schorfheide (2008).

Third, the Taylor weight on inflation is around 1.05 and the weight on marginal costs is zero, implying that the central bank is fully inflation targeting. Interest rate smoothing parameter is 0.73 implying sluggishness in the interest rate to react to inflation.

The intertemporal elasticity of substitution is 0.7. The autoregressive parameters of the shocks are strongly different from one with one exception, the autoregressive parameter for the wage cost-push shocks is close to one. This probably reflects the high persistence of the hours series but also difficulties in identifying the ARMA process of the shock. Therefore in the estimated model the wages are persistent because of the persistent wage costs. To all the other shocks wages react immediately. The entry cost shock is also described by an ARMA process. This might indicate some positive externalities in creating firms which are not explicitly modeled. The technology shock is approximately described by an AR process and the survival shock has only some autocorrelation.

In order to answer the question: what explains inflation dynamics, I look at variance decompositions and impulse response functions of the structural shock. The variance decomposition at the business cycle frequency is based on the counterfactual data generated by including one shock at the time. I use the Hodrick-Prescott filter with the smoothing parameter  $\lambda = 1600$  to remove long run trends, calculate variances and the share of the respective variance from the sum of the individual variances of the data that the five shocks produce. The results of the variance decomposition at the business cycle frequency are presented on Table 3.4. I present the forecast error variance decomposition (FEVD) results and the impulse response functions for the period of 20 quarters after the shock together with the 90% confidence intervals. The line in the middle is calculated at the medians of the parameter estimates.

First column of Table 3.4 presents the benchmark results for the importance of

the estimated 5 shocks in explaining the 5 data series that are matched in the estimation at the business cycle frequency. The shocks to the cost of entry explain around 67% of the variance in inflation at the business cycle frequency. The importance of the entry costs shocks in explaining inflation is also confirmed by the forecast error variance decomposition analysis. Figure 3.2 presents the FEVD results for the entry cost shock. Variations in the cost of entry explain more than half of the variance in inflation during first five years after the shock.

The channel through which entry costs influence inflation is not trivial. A drop in the entry cost, which makes creation of firms more efficient brings a hump-shaped increase in the creation of firms and inflation. As it is good time to invest into creating new firms, demand for labor increases (see Figure 3.3). In order to hire more people, firms pay higher wages the workers. The increase in production costs results in inflation. The central bank increases the interest rate, resulting the costs of production to increase even more. As the number of firms is going up only gradually, therefore it takes time before the increase in the creation of firms results in a higher number of firms in the economy. So markup decreases with a relatively long lag. But as the number of firms stays up for a period of time, the markups are low even when the hours worked and the creation of firms have converged back to the initial levels.

In the reaction to the shock the substitution away from consumption into creating new firms has only little effect, but consumption still drops after the initial shock. As the number of firms increases due to increased entry, consumption reaches back its initial level after 3 years. However this channel moderates the reaction of hours and wages, but does not undo the effect.

The firm survival shock explains around 6% of the variance of inflation at the business cycle frequency and 7-8% from the FEVDs (see Figure 3.4). A drop in the stochastic death rate increases the number of firms and lowers inflation. A 1% increase in the number of firms brings inflation down by 0.05pp. at the time of the impact. There are two channels which lead to a drop in inflation. First, higher number of firms decreases the markup in the economy and lowers inflation. Second, an increase in the number of firms lowers the need to create new firms and labor demand drops leads to a drop in wages.

This effect of the number of firms to inflation can be compared the finding of Cecioni (2009). She looks at the effect of change in the number of firms on the inflation rate and concludes that the number of firms is an important factor determining inflation. She finds that a 10% increase in the number of firms brings

inflation down by 1.4 pp. in the medium horizon. My results show that in case of costly creation of firms it is important to separate how the increase in the number of firms is achieved. If there are many new firms created, the increase in the number of firms can be even inflationary in the short run because of the increase in the costs of production.

Variations in the exogenous technology are the second most important shock in explaining inflation. The technology shocks explain around 18% of the variance in inflation at the business cycle frequency. Technology shock explain 15-20% of the volatility in inflation, with the impact increasing in time because of the persistence of the shock. The share of the technology in explaining inflation is higher than the estimates of Smets and Wouters (1998), who find that productivity can explain around 5% of the variance in inflation at all horizons. The estimated importance of the technology shock is much closer to the estimate of Altig et al. (2005) VAR evidence. Their estimated technology shocks explain around 16% of the variance at the business cycle frequency.

Cost-push shocks have little to say about inflation. In the FEVD the median effect reaches 10% five years after the shock (see Figure 3.7) and 2.5% at the business cycle frequency. This stands in contrast with the findings of Smets and Wouters (1998), who's results show that wage markup shocks explain 50% of the inflation 2.5 years after the shock. However similar to Smets and Wouters (1998) my results show that a higher share of variance explained in inflation by the cost-push shocks at lower frequencies.

Monetary shocks have only some effects on the inflation at the very short run (see Figure 3.5). In spite of the low levels of nominal rigidities and the strong cost-channel, inflation drops after a contractionary monetary shock. The small real effects of monetary policy are often found in the full likelihood estimation of the DSGE models. In this paper zero effect on hours is included in the posterior of the impulse responses. These results are consistent with the agnostic identification approach results of Uhlig (2005).

