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ESSAYS ON MACROECONOMICS

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ESSAYS ON MACROECONOMICS

A Ph.D. Dissertation

by
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Ankara
September 2017

To my parents and sister



ESSAYS ON MACROECONOMICS

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

by

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of
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in

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ANKARA

SEPTEMBER 2017

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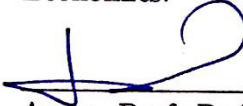
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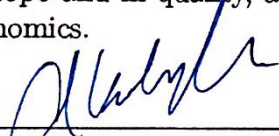
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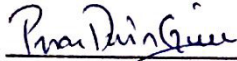
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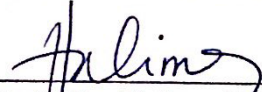
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ABSTRACT

ESSAYS ON MACROECONOMICS

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Ph.D., Department of Economics

Supervisor: Prof. Dr. Refet Soykan Gürkaynak

September 2017

This dissertation consists of four essays on macroeconomics with a special focus on monetary economics, and shows the rationale behind non-optimality of expectation formation both empirically and theoretically.

The first essay is empirical, and studies the role of inflation experience in the formation of inflation expectations in the euro area by investigating whether and to what extent inflation expectations of different forecasters are affected by the inflation they observe in the area they are residing in. We exploit the fact that many forecasters provide forecasts of the euro area inflation and these forecasters are in different firms, located in different countries. Hence there is a spatial dimension in the inflation experience of the forecasters. In particular, we first focus on the expectations of professional forecasters from different countries and ask whether their forecast errors are correlated with the observed inflation in the forecaster's country at the time the expectation was formed. We find that current home inflation unduly affects expectations of next year's euro area inflation, which may be because forecasters think

euro area is more like their own country than it actually is (spatial) and/or think inflation is more strongly auto correlated everywhere than it actually is (temporal). We devise tests to decompose this effect into i) spatial error and ii) temporal error. We provide evidence showing that the source of this error is exclusively the temporal dimension. Forecasters perceive the world to be more serially correlated than it actually is for their home country, and for other countries as well which results in more pronounced and forecastable forecast errors. They understand the spatial dimension of inflation correctly.

The second essay analyzes whether and how model uncertainty affects the amplification mechanism of the New Keynesian models. A first finding on a benchmark New Keynesian model with staggered price setting is that a robust optimal commitment policy necessitates more aggressive policy under a demand shock. Further, bringing additional persistence into the model deteriorates the effectiveness of monetary policy. Hence, allowing for either habit formation or partial indexation of prices to lagged inflation rate requires a stronger response for the policy to a demand shock. Together with the specification doubts, in order to reassure the private sector and signal that it will stabilize the fluctuations in the output gap, the policymaker reacts more aggressively as persistence rises. Although inflation persistence does not change the impact of model uncertainty, habit formation in consumption eliminates -even reverses- the impact of uncertainty on the policy reaction to a supply shock. The policymaker always attributes less importance to nominal interest rate inertia when there are concerns about model uncertainty.

The third essay analyzes how the optimal behavior of a central bank changes

if the central bank has a concern for robustness regarding model uncertainty when there is a possibility of a regime switch in the economy in which the transmission mechanism of monetary policy weakens. The aim is to stress the expectational effects arising from the regime-switching structure. The framework allows identifying the contribution of time-varying doubts about model misspecification on top of the risk of a future weakening of the policy transmission. The result implies a more active policy stance to reduce the possibility to experience a deterioration of monetary transmission mechanism even in normal times.

The fourth essay takes a different turn and measures the monetary policy transmission mechanism in Turkey. Quantifying the impact of policy decisions on financial markets is complicated because of the simultaneous response of policy actions to the asset prices, and possible omitted variables that both variables respond to. This chapter applies a heteroscedasticity-based generalized method of moments (GMM) technique for financial markets in Turkey to overcome these problems. This approach is based on the heteroscedasticity of the policy surprises on monetary policy committee meeting dates to identify the financial market reaction to monetary policy. The findings are used as a cross-check for the widely-used identification technique, namely the OLS-based event study. The results suggest that event study estimates are biased for some asset returns.

Keywords: Endogenous Regime Switching, Inflation Expectations, Monetary Policy, Monetary Policy Transmission, New Keynesian Models, Survey Data

ÖZET

MAKROEKONOMİ ÜZERİNE MAKALELER

Özcan, Gülserim

Doktora, İktisat Bölümü

Tez Yöneticisi: Prof. Dr. Refet Soykan Gürkaynak

Eylül 2017

Bu tez, parasal iktisat odağında, makroekonomi üzerine dört makaleden oluşup rasyonel olmayabilecek beklentileri uygulamalı ve teorik olarak çalışmaktadır.

İlk makale, enflasyon beklentilerinin oluşturulmasında enflasyon deneyiminin rolünü incelemektedir. Makale, farklı tahmincilerin enflasyon beklentilerinin ne ölçüde ikamet ettikleri bölgede gerçekleşen enflasyondan etkilendiğini araştırmaktadır. Özellikle farklı ülkelerdeki profesyonel tahmincilerin Avro bölgesi enflasyon tahminlerine odaklanılarak, bu tahmincilerin tahmin hataları ile ikamet ettikleri ülkelerde gözlemlenen enflasyon arasındaki ilişki ampirik olarak incelenmiştir.

Öncelikle, ana ülkedeki gerçekleşen enflasyon oranı arttıkça, tahmincilerin, Avro bölgesi enflasyon beklentilerini yukarı yönlü güncelledikleri ve bunun da daha yüksek, tahmin edilebilir tahmin hatalarına yol açtığı gösterilmiştir. Bu bulgu tahmincilerin Avro bölgesini kendi ülkelerine olduğundan fazla benzetmesinden veya her yerde enflasyonun gerçekte olduğunda daha güçlü bir şekilde otokorele olduğunu düşünmelerinden kaynaklanıyor olabilir. Yürütülen

testler sonucunda tahmincilerin, enflasyonun mekansal boyutunu doğru bir şekilde anladıkları fakat zamansal olarak hata yaptıkları kanıtlanmıştır. Tahminciler, dünyayı -hem kendi ülkeleri hem de diğer ülkeler için- olduğundan daha fazla ardışık bağıntılı olarak algılamaktadırlar. Bu da belirgin bir şekilde tahmin edilebilen tahmin hatalarına yol açmaktadır.

İkinci makale, belirsizliğin Yeni Keynesyen modellerde amplifikasyon mekanizmasını nasıl etkilediğini araştırmaktadır. Çalışmada belirsizlik kavramı robust (sağlam) kontrol teorisi ile ele alınmıştır. Sağlam kontrol teorisine göre, bir politika yapıcı aklındaki yapısal ekonomik bağıntıların hatalı olabileceğinden endişe ediyorsa para politikasını belirlerken olası en kötü senaryoya göre hareket ederek sağlam sonuçlar üretmeyi hedefler. Tezin bu bölümünde, fiyatların yapışkan olduğu Keynesyen bir modelde belirsizliğin etkisi çalışılmıştır. Bu modelde, optimal para politikasının talep şokuna karşı, belirsizliğin olmadığı duruma kıyasla daha aktif bir duruş sergilediği bulunmuştur. Öte yandan, literatürdeki genel kanının aksine, para politikasının arz şoku karşısındaki duruşu belirsizlik altında zayıflamaktadır. Ayrıca, modele endojen kalıcılık (endogenous persistence) mekanizmaları ilave edildiğinde, para politikasının etkinliği zayıflayacağından politikanın daha da agresif bir hale gelmesi gerekir. Fakat ekonomik birimlerin fayda fonksiyonunda makul düzeyde tüketim alışkanlıklarına yer verildiğinde, belirsizliğin arz şoku karşısında bile daha atılgan bir politikaya yol açtığı görülmüştür.

Üçüncü makalede, ekonomide para politikası aktarımının zayıflayacağı bir rejim değişikliği olasılığı olduğunda optimal para politikasını nasıl belirlendiği araştırılmaktadır. Çalışmanın amacı, rejim değişikliği ihtimalinden doğan bek-

lentsel etkilere vurgu yapmaktır. Oluşturulan model çerçevesi, para politikası etkinliğinin zayıflaması riskinin politika yapıcıları davranışlarına etkisi ayrıştırılmasına olanak vermektedir. Çalışma sonuçlarına göre, merkez bankası gelecekteki etkinliğin azalmasına karşı önlem almak amacıyla, normal zamanlarda dahi daha aktif bir duruş sergilemektedir.

Dördüncü makalede, Türkiye’de para politikası aktarımı ölçülmektedir. Gelişmekte olan ülkelerde, para politikasının varlık fiyatlarına etkisi hakkında pek az bilgi mevcuttur. Para politikasının etkisinin ölçülmesi, politika hareketlerinin ve varlık fiyatlarının eşzamanlı tepkisi ve her iki değişkenin dahil edilmeyen başka değişkenlere tepki vermesi ihtimali nedeniyle karmaşıklaşır. Bu bölüm, bahsi geçen sorunları çözmek için, değişken varyansa dayalı genelleştirilmiş momentler yöntemini Türkiye’deki finansal piyasalara uygulamıştır. Bu yöntem, finansal piyasaların para politikasına tepkisini ölçmek için, politika şokunun para politikası kurulu toplantı günlerindeki değişen varyansına dayanır. Sonuçlar literatürde yaygın olarak kullanılan vaka çalışması ile karşılaştırmalı olarak sunulmuştur. Sonuçlar, bazı varlık getirileri için önceki tahminlerde istatistiksel olarak bir miktar sapma olduğunu göstermektedir.

Anahtar Kelimeler: Belirsizlik, Endojen Değişken Rejim, Enflasyon Beklentileri, Para Politikası, Para Politikası Aktarımı, Yeni Keynesyen Modeller

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CHAPTER 1

INTRODUCTION

Understanding inflation expectations is an integral part of understanding asset pricing and real economic decisions. Central banks try hard to control inflation expectations as these affect behavior and inflation outcomes.

Although most macroeconomic models rely on rationality of economic decision makers, empirical evidence generally reject rational expectations hypothesis. Theoretically, departures from rational expectations hypothesis in several ways is extensively studied in the literature. Adaptive learning, rational inattention, noisy or sticky information and other forms of behavioral explanations are possible approaches to model bounded rationality. Yet, different modelling strategies have different implications and predictions on the dynamics of macroeconomic variables. Hence, it is imperative to understand the expectation formation process.

