ESSAYS ON FORWARD GUIDANCE

A Ph.D. Dissertation

by
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Ankara
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To my parents and sister

ESSAYS ON FORWARD GUIDANCE

Graduate School of Economics and Social Sciences
of
İhsan Doğramacı Bilkent University

by

YILDIZ AKKAYA

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of
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MAY 2014

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy in Economics.

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ABSTRACT

ESSAYS ON FORWARD GUIDANCE

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May 2014

This dissertation consists of three essays on forward guidance, central bank verbal guidance on future policy rates, and shows how economies respond to it both theoretically and empirically.

In the first essay the effects of forward guidance on real economy through interest rate uncertainty is studied as explicit numerical guidance lowers the uncertainty around future interest rates. To analyze the effects of such a policy a New Keynesian model framework incorporating interest rate uncertainty is developed. The results show that a decrease in the uncertainty of interest rates is expansionary in its own right, independent of the level of interest rates the central bank commits to. Thus, distinct from the literature, a new channel for the effectiveness of forward guidance is suggested.

The second essay studies the question of whether the optimal amount of interest rate uncertainty is always zero, or whether monetary policy makers may benefit from an increase in the uncertainty. For this purpose a two-country open economy New Keynesian model with interest rate uncertainty is developed, and the effects of interest rate uncertainty on capital flows and exchange rates are studied. The results emphasize that the impact of an increase in the volatility of interest rate mimics the impacts of an increase in the level of the interest rate, and this suggests that uncertainty about the policy rate path can be used by the central bank as a policy tool.

The third essay is empirical, and analyses the sensitivity of the interest rates of various maturities to monetary policy uncertainty, which depends on the language used in the monetary policy statements. To measure market responses to the announcements, I first calculate monetary policy surprises and uncertainty surprises by using Federal Funds Futures and Eurodollar Options, respectively. In the event-study analysis it is shown that the reduction in the variability of monetary policy rate expectations due to the explicit content of the statements, has significant effect on the long-term treasury notes.

Keywords: Forward Guidance, Monetary Policy, Volatility Shocks, New Keynesian Models, Monetary Policy Surprises, Event Study Methodology.

ÖZET

SÖZLE YÖNLENDİRME ÜZERİNE MAKALELER

AKKAYA, Yıldız

Doktora, İktisat Bölümü

Tez Yöneticisi: Doç. Dr. Refet Soykan Gürkaynak

Mayıs 2014

Bu çalışma merkez bankalarının faiz beklentilerini açıklamalarıyla şekillendirdikleri sözle yönlendirme politikasının, ve ekonomilerin buna verdiği tepkilerin teorik ve ampirik olarak incelendiği üç makaleden oluşmaktadır.

Birinci makalede sözle yönlendirmenin beklenen faiz oranı belirsizliğine etkisi kanalıyla real ekonomiye etkileri çalışımıştır. Sözlü yönlendirme, beklenen faiz oranı belirsizliğini azalttır. Bu politikanın etkilerini analiz etmek için beklenen faiz oranı belirsizliğini bünyesinde barındıran bir Yeni Keynesyen model geliştirilmiştir. Analiz sonuçları beklenen faiz oranı belirsizliğindeki azalmanın, merkez bankasının hangi faiz oranını taahhüt ettiğinden bağımsız olarak genişleyici bir politika aracı olduğunu göstermektedir. Böylelikle literatürden farklı olarak, sözlü yönlendirmenin etkili olduğu başka bir kanal önerilmiştir.

İkinci makalede optimal beklenen faiz oranı belirsizliğinin sıfır olup olmadığı ya da para politikası yapıcılarının belirsizlik artışından fayda sağlayıp sağlayamayacakları sorularına çalışılmıştır. Bu amaçla beklenen faiz oranı belirsizliğini içeren iki ülkeli bir açık ekonomi Yeni Keynesyen model geliştirilmiş ve faiz oranı belirsizliğindeki artışın sermaye akımları ve döviz kuru üzerindeki etkilerine bakılmıştır. Sonuçlar, beklenen faiz oranı belirsizliğindeki artışın, faiz oranı artışıyla aynı etkileri yarattığını göstermektedir ve bu sonuç da, beklenen faiz oranı belirsizliğinin merkez bankalarınca ayrı bir politika aracı olarak kullanılabileceğini önermektedir.

Üçüncü makale uygulamalıdır ve değişik vadelerdeki faiz oranlarının para politikası duyurularında kullanılan üsluba nasıl tepki verdiği incelenmiştir. Piyasaların duyurulara nasıl tepki verdiğini ölçmek için öncelikle para politikası sürprizi ve belirsizlik sürprizi faktörleri sırasıyla Federal Faiz Futures ve Eurodollar opsiyon kontratları kullanılarak hesaplanmıştır. Yapılan vaka çalışması analizinde beklenen faiz belirsizliğini azaltan merkez bankası duyurularının uzun vadeli faiz oranlarında belirgin bir etkisinin olduğu tespit edilmiştir.
Anahtar Kelimeler: Sözle Yönlendirme, Para Politikası, Belirsizlik Şokları, Yeni Keynesyen Modeller, Para Politikası Sürprizleri, Vaka Çalışması Methodu

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

In recent years, policy makers have increasingly utilized forward guidance, or the signaling of the future path of monetary policy, as an important ingredient of their monetary policy mix. Given that central banks at times, such as now, provide explicit numerical guidance and reduce the uncertainty around the policy rate, and at other times be vague about the path of the interest rates, a scholarly study of the effects of changing monetary policy uncertainty is warranted. This thesis aims to provide an analytical understanding of the effects of changing interest rate volatility via forward guidance.

The first essay of the thesis (Chapter 2) studies the effects of changing the uncertainty of the interest rate path on the real economy in a closed economy dynamic New Keynesian model, since it provides a micro founded and trackable framework. In the model, the monetary authority follows a policy rule á la Taylor (Taylor, 1993), and the uncertainty of the interest rate is modeled as an exogenous increase in the volatility of the monetary policy shock. Since the object of interest is implications of a volatility change in the interest rate shock, I use a third order perturbation methodology following Fernandez-Villaverde et al. (2011) by utilizing the PerturbationAIM algorithm developed by Swanson et al. (2006).

Whether and why forward guidance may be an effective policy tool in stimulating demand has been a hot topic of research. The theory on forward guidance has been almost exclusively focusing on the decrease in expected future short rates that this policy engineers (Swanson (2011), Williams and Swanson (2012), Greenwood and Vayanos (2010)). This paper argues that, by its very nature, forward guidance also lowers the uncertainty around future interest rates, and shows that such a decrease in the uncertainty of interest rates is expansionary in its own right, independent of the level of interest rates the central bank commits to.

While volatility shocks have became a new and growing part of the literature since Bloom (2009), these shocks have almost exclusively been shocks to the volatility of total factor productivity, which are seen as exogenous, or in rare studies to fiscal policy, in which case uncertainty increases are an unintentional side effect of fiscal policy. Fernandez-Villaverde et al. (2013) use a New Keynesian model to show that uncertainty is extremely damaging especially if interest rates are constrained at zero. Furthermore, Liu and Leduc (2013) show that due to staggered price adjustments, uncertainty shocks can both reduce consumption and investment at the same time. In the empirical literature, on the other hand, a one standard deviation increase in the macroeconomic volatility is shown to have a 0.5% contractionary effect on annual growth (Engle and Rangel (2008)) through lower consumer spending (Romer (1990)), investment (Bloom (2009)), and finally trade (Handley and Limao

(2012)) channels. The theoretical line of the literature on uncertainty focuses mostly on the effects of an increase in the economic uncertainty and analyzes its results.

The recent literature offers a number of empirical studies of how changes in the interest rate shock volatility affects economic performance, however, there is little work done on the transmission of volatility shocks in a general equilibrium setting. Some of the empirical studies are Chen and Scott (2004), Hadzi-Vaskov and Kool (2006), Edwards (1998). Basu and Bundick (2012) analyze the effects of increased uncertainty of future preferences and technology on output, comparing the dynamics under flexible and sticky price equilibria. The main difference between the previous volatility studies and my work is the source of the volatility.

The main findings of the essay are as follows. First, I show that the impact of a change in the volatility of interest rate mimics the impacts of a change in the level of the interest rate. For instance, in the model, once the nominal interest rate level is kept constant, if we shrunk the estimated monetary policy uncertainty for the pre-crisis period by Ireland (2004) (40 basis points) to zero, it leads to a 70 basis points increase of GDP. Thus, using the volatility of interest rate as a policy tool when the interest rate itself is bound by the zero lower bound constraint, has quantitatively important effects that are similar to interest rate reductions, and this enables the monetary policy authority to carry out further expansionary policy. This is the sense in which uncertainty of the policy rate path can be used by the central bank as a policy tool.

In the second essay of this thesis (Chapter 3), the effects of interest rate uncertainty on capital flows and exchanges rate are analyzed. Since the onset of the financial crisis, the leading central banks, such as Federal Reserve, and Bank of England, started to utilize explicit numerical guidance and quantitative easing type of policies. The excess liquidity mostly flows to the emerging market economies where the interest rate is high, and is feared to create a risk for financial stability. Thus, emerging market central banks' begin to develop unconventional tools as well. Central Bank of the Republic of Turkey (CBRT) started to use time varying volatility explicitly in 2010 by adding information about the policy rate volatility it will *create* to its policy statements. The aim was to increase risk and reduce the Sharpe ratio to hinder capital inflows. Observationally the policy succeeded in reducing short term capital flows but we have no understanding of what such policies do to the domestic economy. This paper aims at filling this gap in the literature.

To fulfill this aim, in the second chapter, I use a dynamic two-country New Keynesian model with incomplete international asset markets, and nominal price rigidities, where we can look into the effects of uncertainty about interest rate path on capital flows and exchange rate. In the model, the monetary authority, as in the first chapter, follows a policy rule á la Taylor (1993), where the interest rate is subject to time varying policy shocks.

There is a growing literature on analyzing the effects of increases in financial and macroeconomic uncertainty on the open economy dynamics. Most of the papers focus on the effects and the transmission mechanism of exchange rate volatility on the real economy. For instance, Benigno et al. (2011) have examined how the exogenous increases in the volatility of nominal and real exchange rates play role in understanding the regularities in international finance. For this purpose, they use an open economy VAR, and show that once the nominal volatility increases the exchange rate appreciates, and volatility shocks are important for the equilibrium levels of exchange and interest rates.

The main findings of this chapter are as follows. First, the impacts of a change in the volatility of interest rate in the open-economy setting also mimics the impacts of a change in the interest rate level. Second, the model shows that an increase in the volatility of the interest rate shock distorts capital flows, and leads to an appreciation in the exchange rate while reducing the output. Changing uncertainty about future policy path is shown to have quantitatively important implications, and monetary policy makers should also consider using this channel while conducting monetary policy.

The findings of the preceding chapters show theoretically that the uncertainty about expected policy path created by forward guidance has significant effects on the model dynamics. By taking an empirical turn, in the third essay (Chapter 4), I compute the sensitivity of the interest rates of various maturities to policy rate uncertainty implied by the language used in the monetary policy statements. To measure these effects, in the first part of this chapter, by following the earlier literature on event studies such as Cook and Hahn (1989), Kuttner (2001), Rigobon and Sack (2004), and Soderstrom and Ellingsen (2004), the one-factor analysis of monetary policy announcements on asset prices for the period from January 2007 through October 2013 is studied. Here, only the effects of monetary policy surprises are taken into consideration, and it is shown that unanticipated federal funds target change have significant effects on short-term assets, however, this effect disappears as the maturity increases.

In the second part of the analysis, building on the work of Gürkaynak et al. (2005), the FOMC announcements are divided into two parts; first part of the announcement, called the target factor, communicates the changes in the current federal funds target rate, and the second part, called the path factor, moves the expected future rates without chaining the current policy rate. While target factor acts more like the monetary policy surprise component in the first part of the paper, the path factor has significant effect on the long-term asset yields. This finding shows that the market participants rely on the FOMC statements about future stance of monetary policy for the purpose of long-term bond pricing in the a sample from January 2007 through October 2013.

Finally, in the third part of the chapter, by using the change in the Eurodollar options implied volatility around the time of the announcements I calculate an uncertainty surprise component, and add this to the event study analysis with path and target factors. The results suggest that the information added to the announcements play a crucial role on stock market index and bond yields through their effects on uncertainty of market participants' expectations, even if on average the expected policy rate remains the same. These findings are also in line with the theoretical model predictions of the previous two chapters. This chapter complements the theoretical work presented in this thesis by stating that the uncertainty about future monetary policy is an instrument itself and especially at times when the policy maker cannot use the policy rate effectively, it can be used as an unconventional monetary policy instrument.

Overall the contribution of this thesis is; first, it adds to the theoretical literature on time-varying volatility in both closed and open economy settings and complements the literature by offering a mechanism through which time-varying volatility has first order impacts. Second, it contributes to the literature where the effects of monetary policy on asset markets are studied by introducing a new factor to the event-study, and by extending the existing analyses for the up-to-date data. Third and most importantly, it proposes a different channel for the effectiveness of forward guidance.

The results suggest that forward guidance is effective not only because the monetary policy maker promise to keep the interest rate at low levels, but also because it reduces the variability of the expected federal funds rate and this itself has expansionary effects.

CHAPTER 2

UNCERTAINTY OF INTEREST RATE PATH AS A MONETARY POLICY INSTRUMENT

Central banks use forward guidance to affect the long term interest rates and stimulate the economy. Given that central banks at times, such as now, provide explicit numerical guidance and reduce the uncertainty around the policy rate, and at other times be vague about the path of the interest rates, a scholarly study of the effects of changing monetary policy variance is needed. This paper aims at providing an analytical understanding of the effects of changing policy interest rate volatility.

Many leading central banks have been offering guidance about the likely future path of the policy, especially during the recent crisis. For instance, in the FOMC meeting statement on December 2008, it is said that "The Federal Open Market Committee decided today to keep its target range for the federal funds rate at 0 to 1/4 percent. The Committee continues to anticipate that economic conditions are likely to warrant exceptionally low levels of the federal funds rate for some time."

On August 2011's statement, the committee also included the information of how long they anticipated the rate would stay at this level as "The Committee agreed to keep the target range for the federal funds rate at 0 to 1/4 percent and to state that economic conditions are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013."

The effects of these announcements on the uncertainty of the policy path can be seen in Figure 2.1.