The second column in Table 3.4 presents the variance decomposition for an estimation of the model where the parameter on the financial friction is calibrated very close to zero  $\xi = 0.01$ . The differences for the variance decomposition of inflation are quite small. The share of the variance explained by the entry cost shock is now 68%, up by one percentage point. The survival shock gains some explanatory power, the share of the variance explained increases from 6 to 11%. The increase comes mainly from the technology shocks, which now explain around

13% of the variance. However the financial friction seems to matter for the relative importance of the real variables.

Entry cost and firm survival shocks explain now a much higher share in hours and consumption than before. In particular the financial friction is important in explaining the qualitative effects of monetary shocks that a monetary contraction decreases entry. In the benchmark model a drop in the interest rate leads to an increase in the creation of firms. This result is also supported by the VAR evidence (see for example Bergin and Corsetti (2005), Lewis (2006) or Uuskula (2007)). However in the model where the financial friction is set to zero, the number of firms decreases after an expansionary monetary shock. This is a common finding in the papers without a financial friction such as Bilbiie et al. (2007)). Therefore the financial friction is important for the real variables and has only limited impact on the relative variances of inflation. This result also confirms the finding of Rabanal (2006) that the cost channel is not important for the inflation variance.

In order to understand the properties of the estimated model I have conducted a few robustness checks, mainly for the values of the calibrated parameters. One of the important parameters is the markup in the intermediate goods sector. Cecioni (2009) calibrates the value equal to around 6%, to a much lower value than in this paper. Differently Bilbiie et al. (2007) fix the value of markup at 35.71%, which is much higher compared to my benchmark results. When I fix the price markup to 10%, technology and wage cost-push shocks are less important and the stochastic rate of survival is more important (see the last column in Table 3.4). When markup is equal to 35.71%, wage shocks have smaller and the entry costs shocks bigger role (third column in Table 3.4).

Following Uhlig (2007), I allow the shock to the interest rate  $\epsilon_{t,i}$  to have an AR structure. The results however show that the value of autoregressive parameter is equal to zero. The posterior likelihood and variance decomposition results are not sensitive to the changes in the parameters on the share of cash goods, money left in the economy, and wage markup. A drop in the value of Frisch elasticity of labor supply to a level consistent with the microeconomic evidence (0.2) increases the importance of entry shocks on consumption and inflation and the magnifies the effect of wage cost-push shocks on hours.

### 3.5 Conclusions

In this paper I augment a medium scale sticky wage and sticky price macroeconomic model with financial frictions and firm turnover and estimate it for the U.S. economy. My results show that the shocks to the cost of entry are important in explaining the variance of inflation over the business cycle. When creating firms is labor intensive, then a drop in the cost of entry leads to increase in the labor demand as many new firms are created. Increase labor demand results in higher marginal costs and inflation. As number of firms increases markups decrease and inflation starts to decrease. In this model financial frictions play only a minor role in explaining the dynamics of inflation.

# Bibliography

- Altig, D., Christiano, L. J., Eichenbaum, M., and Linde, J. (2005). Firm-specific capital, nominal rigidities and the business cycle. *NBER working paper*, (11034):59.
- Bergin, P. and Corsetti, G. (2005). Towards a theory of firm entry and stabilization policy. *NBER working paper*, (11821):37.
- Bergin, P. and Corsetti, G. (2008). The extensive margin and monetary policy. *Journal of Monetary Economics*, 55(7):1222–1237.
- Bilbiie, F. O., Gihoni, F., and Melitz, M. J. (2007). *NBER Macroeconomics Annual 2007*, chapter Monetary Policy and Business Cycles with Endogenous Product Variety.
- Canova, F. (2006). *Methods for Applied Macroeconomic Research*. Princeton University Press.
- Cecioni, M. (2009). Firm entry, competitive pressures and the u.s. inflation dynamics. *mimeo*, page 37.
- Christiano, L. J., Eichenbaum, M., and Evans, C. L. (1997). Sticky price and limited participation models of money: A comparison. *European Economic Review*, 41(6):1201–1249.
- Del Negro, M. and Schorfheide, F. (2008). Forming priors for dsge models (and how it affects the assessment of nominal rigidities). *Journal of Monetary Economics*, 55(7):1191–1208.
- Ireland, P. N. (2001). Sticky-price models of the business cycle: Specification and stability. *Journal of Monetary Economics*, 47:3–18.
- Jacobson, T., Kindell, R., Lindé, J., and Roszbach, K. F. (2008). Firm default and aggregate fluctuations. *CEPR working paper*, (7083).

- Lewis, V. (2006). Macroeconomic fluctuations and firm entry: theory and evidence. *National Bank of Belgium, Working paper research*, (103):33.
- Rabanal, P. (2006). Does inflation increase after a monetary policy tightening? answers based on an estimated dsge model. *Journal of Economic Dynamics and Control*, 31:906–937.
- Ravenna, F. and Walsh, C. E. (2003). The cost channel in a new keynesian model: Evidence and implications. *mimeo*, page 29.
- Rotemberg, J. (1982). Monopolsitic price adjustment and aggregate output. *Review of Economic studies*, 49:517–531.
- Smets, F. and Wouters, R. (1998). Shocks and frictions in u.s. business cycles. a bayesian dsge approach. *NBER working paper*, (6632).
- Uhlig, H. (1999). *Cumputational Methods for the Study of Dynamic Exonomies*, chapter A Toolkit for Analyzing Nonlinear Dynamic Stochastic Models Easily, pages 30–61. Oxford University Press.
- Uhlig, H. (2005). What are the effects of monetary policy on output? results from an agnostic identification procedure. *Journal of Monetary Economics*, 52(2):381–419.
- Uhlig, H. (2007). *International Dimensions of Monetary Policy (National Bureau of Economic Research Conference Report)*, chapter Monetary Policy in Europe vs. the US: What Explains the Difference?, pages 489 – 533. NBER, Inc.
- Uuskula, L. (2007). Limited participation or sticky prices? new evidence from the firm entry and failures. *mimeo*, EUI.
- Vilmi, L. (2009). The effects of firm entry and exit in macroeconomic fluctuations and monetary policy. *University of Oulu Department of Economics Working Papers*, (0904):30.