The first essay of the thesis (Chapter 2) contributes to the line of research on how expectations are formed and how they deviate from the rational expectations hypothesis. This essay empirically studies the role of inflation ex-

perience in the formation of inflation expectations in the euro area by using a survey of professional forecasters. The study investigates whether and to what extent inflation expectations of different forecasters are affected by the inflation they observe in the country they are residing in. To test whether personal experiences play a role in deriving possible deviations from rationality, this chapter focuses on the expectations of professional forecasters from different countries of euro area inflation and asks whether their forecast errors are correlated with the observed inflation in the forecaster's country at the time the expectation was formed. The essay documents a significant correlation between home country inflation and euro area inflation forecast error for the next year. Following up on this finding, the forecast error is decomposed into a spatial error in which forecasters think euro area is more like their own country than it actually is, and a temporal error in which forecasters perceive inflation is more strongly auto correlated everywhere than it actually is. We find that the source of the forecast error is exclusively in the temporal dimension. Forecasters perceive the world to be more (positively) serially correlated than it actually is not only for their own country but also for other countries. Surprisingly, they get the spatial correlation right. To further elaborate the temporal dimension, a global common factor is used in explaining the forecast errors and the result that temporal dimension is the only source of the forecast error is confirmed.

The first essay shows that professional forecasters make systematic errors when forecasting euro area inflation. The expectations of the private agents translates into their actions which determines the effectiveness of the monetary

policy. This is how the first part of the thesis relates to the theoretical essays in which alternative assumptions to rational expectations on expectation formation of decision makers is embraced under uncertainty.

Awareness of the uncertainties regarding the structure of the economy might lead to shifts in the expectation formation of economic agents, and call for fundamental changes in the way policy is conducted. Certainty equivalence principle prescribes an optimal policy that is independent of uncertainty given the expected values of all state variables. However, uncertainty might reveal itself in many different forms that might cause violations of certainty equivalence. Policy makers seek policies that are robust across different (uncertain) states of the world, and optimality of the decision rules necessitates minimizing the impact of any type of uncertainty. How best to react to uncertainty, depending on its different forms, is widely studied by academics to provide guidance for policymakers.

Future paths of exogenous additive errors to the structural equations of the economy are uncertain from the perspective of the policymaker. To deal with these stochastic shocks as *additive uncertainty*, policy instruments are optimally prescribed to be set as if there were no uncertainty.¹

A more sophisticated form of uncertainty is when the policymaker is uncertain about the effects of the policy. In this case, optimal choice of the policy variable will depend on the amount of uncertainty underlying the parameter in question as first pointed out by the seminal work of Brainard (1967). Put differently, this type of uncertainty is *multiplicative* with respect to the policy

¹In a linear-quadratic setting, that is when the structure of the economy is represented by linear equations and the objective function of the policymaker is quadratic, certainty equivalence principle applies.

variable. In such an environment, certainty equivalence does not hold so that a cautious/gradual/attenuated/conservative policy stance is able to optimally repress the effects of uncertainty.

Another example of multiplicative uncertainty is concerned with dynamic responses to shocks. When a policymaker is not sure about the impact of current values of the variables on future values, optimal policy requires reacting more actively/aggressively to keep the current variables stable as suggested by Giannoni (2002) among others. Clearly, caution is not always desirable; and in some cases, aggressiveness is more effective in reducing the effect of uncertainty.

A more general form of uncertainty is when the policymaker faces general *model uncertainty*. When the policymaker can put a structure on the model uncertainty, she can assign prior probabilities to possible different views of the economy. To design a robust policy across competing models, a policymaker first computes economic losses implied by optimal policy prescribed by each model. And she minimizes average expected loss across models, in which the policymaker assigns larger weights for most likely model and smaller weights for least likely model. Hence, she utilizes Bayesian model averaging to insure against undesirable outcomes (as in Levin et al. (2003)). A robust policy under structured model uncertainty is set to work well across alternative models.

On the other extreme, the policymaker might face unstructured uncertainty when she cannot assign probabilities to alternative models of the economy. In this case, policymaker has a reference model of the economy; however, she has doubts about her model and thinks that her model can only approximate the structure of the economy. These are robust control problems.

To accommodate potential model misspecification, she considers a set of alternative models that are difficult to distinguish from her reference model. Decision-making under robust control can be interpreted as a dynamic game between the policymaker and the nature. In this game, nature, or the hypothetical evil agent forms the worst-case strategy for the policymaker, and the policymaker designs the best decision rule given the decision of nature. Hence, a robust policymaker seeks a max-min solution, which maximizes the worst outcome to the policy problem. This type of uncertainty is additive and is reflected as additional disturbances, which can feed back on state variables, in the additive shock processes.

As opposed to structured model uncertainty,² the robust control approach relies on designing optimal policy that would work on the worst possible outcome irrespective of how (un)likely this outcome might be. Hence, in the case of designing robust policy under unstructured uncertainty, policymaker has to set a prior judgment on the worst-case outcome depending on how much she is concerned about model misspecification. Hansen and Sargent (2008) suggest interpreting possible deviations from policymaker's reference models as a collection of the likelihood ratios whose relative entropies with respect to the reference model are bounded by the policymaker's desired degree of robustness.

This thesis aims to provide an analytical understanding of the effects of uncertainty by dissecting the optimal behavior of the monetary authority in forward-looking models. The second part of the thesis is theoretical. The second essay of this thesis (Chapter 3) analyzes whether and how model un-

²See Kara (2002); Giannoni (2002) for examples of a comparison of structured and unstructured model uncertainty.

certainty affects the amplification mechanism of the New Keynesian models by providing a comparison of the dynamics of the models under rational expectations and under model uncertainty under the optimal commitment policy. On modeling uncertainty, this chapter explicitly relies on the robust control literature. I find that the impact of uncertainty on the monetary policy depends on the type of the shock as well as model features.

While being intuitive, the study presents some attracting findings on the optimal policy with a concern for robustness to model misspecification in New Keynesian models. First, the concerns about model uncertainty always make the policymaker attribute less importance to nominal interest rate inertia. Second, the reaction of the policymaker to a demand shock always becomes stronger, i.e. more aggressive, under in the presence of habit formation. The monetary authority reacts aggressively to prevent the fluctuations in marginal utility of the households. However, persistence in inflation smooths out the fluctuations in output, and partially dampens the impact of model uncertainty. Third, the results show that supply shock is more persistent under model uncertainty. Yet, the initial response of the policymaker depends on the type of the model. The models taking habit persistence into consideration calls for an aggressive policy. The policymaker keeps the policy rate lower at first compared to the case under rational expectations for the benchmark model and the model with inflation persistence.

The third part of the thesis (Chapter 4) analyzes theoretically the potential effects of the fear of a changing economic structure on optimal monetary policy. In a world where the presence of an effective lower bound on nominal interest

rate weakens the ability of the central bank in offsetting shocks and stimulating the economy, conducting economic policies that will serve as buffers against this risk becomes relevant.

In this chapter, I allow for regime-dependent elasticity of substitution as a short-cut to model a possible weakening of monetary policy effectiveness subject to an effective lower bound on nominal interest rate. In an environment where the central banker is not able to use her conventional instrument, she has to rely on alternative channels. Although, theoretically, the monetary authority has other, unconventional, tools such as forward-guidance and asset purchase programs to effect the real economy, these tools are proven not to work uniformly well in practice. Hence, alternating states of the economy where monetary authority is forced to switch to unconventional tools is similar to the economic environment in this study especially when unconventional tools do not work as well as the standard policy tool.

The findings of this chapter suggest that awareness of the possibility of hitting the bound leads to shifts in the expectation formation of the private agents, and call for fundamental changes in the way policy is conducted even before the bound has been reached. This study will provide insights for policymakers trying to stimulate the demand and weaken the effects of deep recessions when the constraint on nominal interest rate may bind. The study combines both risk and model uncertainty by allowing for alternating states of the economy. The results of the chapter first demonstrate that weakening of the monetary policy transmission mechanism calls for stronger policy actions in response to shocks in the good state as well. That is, when agents

acknowledge this possible future change in the economic structure, optimal policy becomes more active in normal times as well as near the effective lower bound.

The fourth essay constitutes the final chapter of the thesis and is included to fulfill the publication requirement. The chapter estimates the monetary policy transmission mechanism in Turkey using an identification mechanism that works through the heteroscedasticity in the high-frequency data.

Overall the contributions of this thesis are; first, providing evidence on how the expectation formation of survey respondents deviates from rational expectations. Second, it adds to the theoretical literature on the interaction of guarding against model uncertainty and model features of the forward-looking dynamic stochastic general equilibrium models. Third, it contributes to the literature where optimal policy is analyzed under possible monetary policy regime switches, and by extending the existing analyses for an environment where optimal behavior of the monetary authority is constructed when uncertainty aversion increases with weakening monetary policy transmission. With the help of sophisticated modelling techniques, the study provides policy recommendations for optimal policy conduct.

CHAPTER 2

INFLATION EXPERIENCE AND INFLATION EXPECTATIONS: SPATIAL EVIDENCE

Understanding inflation expectations is an integral part of understanding asset pricing and real economic decisions. Central banks try hard to control inflation expectations as these affect consumption, spending and investment behavior of economic agents and inflation outcomes.

Measuring expectations via surveys is common but the literature shows that survey responses do not reflect rational expectations: survey forecast errors are often forecastable. In particular, Malmendier and Nagel (2016), using the Michigan Survey of household expectations, show that average inflation people experience during their formative years continue to color their expectations decades later and Andrade and Bihan (2013) show that European forecasters make systematic errors in forecasting euro area inflation. A recent survey experiments recorded by Cavallo et al. (2017) demonstrate that consumers form inflation expectations using their memories of supermarket prices.

Theoretically, there are a number of ways to depart from rational expecta-

tions, for instance, Evans and Honkapohja (2001) suggests the adaptive learning to model bounded rationality.¹ Further, rational inattention literature shows how the dynamics of macroeconomic variables are affected when agents have to allocate limited attention to macroeconomic information (Sims, 2003; Reis, 2006; Maćkowiak and Wiederholt, 2009, 2015). Other forms of informational rigidities are considered via noisy or sticky information (Woodford, 2003; Mankiw and Reis, 2002). Coibion and Gorodnichenko (2012, 2015) empirically test how agents' forecast errors respond to structural shocks, and how they are related to past forecast revisions as implied by imperfect information models.

A new line of the literature takes a different stance in explaining expectation formation of economic agents. Among many others, Gabaix (2016) uses an application of sparsity approach in providing behavioral explanations. Bhandari et al. (2016) identifies possible diversions from rationality by deviations of consumer survey expectations from those of professional forecasters, and justify this departure in an environment where agents form expectations relying on the worst-case model with concerns about model misspecification.

It would have been easy to write off these pathologies of survey expectations as reflecting careless or strategic answers or unsophisticated respondents who may not matter at the margin but Ang et al. (2007) argue that survey expectations of inflation are the best forecasts of inflation. More recently, Croushore (2010) and Faust and Wright (2013) provide evidence that surveys of professional forecasts perform better when compared to several statistical

¹See Evans and Honkapohja (2009) for a survey of the literature on adaptive learning and its implications for macroeconomics.

and theoretical model-based forecasts. Further, a lot of "puzzles" in macroeconomics are alleviated when survey expectations are used in models instead of model consistent (rational) expectations. Piazzesi and Schneider (2008) show that understanding the yield curve becomes much easier if survey expectations are used instead of model consistent expectations. Fuhrer (2012) shows the same for the fit of DSGE models by replacing rational expectations with survey expectations since these eliminate the need for adding ad hoc model features such as habit formation and inflation indexation which has limited support in the micro data, and complex error processes to match the dynamic properties of macro data.