Figure 2.1: Level and Uncertainty about Policy Expectations

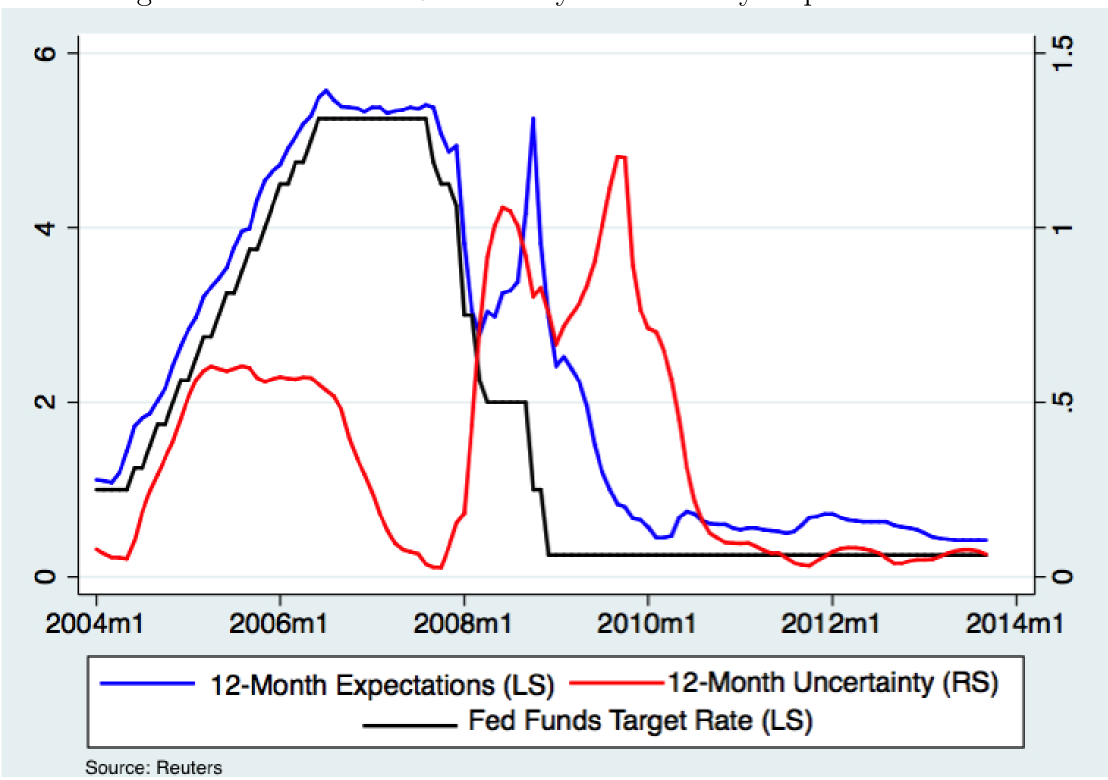


Figure 2.1 shows the federal funds target rate, estimated fed funds rate expectations 12-month ahead and uncertainty around these expectations. The uncertainty is calculated by using Eurodollar future contract prices, as implied volatility. As seen from the figure, after the financial crisis uncertainty about the future interest rates quickly increased while the policy rate and the

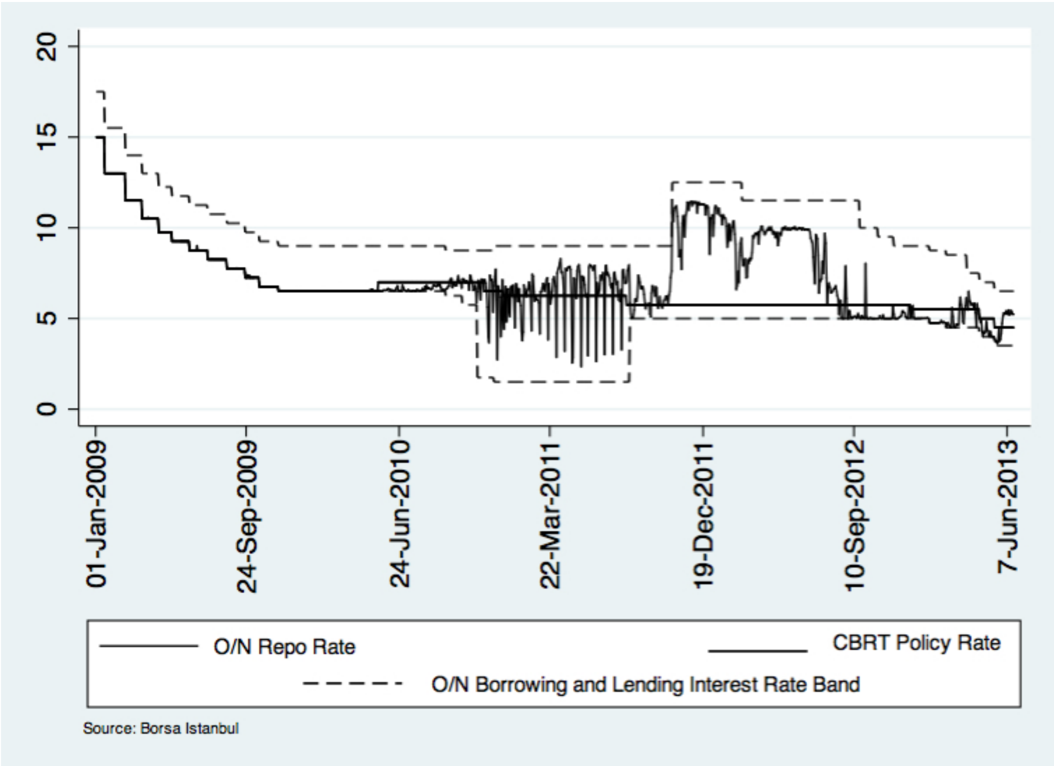
expectations dropped. The rise in the uncertainty indicates an increase in the uncertainty considering the future monetary policy and financial market conditions. After the FOMC announcement of the zero lower bound on interest rates the uncertainty falls but it is only after August 2011, when Federal Reserve Bank used forward guidance in the form of policy rate projection, we observe a record low level of uncertainty. In other words, the uncertainty around policy path is reduced with explicit numerical guidance.

On the other hand, sometimes central banks' official communication is not used for giving certainty but creating uncertainty. The explicit use of time varying volatility is found in Turkish example when in August 2010 the Central Bank began to add information about the policy rate volatility it will *create*, to its policy statements such that "Committee has come to the conclusion that it would be an appropriate policy mix to lower the policy rate and to widen the corridor between overnight borrowing and lending rates so as to allow fluctuations in the short-term interest rates, when needed.". The aim was to counterbalance the flow of capital by changing the predictability of the short term policy rates.[1] This leads to an increase in the uncertainty about future policy rate path (Figure 2.2).

These being said, it is clear that forward guidance can reduce or increase the uncertainty around the expected policy rate, and a greater attention should be paid to the effects and the transmission mechanism of this tool to real economy. The aim of this paper is to analyze the effects of changing uncertainty about interest rate path on real economy.

[1]See Kara (2012), Akkaya and Gürkaynak (2012), and Başçı and Kara (2011) for a discussion of the recent tools utilized by the CBRT.

Figure 2.2: CBRT Interest Rates and O/N Repo Rates



There is a growing literature on evaluating the effects of central banks' communications since the onset of the financial crisis, however, the announcements considered are almost exclusively on the large scale asset purchases (LSAPs). For instance, Krishnamurthy and Vissing-Jorgensen (2011) analyze the impact of announcements associated with quantitative easing 1 and 2, while Gagnon et al. (2011) show that the first LSAP announcement lead to high reductions in the US long term yields with an even-study approach. Joyce et al. (2011) repeats the work of Gagnon et al. (2011) for UK and find UK quantitative easing has similar results on bond yields. Bundick (2013) argues that the impact of forward guidance is limited due to zero nominal bound to be binding constraint, and central banks' response to change in the volatility shocks has not as effective once compared with pre-crisis period.

The importance of the forward guidance has been emphasized in many leading papers. Gürkaynak et al. (2005) showed that the announcements that move future rates for the upcoming year without changing the current fed funds rate has larger impacts on long term bond prices. Campbell et al. (2012) extend this data set until 2011 and to show that forward guidance still has a significant impact on asset prices in a financial crisis episode as well. In this paper, I suggest that the implications of committing to zero lower bound of interest rate works not only by reducing expected future spot rates but also by reducing the uncertainty around them.

In this paper, the effects of changing uncertainty about interest rate path on real economy is studied. To fulfill this aim, I use a closed economy dynamic New Keynesian model as a starting point since it provides a micro founded and trackable framework. In the model the monetary authority follows a policy rule á la Taylor (Taylor, 1993), and the uncertainty about the interest rate is imposed as an exogenous increase in the volatility of the monetary policy shock. Since the object of interest is implications of a volatility change in the interest rate shock, I use a third order perturbation methodology following Fernandez-Villaverde et al. (2011) by utilizing the perturbation AIM algorithm developed by Swanson et al. (2006).

While volatility shocks have been a hot research topic since Bloom (2009), these have almost exclusively been shocks to the volatility of total factor productivity, which are seen as exogenous, or in rare studies to fiscal policy (Fernandez-Villaverde et al., 2013), in which case are an unintentional side effect of fiscal policy. In the empirical literature, one standard deviation increase in the macroeconomic volatility is shown to have a 0.5% contractionary effect on annual growth (Engle and Rangel (2008)) through lower consumer spending (Romer (1990)), investment (Bloom (2009)), and finally trade (Handley and Limao (2012)) channels. The theoretical line of the literature on uncertainty focuses mostly on the effects of an increase in the economic uncertainty and analyzes its results. For instance, Fernandez-Villaverde et al. (2013) use New Keynesian model to show that uncertainty is extremely damaging especially if interest rates are constrained at zero. Furthermore, Basu and Bundick (2012) and Liu and Leduc (2013) show that due to staggered price adjustments, uncertainty shocks can both reduce consumption and investment at the same time.

There is little work done on the transmission of volatility shocks in a general equilibrium setting while the recent literature offers a number of empirical studies of how changes in the interest rate shock volatility affects economic performance. Some of the empirical studies are Chen and Scott (2004), Hadzi-Vaskov and Kool (2006), Edwards (1998). Basu and Bundick (2012) analyze the effects of increased uncertainty of future preferences and technology on output, comparing the dynamics under flexible and sticky price equilibria. The main difference between the previous volatility studies and my paper is the source of the volatility. In most of the studies, the volatility external and is measured from indexes such as VIX[2] and EMBI global spread reported by J.P. Morgan,[3] however, here it is employed by the policy makers as a policy tool, that is, the uncertainty is consciously manipulated by the policy maker.

[2]Bekaert et al. (2012), Basu and Bundick (2012), Bloom (2009)
[3]Fernandez-Villaverde et al. (2011)

The main findings of the paper are as follows. First, I show that the impact of a change in the volatility of interest rate mimic the impacts of a change in the level of the interest rate. For instance, in the closed economy model, once the nominal interest rate level is kept constant, a 40 bps decrease in the uncertainty of policy path leads to a 70 bps increase on GDP. Thus, using volatility of interest rate as a policy tool when the interest rate itself is bound by the zero lower bound constraint has quantitatively important effects that are similar to interest rate reductions, and this would enable the monetary policy authority to carry out further expansionary policy. This is the sense in which uncertainty about the policy rate path can be used by the central bank as a policy tool.

This paper proceeds as follows. Section 2.1 describes the closed economy model environment, while section 2.2 describes the solution method, and studies the results. Section 2.3 concludes.

2.1 The Model

In this section, I present the closed economy model economy which is a fairly standard New Keynesian model with time-varying volatility. The use of New Keynesian models in monetary policy analysis is a common practice. This modeling approach is sufficient for representing the effects of the uncertainty about the interest rate path on real economy since forward looking expectations and optimizations of agents enable the model to produce reasonable impulse response once faced with a monetary policy volatility shock. In the model there are four agents namely; households, intermediate good producers, final good firms, and a monetary policy authority.

Households gain utility from consumption and leisure. They are the owner of intermediate good firms and hold one-period riskless bonds. Intermediate good firms make production by using the capital they own, and labor that they rent from households in a monopolistically competitive environment with Cobb Douglas production technology. These firms are subject to quadratic cost of adjusting prices à la Rotemberg (Rotemberg, 1982). Final good producers are aggregating the intermediate goods and produce the final consumption good in a perfectly competitive environment by using constant return to scale production technology. The monetary authority is following an interest rate rule à la Taylor (Taylor (1993)) and changes in the uncertainty of future policy path is imposed as an exogenous increase in the volatility of the monetary policy shock. The detailed explanation of model environment is given below.

Households

There is a continuum of households in the economy. Households choose their consumption level C_t, labor L_t, one period riskless bond holdings B_{t+1}, to maximize lifetime utility:

$$\max E_t \sum_{t=0}^{\infty} \beta^t U_t(C_t, L_t) = \max E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\psi}}{1+\psi} \right] \tag{2.1}$$

subject to their budget constraint:

$$P_t C_t + \frac{1}{R_t} B_{t+1} \leq W_t L_t + D_t + B_t \tag{2.2}$$

Household receive labor income W_t, lump-sum dividends from the ownership of intermediate goods firm, D_t, and gross nominal return from the one period risk-free bond, R_t. In the utility specification σ denotes the risk aversion parameter, while ψ is the Frish elasticity of labor supply.

First order conditions of the representative household's optimization problem are:

$$\frac{C_t^{-\sigma}}{P_t} = \lambda_t$$

$$L_t^{\psi} = \lambda_t W_t$$

$$1 = \beta R_t E_t \left\{ \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \right\}$$

where λ_t is the Lagrangian multiplier.

The stochastic discount factor $\Lambda_{t,t+1}$ can be calculated as:

$$\begin{aligned} \Lambda_{t,t+1} &= \left(\frac{\partial U_{t+1}}{\partial C_{t+1}} \frac{1}{P_{t+1}} \right) \left(\frac{\partial U_t}{\partial C_t} \frac{1}{P_t} \right)^{-1} \\ &= \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\} \end{aligned}$$

Then we can rewrite the first order conditions by using the stochastic discount factor as:

$$L_t^{\psi} C_t^{\sigma} = \frac{W_t}{P_t} \tag{2.3}$$

$$1 = R_t \beta E_t \left\{ \left(\frac{C_t}{C_{t+1}} \right)^{\sigma} \frac{P_t}{P_{t+1}} \right\} \tag{2.4}$$

Equation (2.3) is the household's intertemporal optimality condition with respect to consumption and leisure that determines the quantity of labor supplied as a function of real wage. Equation (2.4) is the Euler equation for consumption and riskless bonds, showing the optimal allocation of consumption between periods t and $t+1$.

Intermediate Goods Sector

Firms use the labor they rent from households, $L_{i,t}$ and the capital they own, $K_{i,t}$, to produce intermediate goods $Y_{i,t}$ in a monopolistically competitive environment by using constant returns to scale (CRS) Cobb-Douglas production function.

The intermediate goods producers face a quadratic cost of adjusting nominal prices (à la Rotemberg price setting mechanism, (Rotemberg, 1982)), and issue equity shares $D_{i,t}$.

Firm i maximizes its cash flow $\frac{D_{i,t}}{P_{i,t}}$ by choosing $L_{i,t}, I_{i,t}$ and $P_{i,t}$, given aggregate demand Y_t and the price of the final good P_t.

The problem of the firm is then;

$$\max E_t \sum_{j=0}^{\infty} \Lambda_{t+j} \left[\frac{D_{t+j}(i)}{P_{t+j}} \right]$$

subject to

$$\left[\frac{P_{i,t}}{P_t} \right]^{-\theta_\mu} Y_t \leq K_{i,t}^{\alpha} \left[A_t L_{i,t} \right]^{1-\alpha} - \Phi \tag{2.5}$$

where

$$\frac{D_t(i)}{P_t} = \left\{ \left(\frac{P_{i,t}}{P_{t+j}} \right)^{1-\theta_\mu} Y_t - \frac{W_t}{P_t} L_{i,t} - I_{i,t} - \frac{\phi_p}{2} \left[\frac{P_{i,t}}{P_{i,t-1}} \frac{1}{\Pi} - 1 \right]^2 Y_t \right\} \tag{2.6}$$

and $\Lambda_{t,t+j}$ is the real stochastic discount factor. In each period firms can change their price $P_{i,t}$ at a cost. The last term of the Equation (2.6) represents this price adjustment cost (Rotemberg (1982)) where $\phi_p \geq 0$ determines the degree of nominal price rigidity and Π is the measure of gross steady state inflation rate. In the case where $\phi_p = 0$ the model collapses to a flexible price equilibrium. Φ represents the fixed cost of production and A_t is the technology.

The stock of capital evolves according to the law of motion with adjustment costs:

$$K_{i,t+1} = (1-\delta) K_{i,t} - \left[\frac{\phi_K}{2} \left(\frac{I_{i,t}}{K_{i,t}} - \delta \right)^2 \right] K_{i,t} + I_{i,t} \tag{2.7}$$

where δ is the depreciation rate and ϕ_K is the capital adjustment cost parameter.

The first order conditions for the intermediate good firm's profit maximization problem are:

$$\frac{R_t^K}{P_t} = \alpha MC_t K_{i,t}^{\alpha-1} \left[A_t L_{i,t}\right]^{1-\alpha} \tag{2.8}$$

$$\frac{W_t}{P_t} = (1-\alpha) MC_t K_{i,t}^{\alpha} \left[A_t L_{i,t}\right]^{-\alpha} \tag{2.9}$$

$$\begin{aligned} \phi_p \left[\frac{P_{i,t} - \Pi P_{i,t-1}}{P_{i,t-1}\Pi}\right] \left[\frac{P_t}{P_{i,t-1}} \frac{1}{\Pi}\right] &= (1-\theta_\mu) \left[\frac{P_{i,t}}{P_t}\right]^{-\theta_\mu} \\ &+\theta_\mu MC_t \left[\frac{P_{i,t}}{P_t}\right]^{-\theta_\mu - 1} \\ &+\phi_p E_t \left\{\Lambda_{t+1} \frac{Y_{t+1}}{Y_t} \left[\frac{P_{i,t} - \Pi P_{i,t-1}}{P_{i,t-1}\Pi}\right] \left[\frac{P_{i,t+1}}{P_{i,t}\Pi} \frac{P_t}{P_{i,t}}\right]\right\} \end{aligned} \tag{2.10}$$

$$\begin{aligned} q_t = E_t \Bigg\{ \Lambda_{t+1} \Bigg(R_{t+1}^K + q_{t+1} \Bigg(1 - \delta - \frac{\phi_K}{2} \left(\frac{I_{t+1}}{K_{t+1}} - \delta \right)^2 \\ + \phi_K \left(\frac{I_{t+1}}{K_{t+1}} - \delta \right) \left(\frac{I_{t+1}}{K_{t+1}} \right) \Bigg) \Bigg) \Bigg\} \end{aligned} \tag{2.11}$$

$$\frac{1}{q_t} = 1 - \phi_K \left(\frac{I_t}{K_t} - \delta \right) \tag{2.12}$$

where MC_t is the marginal cost of producing intermediate good i, q_t is the price of a marginal unit of installed capital and R_t^K/P_t is the marginal product of capital, paid to the intermediate good firms, who own the capital.