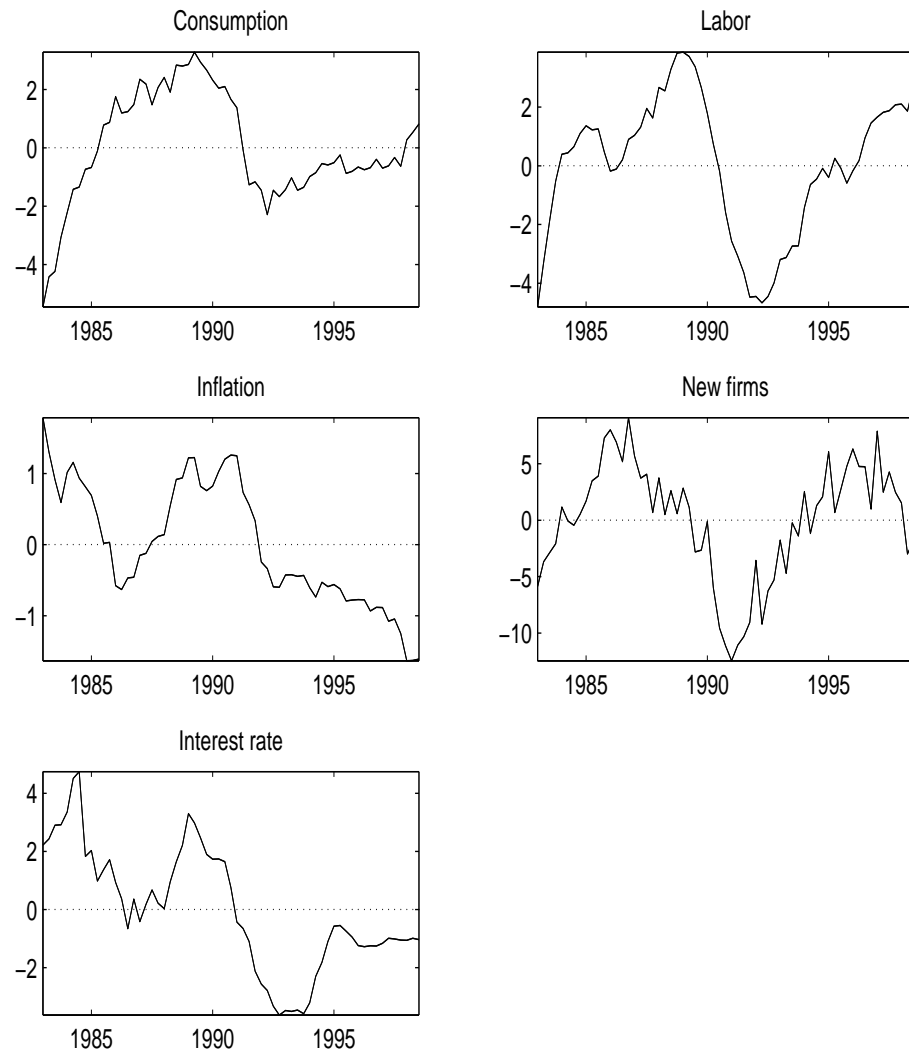


Figure 3.1: Data used in the estimation

Table 3.1: Calibrated parameters

Name	Value	Notes
$\beta$	0.99	Discount factor, yearly interest rate of 4%
$\pi$	1.005	Steady state inflation, yearly 2%
$\delta$	0.025	Share of firms closed each period, 10% per year
$N$	1	Number of firms, normalization
$\xi^{ent}$		Implied by the model, given $N=1$
$A$		Matching $\bar{n} = \frac{1}{3}$
$\mu$	0.25	Mark-up
$\chi$	0.7	Consumption habit
$\kappa$	1	Frisch elast. of labor supply
$\Upsilon$	1.1	Wage markup
$\nu$	0.5	Share of money left in the economy
$\eta$	0.5	Share of cash on hand goods

Table 3.2: Prior distribution of the estimated parameters

Parameter	Distribution	Mean	Std. dev	Notes
$\phi$	normal	17	16	Price stickiness
$\sigma$	normal	1	0.29	Intertemporal elast. of subst.
$\xi$	beta	0.5	0.29 <sup>2</sup>	Share of wages paid in advance
$\omega$	beta	0.5	0.29 <sup>2</sup>	Weight on target wage
$\zeta_x$	beta	0.5	0.29 <sup>2</sup>	Taylor weight on marginal cost
$\zeta_{\pi-1}$	beta	0.5	0.29 <sup>2</sup>	Taylor weight on inflation
$\rho_{iL}$	beta	0.5	0.29 <sup>2</sup>	Interest rate smoothing
$\rho_w$	beta	0.5	0.29 <sup>2</sup>	AR of labor supply shock
$\rho_w^{ma}$	beta	0.5	0.29 <sup>2</sup>	MA of labor supply shock
$\rho_{ent}$	beta	0.5	0.29 <sup>2</sup>	AR of entry cost shock
$\rho_{ent}^{ma}$	beta	0.5	0.29 <sup>2</sup>	MA of entry cost shock
$\rho_{\gamma L}$	beta	0.5	0.29 <sup>2</sup>	AR of technology shock
$\rho_{surv}$	beta	0.5	0.29 <sup>2</sup>	AR of survival shock
$\sigma_i$	inv. gamma	0.1	$\infty$	Std.dev. of mon.pol shock
$\sigma_{ent}$	inv. gamma	0.1	$\infty$	Std.dev. of entry cost shock
$\sigma_{surv}$	inv. gamma	0.1	$\infty$	Std.dev. of survival shock
$\sigma_w$	inv. gamma	0.1	$\infty$	Std.dev. of labor supply shock
$\sigma_{\gamma}$	inv. gamma	0.1	$\infty$	Std.dev. of tech shock