Recent studies support the empirical validity of inflation expectations surveys by documenting that surveys are informative about economics decisions. By using a financially incentivized experiment about investment decisions of households, Armantier et al. (2015) shows that consumers tend to act on their beliefs about future inflation. D'Acunto et al. (2015) finds that German households' willingness to purchase increases with their inflation expectations. Hence, survey expectations matter and it is imperative to understand how they are formed, how exactly they deviate from rational expectations.

The goal of this study is to investigate the role of inflation experience in the formation of inflation expectations by investigating whether and to what extent inflation expectations of different forecasters are affected by the inflation they observe in the country they are residing in.

We use a novel data set by Consensus Economics. We exploit the fact that many forecasters provide forecasts of the euro area inflation and these

forecasters are in different firms, located in different countries. Hence there is a spatial dimension in the inflation experience of the forecasters. Thus, we focus on the expectations of professional forecasters from different countries of euro area inflation and ask whether their forecast errors are correlated with the observed inflation in the forecaster's country at the time the expectation was formed.

The role of geography in explaining the forecast heterogeneity and disagreement among forecasters is explored in the literature.²

We find that a significant correlation between home country inflation and euro area inflation forecast error for the next year. We devise tests to decompose the forecast error into i) a spatial error in which forecasters think euro area is more like their own country than it actually is, and ii) a temporal error in which forecasters perceive inflation is more strongly auto correlated everywhere than it actually is. We document that the source of this error is mostly the temporal dimension. Forecasters perceive the world to be more (positively) serially correlated than it actually is for their home country as well as for other countries. They get the spatial correlation right. To further elaborate the temporal dimension, we empirically test the explanatory power of a global common factor in explaining the forecast errors. With several alternative measures of global inflation, we confirm our initial results that the temporal dimension is the source of the forecast error.

Lately, the relationship between global economic conditions and forecasting

²For instance, see Berger et al. (2008) show that predictions about monetary policy exhibit a significant and systematic regional pattern in the Euro Area and forecast errors of the forecasters are larger as economic developments in their home region differs from the average. Berger et al. (2006) document the same for American professional forecasters.

domestic inflation has drawn attention in the literature.³ Ciccarelli and Monjon (2010) and Kabukcuoğlu and Martínez-García (2016) are example studies documenting the comovement of individual countries' inflation and help understand the role of global inflation in the prediction of local inflation. Moreover, Kearns (2016) dissects the exact opposite angle by studying the predictive power of survey expectations of domestic inflation on the global inflation.⁴ All aside, this is the first study documenting the global factors behind the misperceptions regarding inflation expectations.

The remaining of the paper proceeds as follows. Section 1 describes the Consensus Economics data, section 2 describes the methodology used and studies the results, while section 3 concludes.

2.1 Data

The analysis is carried out using monthly data for annual inflation expectations for the current and the next calendar year. The data source for inflation expectations is Consensus Economics database, and realized inflation rates are from IMF International Financial Statistics (IFS). Consensus Economics asks professional forecasters from different firms residing in different countries for their forecasts of a large number of variables at the beginning of each month. Respondents of the survey are commercial/investment banks, forecast companies, and research institutes.

³While Edge et al. (2010) provides a comparison of the forecast performance of many statistical, judgmental and Dynamic Stochastic General Equilibrium models. Including a global, open economy dimension improves forecast performance substantially.

⁴They contradict with the literature and show that global inflation does not improve the survey forecasts of domestic country inflation, suggesting that survey forecasters have historically already incorporated information on global inflation in their forecasts.

In our analysis, we use the Euro Area consumer price inflation forecast of these institutions. Consensus Economics survey asks the respondents about their end-year inflation forecasts for the current year and the following year at a monthly frequency. Hence, respondents forecast the same annual inflation throughout the year. This monthly data/calendar year fixed-event forecast creates an MA(11) error term.⁵ For instance, next year forecasts collected in January 2008 are for the calendar year 2009 that will begin in 12 months, whereas those in February 2008 are for the same calendar year, which will now begin in 11 months.

To obtain forecasts with a fix horizon of one year ahead, following Celasun et al. (2004) we define one-year-ahead forecasts as a weighted average of the forecasts of the current and the next calendar year as follows:

Definition 1. For each monthly date t , in month m of the year, twelve-month ahead forecast $f_{t+12,t}$ is a weighted average of the end-year forecasts for current year $f_{t+(12-m),t}$ and the end-year forecasts for next year $f_{t+(24-m),t}$:

$$f_{t+12,t} = \frac{(12 - m)(f_{t+(12-m),t}) + m(f_{t+(24-m),t})}{12}$$

Each year, in month m , current year forecast has a forecast horizon $12 - m$; and next year forecast has a $24 - m$ forecast horizon. Moreover, the twelve-month ahead forecast has $12 - m$ months in the current calendar year, and m months in the following year, which constitutes the shares of the current and the next year forecasts.

⁵We do a robustness check by using only data from January observations. A detailed discussion on the error structure can be found in the methodology section.

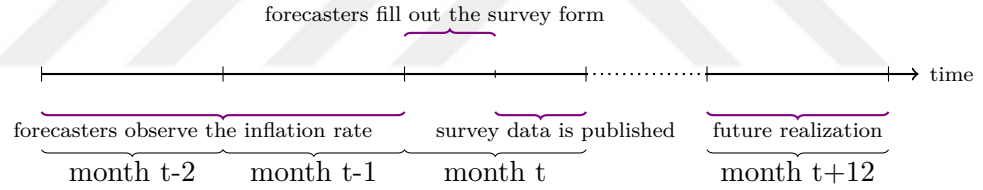
We construct the forecast error as the difference between the actual inflation for the next year and the forecast that was provided in the current month as follows:

Definition 2. For each monthly date t , twelve-month ahead forecast error of forecaster i is the realized monthly year-over-year future inflation, π_{t+12} , minus twelve-month ahead forecast of forecaster i , $f_{t+12,it}$:

$$fe_{i,t} = \pi_{t+12} - f_{t+12,it} \quad (2.1)$$

The timing of releases is summarized in the following figure:

Figure 2.1: The timing of releases



We assume that forecasters have not observed inflation for the month when the survey came out, and it is possible that in some countries the forecasters have not yet seen the official release of inflation for the previous month by the time they provide their forecasts; thus, (publicly available) realized inflation at the time of the forecast belongs to two months before.⁶

To carry out the analysis, we assign home countries for each professional forecaster based on the location of the headquarters of their firms. These professional institutions are from 14 different countries from which Austria,

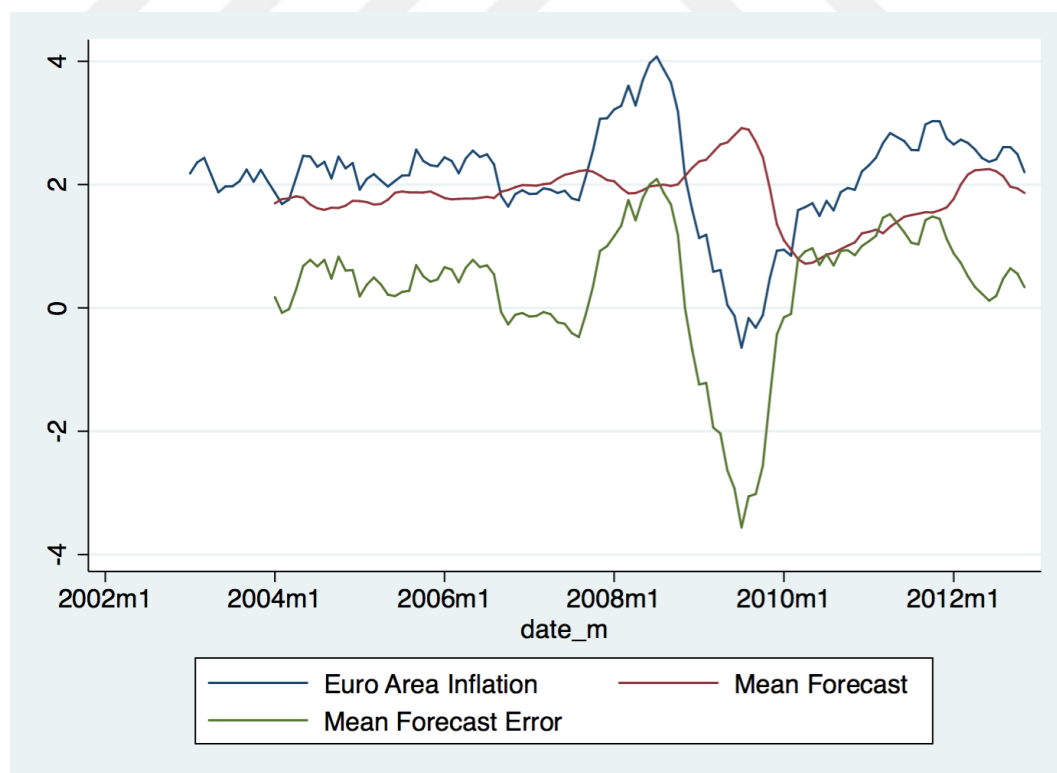
⁶One can argue that even though forecasters have not seen the inflation for the previous month, they have experienced that inflation. The results of the paper is robust to using one-month lagged inflation as well.

Finland, France, Germany, Italy, Netherlands and Spain are from the euro area, and Canada, Denmark, Norway, Sweden, Switzerland, United Kingdom and the United States are outside the euro area. Our panel data of 44 forecasters covers the period 2003:1-2012:12 with approximately 2500 observations.

2.1.1 Evaluation of Mean Forecast Errors

Even though we are interested in analyzing the micro properties of the inflation forecasts, it is imperative to study the mean forecasts to see whether it is comparable to different forecast data used in the literature. Mean forecasts and mean forecast errors together with their realizations are shown in the following figure.

Figure 2.2: Mean Forecast



The mean prediction error is positive and around 0.3, implying that Con-

sensus Economics forecasters, on average, underestimated EA inflation. The only exception is 2009, the year following the financial crisis, in which aggregate demand collapsed sharply. Starting in 2010, mean forecast errors once again turned positive.

2.2 Methodology and Results

The goal of this study is to analyze the effect of inflation experience on the formation of inflation expectations. To empirically test the hypothesis that individual forecast errors of professional forecasters are correlated with home country inflation, we estimate the following fixed effect panel regression:

$$fe_{i,t}^{EA} = \alpha_i + \beta \pi_{i,t-2}^{Home} + \epsilon_{i,t} \quad (2.2)$$

where $fe_{i,t}^{EA}$ is the forecast error of forecaster i , in month t , α_i denotes for the forecaster fixed effect, and $\pi_{i,t-2}^{Home}$ is the realized inflation in home country of forecaster i available at the time of the forecast.