Equations (2.8) and (2.9) represent the marginal revenue of capital and labor respectively. As it can be seen from the Equation (2.10), once the price adjustment cost parameter ϕ_p is equalized to zero the pricing equation collapses to the flexible price equilibrium. Equation (2.11) is the marginal cost of one unit installed capital, while equation (2.12) is the price of a marginal unit of installed capital.

Final Good Sector

The representative final good firm produces the final good, Y_t, in a perfectly competitive environment, using the intermediate goods with the following CRS production function:

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\theta_\mu - 1}{\theta_\mu}} di \right]^{\frac{\theta_\mu}{\theta_\mu - 1}}$$

where $\theta_\mu \geq 1$ denotes the elasticity of substitution between intermediate goods.

The representative firm chooses Y_t and $Y_{i,t}$ to maximize profits subject to production technology, taking all the intermediate goods prices, $P_{i,t}$, and the final good price, P_t, as given. Thus, the maximization problem becomes:

$$\max P_t Y_t - \int_0^1 P_{i,t} Y_{i,t} di$$

The first order conditions yield the following demand function for the intermediate goods:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\theta_\mu} Y_t$$

Using the definition of Y_t and the solution for $Y_{i,t}$ yields:

$$
\begin{aligned}
Y_t &= \left(\int_0^1 \left(\left(\frac{P_{i,t}}{P_t} \right)^{\theta_\mu} Y_t \right)^{\frac{\theta_\mu - 1}{\theta_\mu}} di \right)^{\frac{\theta_\mu}{\theta_\mu - 1}} \\
&= Y_t \left[\int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{1-\theta_\mu} di \right]^{\frac{1}{1-\theta_\mu}}
\end{aligned}
$$

Since the production function exhibits CRS, Y_t can be dropped from both sides of the expression, so that solving for the aggregate price index yields:

$$
P_t = \left[\int_0^1 P_{i,t}^{1-\theta_\mu} di \right]^{\frac{1}{1-\theta_\mu}}
$$

2.1.1 Monetary Policy Rule

I assume that the central bank follows a simple Taylor rule that is subject to an AR(1) process monetary policy shock:

$$
\begin{aligned}
\log(R_t) &= \rho_R \log(R_{t-1}) \\
&+ (1-\rho_R) \left(\log(R) + \rho_\Pi \log \left[\frac{\Pi_t}{\Pi} \right] + \rho_Y \log \left[\frac{Y_t}{Y_{t-1}} \right] \right) + \sigma_t^R \xi_t^R
\end{aligned} \tag{2.13}
$$

where ξ_t^R is a normally distributed random variable with mean zero and variance equal to 1. The main feature of this process is that the standard deviation σ_t^R is not constant, but follows an AR(1) process:

$$
\log(\sigma_t^R) = (1-\rho_{\sigma^R}) \log(\sigma^R) + \rho_{\sigma^R} \log(\sigma_{t-1}^R) + \omega_{\sigma^R} \xi_t^{\sigma^R} \tag{2.14}
$$

where $\xi_t^{\sigma^R}$ is normally distributed random variable with mean zero and unit variance. Thus, the interest rate process exhibits stochastic volatility. The parameters σ^R and ω_{σ^R} control for the degree of mean volatility and stochastic volatility, respectively. I assume that all the stochastic processes are mean reverting and shocks to the volatility, and the level of the interest rate are uncorrelated.

In this setup, two innovations affect the interest rate: ξ_t^R and $\xi_t^{\sigma^R}$. The first innovation changes the rate, while the second innovation affects the standard deviation of ξ_t^R. This point requires further attention since this is where the uncertainty considering the interest rate path is imposed. As previously mentioned the increase in the uncertainty is induced by an exogenous increase in the volatility of the interest rate process which is denoted by $\xi_t^{\sigma^R}$.

Modeling uncertainty about the interest rate path by using stochastic volatility has advantages. First of all, this is intuitive in the sense that the change in the volatility of the interest rate corresponds to an increase in the uncertainty about it. Second, by using stochastic volatility instead of a GARCH process enables to differentiate between the 1^{st} level and 2^{nd} level shocks.

The timing of the events is as follows: up to time t, households live in an environment with the average standard deviation of nominal interest rate; however, at time t, the standard deviation of the shock to the monetary policy shock increases. After that, agents adjust their consumption, saving, labor and investment decisions optimally.

Equilibrium

The Rotemberg assumption on pricing (Rotemberg, 1982) implies that in the model's symmetric equilibrium, all the intermediate firms make identical decisions. Thus, $P_{i,t} = P_t$, $L_{i,t} = L_t$, $K_{i,t} = K_t$, and $D_{i,t} = D_t$ for all $i \in [0, 1]$. In the equilibrium, the market clearing condition $B_t = B_{t-1} = 0$ must hold.

The behavior of equilibrium prices and quantities are described by the conditions above, along with the first order conditions, the law of motions for the exogenous shocks and the central bank's policy rule (i.e. Equations (2.1)-(2.14)).

2.2 Solution Method and Results

Since the focus of this paper is to analyze the effects of second moment shocks (i.e. the shocks to the volatility of exogenous shock processes), I used third order perturbation methodology as in Fernandez-Villaverde et al. (2011). The model is solved numerically in Mathematica, using PerturbationAIM software developed by Swanson et al. (2006). This software routine is developed on the Anderson and Moore (1985) and it computes an nth-order Taylor series approximation to the solution of dynamic-time set of rational expectations equations around a non-stochastic steady state. As a solution technique perturbations methods are chosen over projection or discretization methods because they are much faster and can handle larger models (Gaspar and L. Judd (1997), Aruoba et al. (2006)).

The model is solved with a third order approximation around steady state.

By using first order approximation, we cannot observe the effects of change in the volatility because the solution is certainty equivalent, which means that the stochastic volatility plays no role. In the second order approximation, we can only observe the effects of the change in the volatility of shocks multiplied by the change in the mean of shocks. Thus, neither first nor second order approximations are sufficient. In the third order approximation, however, the second order shock, $\xi_t^{\sigma^R}$, become an independent argument in the policy function, allows us to observe the effects of innovations on the volatility of the monetary policy in the model.

Fernandez-Villaverde et al. (2011) show that time-varying volatility moves the ergodic distribution of the model's endogenous variables away from their deterministic steady state. Hence, the impulse response functions are drawn around the variable's ergodic mean, calculated following the same study. The model is simulated starting from its steady state for 2050 periods and first 2000 periods are disregarded as burn-in. The mean of ergodic distribution for each variable is computed based on the last 50 periods.

In the simulations, interest rate level is kept constant for two complementary reasons. First, the aim of the study is to capture the effects of a change in the volatility of monetary policy shock, thus in an environment where monetary policy tool, nominal interest rate, is adjusted to smooth out this externality, the results may be less powerful. Second, and most importantly, central banks employing forward guidance only change the uncertainty about future path of the policy rate, while the policy rate itself remains constant. Thus, I kept the level of the interest rate constant at its steady state level and analyze the effects of an increase in the uncertainty of the interest rate.

2.2.1 Calibration

While calibrating the model in quarterly frequency, the conventional parameter values in the literature have been used. The capital share of production, $\alpha = 0.33$ is a default choice as the household discount factor, $\beta = 0.9987$, the depreciation rate, $\delta = 0.025$ imply the appropriate capital-output ratio, and intertemporal elasticity of substitution is set to $\eta = 0.25$. The rest of the parameters, excluding the shock process parameters, are calibrated to match the estimated parameters reported in Ireland (2004). The shock process parameters, on the other hand, are calibrated with the values estimated by Fernandez-Villaverde et al. (2011). The list and values of the parameters can be found in Table 2.1.

Table 2.1: Calibration Values for Closed Economy Baseline Model

Parameter	Description	Value
α	Capital share of production	0.333
β	Household discount factor	0.9987
δ	Depreciation rate	0.025
ϕ_p	Degree of nominal price rigidity	160
ξ_{ik}	Investment Capital Ratio Elasticity	2
ϕ_k	Capital Adjustment cost parameter	$1/\xi_{ik}\delta$
σ	The coefficient of relative risk aversion	2
ψ	Inverse of the Frisch wage elasticity	1
η	Intertemporal elasticity of substitution	0.25
θ_μ	Elasticity of substitution	6
ρ_R	Persistent of monetary policy shock	0.90
ρ_{σ^R}	Persistence of the volatility of monetary policy shock	0.85
ω_{σ^R}	Std. of the volatility of monetary policy	0.02

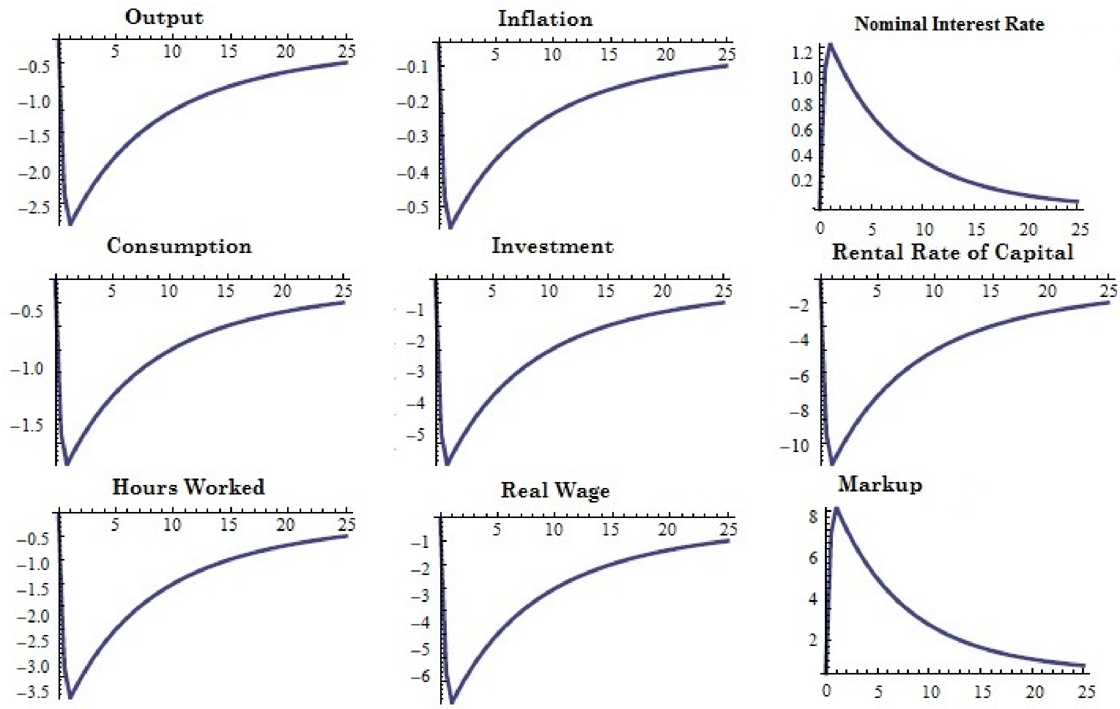
2.2.2 Results

This section presents the results obtained from the analysis of the dynamic behavior of the closed economy model following positive shocks to the level and the volatility of the monetary policy shock. Figure 2.3 plots the impulse responses to a contractionary monetary policy shock, while Figure 2.4 shows the impulse responses of a positive monetary policy volatility shock. The impulse responses for inflation and nominal interest rates are plotted in annualized percent deviations (they are obtained by multiplying by four the responses) from their ergodic mean while the others are plotted just as percent deviations from their ergodic mean.

Figure 2.3 shows the typical impulse responses when faced by a contractionary monetary policy shock. Since the setup is a standard New Keynesian model, an increase in the nominal interest rate leads to a persistent decrease in the output and inflation as expected. This simulation is reported here to show that once we solve the model for first order shock, we do not observe anything different from standard model's impulse responses.

Figure 2.4 shows the impulse responses to an increase in the uncertainty about monetary policy. In the model, after a shock that increases the uncertainty regarding monetary policy, the volatility of the future consumption is also becomes high. Since the utility function is concave in consumption, in other words marginal utilities are convex, from Jensen's inequality, an increase in the volatility of consumption leads to a decrease in the level of expected consumption. In other words, an increase in the volatility of monetary policy leads to an increase in the precautionary savings of the households, thus, induce a

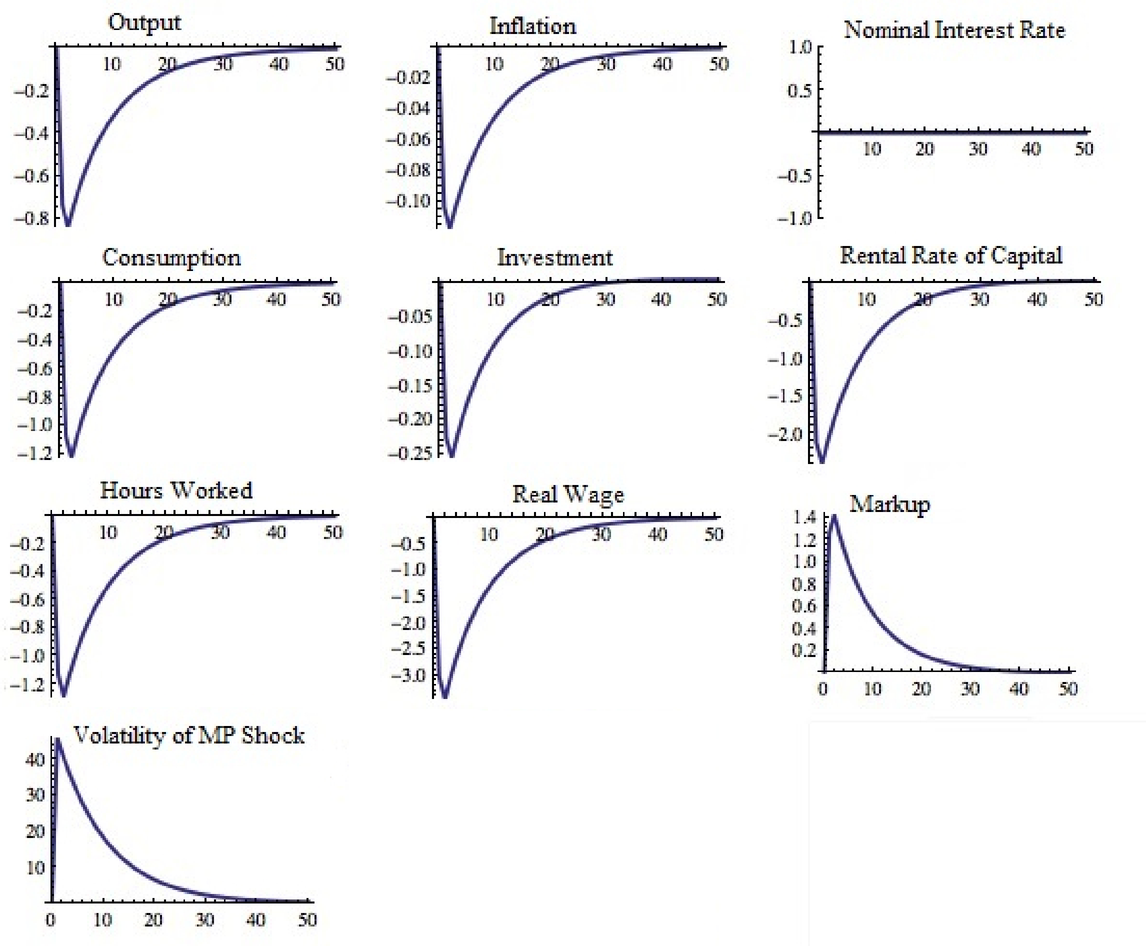
Figure 2.3: Impulse responses of closed economy model to a monetary policy shock



fall in their consumption. The effects of willingness to increase precautionary savings also induces an increase in the precautionary labor supply due to the fact that both leisure and consumption are normal goods. This means, the household starts to supply more labor for a given level of real wage. As a results the firms' marginal costs will decrease. Since prices are adjusted slowly due to staggered prices, the reduction in the marginal cost will increase the firms' markup and this will lead a reduction in the firms' labor demand and investment. All those effects combine to induce a reduction in the output.