Table 3.3: Posterior distribution of the estimated parameters

Parameter	Prior	Posterior moments			
	Mean	Mean	Median	5%	95%
$\phi$	17	11.11	10.97	7.45	15.24
$\sigma$	1	0.73	0.69	0.64	0.84
$\xi$	0.5	0.81	0.83	0.59	0.98
$\omega$	0.5	0.98	0.98	0.95	1.00
$\zeta_x$	0.5	0.00	0.00	0.00	0.00
$\zeta_\pi - 1$	0.5	0.05	0.05	0.03	0.08
$\rho_{iL}$	0.5	0.73	0.73	0.70	0.77
$\rho_w$	0.5	1.00	1.00	0.99	1.00
$\rho_w^{ma}$	0.5	0.09	0.06	0.04	0.17
$\rho_{ent}$	0.5	0.62	0.57	0.44	0.90
$\rho_{ent}^{ma}$	0.5	0.86	0.91	0.64	0.95
$\rho_{\gamma L}$	0.5	0.94	0.95	0.90	0.98
$\rho_{surv}$	0.5	0.13	0.12	0.10	0.18
$\sigma_i$	0.1	0.84	0.85	0.71	0.95
$\sigma_{ent}$	0.1	1.03	0.99	0.89	1.24
$\sigma_{surv}$	0.1	1.83	1.82	1.58	2.06
$\sigma_w$	0.1	1.68	1.64	1.53	1.97
$\sigma_\gamma$	0.1	0.60	0.61	0.52	0.67

Table 3.4: In sample variance decompositions

	Benchmark	No fin frict	markup 0.3571	Markup 0.1
Entry				
consumption	14.28	14.57	14.1	8.64
hours	24.19	46.71	37.89	27.45
inflaton	67.46	68.50	70.25	68.56
entry	37.40	50.66	44.98	36.84
interest rate	49.46	54.71	49.03	67.82
Survival				
consumption	26.16	46.50	38.42	42.90
hours	2.39	8.98	3.46	17.28
inflaton	6.10	10.81	5.26	24.78
entry	9.04	17.98	9.71	45.04
interest rate	4.32	9.50	4.05	24.73
Wage cost				
consumption	48.00	28.16	33.96	33.26
hours	63.46	40.38	50.61	49.31
inflaton	2.58	2.25	1.15	1.02
entry	21.18	11.52	15.03	10.07
interest rate	2.12	1.76	0.85	0.97
Technology				
consumption	11.02	10.30	13.07	11.96
hours	9.92	3.67	7.93	5.78
inflaton	17.82	13.07	17.11	1.82
entry	32.22	19.82	30.25	6.77
interest rate	14.35	10.71	13.04	1.60
Monetary				
consumption	0.54	0.47	0.46	3.23
hours	0.04	0.25	0.12	0.18
inflaton	6.04	5.37	6.22	3.83
entry	0.16	0.03	0.03	1.28
interest rate	29.74	23.31	33.02	4.88