Equation (2.2) enables us to control for unobserved heterogeneity among forecasters. This method has the advantage of allowing for the existence of general patterns of correlation between the unobserved forecaster effects and euro area inflation forecasts.⁷

⁷We obtained very similar results from the pooled OLS regressions. We do not show those results here, considering that the forecasters located in different countries may be different. Thus, the error term and location will be correlated and OLS will be biased.

2.2.1 Corrupting Effect of Home Inflation

As shown in Table 2.1, fixed effects panel regressions demonstrate a strong forecasting effect of home inflation on euro area inflation forecast errors. We use heteroskedasticity adjusted standard errors but the serial correlation induced by the monthly forecasts of annual inflation remains. A brute force method of controlling for this is to use forecasts made in one month of the year only ⁸, which greatly reduces the sample size but makes sure that the MA term is no longer present. The result remains statistically and economically significant and of similar magnitude across different specifications.

Table 2.1: The Effect of Home Inflation (FE)

	Fixed Effects	Fixed Effects (January)
	EA 1-yr-ahead Fcast Error	EA 1-yr-ahead Fcast Error
Lagged Home Inf	-0.597*** (0.0833)	-0.545*** (0.087)
Constant	1.519*** (0.167)	1.314*** (0.169)
Observations	2,595	201
R-squared	0.289	0.332
Number of panel_id	44	37

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The negative coefficient suggests that when forecasters observe high home inflation they raise their forecasts of euro area inflation too much, so that the forecast error (realized minus forecasted inflation) is predictably low. This is in clear contradiction with rational expectations because forecast errors should not be predictable with any available information at the time of the forecast under rational expectations.

To understand the source of the strong forecasting effect of home inflation,

⁸The results are qualitatively the same for all months. We present the results for the first month of the year.

we decompose the dependent variable. Table 2.2 reports the responses of future EA inflation and expectations for next year's euro area inflation. The results suggest that current home inflation and the future EA inflation are negatively correlated but forecasters perceive a positive correlation. This result may be due to both a spatial mistake in expectations formation and/or a temporal one.

Table 2.2: The effect of home inflation- Decomposing the Dependent Variable

	Fixed Effects	Fixed Effects (January)	Fixed Effects	Fixed Effects (January)
	Realized Future EA Inf		Forecasted Future EA Inf	
Lagged Home Inf	-0.318*** (0.0592)	-0.338*** (0.096)	0.278*** (0.030)	0.208*** (0.062)
Constant	2.785*** (0.119)	2.681*** (0.186)	1.266*** (0.060)	1.368*** (0.120)
Observations	2,595	201	2,595	201
R-squared	0.125	0.153	0.349	0.166
Number of panel_id	44	37	44	37

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

We find that current home inflation unduly affects expectations of next year's euro area inflation, which may be because forecasters think euro area is more like their own country than it actually is (spatial) and/or think inflation is more strongly auto correlated everywhere than it actually is (temporal) as demonstrated by Figure 2.3. Hence, further elaboration is needed to separate these two channels.

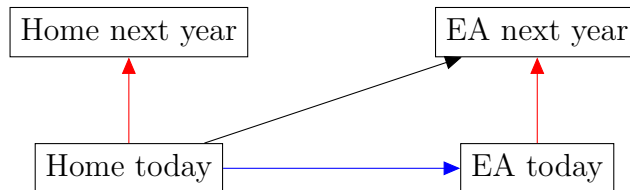


Figure 2.3: Spatial Dimension versus Temporal Dimension

To investigate which dimension the forecasters are missing, we first compare the correlation between the realized and the perceived home and EA inflation rates in Table 2.3 in order to test for the presence of spatial errors. In addition, we analyze the temporal dimension by comparing the correlation between the realized current and future EA inflation, and the correlation between perceived current and future EA inflation rates. Alternatively, we propose comparing the correlation between the realized current and future home country inflation, and the correlation between perceived current and future home country inflation rates.

Table 2.3: Spatial Dimension

	Fixed Effects	Fixed Effects
	Current EA Inf	EA Inf Forecast
Current Home Inf	0.655*** 0.013	
Home Inf Forecast		0.541*** (0.015)
Constant	4.153*** (0.020)	3.191*** (0.020)
Observations	2595	2595

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2.4: Temporal Dimension I

	Fixed Effects	Fixed Effects
	Realized Future EA Inf	Forecasted Future EA Inf
Lagged EA Inf	-0.466*** (0.029)	0.478*** (0.008)
Constant	5.006*** (0.020)	3.003*** (0.020)
Observations	2595	2595

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Tables 2.3 and 2.4/Table 2.5 show that forecasters' perception of the cor-

Table 2.5: Temporal Dimension II

	Fixed Effects	
	Realized Future Home Inf	Forecasted Future Home Inf
Lagged Home Inf	-0.305*** (0.031)	0.381*** (0.014)
Constant	5.542*** (0.020)	4.012*** (0.020)
Observations	2595	2595
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

relation of home and EA inflations is lower than it actually is; however the difference between these two is not statistically significant. Moreover, they perceive the correlation in the time dimension to be positive, whereas in reality is negative, which gives the overall negative coefficient. Thus, misperception comes from the temporal dimension so that forecasters perceive the world to be more (positively) serially correlated than it actually is, not only for their own country but also for other countries.

2.2.2 The Effect of a Global Common Factor

The dominance of the temporal mistake in the forecast error needs further elaboration. To empirically test the hypothesis that there is a time-varying global common factor driving the results, we conduct principal component analysis on the inflation rates in countries where the forecasters are residing in.⁹ The first common factor from the analysis is interpreted as the global inflation rate that the forecasters experience.

We estimate equation (2.3) to analyze the effect of global inflation on the

⁹The details of the analysis can be found in the appendix.

EA inflation forecast error.

$$fe_{i,t}^{EA} = \alpha_i + \beta_1 \pi_{i,t-2}^{Home} + \beta_2 \pi_{t-2}^{Global} + \epsilon_{i,t} \quad (2.3)$$

where $\pi_{i,t-2}^{Home}$ is the realized inflation in home country available at the time of the forecast, and $\pi_{i,t-2}^{Global}$ denotes for the global inflation available at the time of the forecast.

Table 2.6: The Effect of Global Inflation

	Fixed Effects	Fixed Effects (January)
	EA 1-yr-ahead Fcast Error	EA 1-yr-ahead Fcast Error
Lagged Home Inf	-0.037 (0.073)	-0.130* (0.059)
Lagged Global Inf	-0.213*** (0.023)	-0.214*** (0.016)
Constant	0.447*** (0.142)	0.536*** (0.114)
Observations	2,595	201
# of panel id	44	37
R-squared	0.441	0.597
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

The results of the regression where we include the global inflation factor as well as home inflation as explanatory variables (summarized in table 2.6) are not surprising, and confirm our initial results that the temporal dimension is the source of the forecast error (This result favors the dominance of time series dimension). When we include the global inflation factor, home inflation is no longer statistically significant. Instead, global factor has a strong forecasting effect (-0.213, significant at the 1 percent significance level) on the EA inflation forecast error. These results put forward that, on average, forecasters significantly under-predict EA inflation by 213 basis points; and they increase their forecasts by approximately 100 basis points when they observe a 1 percent

increase in the global inflation factor.

2.2.3 Alternative Measures of Global Inflation

In the previous section, we document systematic errors in EA inflation forecast errors. Forecasts are correlated with the global inflation factor calculated by principal component analysis on individual country inflation rates. In this section, we analyze the alternative measures of global inflation. According to the Table 2.7, the predictive power of the global inflation measures calculated by the principal component analysis is lower than the other measures of global inflation.

Table 2.7: Alternative Measures of Global Inflation

Pooled OLS				
EA 1-yr-ahead Fcast Error				
Lagged Home Inf	0.00222 (0.0465)	-0.016 (0.052)	0.006 (0.037)	0.013 (0.052)
Lagged Global Inf	-0.221*** (0.0164)			
Lagged Global Inf2		-0.252*** (0.020)		
Lagged EA Inf			-0.896*** (0.057)	
Lagged World Inf				-0.817*** (0.053)
Constant	0.370*** (0.0826)	0.388*** (0.094)	2.169*** (0.066)	3.440*** (0.120)
Observations	2,595	2,595	2,595	2,595
R-squared	0.439	0.427	0.455	0.518

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Sources: World inflation and inflation for developed countries are from IMF. Global factor is the first component of the principal component analysis. Global factor2 is constructed as the weighted average of the first two principal components, where the weights are constructed as the share of the corresponding eigenvalue over the sum of the two relevant eigenvalues.

Table 2.8 documents the correlation matrix of alternative measures of global inflation. Alternative measures of global inflation are highly correlated with each other. We believe that the information on the global factors are en-

Table 2.8: Correlation Matrix of Alternative Measures of Global Inflation

(1)	
inf_ea_m	
inf_ea_m	1
inf_world_m	0.899***
globalfactor	0.980***
globalfactor2	0.969***
homeinf_m	0.675***
inf_world_m	
inf_world_m	1
globalfactor	0.950***
globalfactor2	0.956***
homeinf_m	0.642***
globalfactor	
globalfactor	1
globalfactor2	0.998***
homeinf_m	0.685***
globalfactor2	
globalfactor2	1
homeinf_m	0.679***
homeinf_m	
homeinf_m	1
<i>N</i>	2595
<i>t</i> statistics in parentheses	
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$	

compassed by the alternative measures. Our goal is to include all time-varying measures as much as possible in the analysis. To achieve that we will calculate the net contribution of each variable on the EA forecast error.¹⁰

We continue the analysis with EA inflation and the world inflation rates.¹¹

2.2.4 EA Inflation, World Inflation and Interaction Effects

We estimate equation (2.4) to analyze the effect of global inflation on the EA inflation forecast error.

$$fe_{i,t}^{EA} = \alpha_i + \beta_1 \pi_{t-2}^{EA} + \beta_2 \epsilon_{t-2}^{World} + \beta_3 (\pi_{t-2}^{EA} \times \epsilon_{t-2}^{World}) + \epsilon_{i,t} \quad (2.4)$$

where π_{t-2}^{EA} is the realized inflation in the EA available at the time of the forecast, and ϵ_{t-2}^{World} denotes for the world inflation net of EA inflation available at the time of the forecast, and $(\pi_{t-2}^{EA} \times \epsilon_{t-2}^{World})$ is the interaction term between the EA and world inflation rates.

Table 2.9 reports the results of the regression of one-year-ahead EA inflation forecast error on lagged EA inflation and/ or world inflation, and their interaction effects.¹² Lagged EA inflation and world inflation rates have strong forecasting effects on the EA inflation forecast error. On average, forecasters significantly under-predict EA inflation; and they increase their forecasts by

¹⁰The details of the calculation can be found in the appendix.

¹¹The world inflation rate- net of EA inflation- is the residual from the regression of EA inflation on the world inflation.