If we compare the figures 2.3 and 2.4, we observe that a positive volatility

Figure 2.4: Impulse responses of closed economy model to a monetary policy volatility shock

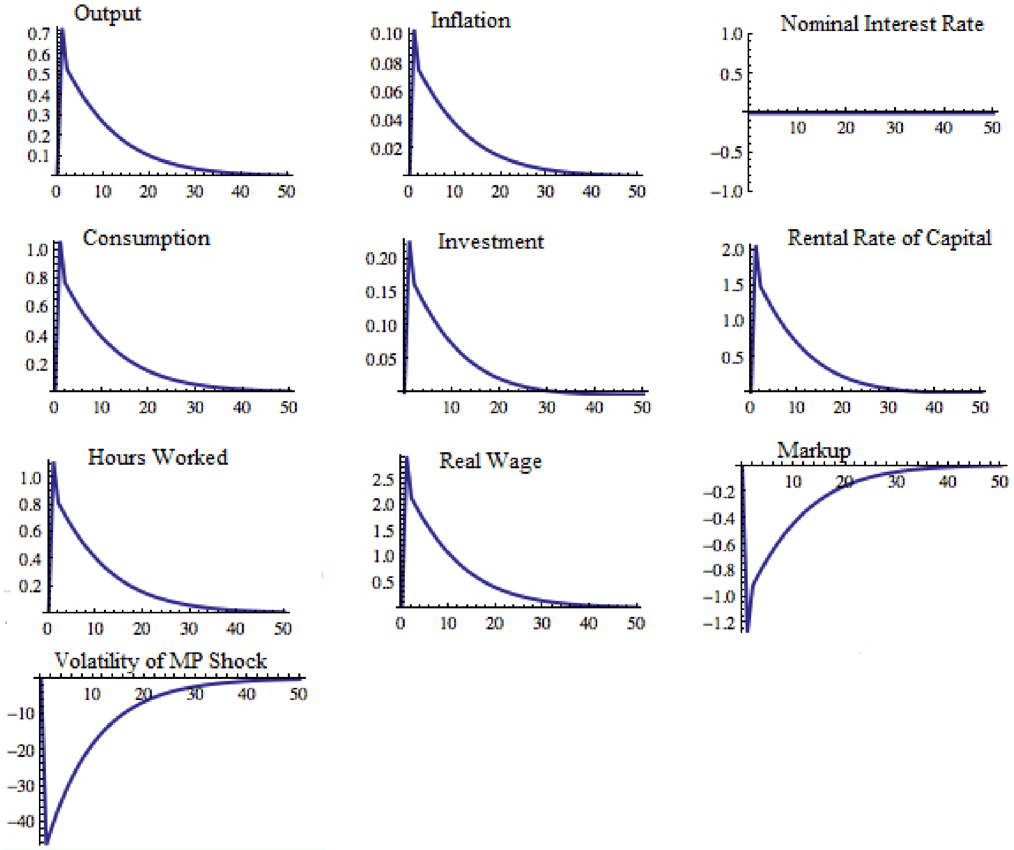


shock leads to almost same type of impulse responses with a contractionary monetary policy shock. In addition, it is obvious from the figures that investment contraction is much greater for an interest rate level shock while the consumption contraction is much greater for the uncertainty shock. This also suggests that uncertainty works through precautionary savings on consumption.

The symmetric case occurs when the economy is hit by a shock that reduces the uncertainty such as monetary policy authority starting to give explicit numerical guidance about the future path of policy rate (Figure 2.5). If we start with the monetary policy shock estimated for pre-crisis period and monetary authority shrunk it to zero by implementing forward guidance, we observe a 70 bps of an easing on output. This quantitatively large effect also occurs since in the simulations the monetary authority is restricted to keep the interest rates at the steady state value. This restriction put on the interest rate resembles the environment with a binding zero lower bound constraint. Many leading central banks have reduced the interest rate to zero level and cannot respond to changes in macroeconomic variables like firms' investment decisions or household consumption by further decrease in the policy rate.

Thus, from the closed economy model we can conclude that forward guidance works not only by reducing expected future spot rates but also by reducing the uncertainty around them, which is itself expansionary. Ergo, reducing the uncertainty of interest rate, for example by committing to an interest rate path, is expansionary at any level of interest rates, not only when the commitments is to zero interest rates. This is the sense that the policy rate path uncertainty can be used by the central bank as a policy tool.

Figure 2.5: The Impulse Responses of the Closed Economy Model to a Negative MP Volatility Shock



2.3 Conclusion

The recent financial crisis has led central banks to employ unconventional measures, including more frequent use of forward guidance. Whether and why forward guidance may be an effective policy tool in stimulating demand has been a hot topic of research. The theory on forward guidance has been almost exclusively focusing on the decrease in expected future short rates that this policy engineers. This paper argues that, by its very nature, forward guidance also lowers the uncertainty around future interest rates, and shows that such a decrease in the uncertainty of interest rates is expansionary in its own right, independent of the level of interest rates the central bank commits to.

The results show that, the impacts of a change in the volatility of interest rate mimic the impacts of a change in the interest rate level, and changing the uncertainty around policy expectations, without changing the policy rate, has quantitatively important effects on the model dynamics in the New Keynesian framework. In other words, a 40 bps decrease in the uncertainty of policy path creates a 70 bps increase in the output.

Central banks seem to change the uncertainty of future interest rates, at times being more vague and at other times being clearer about the path of the interest rate, in addition to the uncertainty that comes from the real economy. This paper is a positive study of the consequences of such interest rate uncertainty changes. A key research question remains the normative one, whether central banks should use this instrument or whether the optimal amount of interest rate uncertainty is always zero. That requires a better understanding of why central banks may see the level of interest rates and the volatility of the rates as having different impacts on the real economy. This will be an important research area in the future.

CHAPTER 3

UNCERTAINTY OF INTEREST RATE PATH AS A MONETARY POLICY INSTRUMENT AND OPEN ECONOMY DYNAMICS

"Constructive ambiguity" has long been a fixture of central bankers' jargon, letting them at times be vague about the future path of interest rates. The effects of this on the real economy, in particular on inflation and output, has not been studied.

This is useful both to understand the effects of the implicit use of interest rate volatility, as in "constructive ambiguity" and moving away from that; and also to understand its use explicitly to deter capital flows in small open economies. Since the onset of the financial crisis, the leading central banks, such as Federal Reserve, and Bank of England, started to utilize explicit numerical guidance and quantitative easing type of policies. The excess liquidity mostly flow to the emerging market economies where the interest rate is high, and created a risk for financial stability. Thus, emerging market central banks' develop unconventional tools. Central Bank of Republic of Turkey (CBRT) started to use time varying volatility explicitly in 2010 by adding information about the policy rate volatility it will *create* to its policy statements. The aim was to increase risk and reduce the Sharpe ratio to hinder capital inflows. Observationally the policy succeeded in reducing short term capital flows but we have no understanding of what such policies do to the domestic economy.

In light of these observations, the aim of this paper is to analyze the effects of interest rate uncertainty shocks on capital flows and exchange rates. To fulfill this aim I use a dynamic two-country New Keynesian model with incomplete international asset markets, and nominal price rigidities, where we can look into the effects of uncertainty about interest rate path on capital flows and exchange rate. In the model, the monetary authority follows a policy rule á la Taylor (1993), where the interest rate is subject to time varying policy shocks. Since the point of interest is to capture the implications of a volatility change in the interest rate shock, I use third order perturbation methodology following Fernandez-Villaverde et al. (2011) by utilizing the PerturbationAIM algorithm developed by Swanson et al. (2006). The third order perturbation is necessary because in the first-order approximation, stochastic volatility would disappear since the solution of the model would be certainty equivalent, and in the second-order approximation, we can observe only the impact of the product of mean volatility and stochastic volatility in the policy function.

There is a growing literature on analyzing the effects of increases in financial and macroeconomic uncertainty on the open economy dynamics. Most of the papers focus on the effects, and the transmission mechanism of exchange rate volatility on the real economy. For instance, Benigno et al. (2011) have examined how the exogenous increases in the volatility of nominal and real exchange rates play role in understanding the regularities in international finance. For this purpose they conduct both empirical and theoretical analysis. In the empirical part, by using an open economy VAR, they show that once the nominal volatility increases the exchange rate appreciates, and volatility shocks are important for the equilibrium levels of exchange and interest rates. In the theoretical part, the authors develop a two-country open-economy model which incorporates complete financial asset markets, nominal price rigidities and Epstein-Zin preferences (Epstein and Zin (1989)) and solve the model with a second order approximation technique developed by Benigno et al. (2013). Their theoretical model findings are in line with the empirical analysis's results. In addition, Akkaya (2014) studies the effects of uncertainty changes in a closed economy setup, however, due to the use of risk averse agents an increase in the volatility may always result in an output deterioration in those models. Thus, to answer the question of whether the optimal amount of interest rate uncertainty is always zero we need open economy framework so we can observe different channels that an increase in the volatility to be effective.

For this analysis, a two-country model environment is crucial since one of the aims is to address the changes in the capital flows when one of the countries use the interest rate uncertainty as a monetary policy tool. However, in the literature there are many studies where the effects of alternative monetary policies is considered in a small open economy framework. Gali and Monacelli (2005), develop a model of small open economy, as a continuum of economies making up the world economy, with complete asset market structure and staggered price setting. They analyze the welfare effects of alternative monetary policy regimes and find that domestic inflation-based Taylor rule dominates CPI inflation based Taylor rule, and exchange rate peg. This finding is mostly due to the terms of trade factor in the New Keynesian Phillips curve equation with output gap as an pushing-cost variable, and thus creates a new source of inflationary pressure.

The assumption of incomplete financial assets is also important for the analysis because in complete asset markets, once a shock hits the economy we can only observe the effects through the distortions coming from market power of the firms, and sticky prices. The current account channel plays no role since agents are able to trade in such a way to avoid shifts across countries. Thus, the only way to observe the effects of change in the uncertainty of monetary policy on capital flows is to assume incomplete asset market structure.

The main findings of the paper are as follows. First, I show that the impact of a change in the volatility of interest rate in the open economy model mimics the impacts of a change in the level of the interest rate. Thus, using volatility of interest rate as a policy tool when the interest rate itself is bound by the zero lower bound constraint has similar effects to interest rate reductions, and this would enable the monetary policy authority to carry out further expansionary policy. This is the sense in which uncertainty about the policy rate path can be used by the central bank as a policy tool. In addition, model results' indicate that an increase in the volatility of the future interest rate also reduces output and current account which means that an increase in the monetary policy uncertainty mainly cause households to hold more precautionary savings. The model predicts that when uncertainty about future interest rate path is increased by one standard deviation, it produces a peak decline of about 0.1 percent in output.

This paper proceeds as follows. Section 3.1 exhibits numerically how the CBRT uses an interest rate band as a policy tool, while section 3.2 introduces the model environment. Section 3.3 shows the solution method and studies the results, and section 3.4 concludes.

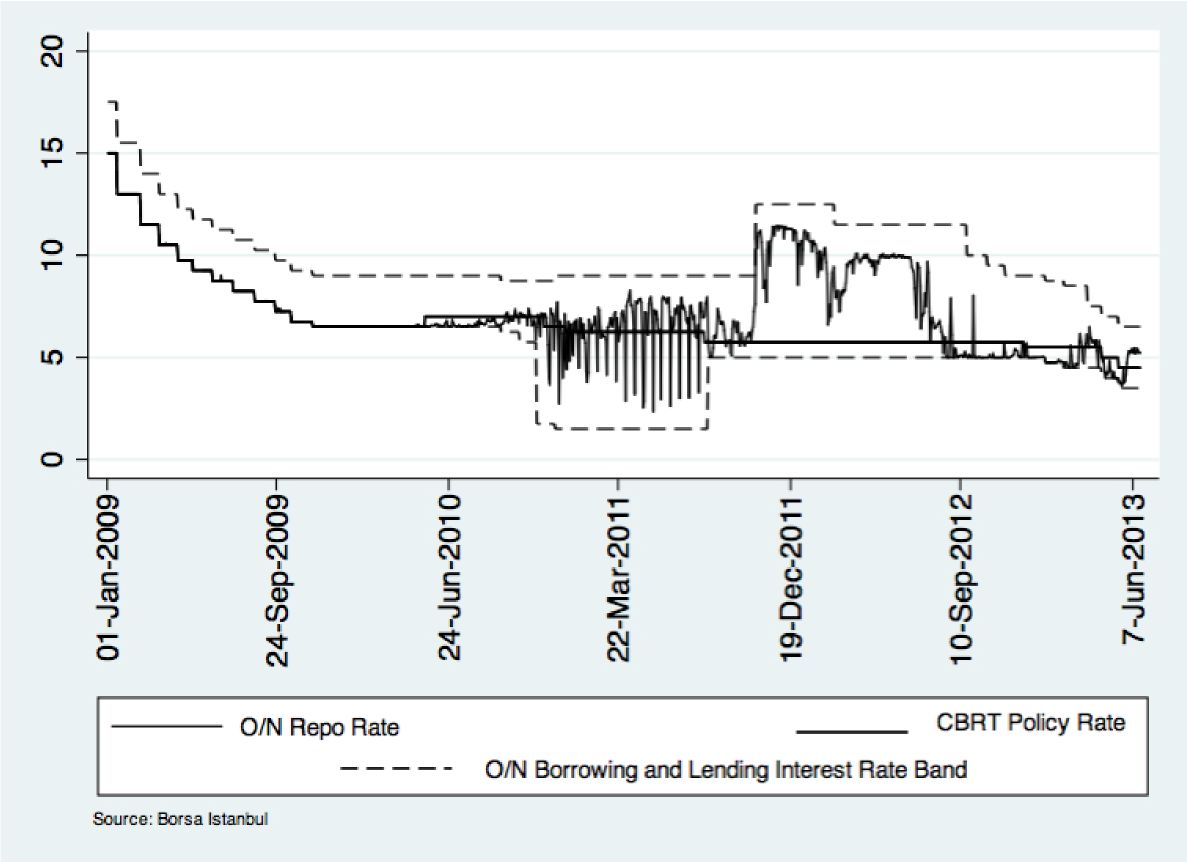
3.1 The Macroprudential Policy Tools in Turkey

Following the onset of financial crisis, the developed economies started to use policies that extremely eases the credit conditions. Those increase in the liquidity in the developed economy mainly flow to high interest rate countries, in other words emerging market economies and created risk on financial stability. To alleviate the sudden stop risk (Calvo (1998), Aguiar and Gopinath (2007)) as a country that faced huge amounts of capital inflows, Turkey took some extreme measures.

In the last quarter of 2010, the CBRT adjusted its monetary policy by placing more weight on credit growth, exchange rate developments, and balancing the domestic and external demand. To prevent nominal appreciation due to short-term capital inflows and accelerating credit, the CBRT sterilized foreign exchange purchases and differentiated unremunerated reserve requirements by maturity and currency denomination. The one-week repo rate, which became the policy rate in 2010, was not raised, but the interest rate corridor - defined as the difference between overnight borrowing and lending rates - was widened by lowering the borrowing rate.

The CBRT has been using the overnight interest rate band as as a part of its policy mix frequently since late 2010 (Figure 3.1).

Figure 3.1: CBRT Interest Rates and O/N Repo Rates



In November 2010, the CBRT widened the overnight interest rate corridor by lowering the borrowing rate by 400 basis points in order to instigate the lengthening of the maturities in Turkish lira transactions, and to lower the risks regarding financial stability (Başçı and Kara (2011)).The aim for this widening was to increase interest rate volatility at the lower end so as to discourage short-term capital inflows.

In August 2011, the CBRT has decided to narrow the band to reduce the down side volatility in the short-term interest rate by increasing the overnight borrowing interest rate. However, due to the depreciation of Turkish lira in October 2011 and the base effects of unprocessed food prices, inflation rose dramatically. Subsequently, to prevent the effects of these events on medium term inflation expectations, the interest rate band widen again by increasing the overnight lending rate.

The results of this unorthodox monetary policy mix implemented by the CBRT is, however, mixed. It has contributed not only to the required depreciation of the Turkish lira, especially in between the end of 2010 and mid 2011, but also helped to contain exchange rate volatility which has enabled the rebalancing of growth from domestic to external demand.

On the negative side, this policy mix was not able to deliver low and stable inflation. In March 2011, consumer price inflation was 3.9%. However, in December 2011, it reached 10.4% - far above the CBRT's 5.5±2% time-varying target. By October 2012, the inflation rate was 7.8% , still higher than the CBRT's end of year target.

Furthermore, there are concerns that this new regime will reduce the transparency and independency of monetary policy (OECD (2012)). Finally, while increased interest rate volatility helped to deter short-term capital inflows, it may be detrimental to investment and could complicate the formation of interest rate expectations, feeding into inflation expectations. This is the main focus of this paper.

In the next section the open economy model that is developed to study the effects of interest rate uncertainty on capital flows and exchange rates is introduced.

3.2 The Open Economy Model

In this section, I present the two-country New Keynesian model with time-varying interest rate volatility. I assume that there is an incomplete asset market structure at the international level which limits risk sharing possibilities and amplifies the effect of monetary policy on the cost of borrowing.

There are two types of firms in the model; intermediate good firms and final good firms. Intermediate good firms produce differentiated goods using both capital and labor as inputs. These firms set prices under producer currency pricing and face quadratic cost for price adjustment. Final good firms act in a competitive market environment, producing consumption good by aggregating intermediate goods that they buy from home and foreign intermediate good producers.

The model environment consisting of households, firms and a monetary policy authority for the home country are described below. The analogous optimization problems apply to the foreign country, not reported here for brevity, however, can be found in the Appendix A. The foreign variables are denoted with an asterisk (*).