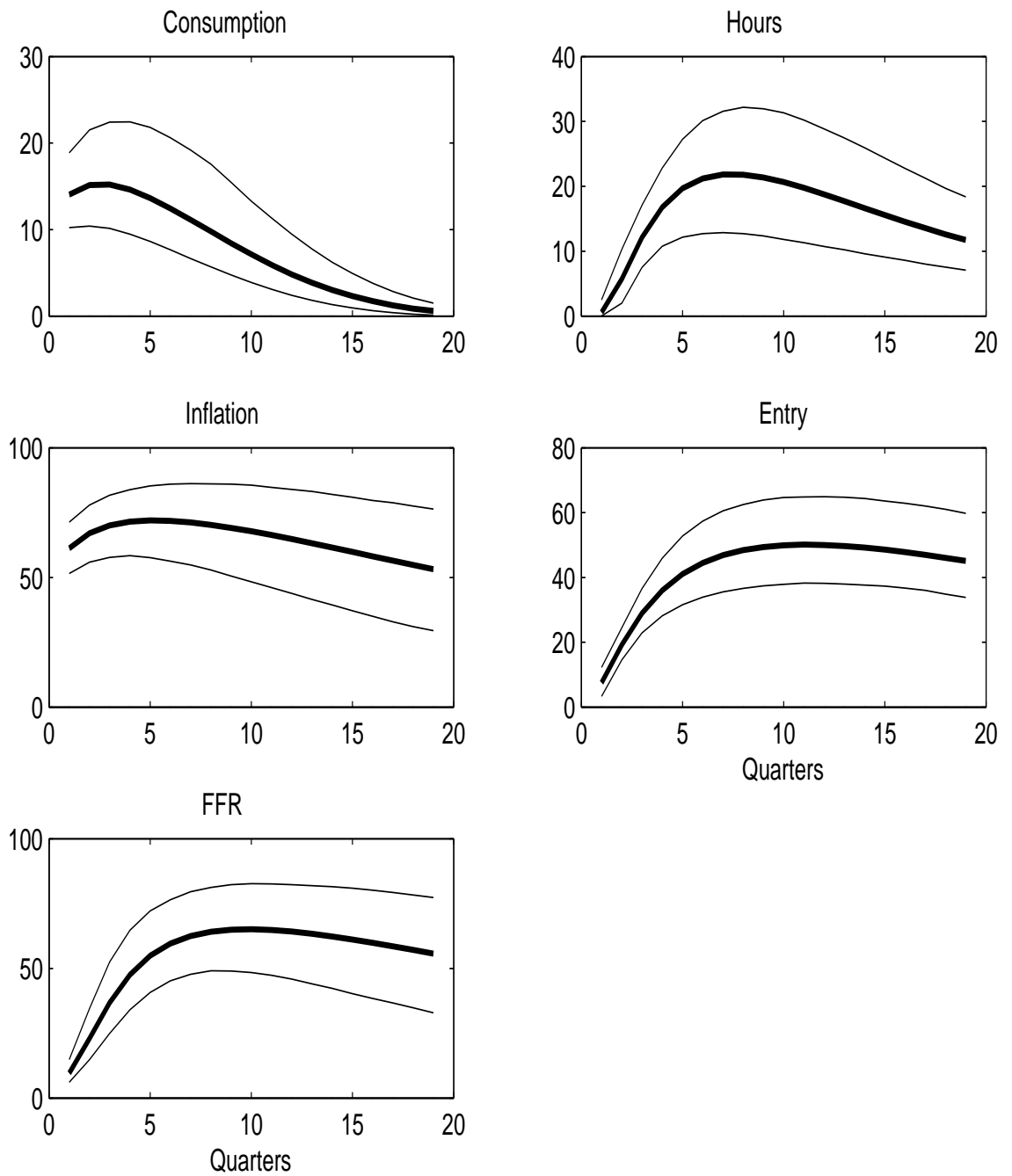


Figure 3.2: Forecast error variance decomposition, Entry cost shock

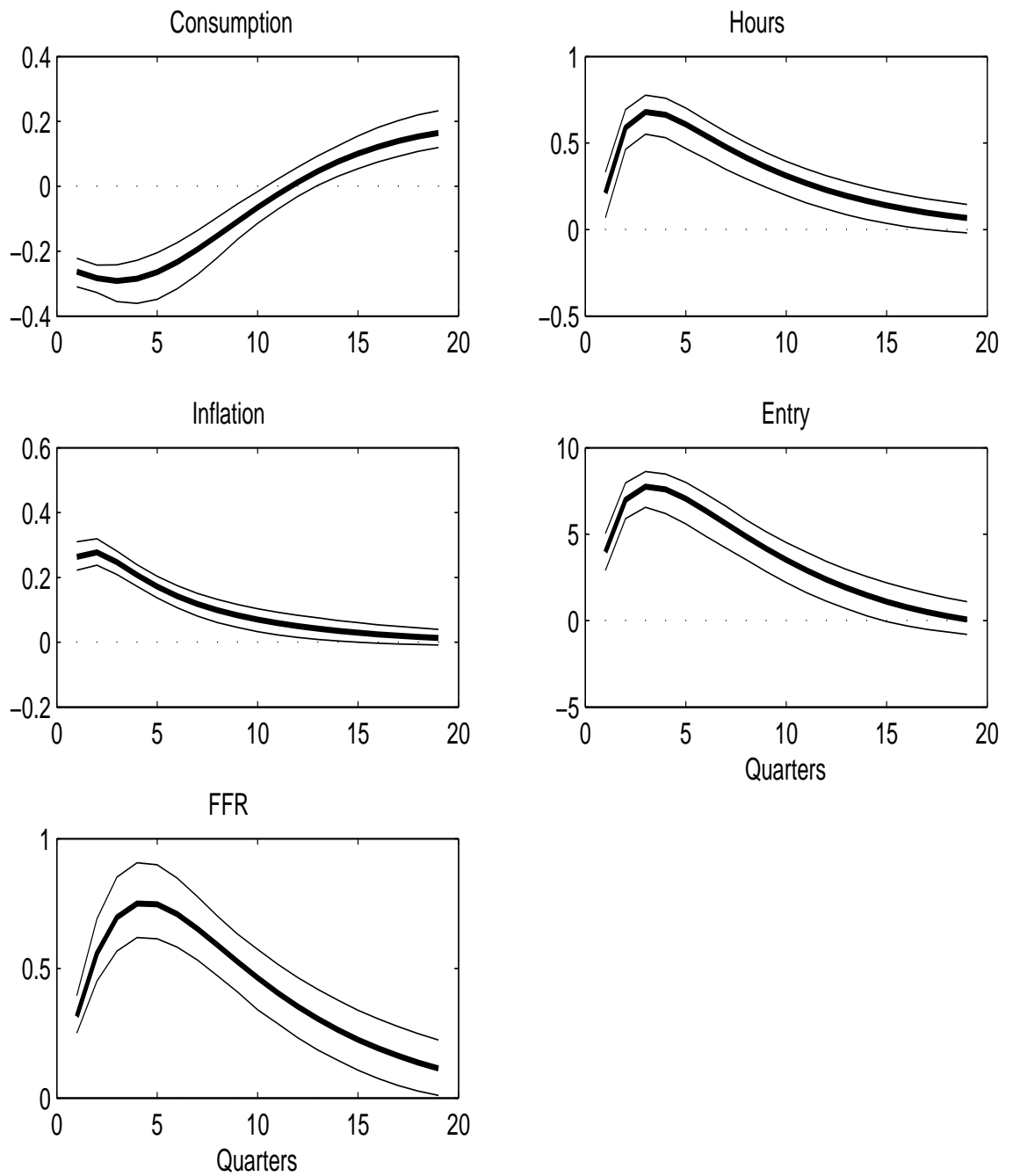