¹²Since we show that home inflation-the residual from the regression of home inflation on EA and world inflation rates- is not statistically significant with time-varying global inflation measures, we do not report the results with the home inflation as an additional explanatory variable here.

Table 2.9: EA Inflation, World Inflation and Interaction Effects

EA 1-yr-ahead Fcast Error				
Lagged EA Inf	-0.895*** (0.0234)		-0.868*** (0.022)	-0.702*** (0.027)
Lagged World Inf		-0.827*** (0.049)	-0.700*** (0.029)	0.174*** (0.057)
(Lagged EA Inf x Lagged World Inf)				-0.376*** (0.026)
Constant	2.174*** (0.0483)	0.357*** (0.002)	2.142*** (0.045)	1.802*** (0.055)
Observations	2,786	2,786	2,786	2,786
R-squared	0.456	0.101	0.528	0.539
Number of panelId	45	45	45	45

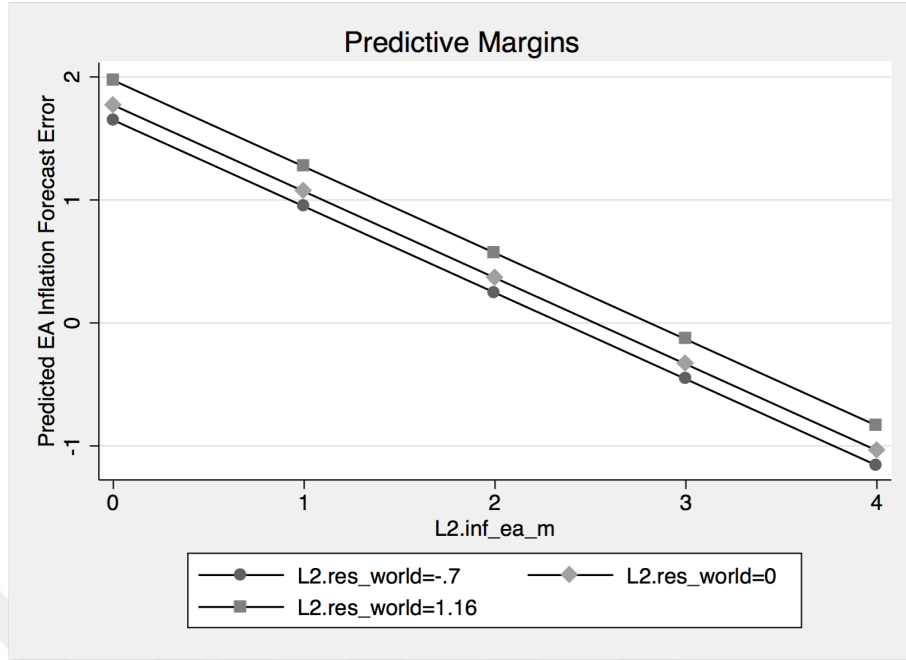
Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

more than 800 basis points in response to 1 percent increase in the EA inflation/world inflation respectively. At the same time, the interaction term between these variables is negative and statistically significant at the 1 percent significance level. Negative interaction effects imply that the corrupting effect of EA inflation increases by world inflation. That is the effect of EA inflation gets stronger by approximately 400 basis points for higher levels of world inflation. Figure 2.4 illustrates the interaction effects between EA inflation and world inflation.

In order to analyze the source of the strong forecasting effect of EA and world inflation rates, we decompose the dependent variable. Table 2.10 reports the responses of future EA inflation and expectations for next year's euro area inflation. The results suggest that current EA inflation together with world inflation rate and the future EA inflation are negatively correlated but forecasters perceive a positive correlation.

Figure 2.4: Interaction Effects



2.3 Robustness Checks

We separately analyzed pre-crisis and post-crisis periods. We find that corrupting effect of EA inflation weakens after the crisis. Although the behavior of inflation itself is mildly different, the behavior of inflation forecasts is not. Professional forecasters always perceive future euro area inflation to be more correlated with current inflation than it actually is. Moreover, the results are similar for euro area and non-euro area countries. However, forecasters from non-euro area countries make slightly larger forecastable errors.

2.4 Conclusion

In this paper, we study the impact of current inflation experience on expectations of professional forecasters of euro area inflation with micro level data. We use a novel dataset which allows us to keep track of the evolution of

predictions regarding euro area inflation as well as home country inflation of individual forecasters.

Home inflation is significantly correlated with euro area (EA) inflation forecast error. We decompose this effect into i) spatial error, and ii) temporal error. We document that the source of this error is mostly the temporal dimension. They understand the spatial correlation correctly. The bottom line of this study is that forecasters perceive the world to be more serially correlated than it actually is for their home country, and for other countries as well.



Table 2.10: EA and World Inflation rates- Decomposing the Dependent Variable

	Fcast	Future	Fcast	Future	Fcast	Future	Fcast	Future
Lagged EA Inf	0.439*** (0.0143)	-0.456*** (0.016)			0.445*** (0.014)	-0.423*** (0.012)	0.403*** (0.015)	-0.299*** (0.019)
Lagged World Inf			-0.105*** (0.025)	-0.933*** (0.027)	-0.170*** (0.016)	-0.871*** (0.018)	-0.394*** (0.028)	-0.221*** (0.062)
(Lagged EA Inf x Lagged World Inf)							0.096*** (0.014)	-0.279*** (0.026)
Constant	0.914*** (0.0295)	3.088*** (0.034)	1.822*** (0.001)	2.179*** (0.001)	0.906*** (0.029)	3.049*** (0.025)	0.994*** (0.031)	2.796*** (0.039)
Observations	2,786	2,786	2,786	2,786	2,786	2,786	2,786	2,786
R-squared	0.605	0.181	0.009	0.197	0.629	0.351	0.633	0.361
Number of panelId	45	45	45	45	45	45	45	45

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2.11: Before-During-After the Crisis

EA 1-yr Fcast Error	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Before			During			After		
Lagged EA Inf	-1.312*** (0.0504)	-1.270*** (0.051)	-1.069*** (0.070)	-1.085*** (0.023)	-0.916*** (0.011)	-0.965*** (0.031)	-0.208*** (0.020)	-0.208*** (0.021)	-0.015 (0.021)
Lagged World Inf		0.454*** (0.033)	-1.025*** (0.332)		-1.314*** (0.053)	-1.588*** (0.185)		-0.022 (0.043)	0.794*** (0.047)
(Lagged EA Inf x Lagged World Inf)			0.685*** (0.153)			0.106 (0.061)			-0.523*** (0.039)
Constant	3.269*** (0.109)	3.298*** (0.107)	2.867*** (0.149)	2.053*** (0.051)	2.184*** (0.038)	2.288*** (0.079)	1.284*** (0.032)	1.293*** (0.043)	0.983*** (0.037)
Observations	1,478	1,478	1,478	732	732	732	576	576	576
R-squared	0.363	0.386	0.388	0.604	0.695	0.695	0.213	0.214	0.312
Number of panelId	41	41	41	37	37	37	33	33	33

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2.12: In the EA- Out the EA

EA 1-yr Fcast Error	(1)	(2)	(3)	(4)	(5)	(6)
		in the EA			out the EA	
Lagged EA Inf	-0.874*** (0.0371)	-0.856*** (0.036)	-0.688*** (0.045)	-0.917*** (0.023)	-0.881*** (0.024)	-0.717*** (0.027)
Lagged World Inf		-0.681*** (0.034)	0.198* (0.083)		-0.718*** (0.043)	0.146* (0.074)
(Lagged EA Inf x Lagged World Inf)			-0.382*** (0.038)		-0.368*** (0.037)	
Constant	2.107*** (0.0763)	2.092*** (0.075)	1.746*** (0.093)	2.245*** (0.047)	2.195*** (0.049)	1.862*** (0.055)
Observations	1,433	1,433	1,433	1,353	1,353	1,353
R-squared	0.453	0.521	0.533	0.460	0.536	0.546
Number of panel_id	23	23	23	22	22	22

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2.13: In the EA: Before-During-After the Crisis

EA 1-yr Fcast Error	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Before			During			After		
Lagged EA Inf	-1.287*** (0.0941)	-1.241*** (0.095)	-1.076*** (0.130)	-1.059*** (0.024)	-0.911*** (0.010)	-0.959*** (0.048)	-0.214*** (0.027)	-0.214*** (0.028)	-0.004 (0.028)
Lagged World Inf		0.478*** (0.031)	-0.735* (0.349)		-1.261*** (0.090)	-1.530*** (0.310)	0.020 (0.040)	0.883*** (0.047)	
(Lagged EA Inf x Lagged World Inf)			0.562*** (0.166)			0.104 (0.091)		-0.565*** (0.054)	
Constant	3.189*** (0.203)	3.214*** (0.200)	2.862*** (0.276)	1.964*** (0.053)	2.117*** (0.057)	2.220*** (0.133)	1.275*** (0.042)	1.267*** (0.053)	0.932*** (0.041)
Observations	771	771	771	368	368	368	294	294	294
R-squared	0.357	0.385	0.386	0.610	0.693	0.694	0.232	0.233	0.348
Number of panelId	22	22	22	19	19	19	16	16	16

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2.14: Out the EA: Before-During-After the Crisis

EA 1-yr Fcast Error	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Before			During			After		
Lagged EA Inf	-1.340*** (0.0209)	-1.302*** (0.016)	-1.060*** (0.054)	-1.112*** (0.033)	-0.920*** (0.021)	-0.972*** (0.045)	-0.200*** (0.035)	-0.201*** (0.035)	-0.028 (0.032)
Lagged World Inf		0.427*** (0.063)	-1.342** (0.503)		-1.362*** (0.050)	-1.644*** (0.229)		-0.069 (0.065)	0.690*** (0.051)
(Lagged EA Inf x Lagged World Inf)			0.818** (0.232)			0.109 (0.088)			-0.476*** (0.059)
Constant	3.355*** (0.0450)	3.388*** (0.044)	2.870*** (0.118)	2.148*** (0.074)	2.250*** (0.048)	2.357*** (0.094)	1.293*** (0.056)	1.318*** (0.073)	1.038*** (0.058)
Observations	707	707	707	364	364	364	282	282	282
R-squared	0.368	0.388	0.391	0.599	0.696	0.697	0.194	0.197	0.278
Number of panelId	19	19	19	18	18	18	17	17	17

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

CHAPTER 3

THE AMPLIFICATION OF THE NEW KEYNESIAN MODELS AND ROBUSTLY OPTIMAL MONETARY POLICY

3.1 Motivation

Dynamic stochastic general equilibrium (DSGE) models combined with Bayesian methods of inference have become the mainstream device for research on monetary policy analysis. In its simple form,¹ the model lacks endogenous persistence than those present in the data. To improve the match with the data, many types of shocks together with adjustment costs are introduced into the model.² Yet, in complex, elaborate DSGE setups containing several frictions, some of these shocks are hard to validate.³

From the perspective of a policymaker, a highly related discussion would be acknowledging the possible uncertainties about the structure of the economy. When one deviates from the assumption of perfect knowledge in several

¹See Woodford (2011) and Galí (2015) for the basic setup.