3.2.1 Households

There is a continuum of households in the economy. Households derive utility from consumption, C_t, and disutility from supplying labor, L_t. They are the owner of intermediate good firms and the capital stock.

The optimization of home country representative household can be written as:

$$\max E_t \sum_{t=0}^{\infty} \beta^t U_t(C_t, L_t) = \max E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\psi}}{1+\psi} \right] \tag{3.1}$$

subject to the period budget constraint:

$$P_t(C_t + I_t + AC_{I,t} + \frac{1}{R_{t-1}} B_{H,t}) + S_t \frac{1}{R_{t-1}^*} B_{F,t} + AC_{B,t}$$
$$= B_{H,t-1} + S_t B_{F,t-1} + W_t L_t + P_t r_t K_t + \Pi_t$$

where

$$AC_{I,t} = \frac{\psi_I}{2} \frac{(K_t - K_{t-1})^2}{K_t} \tag{3.2}$$

$$AC_{B,t} = \frac{\psi_B}{2} \frac{(S_t(B_{F,t} - B_F))^2}{P_{H,t} Z_t} \tag{3.3}$$

$$I_t = (K_t - (1-\delta) K_{t-1}) \tag{3.4}$$

The household receives income from supplying labor W_t, and renting capital r_t, and receives profits from ownership of home intermediate good firms, Π_t. The household can invest in two types of assets: a noncontingent nominal bond denominated in home currency $B_{H,t}$ with a return R_t, and a noncontingent nominal bond denominated in foreign currency $B_{F,t}$ which pays an interest rate R_t^* where S_t represents the nominal exchange rate, defined as the home currency price of a unit of foreign currency. The capital is subject to depreciation with a constant rate, δ, and to quadratic adjustment cost that depends on the parameter, ψ_I (Equation (3.2)). Following Schmitt-Grohe and Uribe

(2003), there is an adjustment cost on foreign bond holdings (Equation (3.3)) to induce stationarity in net foreign asset position and ψ_B is the parameter that represents this cost of undertaking positions in the foreign bonds market.[1] Here, home and foreign bonds are treated separately to ensure that there exists a determinate allocation between home and foreign currency bonds which is required by the second and higher order solutions. Z_t represents the total output level.

The first order conditions of the representative household's optimization problem are given as:

$$\frac{L_t^{\psi}}{C_t^{-\sigma}} = \frac{W_t}{P_t} \tag{3.5}$$

$$\frac{1}{R_t} = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\} \tag{3.6}$$

$$\begin{aligned} E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \frac{S_t}{S_{t+1}} R_t^* \left(1 + \frac{\psi_B S_t (B_{F,t} - B_F)}{P_{H,t} Z_t} \right)^{-1} \right\} \\ = E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} R_t \right\} \end{aligned} \tag{3.7}$$

[1] Due to the assumption of incomplete markets, shocks can create permanent wealth reallocations and that would lead to nonstationarity. However, the introduction of risk premium term as a function of debts makes wealth allocations go back to their initial distributions in the long run and thus enables the computation of the second moments.

$$\left(1+\frac{\psi_I(K_t-K_{t-1})}{K_{t-1}}\right) = \beta E_t\left\{\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\right. \left.\left(r_{t+1}+(1+\delta)+\frac{\psi_I}{2}\frac{K_{t+1}^2-K_t^2}{K_t^2}\right)\right\} \tag{3.8}$$

Equation (3.5) is the household's intertemporal optimality condition with respect to consumption and leisure, where Equation (3.6) represents the consumption Euler. Equation (3.7) is the interest parity condition with the risk premium. This is the equation that sets the main relationship between domestic interest rates, foreign interest rates and exchange rate. As shown in the numerical simulations, the financial trade adjustment parameter ψ_B plays an important role in the before mentioned relationship, and depending on the calibrated value selected for the it the results may alter. Finally, Equation (3.8) is the optimality condition of capital accumulation.

The stochastic discount factor, $\Lambda_{t,t+1}$ is given as:

$$\begin{aligned}\Lambda_{t,t+1} &= \left(\frac{\partial U_{t+1}}{\partial C_{t+1}}\frac{1}{P_{t+1}}\right)\left(\frac{\partial U_t}{\partial C_t}\frac{1}{P_t}\right)^{-1}\\ &= \beta E_t\left\{\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\frac{P_t}{P_{t+1}}\right\}\end{aligned}$$

Also, the current account can be defined as:

$$CA_t = (B^*_{H,t}-B^*_{H,t-1}) - S_t(B_{F,t}-B_{F,t-1}) \tag{3.9}$$

In the model, uncovered interest parity condition does not hold and the spread in the nominal interest rates reflect a premium on the top of expected exchange rate depreciation. This premium called the risk premium. Depending on the home country being a borrower or a lender in the market, it will take positive or negative values. The risk premium enables to give an explicit role to the net foreign asset position in the risk sharing condition by breaking the monotonic positive relation between real exchange rate, and relative consumption.

3.2.2 Firms

In the model there are two types of firms, namely; final good producers, and intermediate good producers, explained in detail below.

3.2.3 Final Good Sector

Final good producers are perfectly competitive, and the representative firm produces the final good, Y_t, by using the intermediate goods from home and foreign country with the following constant returns to scale production function:

$$Y_t = \left[a^{1/\mu} Y_{H,t}^{\frac{\mu-1}{\mu}} + (1-a)^{1/\mu} Y_{F,t}^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}}$$

where

$$Y_{H,t} = \left(\int_0^1 y_{H,t}(i)^{(\lambda-1)/\lambda} di \right)^{\lambda/(\lambda-1)} \tag{3.10}$$

$$Y_{F,t} = \left(\int_0^1 y_{F,t}(j)^{(\lambda-1)/\lambda} dj \right)^{\lambda/(\lambda-1)} \tag{3.11}$$

where $\mu \geq 1$ denotes the elasticity of substitution between home and foreign goods, λ is the elasticity of substitution between intermediate goods produced within the same country, and a is the share of home goods used in the production of final goods in home country, thus $1 - a$ becomes a natural index of openness. Lower cases represent the individual firms' output.

The representative firm chooses Y_t, $Y_{H,t}$, and $Y_{F,t}$ to maximize profits subject to production technology, taking all the intermediate goods prices, $P_{H,t}$, $P_{F,t}$, and the final good price, P_t, as given. $P_{H,t}$, $P_{F,t}$ are price indexes of home goods and foreign goods respectively, both in home currency. Thus, the maximization problem becomes:

$$\max P_t Y_t - P_{H,t} Y_{H,t} - P_{F,t} Y_{F,t}$$

The price index, P_t, is defined as:

$$P_t = \left[a P_{H,t}^{1-\mu} + (1-a) P_{F,t}^{1-\mu} \right]^{\frac{1}{1-\mu}}$$

where

$$P_{H,t} = \left(\int_0^1 p_{H,t}(i)^{(1-\lambda)} di \right)^{1/(1-\lambda)} \tag{3.12}$$

$$P_{F,t} = \left(\int_0^1 p_{F,t}(j)^{(1-\lambda)} dj \right)^{1/(1-\lambda)} \tag{3.13}$$

Given the problem of the final good producer, the demand will be allocated between home and foreign goods as:

$$Y_{H,t} = a\left(\frac{P_{H,t}}{P_t}\right)^{-\mu} Y_t \tag{3.14}$$

$$Y_{F,t} = (1-a)\left(\frac{P_{F,t}}{P_t}\right)^{-\mu} Y_t \tag{3.15}$$

and the demands for individual goods are:

$$y_{H,t}(i) = \left(\frac{p_{H,t}(i)}{P_{H,t}}\right)^{-\lambda} Y_{H,t} \tag{3.16}$$

$$y_{F,t}(j) = \left(\frac{p_{F,t}(j)}{P_{F,t}}\right)^{-\lambda} Y_{F,t} \tag{3.17}$$

Analogous definitions apply to the foreign country.

3.2.4 Intermediate Goods Sector

Firms use the labor $L_t(i)$ and capital $K_t(i)$ they rent from households to produce intermediate goods $z_t(i)$ in a monopolistically competitive environment by using constant-returns to scale Cobb-Douglas production function.

The intermediate good producers face a quadratic cost of adjusting nominal prices à la Rotemberg price setting mechanism (Rotemberg, 1982), and firms set prices in their own currency both for sales domestically and sales abroad, that is the essence of producer currency pricing.

The currency of price setting behavior of the firms plays an important role in the model structure and behavior. In most of the New Keynesian Open Economy models law of one price assumption holds, and once aggregating across goods, purchasing power parity holds. Thus there is a full pass through of exchange rate movements to import prices, in other words, Producer Currency Pricing (PCP) where the firms set prices in the seller's currency is practiced. However, empirical evidence suggests that purchasing power parity does not hold thus Betts and Devereux (1996) introduce an alternative assumption that some firms set prices in buyers' currency, namely Local Currency Pricing (LCP). Many authors follow this assumption (Chari et al. (2002), Kollmann (2001)) since LCP is able to capture many key empirical features.

Several other papers, by endogenizing the currency pricing behavior show that; i) under complete asset markets, firms denominate the sales in the most stable currency (Devereux and Engel (2001)), ii) under incomplete asset markets PCP is an equilibrium outcome only if domestic firms have higher market share in foreign markets (Wincoop and Bacchetta (2000)). Furthermore, Corsetti and Pesenti (2002) show that if the exchange rate variability is high firms practice PCP while monetary policy authorities have incentives to choose flexible exchange rate regime.

In this analysis, since there is an exogenous variability in the interest rate and this has effects on exchange rate variability, it is important to observe the effects of changes in exchange rate on pricing behavior of the firms. Thus PCP is assumed.

In the model, firm i maximizes its cash flow $\Pi_{H,t}(i)$ by choosing $L_t(i), I_t$ and $p_{H,t}(i)$, given aggregate demand $z_t(i)$, and the price of the final good P_t.

The problem of the firm is then;

$$\max E_t \sum_{j=0}^{\infty} \Lambda_{t+j} \Pi_{H,t}(i)$$

where

$$\begin{aligned} \Pi_{H,t}(i) &= p_{H,t}(i) z_t(i) - \\ & \left(\frac{(r_t P_t)^{\alpha} W_t^{1-\alpha}}{A_t \alpha^{\alpha} (1-\alpha)^{1-\alpha}} + \frac{\psi_P}{2} \frac{(p_{H,t}(i) - p_{H,t-1}(i))^2}{p_{H,t-1}(i)} \right) z_t(i) \end{aligned} \tag{3.18}$$

subject to

$$z_t(i) = A_t K_t^{\alpha}(i) L_t^{1-\alpha}(i) = y_{H,t}(i) + y_{H,t}^{*}(i) \tag{3.19}$$

and

$$y_{H,t}(i) = \left(\frac{p_{H,t}(i)}{P_{H,t}} \right)^{-\lambda} Y_{H,t} \tag{3.20}$$

and $\Lambda_{t,t+j}$ is the stochastic discount factor. In each period, firms can change their price $p_{H,t}(i)$ at a cost. The last term of the equation (3.18) represents this price adjustment cost (Rotemberg (1982)) where $\psi_P \geq 0$ determines the degree of nominal price rigidity. In the case where $\psi_p = 0$ the model collapses to a flexible price equilibrium.

The first order conditions for the intermediate good firm are:

$$P_t r_t K_{t-1}(i) = \frac{\alpha}{1-\alpha} W_t L_t(i) \tag{3.21}$$

$$
\begin{aligned}
p_{H,t}(i) &= \frac{\lambda}{(\lambda-1)}\left(\frac{(r_tP_t)^{\alpha}W_t^{1-\alpha}}{A_t\alpha^{\alpha}(1-\alpha)^{1-\alpha}} + \frac{\psi_P}{2}\frac{(p_{H,t}(i)-p_{H,t-1}(i))^2}{p_{H,t-1}(i)}\right) \\
&+\frac{\psi_P}{\lambda-1}p_{H,t}(i)\left(1-\frac{p_{H,t}(i)}{p_{H,t-1}(i)}\right) \\
&+ \frac{1}{2}\frac{\psi_P}{\lambda-1}P_{H,t}(i)E_t\left\{\Lambda_{t,t+1}\left(1-\frac{p_{H,t+1}^2(i)}{p_{H,t}^2(i)}\right)\frac{Y_{H,t+1}}{Y_{H,t}}\right\} \qquad (3.22)
\end{aligned}
$$

Equation (3.21) shows the trade-off between capital and labor inputs, while equation (3.22) represents the price setting behavior. If the price adjustment cost parameter ϕ_P, the model collapses to the flexible price equilibrium. The pricing equation has three parts, the first line of equations represents the marginal costs and pricing markup while the second and third lines can be interpreted as past depending and forward looking components, respectively. As it can be seen from the equation, big price changes are costly, and firms want to avoid that due to adjustment costs. On the other hand, if firms expects a rise in the prices in the future then it is less costly to adjust the prices today because the more they delay the price change, the bigger the change gets and it induces more costs.

In the symmetric equilibrium $p_{H,t}(i) = P_{H,t}$.

3.2.5 Monetary Policy Rule

As in the first chapter, the central bank follows a simple Taylor type feedback rule that is subject to an AR(1) process monetary policy volatility shock such as:

$$
\begin{aligned}
\log(R_t) &= \rho_R \log(R_{t-1}) + \\
&(1-\rho_R)\left(\log(R) + \rho_\Pi \log\left[\frac{\Pi_t}{\Pi}\right] + \rho_Y \log\left[\frac{Y_t}{Y_{t-1}}\right]\right) + \sigma_t^R \xi_t^R
\end{aligned} \tag{3.23}
$$

where ξ_t^R is a normally distributed random variable with mean zero and variance equal to 1. The standard deviation σ_t^R is also not constant, but follows an AR(1) process:

$$
\log(\sigma_t^R) = (1-\rho_{\sigma^R})\log(\sigma^R) + \rho_{\sigma^R}\log(\sigma_{t-1}^R) + \omega_{\sigma^R}\xi_t^{\sigma^R} \tag{3.24}
$$

where $\xi_t^{\sigma^R}$ is normally distributed random variable with mean zero and unit variance. Thus, the interest rate process exhibits stochastic volatility with the parameters σ^R and ω_{σ^R} controlling for the degree of mean volatility, and stochastic volatility, respectively.

In this setup, two innovations affect the interest rate: ξ_t^R and $\xi_t^{\sigma^R}$. The first innovation changes the rate, while the second innovation affects the standard deviation of ξ_t^R. This point requires further attention since this is where the uncertainty considering the interest rate path is imposed. As previously mentioned the increase in the uncertainty is induced by an exogenous increase in the volatility of the interest rate process which is denoted by $\xi_t^{\sigma^R}$.

3.2.6 Equilibrium

The Rotemberg assumption (Rotemberg, 1982) implies that in the model's symmetric equilibrium, all the intermediate firms make identical decisions.

Thus, $p_{H,t}(i) = P_{H,t}$, $L_{i,t} = L_t$, and $K_{i,t} = K_t$ for all $i \in [0, 1]$.

Market clearing for home goods market requires:

$$Y_{H,t} + Y^*_{H,t} = Z_t \tag{3.25}$$

and for the home bond market:

$$B_{H,t} + B^*_{H,t} = 0 \tag{3.26}$$

Total home final good demand must be equal to final goods supply:

$$Y_t = C_t + I_t + AC_{I,t} + \frac{AC_{B,t}}{P_t} + \int_0^1 \left(\frac{\psi_P}{2} \frac{(p_{H,t}(i) - p_{H,t-1}(i))^2}{p_{H,t-1}(i)} di \right) \frac{Z_t}{P_t} \tag{3.27}$$

Home balance of payments condition can be written as:

$$(B_{H,t} - B_{H,t-1}) + S_t(B_{F,t} - B_{F,t-1}) = (P_{H,t}Z_t) + i_{t-1}B_{H,t-1} + S_t i^*_{t-1}B_{F,t-1} - P_tY_t \tag{3.28}$$

where $R_t = 1 + i_t$. The foreign balance of payments condition, on the other hand is given as:

$$\frac{1}{S_t}(B^*_{H,t} - B^*_{H,t-1}) + (B^*_{F,t} - B^*_{F,t-1}) = (P^*_{F,t}Z^*_t) + \frac{1}{S_t} i_{t-1}B^*_{H,t-1} + i^*_{t-1}B^*_{F,t-1} - P^*_tY^*_t \tag{3.29}$$

The behavior of equilibrium prices and quantities are described by, the conditions above along with the first order conditions, the law of motions for the exogenous shocks and the central bank's policy rule (i.e. equations 3.1-3.29) for home economy and their analogous counterparts for foreign economy.