Figure 3.3: Impulse response functions, Entry cost shock

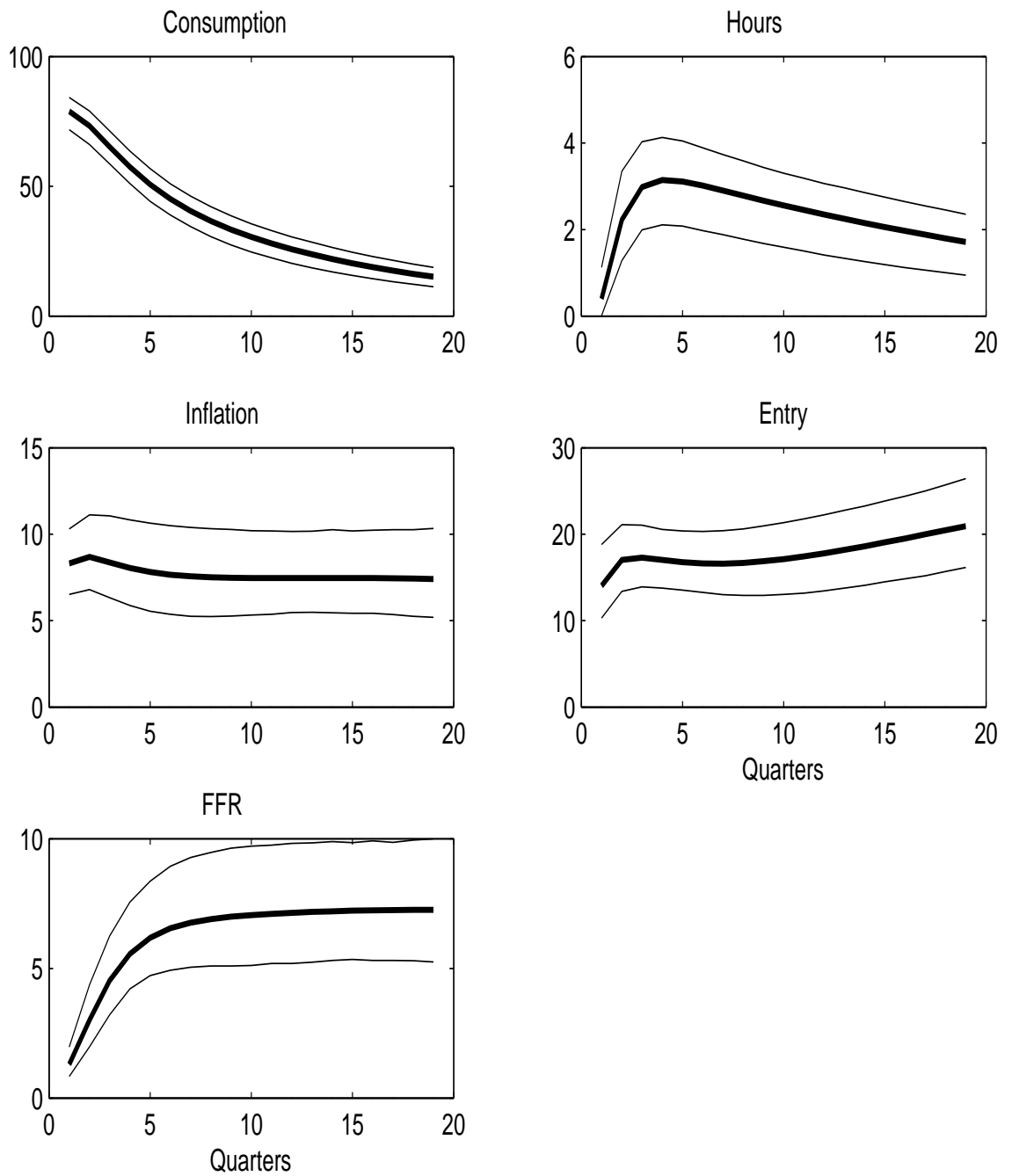


Figure 3.4: Forecast error variance decomposition, Firm survival shock