²See Smets and Wouters (2007), Fernández-Villaverde and Rubio-Ramírez (2006), and Fernández-Villaverde (2009) for a medium-scale model.

³See Chari et al. (2009) for a discussion.

ways, the propagation of shocks, hence implied policy suggestion could change substantially. For instance, although the literature on uncertainty pioneered by Brainard (1967) advised more cautious behavior for the policymaker when faced with ambiguity about parameters of the model, there may be fundamental uncertainties regarding the true data generating process. The monetary authority facing uncertainty about the model or about the exogenous disturbances might find it optimal to respond aggressively to fluctuations in the economy as discussed in the introduction of this thesis. Therefore, introducing uncertainty into an otherwise standard New Keynesian model can improve the propagation of the shocks, the fit of the model with the data, and relieve the DSGE models from the criticism of several, unfounded shocks. Together with a sound economic intuition, allowing model uncertainty can improve the reliability of the policy suggestions derived from the model.

This chapter aims to provide some additional insights to the optimal policy literature by introducing uncertainty in New Keynesian models with various features, with a particular focus on understanding whether and how the extensions of the simple New Keynesian model affect the design of optimal monetary policy under uncertainty. To that end, a real rigidity, habit formation, and/or an additional nominal rigidity, inflation persistence, is introduced into the benchmark model, and optimal monetary policy under model uncertainty à la Hansen and Sargent (2008) is derived to analyze how model uncertainty interacts with the additional ingredients of the model. Furthermore, the dynamics of these four models are demonstrated and compared in terms of their impulse responses and the design of optimal monetary policy under rational

expectations as well as under uncertainty.

I first consider an analysis on what is already known by presenting a simple New Keynesian model with Calvo price stickiness as a benchmark. In the benchmark model, I study the optimal commitment and discretionary policy in response to a supply shock to the Phillips curve as well as in response to a demand shock to the IS equation. Following Hansen and Sargent (2008), I characterize optimal policy under unstructured uncertainty. To represent model misspecification, I consider additional disturbances in the shock processes. I show how the problem of the monetary authority differs when she internalizes this type of model uncertainty to find the optimal policy response in the worst-case realization of the shock process that represents model misspecification. The comparison of the model dynamics from the ones obtained under rational expectations generates a picture on how model uncertainty has an impact on the amplification mechanism of the shocks. Subsequently, by adding i) the habit formation, and ii) indexation to past inflation, I aim to see the contribution of each ingredient one-by-one into the basic framework. Next, I introduce iii) habit formation together with inflation persistence to see the interaction of these two features on the dynamics of the model.⁴

Under model uncertainty, when the economy faces a shock to aggregate demand, the monetary authority guards against model misspecification and formulates a more aggressive policy that would work well under the worst possible outcome of the shock. Central bank not only increases the nominal interest rate to a higher level compared to the case under rational expectations

⁴I restrict the extensions to add persistence in the IS and Phillips relations to keep the results under model uncertainty comparable across encompassing models.

but also keeps it that way for a longer time. Although the responses of output gap and inflation seem close with and without model uncertainty, it takes longer for inflation to go back to the steady state. Yet, as a response to a supply shock, the monetary authority takes a cautious stance.

When I allow for household utility to depend on both current consumption and on past consumption (as a reference level), the optimal consumption decision of the household takes into account not only the change in consumption but also the level of consumption, which ensures persistence in aggregate demand. Compared to the benchmark model, optimal response of the policymaker under a demand shock is to raise the nominal rate substantially to keep the fluctuations in the output gap under control by allowing for a disinflationary process for the inflation rate. At the same time, when the source of the shock comes from the supply side, habit formation in consumption provides responses similar to the benchmark model.

I allow for indexation to past inflation by assuming that only some fraction of firms sets prices optimally whereas the remaining firms choose a price according to past inflation rate and the price set by both optimizing and non-optimizing firms in the previous period. Allowing for indexation to past inflation adds a backward-looking component into the Phillips Curve. A reasonable persistence in inflation leads the responses under a supply shock amplified for the nominal rate, inflation rate and the output gap.

While being intuitive, the study proposes some attracting findings on the optimal policy with a concern for robustness to model misspecification in New Keynesian models. First, the concerns about model uncertainty always make

the policymaker to attribute less importance to nominal interest rate inertia. Second, the reaction of the policymaker to a demand shock always becomes stronger, i.e. more aggressive under in the presence of habit formation. The monetary authority reacts aggressively to prevent the fluctuations in marginal utility of the households. However, persistence in inflation smooths out the fluctuations in output, and partially dampens the impact of model uncertainty. Third, the results show that a supply shock has more persistent effects under model uncertainty. Yet, the initial response of the policymaker depends on the type of the model. The models taking habit persistence into consideration calls for an aggressive policy. The policymaker keeps the policy rate lower at first compared to the case under rational expectations for the benchmark model and the model with inflation persistence.

The paper is organized as follows. In section 3.2, the model is constructed and details of the optimal monetary policy design is discussed. Section 3.3 presents some extensions to the benchmark model. Section 3.4 concludes.

3.2 Optimal Monetary Policy

A welfare criterion for the monetary authority can be derived by taking a second-order approximation to the representative household's utility function;⁵ however, these are proven to be very model dependent and not robust. Instead, many central banks are assigned to pursue a simple objective that involves only a small set of economic variables. A simple mandate offers more transparent

⁵Several papers derive a utility-based welfare criterion following Rotemberg and Woodford (1998). See Edge (2003) for the derivation of a welfare criterion for a model with capital accumulation; Leith et al. (2012) for a model with external habit formation

monetary policy and easier communication with the public. Moreover, a simple objective is found to be more robust to structured model and parameter uncertainty compared to a complicated state-contingent policy.⁶

Since the aim of this paper is keep the setup as simple as possible to make the results of different models comparable, I assume a simple objective for the central bank so the policy maker chooses $\{y_t, \pi_t, r_t\}$ which minimizes the following standard loss function:

$$\left(\frac{1}{2}\right)E_t \sum_{t=t_0}^{\infty} \beta^t \{[\pi_t^2 + \lambda_y y_t^2 + \lambda_r (r_t - r_{t-1})^2]\} \quad (3.1)$$

where π , y and r denotes for the inflation rate, the output gap and the nominal interest rate respectively. $\lambda_y, \lambda_r > 0$ are weights of the stabilization of the output gap, and the change in the nominal interest rate.

This welfare criterion implies triple mandate for the policymaker; namely deviation of the inflation rate from its optimal rate, deviation of output from its natural level and interest rate smoothing.⁷ The rationale for assigning a positive weight for the nominal interest rate in the objective of the central bank can be derived from a model with transaction frictions which justifies the presence of real money balances together with consumption and leisure in utility as shown by Woodford (2011). An ad hoc reason for including the interest rate is to prevent large fluctuations in the short-term nominal rate that might increase the term premium and the long-term interest rate. Hence, by

⁶Svensson (2010), and recently Debortoli et al. (2016) elaborate more on this point.

⁷A recent contribution by Davig and Gürkaynak (2015) advocates a case for the single mandate for monetary authority in an environment where multiple objectives can create disincentive motives for other policymakers. Here, I abstract from these kind of strategic interaction among policy authorities.

implying a degree of commitment to future rates, interest rate smoothing enables the policymaker to keep aggregate demand and inflation under control by guiding long-term bond rates. Furthermore, a policymaker incorporating the zero lower bound on the policy rate reduces the likelihood of hitting the bound by decreasing the financial market volatility when the economy is subject to large shocks.

The policymaker designs optimal monetary policy by minimizing the expected loss using all information available up to the current period (which does not include the knowledge about the true model) and taking the structural equations governing the economy as constraints. I assume credible commitment on the side of the policymaker. By committing to a policy rule, policymaker determines optimality conditions to hold in any future period; hence she takes advantage of being able to affect the formation of private sector expectations. In this section, I will derive optimal commitment policy for a benchmark New Keynesian model under rational expectations and under model uncertainty.

3.2.1 Microeconomic Foundations of the Benchmark Model

This section presents the baseline micro-founded general equilibrium model that will serve as the benchmark setting for the robust models.

The model is a simple New Keynesian model with price stickiness. I first explain the characteristics of the model. Then, I will show the linearized versions of the set of conditions characterizing the general equilibrium.⁸

⁸Derivations can be found in the appendix.

The representative household derives utility from consumption and leisure by maximizing the following separable utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\eta}}{1+\eta} \right\} \quad (3.2)$$

where $0 < \beta < 1$ is the discount factor, $\sigma \geq 0$ is the inverse of the intertemporal elasticity of substitution, $\eta \geq 0$ is the inverse of Frisch labor supply elasticity. C_t and L_t are consumption and hours worked respectively. At the beginning of each period t , representative household has B_{t-1} nominal bonds, with a nominal gross interest rate of R_{t-1} ; and buys new bonds B_t . Also, household earns $w_t L_t$ labor income, and Φ_t firm's profits. Each household maximize (3.2) subject to the sequence of intertemporal budget constraints:

$$P_t C_t + B_t \leq B_{t-1} R_{t-1} + P_t [w_t L_t] + \Phi_t \quad (3.3)$$

The household's optimality conditions are as follows:

$$\begin{aligned} w_t &= L_t^\eta C_t^\sigma \\ \left(\frac{C_t^{-\sigma} / P_t}{E_t C_{t+1}^{-\sigma} / P_{t+1}} \right) &= \beta R_t \\ C_t^{-\sigma} &= \beta E_t \left[C_{t+1}^{-\sigma} R_t \frac{P_t}{P_{t+1}} \right] \end{aligned} \quad (3.4)$$

For the production side, I follow the typical intermediate-final good producer setup. Final good Y_t is produced using the following intermediate goods aggregator:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}$$

Intermediate good firms are monopolistically competitive. The corresponding demand for an intermediate good i is:

$$Y_t(i) = Y_t \left(\frac{P_t(i)}{P_t} \right)^{-\xi}$$

where ξ denotes for the constant price elasticity of demand, $P_t(i)$ is the price of the intermediate good i , and P_t is the price of the final good. The aggregate production function is

$$F(L_t) = L_t^{1-\alpha}$$

The first order conditions with respect to the cost minimization problem of firm's yields:

$$w_t = z_t F'(L_t) = (1 - \alpha) z_t L_t^{-\alpha} = (1 - \alpha) z_t \frac{Y_t}{L_t} \quad (3.5)$$

where z_t is the marginal cost of production. Prices are sticky à la Calvo (1983). Each period a fraction $(1 - \theta)$ of firms gets a signal to reoptimize their prices. Firms maximize the sum of discounted profits:

$$E_t \sum_{j=t}^{\infty} \theta^j \left(\frac{1}{\prod_{i=0}^j R_i} \right)^j \left[\left(\frac{P_t(i)}{P_t} \right)^{-\xi} Y_t \left(\frac{P_t(i)}{P_t} \right) - z_t \right] \quad (3.6)$$

where z denotes for the marginal cost. The profit maximization conditions produce a log-linearized New Keynesian Phillips Curve (NKPC) of the form:

$$\pi_t = \beta E_t \pi_{t+1} + \left\{ \frac{(1 - \theta)(1 - \beta\theta)}{\theta} \right\} z_t \quad (3.7)$$

Log-linearized optimality conditions can be summarized by a Phillips equation with a supply shock, and an IS equation with a demand shock as shown in the following table. The shocks are assumed to follow AR(1) processes. The lower-case letters denotes the deviations of the variables from their steady states values.