3.3 Solution Method and Results

The solution methodology is the same as the closed economy counterpart, that is, the model is solved with third order perturbation methodology. Since the model incorporate the incomplete asset market structure, Euler equations impose a unit root in the marginal utility of wealth and this inhibits the calculation of higher order moments. Schmitt-Grohe and Uribe (2003) presents five different ways of dealing with this non-stationarity problem where they solve the model using a linear approximation solution. Seoane (2011) extend their analysis for the nonlinear solution methods, which is the point of interest in this chapter. The author finds that the calibration has an important role on the model outcomes such that the calibrated values that replicates same steady state values may not generate the same second order moments for some endogenous variables. Indeed as it can be seen from the results in this section, with higher order solution, the findings are quite dependent on the calibration parameters.

3.3.1 Calibration

The model is calibrated in quarterly frequency by using parameter values that are conventional in the literature. For the home economy, the discount factor, β, is set at 0.99, implying a riskless annual return of approximately 4 percent in the steady state. The inverse of intertemporal substitution σ is taken as 2. The inverse of the elasticity of labour supply ψ is set to 2 which implies that 1/2 of the time is spent on working.

The degree of openness $1-a$ is set to be 0.5 which implies there is no home bias neither in production, nor in consumption. Also, the share of capital in production α is taken to be 0.35, consistent with other studies.

Following Devereux et al. (2006), the elasticity of substitution between differentiated goods of the same origin λ is taken as 11, implying a flexible price equilibrium mark-up of 1.1. Price adjustment costs ψ_i and ψ_m assumed to be 120 for all sectors. The quarterly depreciation rate δ is 0.025, a conventional value used in the literature.

In the baseline calibration, the Taylor rule is calibrated following the literature and interest rate smoothing parameter ρ_R is chosen as 0.5 with ρ_Π as 1.5, and both ρ_Y and ρ_S are taken as 0.5. The foreign economy is also calibrated following the same fashion. Table 3.1 summarizes the values that are used for the model parameters.

Table 3.1: Calibration Values for Open Economy Baseline Model

Parameter	Description	Value
α	Capital share of production	0.35
β	Household discount factor	0.99
δ	Depreciation rate of Capital	0.025
ψ_P	Degree of nominal price rigidity	120
ψ_I	Capital Adjustment cost parameter	120
σ	The coefficient of relative risk aversion	2
ψ	Inverse of the Frisch wage elasticity	2
$1-a$	Degree of openness	0.5
λ	Elasticity of substitution between differentiated goods	11
ρ_R	Persistent of monetary policy shock	0.90
ρ_Π	CB reaction coefficient on inflation	1.5
ρ_Y	Output gap smoothing parameter	0.5
ρ_S	Exchange rate smoothing parameter	0.5
ρ_{σ^R}	Persistence of the volatility of monetary policy shock	0.85
ω_{σ^R}	Std. of the volatility of monetary policy	0.02
ρ_A	Persistent of technology shock	0.90
ρ_{σ^A}	Persistence of the volatility of technology shock	0.83
ω_{σ^A}	Std. of the volatility of technology	0.05

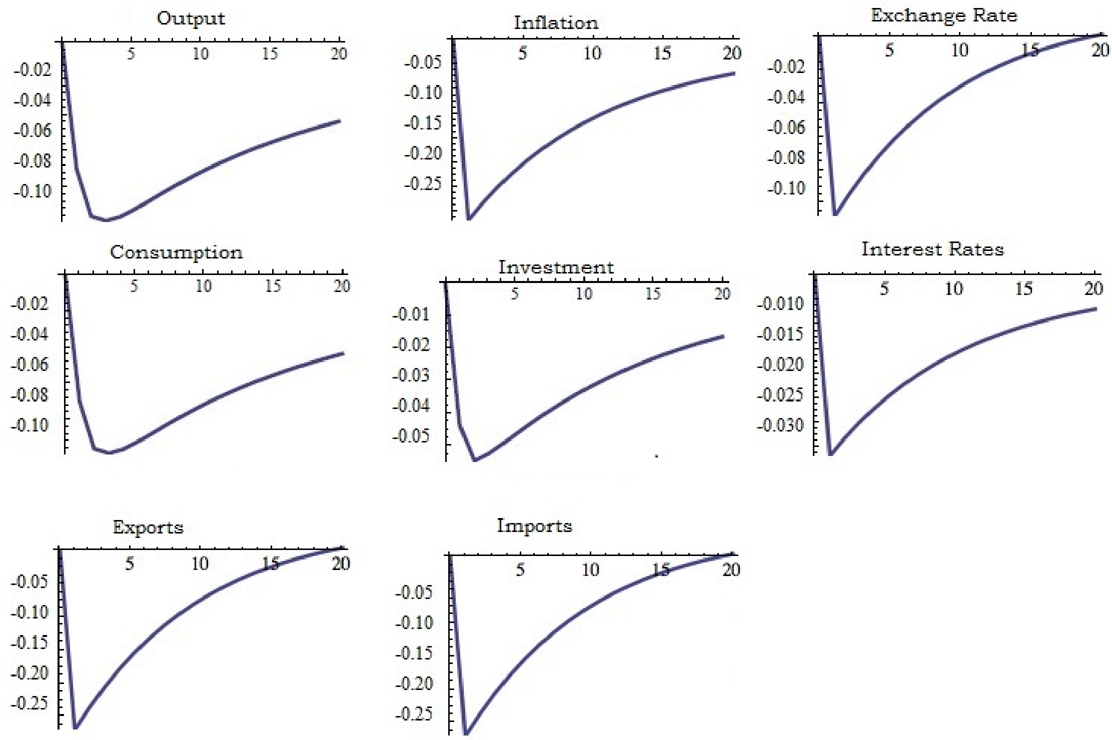
The following section discusses the dynamic behavior of the model after a volatility shock to the monetary policy.

3.3.2 Results

This section presents the results obtained from the analysis of the dynamic behavior of the model economy following positive shock to the volatility of the monetary policy shock. Figure 3.2 and 3.3 plot the impulse responses to a monetary policy volatility shock. The impulse responses for inflation and nominal interest rates are plotted in annualized percent deviations from their ergodic mean, while the others are plotted as percent deviations from their ergodic mean. The model is simulated starting from its steady state for 2096 periods and first 2000 periods are disregarded as burn-in. The mean of ergodic distribution for each variable is computed based on the last 96 periods.

A higher volatility of interest rate shock leads consumption and inflation also be more volatile in the future. Thus, representative household wants to decrease the consumption and increase the labor supply after an increase in the uncertainty about future policy path. An increase in the labor supply reduces the cost of labor for intermediate good producers. Due to Rotemberg price adjustment, this decrease leads to an increase in the firm's markup, decreasing firm's demand for labor, which lowers the real wage earned by the household. Hence, due to the reduction in the demand for labor, investment falls. In this model, inflation depends on the real marginal costs of the firm, which depends on the rental rate of capital and the real wage. Since both the rental rate of capital and the real wage decrease, the marginal cost of production falls,

Figure 3.2: Impulse responses of open economy model to a monetary policy volatility shock

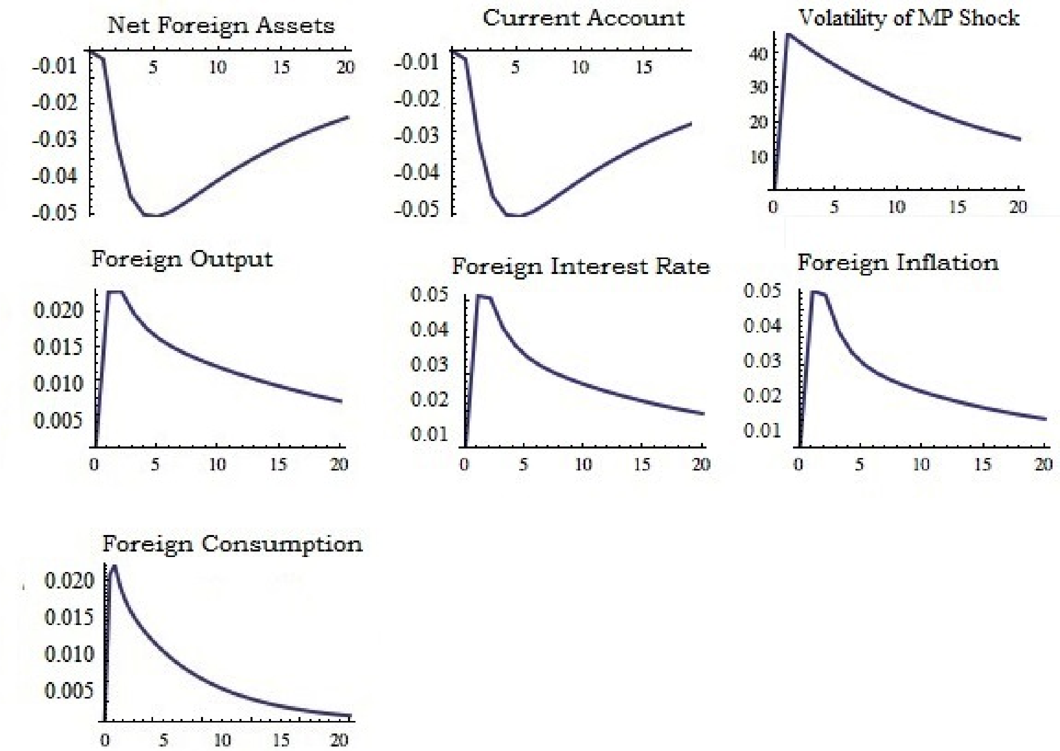


leading to a decline in the inflation.

For this exercise, in response to a monetary policy volatility shock the level of the interest rate is also changing due to the use of Taylor type feedback rule for monetary policy.[2] Fixing the interest rate to its steady state level for two-county New Keynesian model induce problems in keeping the determinacy of equilibria, thus I allow for the changes in the level of the interest rate once the economy is hit by a second order shock. Allowing for the changes in the level of interest rate lead to a smaller magnitude impulse responses than would have been obtained in the case of fixing it to its steady state level, but still

[2]Shocks to the volatility of the monetary policy shock have effects on output and inflation, and those effects feedback into the level of the interest rate.

Figure 3.3: Impulse responses of open economy model to a monetary policy volatility shock - Cont'd



the results hold.

In the two-country setup, to smooth consumption over time, home households increase the home and foreign bond holdings, leading to a decrease in the net foreign asset position and current account falls. As it can be seen from the interest rate parity equation below an increase in the interest rate uncertainty, combined with consumption reduction induces an appreciation in the exchange rate.

$$E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \frac{S_t}{S_{t+1}} R_t^* \left(1 + \frac{\psi_B S_t (B_{F,t} - B_F)}{P_{H,t} Z_t} \right)^{-1} \right\}$$
$$= E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} R_t \right\}$$

Thus, the decrease in the consumption and investment combine to lead to a decrease in the output.

3.4 Conclusion

The recent financial crisis has led central banks to rely more on their official communication channels. Signaling about the likely future path of policy rate can either be done by providing explicit numerical guidance or instead, using a vague language and create uncertainty. We can observe the explicit guidance example on Federal Reserve and ECB policies, and as shown this leads to a decrease in the uncertainty about future policy rate path. On the other hand, allowing fluctuations in the policy rate as seen in the Turkish example leads to a more volatile policy rate. CBRT cites the concerns about capital flows while increasing the uncertainty about expected policy path.

This chapter aims at analyzing the effects of an increase in the interest rate uncertainty on macroeconomic variables in a two-country New Keynesian framework. The results show that, the impacts of a change in the volatility of interest rate mimic the impacts of a change in the interest rate level. The findings in the two-country New Keynesian model suggest that an increase in the volatility of the interest rate shock distorts capital flows, and leads to an appreciation in the exchange rate while reducing the output. Changing uncertainty about future policy path is shown to have quantitatively important implications, and monetary policy makers should also consider using this channel while conducting monetary policy.

CHAPTER 4

POLICY PATH UNCERTAINTY AND ASSET PRICES

Monetary policy makers have been providing guidance about the future stance of monetary policy by using their official communications for at least twenty years. After the recent financial crisis the announcements gained more importance as the traditional tool of monetary policy - policy rate- was reduced to zero. Central banks have started to use these announcements as a substitute for lower interest rate levels since the announcements of keeping the interest rate lower for a period of time, through the expectation hypothesis, affects the long rates, and creates extra stimulus to the economy. However, the effects of the announcements –i.e. forward guidance– is not limited to this channel. Through official communication central banks affect the variability of the policy rate beliefs, and the more the announcements contain policy rate commitments, the more the uncertainty about the expected policy rate declines.

The aim of this study is to compute the sensitivity of the interest rates of various maturities to the language used in the monetary policy statements.

To measure these effects, in the first part of the analysis, by following the earlier literature on event studies such as Cook and Hahn (1989), Kuttner (2001), Rigobon and Sack (2004), and Soderstrom and Ellingsen (2004), a one-factor analysis of monetary policy announcements on asset prices for the period from January 2007 through October 2013 is studied. Here, only the effects of monetary policy surprises are taken into consideration, and shown that unanticipated federal funds target change have significant effects on short-term assets, however, this effect disappears as the maturity increases.

In the second part of the analysis, building on the work of Gürkaynak et al. (2005), the FOMC announcements are divided into two parts; first part of the announcement, called the target factor, communicates the changes in the current federal funds target rate, and the second part, named as path factor, moves the expected future rates without chaining the current policy rate. While target factor acts more like monetary policy surprise component of the first part analysis, the path factor has significant effect on the long-term asset yields. This finding shows that the market participants rely on the FOMC statements about future stance of monetary policy for a sample from January 2007 through October 2013.

The context of the FOMC announcements, on the other hand, has changed throughout the course of current financial crisis. In the FOMC meeting statement on December 2008, it is stated that "The Federal Open Market Committee decided today to keep its target range for the federal funds rate at 0 to 1/4 percent. The Committee continues to anticipate that economic conditions are likely to warrant exceptionally low levels of the federal funds rate for some time.”

Later on the August 2011 statement, the committee also included information of how long they anticipated the rate would stay at this level as “The Committee agreed to keep the target range for the federal funds rate at 0 to 1/4 percent and to state that economic conditions are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013.”

Those two announcements, despite the fact that the communicated expected policy rate is about the same, have different language. The first one comes with a wide distribution while the latter with a tight distribution, meaning that the variability of the expected future policy rate is higher in the first statement, while it is low in the second. These differences in the communication can no longer be identified by using the path factor only. Thus, in the third part of the analysis, ‘uncertainty surprise’ component, that measures the changes in the interest rate uncertainty, is added as another factor. In this analysis, it is showed that the uncertainty surprise plays an important role, especially in the long-term asset yields such that as FOMC provide more explicit guidance, it boosts the stock market.

The analysis in this chapter shows evidence on the effectiveness of the monetary policy even when the traditional tool cannot be used due to zero lower bound constraint. In the recent years there is a rapidly growing literature on the monetary policy effectiveness by assessing the effects of unconventional policies. Swanson (2011) by using high frequency data made an even-study of Operation Twist and compares its effects to the recent quantitative policy announced by the Federal Reserve. In a more recent study, Williams and

Swanson (2012) measure the effects of zero lower bound on interest rates of any maturity by estimating high-frequency sensitivity of those interest rates to macroeconomic announcements. They find that even if the zero lower bound is a binding constraint, treasury yields with a year and more maturity were responsive to the macroeconomic news between 2008 and 2010, however, this effect disappears after 2011. Wright (2011), on the other hand, identifies the effects of monetary policy shocks on various long term interest rates by using structural VAR with daily data for the period November 2008 to December 2010. Doh (2010), and Greenwood and Vayanos (2010) quantify the effects of unconventional open-market operations on changing the yields of assets with different maturity for the same period.

There is also a growing literature on analyzing the effects of forward guidance theoretically. Most of these works impose forward guidance into the model as a factor that keeps the interest rate level at zero for a predetermined period (Campbell et al. (2012), Negro et al. (2012), Bianchi and Melosi (2013)).

The contribution of this analysis is twofold. First, it contributes to the literature where the effects of monetary policy on asset markets are studied by extending the existing analyses for the up-to-date data. Second and most importantly, it identifies a different channel for the effectiveness of forward guidance. The results suggest that forward guidance is effective not only because the monetary policy maker promise to keep the interest rate at low levels, but also because it reduces the variability of the expected federal funds rate and this has expansionary effect itself.

The remaining of the paper proceeds as follows. Section 4.1 gives some examples of recent use of forward guidance by leading central banks. Section 4.2 describes the data and methodology used, and studies the results, while section 4.3 concludes.

4.1 Forward Guidance and Reducing Uncertainty

After the financial crisis, to stimulate the economy, leading monetary policy makers reduced the policy rates to zero bound levels. Therefore, the traditional tool of monetary policy - short term interest rate - can no longer be used as before. In this environment, in addition to other unconventional tools, forward guidance became a policy tool of the utmost importance. Since central banks can no longer affect the long term interest rates via short term rate, they started to signal about the future path of policy rate for this purpose. Eggertsson and Woodford (2003) show that, at the zero nominal bound on the interest rates, the unconventional monetary policy can lower long-term bond yields only if central banks can make a credible commitment to keep interest rates low even after the economy recovers. Thus, in the light of their work, most of the policy makers include projected forward paths for their policy rate in their announcements. A few examples of the use of forward guidance, other than the way Federal Reserve Bank implements this policy tool, can be found below:

The European Central Bank who had firmly refused to offer guidance on its future policy before, stated on July 2013 that “it would keep interest rates low for an extended period of time".