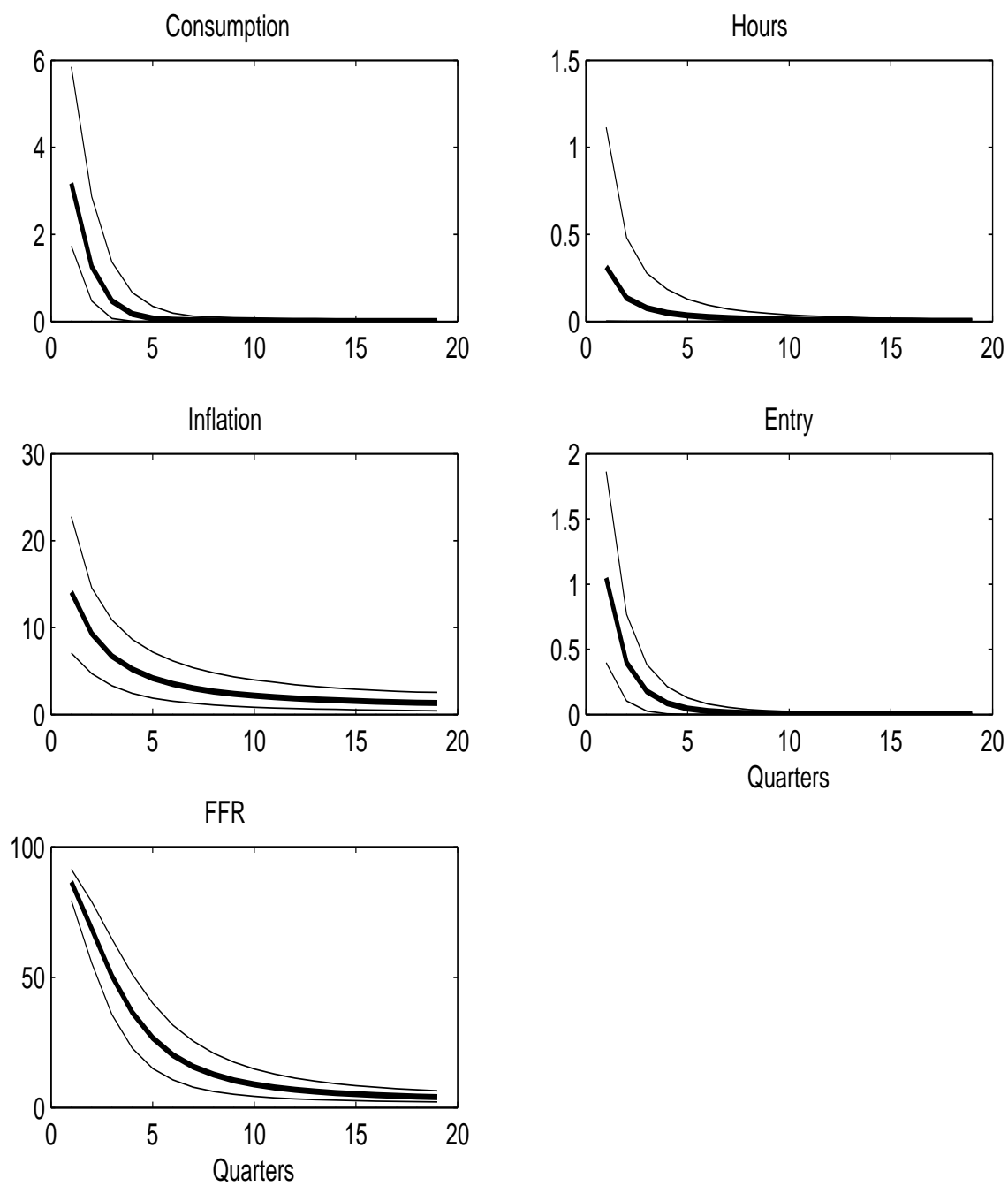


Figure 3.5: Forecast error variance decomposition, Monetary shock



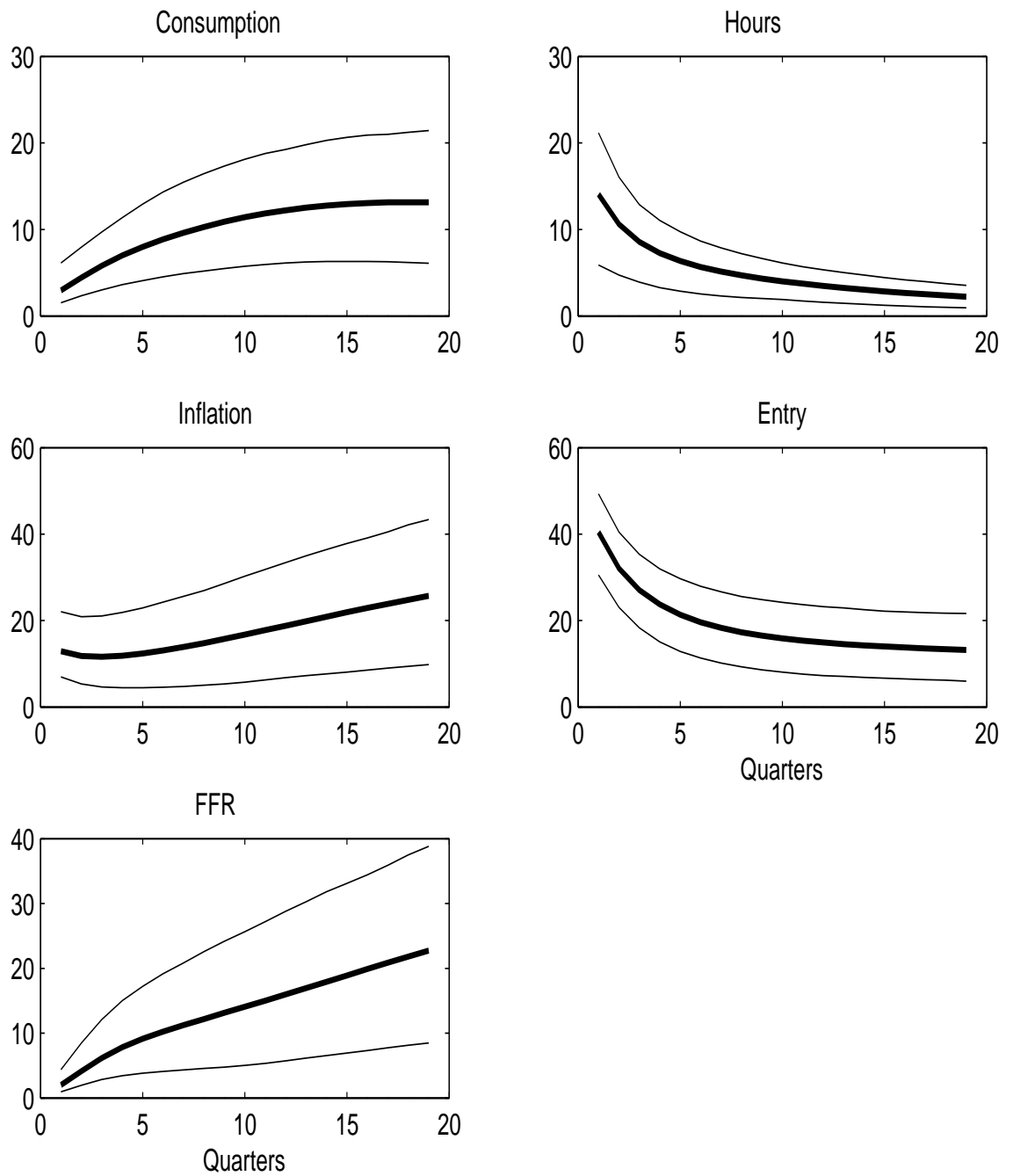