On the other hand, sometimes forward guidance is not used for giving certainty but creating uncertainty. We can find an example of the use of constructive ambiguity in Turkish example. The CBRT stated in the committee meeting announcement on December 2010 that "Committee has come to the conclusion that it would be an appropriate policy mix to lower the policy rate and to widen the corridor between overnight borrowing and lending rates so as to allow fluctuations in the short-term interest rates, when needed." This leads to a decrease in the predictability of the policy rate.

These being said, it is clear that forward guidance affects the uncertainty around the expected policy rate, and a greater attention should be paid to the effects and the transmission mechanism of this tool to financial markets.

4.2 Data and Methodology

To measure the markets' reaction to monetary policy announcements, following Kuttner (2001) I estimate the following regression equation:

$$\Delta y_t = \alpha + \beta \Delta r_t^u + \epsilon_t \tag{4.1}$$

where Δy_t denotes the change in a stock market index or a bond yield over a day around the monetary policy announcements, Δr_t^u denotes the surprise component of the change in the federal funds target rate measured by using federal funds futures, and ϵ_t is a stochastic error term.

Following Kuttner (2001), to estimate Equation (4.1) daily data is used, for a sample consisting of 54 FOMC monetary policy announcement from January 2007 through October 2013. The use of daily data is crucial here because in order to satisfy the basic regression assumption that ϵ_t being orthogonal to Δr_t^u one should use frequent data so that the response of financial markets is limited to announcements.

For each monetary policy announcement, by using federal funds futures, I measure the surprise component of the change in the federal funds target rate. Federal funds futures have been used as a proxy to measure the expectations of Federal Reserve Board's policy. The futures market was established in October 1988 at the Chicago Board of Trade. In this market, along with a spot-month contract based on the current month's funds rate, contracts based on one- through five-month Federal Funds are traded. Federal funds futures' contracts' settlement price is based on the average of the relevant month's effective overnight federal funds rate thus daily changes in this rate reflects the revisions in the market participants' expectations over the rest of the month. To get the correct measure of the expected funds rate on any specific day, the time-averaging is undone by considering the remaining days of the month effect.

Then, following Kuttner (2001), one-day surprise component in the spot-month's futures rate can be calculated as:

$$\Delta r_t^u = \frac{m_s}{m_s - t}\left(f_{s,t}^0 - f_{s,t-1}^0\right)$$

where $f_{s,t}^0$ is spot-month futures rate on day t of month s (m_s). For the first day of month, however, instead of using $f_{s,t-1}^0$ one-month futures rate from the last day of the previous month $f^0_{s-1,t}$ would be used.

The surprise component series calculated with this formulation can be found in the Appendix B.

Table 4.1 represents the results for the regression Equation (4.1) estimated using daily data on equity prices and bond yields. The independent variable is the monetary policy surprise component of the change in the federal funds target rate, calculated by using federal funds futures as described above. In this analysis, the dependent variable is the change in the yields of three- six-month bills, two- five- ten-year notes with S&P500 index.

Table 4.1: Response of Asset Prices to MP Surprise Component

	Constant (std error)	Monetary Policy Surprise (std error)	R^2
S&P	0.613***	-1.761**	0.018
	(0.226)	(0.810)	
Three-Month Bill	-0.013***	0.185***	0.188
	(0.006)	(0.030)	
Six-Month Bill	-0.009*	0.163***	0.201
	(0.005)	(0.034)	
Two-Year Note	0.010	-0.007	0.0002
	(0.079)	(0.106)	
Five-Year Note	-0.009	-0.056	0.003
	(0.015)	(0.059)	
Ten-Year Note	-0.006	-0.048	0.002
	(0.016)	(0.058)	

Note: The sample period is January 2007-October 2013, for a total of 54 FOMC announcements. Heteroskedasticity-robust standard errors are in parentheses. *, ** and *** denote significance at the 10 percent, 5 percent, and 1 percent, respectively.

As it can be seen from the Table 4.1, for this period, the response of three- and six-month bills to an unanticipated monetary policy action is highly significant, however, this significance disappears with the longer maturities. In addition, comparing the results to of this regression to the findings of Kuttner (2001) (or to more recent similar studies as Gürkaynak et al. (2005)), we see that the responses of yields and stock market index to surprise changes in the federal funds target rate are decreased for the analysis period. This is mostly due to the zero lower bound becoming a binding constraint after December 2008 and we can no longer assume that the effects of announcements on asset prices are mostly described by the surprise component of the change in the federal funds target rate.

In a recent study Gürkaynak et al. (2005), by using a sample from June 1991 through December 2004, find that the effects of FOMC announcements on treasury yields and equity prices are not only associated with surprise changes in the federal funds target rate. They measure the surprise changes in the expected future spot interest rates due to FOMC announcements, by using high frequency data on prices of federal funds futures and eurodollar future contracts, and estimate two factors, namely target factor and path factor. Target factor is defined as the unexpected change in the current federal funds target rate while path factor is defined as the remaining aspects of the FOMC announcements that without changing the current federal funds rate moves the expected future rates.

Thus, following the methodology defined in Gürkaynak et al. (2005), I estimate the target and path factor for the period from January 2007 through October 2013, and estimate the following regression equation:

$$\Delta y_t = \alpha + \beta_1 \Delta TF_t + \beta_2 \Delta PF_t + \epsilon_t \tag{4.2}$$

for each monetary policy announcement, and again for treasury yields and equity prices. The results are reported in Table 4.2.

Table 4.2: Response of Asset Prices to Target and Path Factors

	Constant (std error)	Target Factor (std error)	Path Factor (std error)	R^2
S&P	0.560***	1.980**	-0.244	0.071
	(0.208)	(0.659)	(0.195)	
Three-Month Bill	-0,019***	0.191***	-0.0004	0.189
	(0.006)	(0.032)	(0.008)	
Six-Month Bill	-0.015***	0.167***	0.015	0.448
	(0.004)	(0.016)	(0.005)	
Two-Year Note	-0.008	0.025	0.040***	0.535
	(0.007)	(0.024)	(0.008)	
Five-Year Note	-0.0074	-0.0639**	0.048***	0.386
	(0.015)	(0.059)	(0.810)	
Ten-Year Note	-0.005	-0.067*	0.045**	0.320
	(0.031)	(0.038)	(0.017)	

Note: The sample period is January 2007-October 2013, for a total of 54 FOMC announcements. Target and path factors are as defined in Gürkaynak et al. (2005). Heteroskedasticity-robust standard errors are in parentheses. *, ** and *** denote significance at the 10 percent, 5 percent, and 1 percent, respectively.

From Table 4.2 we can see that yields on longer duration treasury notes respond to path factor more significantly, while the shorter duration treasury bills responds substantially to target factor. Quantitatively speaking, 1 percentage point innovation to the path factor causes responses 4, 4.8 and 4.5 basis points in two-, five- and ten-year treasury yields, respectively, showing that path factor has greater impacts on the long end of the yield curve. Once we check the stock market response we see that, the effect of announcements on stock prices is also substantial, confirming our expectations, since stock prices index also have very long durations. The findings suggest that market participants think the FOMC announcements contain reliable information about the future stance of monetary policy action. In Gürkaynak et al. (2005), the authors also conclude the same results for a different period and here I verify that the findings still hold for the recent episode.

The period focused on this paper is unique when it is compared to the periods used in other papers in the existing literature[1]. The uniqueness of the period arises from the FOMC reducing the policy rate to zero nominal levels on December 2008 to alleviate the effects of financial crisis and up until now the federal funds target rate is kept at this level. Thus, the federal target rate change is zero, however, the FOMC announcements contains different levels of information.

Having shown that the information context of the FOMC statements play an important role for the January 2007-October 2013 period, next step is to show how the differences in the information embedded in the FOMC statements play role for the asset market responses. Thus, another factor called 'uncertainty surprise' is added to the analysis.

4.2.1 Measuring Uncertainty Surprise

In the literature using option prices to measure the interest rate uncertainty is a common way since option prices depend on the perceived volatility of the underlying asset, and thus can be used to quantify the expected volatility of an asset's price. In this paper I use the implied volatility calculated by using 3-month Eurodollar options as a measure of interest rate uncertainty.

Options are derivative assets, meaning that their payoffs depend on the price of the underlying asset. For Eurodollar options, the underlying asset is Eurodollar futures contract, whose payoff is tied to the three-month London interbank offered rate (LIBOR). These options are among the most actively

[1] Kuttner (2001) focused on June 1989-February 2000 while Gürkaynak et al. (2005) made the analysis for January 1990-December 2004. Cochrane and Piazzesi (2002), and Soderstrom and Ellingsen (2004) also focus on the pre-financial crisis period.

traded exchange-listed interest rate options contracts in the world, traded at the Chicago Mercantile Exchange Group. Their price depends on uncertainty about LIBOR's future value and this uncertainty is reported as 'implied volatility', that is the variability of the underlying LIBOR rate implied by the price of the option. LIBOR rate is not exactly the fed funds rate, however, it is highly tied to the latter. Thus, by using Black-Scholes (Black and Scholes (1972)) option pricing model, I calculate the implied volatility for three-month Eurodollar options.

Black-Scholes formula represents the value of a European option [2] (C), as a function of the underlying asset price (S), interest rate (r), the strike price (X), time to expiry (T), and the underlying asset return's variance (σ) as:

$$C = S_0 N(d_1) - X e^{-rT} N(d_2) \tag{4.3}$$

where

$$d_1 = \frac{\log(S_0/X) + (r + \sigma^2/2)T)}{\sigma\sqrt{T}}$$

and

$$d_2 = \frac{\log(S_0/X) + (r - \sigma^2/2)T)}{\sigma\sqrt{T}}$$

$N(.)$ is the cumulative normal density function.

Even if the Black-Scholes model makes important assumptions on the distribution of underlying asset prices, riskless rate, and transaction costs such that underlying asset returns follow a lognormal distribution, riskless rate is

[2] Black-Scholes formula applies to European options only because they can only be exercised on expiry date. American options, on the other hand, can be exercised any time prior to expiry.

a known function, and there is no transaction costs or no arbitrage condition, it is widely used for option price calculations, and also for implied volatility analyses.

In the calculation of European option prices all of the arguments other than variance of the underlying asset are observable. Most of the time Equation (4.3) is inverted to calculate this term – implied volatility– in terms of observed quantities. In this analysis, following Neely (2005) I calculate the Black-Scholes implied volatility as:

$$\hat{\sigma}^2_{BS} = \left(1 - \frac{1}{8}\frac{Var(\bar{V}_{t,T})}{(E_t\bar{V}_{t,T})^2}\right)^2 E_t\bar{V}_{t,T} \tag{4.4}$$

where

$$\bar{V}_{t,T} = \frac{1}{T-t}\int_{\tau}^{T} V_{\tau} d\tau \tag{4.5}$$

represents the average variance until expiry.

Table 4.3 shows the summary statistics of the uncertainty surprise measure, that is calculated as described above for monetary policy announcement dates the period from January 2007 through October 2013.

Table 4.3: Summary Statistics for Uncertainty Surprise

	Observation	Mean	Std. Dev.	Min	Max
Uncertainty Surprise	54	-0.01535	0.03989	-0.18956	0.1061

To measure the effects of different types of forward guidance that have been employed, including commitments to keep rates at zero for a specific period of time, and commitments to keep rates at zero until the macroeconomic conditions have changed, the regression below is estimated.

$$\Delta y_t = \alpha + \beta_1 \Delta TF_t + \beta_2 \Delta PF_t + \beta_3 \Delta US_t + \epsilon_t \tag{4.6}$$

where US_t is the uncertainty surprise measure calculated as described above, while TF_t and PF_t are target and path factors, respectively.

Path factor and uncertainty surprise component are both about expectations mostly shaped with the information got from announcements. Despite the fact that we can distinguish between those two by using different instruments for measurement, we still need to control for the correlation so that we can be sure of the estimation efficiency. Table 4.4 shows the correlation analysis results.

Table 4.4: Correlations Between Target Factor, Path Factors and Uncertainty Surprise

	Target Factor	Path Factor	Uncertainty Surprise
Target Factor	1.000		
Path Factor	0.000	1.000	
Uncertainty Surprise	0.118	0.376	1.000

The correlation between uncertainty surprise and the path factor being 0.376 suggests that there is no problem of multicollinearity between factors. Thus, we can continue with the regression analysis.

The results of the regression estimation is given in Table 4.5.

As it can be seen from the table the uncertainty component added to the analysis play an important role, especially for the long-term asset yields. An increase in the uncertainty surprise can be interpreted as an increase in the uncertainty about monetary policy, and the results show that this increase will

Table 4.5: Response of Asset Prices to FOMC Announcements

	Target Factor	Path Factor	Uncertainty Surprise	R^2
S&P	1.918**			0.017
	(0.779)			
		-0.253		0.044
		(0.233)		
			-22.505***	0.342
			(4.446)	
	2.971***	0.017	-24.153***	0.407
	(0.526)	(0.193)	(4.520)	
Two-Year Note	0.028			0.002
	(0.064)			
		0.041***		0.520
		(0.008)		
			0.499**	0.076
			(0.214)	
	0.026	0.041***	0.046	0.52
	(0.030)	(0.009)	(0.201)	
Five-Year Note	-0.058			0.003
	(0.048)			
		0.050***		0.370
		(0.015)		
			1.214***	0.217
			(0.296)	
	-0.496***	0.041**	0.839***	0.462
	(0.027)	(0.016)	(0.254)	
Ten-Year Note	-0.065			0.004
	(0.039)			
		0.047**		0.314
		(0.017)		
			1.155***	0.192
			(0.030)	
	-0.100**	0.037**	0.816***	0.40
	(0.037)	(0.018)	(0.230)	

Note: This table reports the results of regressions of daily S&P returns, and note rates of different maturities onto the path and volatility surprises on FOMC announcement days. Target and path factors are as defined in Gürkaynak et al. (2005), while the uncertainty surprise is the change in the daily change in the annualized options-implied volatility on that contract. Interest rates and implied volatilities are measured in percentage points, stock prices are measured as 100 times log price changes. The sample period is January 2007-October 2013, for a total of 54 FOMC announcements. Heteroskedasticity-robust standard errors are in parentheses. *, ** and *** denote significance at the 10 percent, 5 percent, and 1 percent, respectively.

cause yields to rise, and stock market index to fall. The $S\&P$ coefficient is estimated to be too high, stating that a 4 bps reduction in uncertainty leads to a 1% increase in the $S\&P$. One possible explanation to this high response could be the measure of uncertainty surprise itself. Implied volatility calculated by using Eurodollar options also contains the financial market uncertainty, and during the sample period this uncertainty skyrocketed. Thus, as a financial market measure, $S\&P$ has the largest response to the innovations, in other words to the uncertainty changes on the monetary policy announcement dates.

The results suggest that the information added to the announcements play a crucial role, and indeed it has significant effect on market participants' expectations even if on average the expected policy rate remains the same.

The significance of the channel also suggest that forward guidance is not only effective because the monetary policy maker promise to keep interest rate at low levels, but also because it reduces the variability of the expected federal funds rate. From the regression results we can see that the more informative the statements, the less volatile the policy expectations, and thus the higher the yields of the long-term asset. In other words reducing the uncertainty about expected future federal rates is shown to be expansionary policy action itself.

These findings are also in line with the theoretical model predictions of the previous two chapters. Thus completes the theoretical work by stating that the uncertainty about future monetary policy is an instrument itself and especially on times where the policy maker cannot use the policy rate effectively, it can be use as an unconventional monetary policy instrument.

4.3 Conclusion

Does the language of the FOMC announcements matter even if the policy rate communicated is on average the same? The findings in this chapter suggest that it is the case. Indeed the empirical analysis shows that market participants rely on the information context of the FOMC announcements and the difference in this context, in return, effects the financial asset yields.

I began this chapter by asking whether the monetary policy surprise component, measured by federal fund futures, have significant effects on asset prices for the period from January 2007 through October 2013, and the event-study analysis shows that the surprise component has significant effects for short-term treasury yields. Then, I continue to the analysis, by differentiating the factors that effects asset yields depending on the FOMC announcements' context. Following Gürkaynak et al. (2005) two factors; target factor that changes the current federal funds rate, and path factor that changes the expected future rates without changing the current policy rate is estimated. The regression analysis shows that the long term assets respond more significantly to the changes in the path factor whereas the short term assets respond more to the changes in the target factor. This result suggest that market participants rely on FOMC announcements, and the information communicated in those statements regarding the future expected policy rate.

The current financial crisis lead many central banks to lower their interest rate the zero and the policy announcements gain even more importance. Having showed that for long-term assets yields respond significantly to the information embedded into the statement, the natural question arises whether the language used in these statements, in other words, the expected policy rate uncertainty, matter. In the event-study analysis it is shown that the more precise the information in the statements, the less variable the monetary policy rate expectations, and this has significant effect especially on the long-term treasury notes.

The findings have important implications for the literature where the effects of monetary policy on asset markets are studied, and on the effectiveness of forward guidance through a different channel. The results suggest that forward guidance is effective not only because the monetary policy maker promise to keep interest rate at low levels, but also because it reduces the variability of the expected federal funds rate and this effect is expansionary itself.

In the lights of the findings in this empirical work, to see the effects of zero lower bound on long term yields a term structure model incorporating the zero lower bound constraint will be studied as a future work.

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APPENDICES

A Foreign Country Open Economy Model

Households

There is a continuum of households in the economy. Household derive utility from consumption, C_t, and disutility from supplying labor, L_t. They are the owner of intermediate good firms and the capital stock.

The optimization of foreign country representative household can be written as:

$$\max E_t \sum_{t=0}^{\infty} \beta^t U_t^*(C_t^*, L_t^*) = \max E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{*,1-\sigma}}{1-\sigma} - \frac{L_t^{*,1+\psi}}{1+\psi} \right] \tag{A.1}$$

subject to the period budget constraint:

$$\begin{aligned} P_t^*(C_t^* + I_t + AC_{I,t}^* + \frac{1}{R_{t-1}^*} B_{F,t}^*) + \frac{1}{S_t} \frac{1}{R_{t-1}} B_{F^*,t}^* + AC_{B,t}^* \\ = B_{F,t-1}^* + \frac{1}{S_t} B_{H,t-1}^* + W_t^* L_t^* + P_t^* r_t^* K_t^* + \Pi_t^* \end{aligned}$$

where

$$AC_{I,t}^* = \frac{\psi_I}{2} \frac{(K_t^* - K_{t-1}^*)^2}{K_t^*} \tag{A.2}$$

$$AC_{B,t}^* = \frac{\psi_B}{2} \frac{(B_{H,t}^* - B_H^*)^2}{S_t P_{F,t}^* Z_t^*} \tag{A.3}$$

$$I_t^* = \left(K_t^* - (1-\delta)K_{t-1}^*\right) \tag{A.4}$$

The household receives income from supplying labor W_t^*, and renting capital r_t^* and receives profits from ownership of home intermediate good firms, Π_t^*. The household can invest in two types of assets: a noncontingent nominal bond denominated in their currency $B_{F,t}^*$ with a return R_t^* and a noncontingent nominal bond denominated in home country currency $B_{H,t}^*$ which pays an interest rate R_t where S_t again represents the nominal exchange rate, defined as the home currency price of a unit of foreign currency. The capital is subject to depreciation with a constant rate, δ, and to quadratic adjustment cost that depends on the parameter, ψ_I. Z_t^* represents the total output level.

The first order conditions of the representative household's optimization problem are given as:

$$\frac{L_t^{*,\psi}}{C_t^{*,-\sigma}} = \frac{W_t^*}{P_t^*} \tag{A.5}$$

$$\frac{1}{R_t^*} = \beta E_t \left\{ \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \frac{P_t^*}{P_{t+1}^*} \right\} \tag{A.6}$$

$$\begin{aligned} E_t \left\{ \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \frac{P_t^*}{P_{t+1}^*} \frac{S_{t+1}}{S_t} R_t \left(1 + \frac{\psi_B (B_{H,t}^* - B_H^*)}{S_t P_{F,t}^* Z_t^*} \right)^{-1} \right\} \\ = E_t \left\{ \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \frac{P_t^*}{P_{t+1}^*} R_t^* \right\} \end{aligned} \tag{A.7}$$

$$\begin{aligned} \left(1 + \frac{\psi_I (K_t^* - K_{t-1}^*)}{K_{t-1}^*} \right) = \beta E_t \left\{ \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \right. \\ \left. \left(r_{t+1}^* + (1+\delta) + \frac{\psi_I}{2} \frac{K_{t+1}^{*,2} - K_t^{*,2}}{K_t^{*,2}} \right) \right\} \end{aligned} \tag{A.8}$$

Equation (A.5) is the household's intertemporal optimality condition with respect to consumption and leisure, where Equation (A.6) represents the consumption Euler. Equation (A.7) is the interest parity condition with the risk premium, while Equation (A.8) is the optimality condition of capital accumulation.

The stochastic discount factor, $\Lambda^*_{t,t+1}$ is given as:

$$\begin{aligned}\Lambda^*_{t,t+1} &= \left(\frac{\partial U^*_{t+1}}{\partial C^*_{t+1}}\frac{1}{P^*_{t+1}}\right)\left(\frac{\partial U^*_t}{\partial C^*_t}\frac{1}{P^*_t}\right)^{-1} \\ &= \beta E_t\left\{\left(\frac{C^*_{t+1}}{C^*_t}\right)^{-\sigma}\frac{P^*_t}{P^*_{t+1}}\right\}\end{aligned}$$

Also, the current account can be defined as:

$$CA^*_t = (B_{F,t} - B_{F,t-1}) - \frac{1}{S_t}(B^*_{H,t} - B^*_{H,t-1}) \tag{A.9}$$

Firms

In the model there are two types of firms, namely; final good producers and intermediate good producers, explained in detail below.

Final Good Sector

Final good producers are perfectly competitive, and the representative firm produces the final good, Y_t, by using the intermediate goods from home and foreign country with the following constant returns to scale production function:

$$Y^*_t = \left[(1-a)^{1/\mu}Y_{F,t}^{*,\frac{\mu-1}{\mu}} + a^{1/\mu}Y_{H,t}^{*,\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}}$$

where

$$Y^*_{F,t} = \left(\int_0^1 y^*_{F,t}(i)^{(\lambda-1)/\lambda}di\right)^{\lambda/(\lambda-1)} \tag{A.10}$$

$$Y^*_{H,t} = \left(\int_0^1 y^*_{H,t}(j)^{(\lambda-1)/\lambda} dj \right)^{\lambda/(\lambda-1)} \tag{A.11}$$

where $\mu \geq 1$ denotes the elasticity of substitution between home and foreign goods, λ is the elasticity of substitution between intermediate goods produced within the same country and $1 - a$ is the share of foreign goods used in the production of final goods in foreign country, thus a becomes a natural index of openness. Lower cases represent the individual firms' output.

The representative firm chooses Y^*_t, $Y^*_{H,t}$, and $Y^*_{F,t}$ to maximize profits subject to production technology, taking all the intermediate goods prices, $P^*_{H,t}$, $P^*_{F,t}$, and the final good price, P^*_t, as given. $P^*_{H,t}$, $P^*_{F,t}$ are price indexes of home goods and foreign goods respectively, both in foreign currency. Thus, the maximization problem becomes:

$$\max P^*_t Y^*_t - P^*_{F,t} Y^*_{F,t} - P^*_{H,t} Y^*_{H,t}$$

The price index, P^*_t, is defined as:

$$P^*_t = \left[(1-a) P^{*,1-\mu}_{F,t} + a P^{*,1-\mu}_{H,t} \right]^{\frac{1}{1-\mu}}$$

where

$$P^*_{F,t} = \left(\int_0^1 p_{F,t}(i)^{*,(1-\lambda)} di \right)^{1/(1-\lambda)} \tag{A.12}$$

$$P^*_{H,t} = \left(\int_0^1 p_{H,t}(j)^{*,(1-\lambda)} dj \right)^{1/(1-\lambda)} \tag{A.13}$$

Given the problem of the final good producer, the demand will be allocated between home and foreign goods as:

$$Y^*_{F,t} = (1-a) \left(\frac{P^*_{F,t}}{P^*_t} \right)^{-\mu} Y^*_t \tag{A.14}$$

$$Y^*_{H,t} = a \left(\frac{P^*_{H,t}}{P^*_t} \right)^{-\mu} Y^*_t \tag{A.15}$$

and the demands for individual goods are:

$$y^*_{F,t}(i) = \left(\frac{p^*_{F,t}(i)}{P^*_{F,t}} \right)^{-\lambda} Y^*_{F,t} \tag{A.16}$$

$$y^*_{H,t}(j) = \left(\frac{p^*_{H,t}(j)}{P^*_{H,t}} \right)^{-\lambda} Y^*_{H,t} \tag{A.17}$$

Intermediate Goods Sector

Firms use the labor $L^*_t(i)$ and capital $K^*_t(i)$ they rent from households to produce intermediate goods $z^*_t(i)$ in a monopolistically competitive environment by using constant-returns to scale Cobb-Douglas production function.

The intermediate good producers face a quadratic cost of adjusting nominal prices à la Rotemberg price setting mechanism (Rotemberg, 1982), and firms set prices in their own currency both for sales domestically and sales abroad, that is the essence of producer currency pricing.

Firm i maximizes its cash flow $\Pi^*_{F,t}(i)$ by choosing $L^*_t(i), I_t$ and $p^*_{F,t}(i)$, given aggregate demand $z^*_t(i)$ and the price of the final good P^*_t.

The problem of the firm is then;

$$\max E_t \sum_{j=0}^{\infty} \Lambda^*_{t+j} \Pi^*_{F,t}(i)$$

where

$$\Pi^*_{F,t}(i) = p^*_{F,t}(i) z^*_t(i) - \left(\frac{(r^*_t P^*_t)^\alpha W^{*,1-\alpha}_t}{A^*_t \alpha^\alpha (1-\alpha)^{1-\alpha}} + \frac{\psi_P}{2} \frac{(p^*_{F,t}(i) - p^*_{F,t-1}(i))^2}{p^*_{F,t-1}(i)} \right) z^*_t(i) \tag{A.18}$$

subject to

$$z^*_t(i) = A^*_t K^{*,\alpha}_t(i) L^{*,1-\alpha}_t(i) = y^*_{F,t}(i) + y_{F,t}(i) \tag{A.19}$$

and

$$y^*_{F,t}(i) = \left(\frac{p^*_{F,t}(i)}{P^*_{F,t}}\right)^{-\lambda} Y^*_{F,t} \tag{A.20}$$

and $\Lambda^*_{t,t+j}$ is the stochastic discount factor. In each period, firms can change their price $p^*_{F,t}(i)$ at a cost.

The first order conditions for the intermediate good firm are:

$$P^*_t r^*_t K^*_{t-1}(i) = \frac{\alpha}{1-\alpha} W^*_t L^*_t(i) \tag{A.21}$$

$$\begin{aligned} p^*_{F,t}(i) = \frac{\lambda}{(\lambda-1)} \Bigg(\frac{(r^*_t P^*_t)^\alpha W_t^{*,1-\alpha}}{A_t \alpha^{*,\alpha}(1-\alpha)^{1-\alpha}} \\ + \frac{\psi_P}{2} \frac{(p^*_{F,t}(i) - p^*_{F,t-1}(i))^2}{p^*_{F,t-1}(i)} \Bigg) + \frac{\psi_P}{\lambda-1} p^*_{F,t}(i) \left(1 - \frac{p^*_{F,t}(i)}{p^*_{F,t-1}(i)}\right) \\ + \frac{1}{2}\frac{\psi_P}{\lambda-1} P^*_{F,t}(i) E_t \left\{ \Lambda_{t,t+1} \left(1 - \frac{p^{*,2}_{F,t+1}(i)}{p^{*2}_{F,t}(i)}\right) \frac{Y^*_{F,t+1}}{Y^*_{F,t}} \right\} \end{aligned} \tag{A.22}$$

Equation (A.21) shows the trade-off between capital and labor inputs, while equation (A.22) represents the price setting behavior.

In the symmetric equilibrium $p^*_{F,t}(i) = P^*_{F,t}$.

B Estimated Factors Data

Table A.1: Target and Path Factors

Date	Target Factor	Path Factor	Date	Target Factor	Path Factor
31-Jan-07	0.03	-0.16	28-Apr-10	0.02	0.05
21-Mar-07	0.04	-1.33	23-Jun-10	0.02	0.4
09-May-07	0.02	0.81	10-Aug-10	0.03	-0.32
28-Jun-07	0.02	01.19	21-Sep-10	0.03	-0.7
07-Aug-07	0.02	0.79	03-Nov-10	0.02	-0.11
18-Sep-07	0.03	-4.37	14-Dec-10	0.02	2.62
31-Oct-07	-0.13	2.17	26-Jan-11	0.02	0.32
11-Dec-07	0.03	-0.61	15-Mar-11	0.02	2.00
22-Jan-08	-0.42	0.46	27-Apr-11	0.02	0.30
30-Jan-08	-0.10	-0.05	22-Jun-11	0.02	0.06
18-Mar-08	0.01	3.09	09-Aug-11	0.03	-0.77
30-Apr-08	-0.12	-0.99	21-Sep-11	0.03	0.81
25-Jun-08	0.02	-0.65	02-Nov-11	0.02	0.06
05-Aug-08	0.02	-0.23	13-Dec-11	0.02	0.41
16-Sep-08	-0.09	2.16	25-Jan-12	0.02	-0.09
08-Oct-08	0.0	0.6	13-Mar-12	0.03	0.55
29-Oct-08	-0.8	-0.65	25-Apr-12	0.02	-0.18
25-Nov-08	-0.03	-2.87	20-Jun-12	0.03	0.07
01-Dec-08	-0.01	0.00	01-Aug-12	0.02	0.29
16-Dec-08	0.05	-3.23	13-Sep-12	0.03	0.01
28-Jan-09	0.03	-0.05	24-Oct-12	0.04	0.07
18-Mar-09	0.03	-3.93	12-Dec-12	0.02	0.13
29-Apr-09	0.02	0.06	30-Jan-13	0.02	-0.02
24-Jun-09	-0.01	0.55	20-Mar-13	0.02	0.01
12-Aug-09	0.02	-1.34	01-May-13	0.02	0.15
23-Sep-09	0.02	-0.93	19-Jun-13	0.02	0.57
04-Nov-09	0.02	-0.3	31-Jul-13	0.03	0.12
16-Dec-09	0.03	-0.42	18-Sep-13	0.03	-0.20
27-Jan-10	0.02	0.76	30-Oct-13	0.02	0.13
16-Mar-10	0.02	3.22			

Table A.2: Monetary Policy and Uncertainty Surprises

Date	MP Surprise	Uncer. Surprise	Date	MP Surprise	Uncer. Surprise
31-Jan-07	0.00	-0.49	28-Apr-10	0.00	-1.47
21-Mar-07	1.72	-.66	23-Jun-10	-1.25	-0.87
09-May-07	0.00	-1.63	10-Aug-10	0.00	-1.47
28-Jun-07	0.00	-1.84	21-Sep-10	0.00	-4.05
08-Aug-07	0.00	-3.62	03-Nov-10	0.80	-2.52
18-Sep-07	0.00	-2.27	14-Dec-10	0.48	10.61
31-Oct-07	-2.41	-4.35	26-Jan-11	-0.50	1.88
11-Dec-07	0.82	0.38	15-Mar-11	0.00	8.54
22-Jan-08	-1.94	.	27-Apr-11	0.00	-0.04
30-Jan-08	-2.00	-3.98	22-Jun-11	0.00	-1.36
18-Mar-08	-2.58	-5.68	09-Aug-11	0.37	-18.96
30-Apr-08	-8.42	-1.46	21-Sep-11	0.94	-0.89
25-Jun-08	1.00	-1.24	02-Nov-11	0.00	-3.46
05-Aug-08	-0.31	-1.21	13-Dec-11	0.43	0.97
16-Sep-08	-13.27	-1.33	25-Jan-12	-0.50	-5.15
08-Oct-08	-4.93	3.15	13-Mar-12	0.46	1.46
29-Oct-08	-7.5	-4.71	25-Apr-12	0.00	-1.31
25-Nov-08	-1.25	-6.05	20-Jun-12	0.83	0.21
01-Dec-08	-0.27	0.00	01-Aug-12	0.00	0.82
16-Dec-08	3.32	-9.04	13-Sep-12	0.47	-2.96
28-Jan-09	0.00	-1.84	24-Oct-12	01.29	-1.23
18-Mar-09	-0.65	-3.67	12-Dec-12	0.40	0.83
29-Apr-09	0.00	0.19	30-Jan-13	0.50	0.09
24-Jun-09	-6.00	-3.81	20-Mar-13	0.00	-.062
12-Aug-09	-0.43	-3.18	01-May-13	-2.05	-1.12
23-Sep-09	0.10	-1.45	19-Jun-13	0.00	4.8
04-Nov-09	0.10	-1.4	31-Jul-13	0.52	0.04
16-Dec-09	0.03	-1.6	18-Sep-13	0.00	-8.18
27-Jan-10	0.10	1.3	30-Oct-13	0.00	-.007
16-Mar-10	0.10	-.053			