Figure 3.6: Forecast error variance decomposition, Technology shock

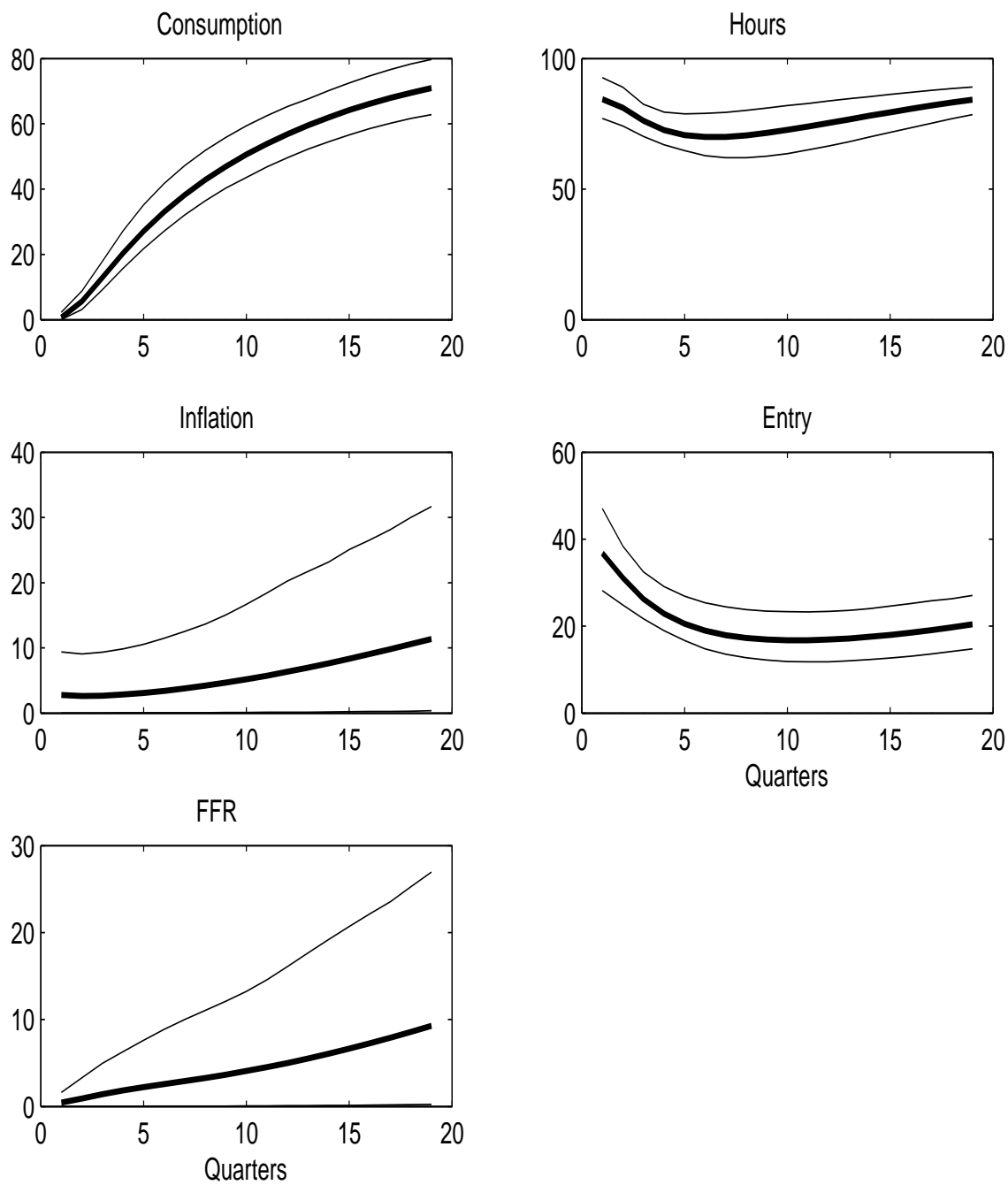


Figure 3.7: Forecast error variance decomposition, Wage cost-push shock