Table 3.1: The Benchmark Model

Phillips Curve	$\pi_t = \beta E_t \pi_{t+1} + \Omega y_t + e_t$
IS Curve	$y_t = E_t y_{t+1} - \frac{1}{\sigma}(r_t - E_t \pi_{t+1}) + u_t$
Supply Shock	$e_t = \rho_e e_{t-1} + \epsilon_t, \quad \epsilon_t \sim N(0, 1), \quad \rho_e < 1$
Demand Shock	$u_t = \rho_u u_{t-1} + v_t, \quad v_t \sim N(0, 1), \quad \rho_u < 1$

where $\Omega = \left\{ \frac{(1-\theta)(1-\beta\theta)}{\theta} \left(\frac{\alpha+\eta}{1-\alpha} \right) + \sigma \right\}$, π and r denotes for the inflation rate and the nominal interest rate respectively.

3.2.2 Optimal Commitment Policy under Rational Expectations

Following Woodford (2011), I form the Lagrangian of the policymaker for the benchmark model as

$$\begin{aligned}
\min_{\{\pi_t, y_t, i_t\}_{t=0}^{\infty}} E_0^{RE} \sum_{t=0}^{\infty} \beta^t & \left\{ \left[\left(\frac{1}{2} \right) \pi_t^2 + \left(\frac{1}{2} \right) \lambda_y y_t^2 + \left(\frac{1}{2} \right) \lambda_r (r_t - r_{t-1})^2 \right] \right. \\
& + s_{1,t} (\pi_t - \beta \pi_{t+1} - \Omega y_t - e_t) \\
& \left. + s_{3,t} \left(y_t - y_{t+1} + \frac{1}{\sigma} (r_t - \pi_{t+1}) - u_t \right) \right\} \quad (3.8)
\end{aligned}$$

The first-order conditions with respect to π_t , y_t and r_t are as follows:

$$\begin{aligned}\pi_t + s_{1t} - s_{1t-1} - \frac{1}{\beta\sigma}s_{3t-1} &= 0 \\ \lambda_y y_t - \Omega s_{1t} + s_{3t} - \frac{1}{\beta}s_{3t-1} &= 0 \\ \lambda_r(r_t - r_{t-1}) - \beta\lambda_r(r_{t+1} - r_t) + \frac{1}{\sigma}s_{3t} &= 0\end{aligned}\tag{3.9}$$

at each date $t \geq 0$, with the initial conditions⁹

$$s_{1,-1} = s_{3,-1} = 0\tag{3.10}$$

implying that the monetary authority has no previous commitment at the initial period. Here, E^{RE} is the expectations operator derived from the model under rational expectations.

The optimal policy under rational expectations for the benchmark model is the commitment solution $\{y_t, \pi_t, r_t, s_{1t}, s_{3t}\}$ to the system of first-order conditions (3.9) initial conditions (3.10) together with the stochastic versions of IS and Phillips equations summarized in Table 3.1.

3.2.3 Introducing Uncertainty

To allow for model uncertainty, I introduce a second type of disturbances in the shock process in Table 3.1.

⁹According to Woodford (2011), the Lagrange multipliers can be specified in a way that make the policy optimal in a timeless perspective. Time-zero optimal solution is subject to time-inconsistency problem since policymakers gain by reoptimizing in later periods. By ignoring the first order conditions for the initial period Woodford's approach is time-invariant. I leave the comparison of both types of commitment policies for further research.

$$e_t = \rho_e e_{t-1} + \epsilon_t, \quad \epsilon_t \sim N(0, 1), \quad |\rho_e| < 1 \quad (3.11)$$

$$u_t = \rho_u u_{t-1} + v_t, \quad v_t \sim N(0, 1), \quad |\rho_u| < 1$$

which leads:

$$\begin{aligned} e_t &= \rho_e e_{t-1} + [\epsilon_t + v_t^e] \\ u_t &= \rho_u u_{t-1} + [v_t + v_t^u] \end{aligned} \quad (3.12)$$

When (3.12) is the true shock process, the error terms in (3.11) are distributed as $N(v_t^e, 1)$ and $N(v_t^u, 1)$ rather than as $N(0, 1)$. Therefore, the misspecification in (3.11) is captured by allowing the conditional mean of the shock vector (3.12) that actually generates the data to feed back arbitrarily on the history of the state variables.¹⁰

Moreover, the model with (3.11) is assumed to be a good approximation under the following restriction of the distortion.¹¹

$$E_t \sum_{\tau=0}^{\infty} \{[v_{t+\tau}^e]^2 + [v_{t+\tau}^u]^2\} \leq \eta_0, \quad \eta_0 > 0 \quad (3.13)$$

Under model uncertainty, the robust policymaker considers the model presented in the previous section as the reference model, which represents the most

¹⁰In the New Keynesian models studied in this paper, the state variables are the disturbance terms. Thus, the presence of v_t^e and v_t^u indicates the model misspecification.

¹¹The distortion can also be interpreted as a measure of the discrepancy between the distorted and approximating models.

likely description of the economic structure. However, the policymaker knows that this model could be subject to a wide range of distortions with (3.12) satisfying (3.13). Such a policymaker reformulates its optimization problem to obtain a policy rule that performs well even if the underlying structure of the economy deviates from the reference model. Following Hansen and Sargent (2008), to reformulate the problem under robust control, I introduce a fictitious evil agent who shares the same reference model that the policymaker considers and tries to maximize the same objective function (3.1). Hence the policymaker's problem (3.1) can be represented by a two-person zero-sum game or a Stackelberg problem. While the evil agent chooses a model from the available set of alternative models, the central bank designs its policy optimally to perform well in this worst-case scenario. Note that the most likely outcome of the model, the approximating model,¹² is when the policymaker sets policy -assuming that the private agents share the same worst-case model and form expectations accordingly-, yet there is no such misspecification in reality. To put differently, an approximating model will be the model where the structure of the economy evolves without any misspecification in the disturbances; however, the monetary authority finds it optimal to consider the worst possible scenario when conducting policy.

The game between the policymaker and the evil agents is represented by the following extremization problem that is the joint maximization and the minimization problem subject to the distorted model where the shock process

¹²The details of the solution algorithm for the approximating model is described in Appendix C.

is given by (4.10) and the entropy constraint (4.13).

$$\min_{\{v_{t+1}^e, v_{t+1}^u\}_{t=0}^\infty} \max_{\{\pi_t, y_t, r_t\}_{t=0}^\infty} E_t^{RC} \sum_{t=t_0}^\infty \beta^t \{[\pi_t^2 + \lambda_y y_t^2 + \lambda_r (r_t - r_{t-1})^2]\} \quad (3.14)$$

subject to

$$\pi_t = \beta E_t^{RC} \pi_{t+1} + \Omega y_t + e_t \quad (3.15)$$

$$e_t = \rho_e e_{t-1} + [\epsilon_t + v_t^e] \quad (3.16)$$

$$y_t = E_t^{RC} y_{t+1} - \frac{1}{\sigma} (r_t - E_t^{RC} \pi_{t+1}) + u_t \quad (3.17)$$

$$u_t = \rho_u u_{t-1} + [v_t + v_t^u] \quad (3.18)$$

$$E_t^{RC} \sum_{\tau=0}^\infty \{[v_{t+\tau}^e]^2 + [v_{t+\tau}^u]^2\} \leq \eta_0 \quad (3.19)$$

where E^{RC} denotes for the expectations operator of the distorted model. To make the model compatible with the rational expectations framework discussed in the previous section, I assume that the policymaker and the private agents have the same information set, and they form expectations about future variables in a homogeneous manner. Hence, the private agents share the policymaker's approximating model and the degree of concern for robustness as in Giordani and Söderlind (2004). Note that expectations under model misspecification will differ from those under rational expectations since the former includes the behavior of the hypothetical evil agent as well.

The monetary authority chooses the paths for $\{\pi_t, y_t, r_t\}$ that minimizes the loss function (3.1). Under model misspecification, the evil agent is supposed to choose v_{t+1}^e and v_{t+1}^u that maximizes the loss function under the budget

constraint (4.13).

Following Walsh (2004), I write the Lagrangian as the multiplier version of the Stackelberg problem defined in Hansen and Sargent (2008) as follows:

$$\begin{aligned}
\min_{\{v_{t+1}^e, v_{t+1}^u\}_{t=0}^\infty} \max_{\{\pi_t, y_t, r_t\}_{t=0}^\infty} E_t^{RC} \sum_{i=0}^{\infty} \beta^i \{ & \left(\frac{1}{2}\right) \pi_{t+i}^2 + \left(\frac{1}{2}\right) \lambda_y y_{t+i}^2 + \left(\frac{1}{2}\right) \lambda_r (r_{t+i} - r_{t+i-1})^2 \\
& - \left(\frac{1}{2}\right) \beta \Theta ([v_{t+i+1}^e]^2 + [v_{t+i+1}^u]^2) \\
& + s_{1t+i} (\pi_{t+i} - \beta \pi_{t+i+1} - \Omega y_{t+i} - e_{t+i}) \\
& + s_{2t+i} (\rho_e e_{t+i-1} + [\epsilon_{t+i} + v_{t+i}^e] - e_{t+i}) \\
& + s_{3t+i} (y_{t+i} - y_{t+i+1} + \frac{1}{\sigma} (r_{t+i} - \pi_{t+i+1}) - u_{t+i}) \\
& + s_{4t+i} (\rho_u u_{t+i-1} + [v_{t+i} + v_{t+i}^u] - u_{t+i}) \} \quad (3.20)
\end{aligned}$$

where $0 < \Theta < \infty$ represents the monetary authority's preference for the degree of robustness. Θ can be interpreted as a Lagrange multiplier on the constraint (4.13) measuring the size of the set of models surrounding the reference model. Hansen and Sargent (2008) show that Θ is positively related to η_0^{-1} . As Θ rises (or as η_0 gets smaller in (4.13)) the policymaker becomes less concerned about model uncertainty, and $\Theta = \infty$ (equivalently $\eta_0 = 0$) corresponds to the rational expectations solution with $v_t = 0$ for all t .¹³

I obtain the following first order conditions with respect to the choice variables of the policymaker and the evil agents, π_t , y_t , r_t , e_t , u_t , v_{t+1}^e , and v_{t+1}^u for the optimal commitment policy:

¹³For now, I take the connection between Θ and η_0 as given but in Section 3.2.5 I describe how to calibrate a reasonable value for the robustness parameter Θ using detection probabilities.

$$\begin{aligned}
\pi_t + s_{1t} - s_{1t-1} - \frac{1}{\beta\sigma}s_{3t-1} &= 0 \\
\lambda_y y_t - \Omega s_{1t} + s_{3t} - \frac{1}{\beta}s_{3t-1} &= 0 \\
\lambda_r(r_t - r_{t-1}) - \beta\lambda_r(r_{t+1} - r_t) + \frac{1}{\sigma}s_{3t} &= 0 \\
-s_{1t} + \rho_e s_{2t} - \frac{1}{\beta}s_{2t-1} &= 0 \\
-s_{3t} + \rho_u s_{4t} - \frac{1}{\beta}s_{4t-1} &= 0 \\
-\beta\Theta v_{t+1}^e + s_{2t} &= 0 \\
-\beta\Theta v_{t+1}^u + s_{4t} &= 0
\end{aligned} \tag{3.21}$$

The associated equilibrium conditions for the robust policy maker are the first-order conditions¹⁴ summarized in Equation (3.21) together with the following structural equations:

$$\begin{aligned}
\pi_t &= \beta E_t^{RC} \pi_{t+1} + \Omega y_t + e_t \\
e_t &= \rho_e e_{t-1} + [\epsilon_t + v_t^e] \\
y_t &= E_t^{RC} y_{t+1} - \frac{1}{\sigma}(r_t - E_t^{RC} \pi_{t+1}) + u_t \\
u_t &= \rho_u u_{t-1} + [v_t + v_t^u]
\end{aligned} \tag{3.22}$$

3.2.4 Robust Monetary Policy Under Discretion

In this section, I present discretionary solution for the optimal policy in the Benchmark model. Under discretion, a rational policymaker is unable to

¹⁴One has to take into consideration the first order condition for the initial period by letting $s_{1,t-1}, s_{2,t-1} = 0$ for $t = 0$. Since there are no previous commitment in the initial period, the monetary authority finds it optimal to consider expectations as fixed for $t = 0$.

commit to future policy actions. To stress the point that the policymaker cannot affect the expectations of the private sector about future variables, I reformulate the Lagrangian as:

$$\begin{aligned} \min_{\{\pi_t, y_t, i_t\}} \frac{1}{2} [\pi_t^2 + \lambda_y y_t^2 + \lambda_r (r_t - r_{t-1})^2] + \frac{1}{2} E_t^{RE} \sum_{j=t+1}^{\infty} \beta^{j-t} [\pi_t^2 + \lambda_y y_t^2 \lambda_r (r_t - r_{t-1})^2] \\ + s_{1,t} (\pi_t - \beta \pi_t^e - \Omega y_t - e_t) \\ + s_{3,t} (y_t - y_t^e + \frac{1}{\sigma} (r_t - \pi_t^e) - u_t) \} \quad (3.23) \end{aligned}$$

Here, we assume that the monetary authority optimizes taking expectations of future variables as given, which allows to write $E_t \pi_{t+1} = \pi_t^e$ and $E_t y_{t+1} = y_t^e$. The first-order conditions with respect to π_t , y_t and r_t are found as:

$$\begin{aligned} \pi_t + s_{1t} &= 0 \\ \lambda_y y_t - \Omega s_{1t} + s_{3t} &= 0 \\ \lambda_r (r_t - r_{t-1}) + \frac{1}{\sigma} s_{3t} &= 0 \end{aligned} \quad (3.24)$$

The optimal policy under rational expectations for the benchmark model is the discretionary solution $\{y_t, \pi_t, r_t, s_{1t}, s_{3t}\}$ to the system of first-order conditions (3.24) initial conditions (3.10) together with the stochastic versions of IS and Phillips equations summarized in Table 3.1.

To formulate model misspecification in the policymaker's problem, the concept of robustness is used as a metaphor; thus, the hypothetical evil agent solves his optimization problem when and only when the monetary authority

does. Hence while introducing model uncertainty under discretion, one has to take into account the fact that the optimal policy does not have an impact on the private sector expectations so the forward-looking variables are taken as given. Because the planner optimizes every period, I allow the evil agent to apply the same conjecture.

In the implied zero-sum-game between the policymaker and the hypothetical evil agent, both players choose their control variables, that are $\{v_t^e, v_t^u\}$ and $\{\pi_t, y_t, r_t\}$ sequentially. The Lagrangian for the policy problem under discretion can be written as follows:

$$\begin{aligned}
\min_{\{v_t^e, v_t^u\}} \max_{\{\pi_t, y_t, r_t\}} \{ & \frac{1}{2} [\pi_t^2 + \lambda_y y_t^2 + \lambda_r (r_t - r_{t-1})^2] - (\frac{1}{2}) \Theta([v_t^e]^2 + [v_t^u]^2) \\
& + s_{1t} (\pi_t - \beta \pi_t^e - \Omega y_t - e_t) \\
& + s_{2t} (\rho_e e_{t-1} + [\epsilon_t + v_t^e] - e_t) \\
& + s_{3t} (y_t - y_t^e + \frac{1}{\sigma} (r_t - \pi_t^e) - u_t) \\
& + s_{4t} (\rho_u u_{t-1} + [v_t + v_t^u] - u_t) \} \quad (3.25)
\end{aligned}$$

One can obtain the following first order conditions:

$$\begin{aligned}
\pi_t + s_{1t} - s_{1t-1} &= 0 \\
\lambda_y y_t - \Omega s_{1t} + s_{3t} &= 0 \\
\lambda_r (r_t - r_{t-1}) + \frac{1}{\sigma} s_{3t} &= 0 \\
-s_{1t} + \rho_e s_{2t+1} - \frac{1}{\beta} s_{2t} &= 0
\end{aligned}$$

$$\begin{aligned}
-s_{3t} + \rho_u s_{4t+1} - \frac{1}{\beta} s_{4t} &= 0 \\
-\Theta v_t^e + s_{2t} &= 0 \\
-\Theta v_t^u + s_{4t} &= 0
\end{aligned} \tag{3.26}$$

3.2.5 Calibration

Deep Parameters of the Model

For the baseline calibration, I use the values from Galí (2015). I choose the habit persistence parameter to be consistent with the literature.¹⁵

Table 3.2: Benchmark Calibration

Parameter	Description	Values
Parameters for the baseline model		
β	Discount Factor	0.99
σ	Inverse of the Elasticity of Intertemporal Substitution	2.75
η	Inverse of the Frisch Labor Supply Elasticity	5
θ	Calvo Price Stickiness Parameter	0.75
$(1 - \alpha)$	Labor Share in the Production Function	0.75
λ_y	Weight of the output gap in loss function	0.25
λ_r	Weight of the interest rate in loss function	0.3
Θ	Robustness Parameter	12.5

I calibrate the fraction of the backward-looking firms as 0.25 to produce a backward looking component in the Phillips curve to be quantitatively modest which is consistent with the estimates of Galí et al. (2005). In the next section, I will present how the dynamics are affected for a variety of parameter values. Yet, the results are quite robust under the specification of the model parameters presented in Table 3.2.

¹⁵For instance, see Smets and Wouters (2007)

The Degree of Robustness

As in Hansen and Sargent (2008) and Giordani and Söderlind (2004), I use likelihood ratio test to calculate the detection error probabilities. I exploit the fact that each value of the robustness parameter Θ is associated with a set of alternative models $\tilde{M}$. The model with the largest distance to the reference model for each Θ is the corresponding worst-case model $m^W \in \tilde{M}$. A robust decision maker seeking to learn about the true data generating process assigns unconditional probabilities to both her reference model in mind, m^0 and the worst-case model m^W . By allowing a the probability of the reference model and the worst-case model to be 50%, i.e. $Pr(m^W) = Pr(m^0) = 0.5$, the decision maker treats both models to be equally likely ex-ante. In what follows, with the help a likelihood ratio test ¹⁶, the decision maker updates her beliefs about the likelihood of each model as new observations emerges.

Let (L_A) denote for the probability of the likelihood of the observations under a of model A. The test favors the reference model when

$$\left(\frac{L_{m^0}}{L_{m^W}} > 1 \right)$$

, and selects the worst-case model as the true data generating process when

$$\left(\frac{L_{m^W}}{L_{m^0}} > 1 \right)$$

.

¹⁶I utilize the Matlab code of Giordani and Söderlind (2004) when calculating detection error probabilities. Required state-space representations can be found in the appendix of the thesis.

To define the detection error probability, one has to differentiate between the Type-I error and Type-II errors defined as follows:

$$Type - I \equiv \left(\frac{L_{m^W}}{L_{m^0}} > 1 | m^0 \right) \quad (3.27)$$

$$Type - II \equiv \left(\frac{L_{m^0}}{L_{m^W}} > 1 | m^W \right) \quad (3.28)$$

Here, Type-I error is making the incorrect deduction in favor of the worst-case model although the reference model generates the data. Accordingly, Type-II error is selecting the reference model although the worst-case model is the true data generating process.

A detection-error probability is the probability that an econometrician observing equilibrium outcomes would make a wrong deduction about whether two competing models generate the data. Using two-types of errors mentioned above, one can define the detection error probability as follows:

$$p(\Theta^{-1}) \equiv Pr(m^0) * Pr(Type - I) + Pr(m^W) * Pr(Type - II) \quad (3.29)$$

The idea is to connect the value of the robustness parameter Θ to the probability of making the incorrect choice of model between the reference model and the worst-case model.

For $Pr(m^W) = Pr(m^0) = 0.5$, one obtains the following:

$$p(\Theta^{-1}) \equiv 0.5 * Pr(Type - I) + 0.5 * Pr(Type - II) \quad (3.30)$$

A robust agent wants to guard against all alternative models which he can

tell the difference from the reference model at most $100(1 - p(\Theta^{-1}))$ percent of the time. Hence, the detection error probability of 50% implies that two data generating processes are almost the same, and differentiating between the reference model and the worst-case model is not possible. With a detection error probability closer to zero, the econometrician is able to detect the true data generating process since the models are highly different. I choose the value of Θ to achieve 20% of detection error probability.

Note the empirical probabilities of two-types of errors as follows:

$$Type - I = \left(\frac{\sum_{j=1}^N \frac{(L_{m^W})_i}{(L_{m^0})_i} > 1 | m^0}{N} \right) \quad (3.31)$$

$$Type - II = \left(\frac{\sum_{j=1}^N \frac{(L_{m^0})_i}{(L_{m^W})_i} > 1 | m^W}{N} \right) \quad (3.32)$$

3.2.6 Impulse Responses

With a concern for model uncertainty, the policymaker sets the policy that would work well under the worst possible model misspecification. Table 3.3 demonstrate robust optimal commitment policy responses in comparison to policy without any concern for robustness.

Table 3.3: The Impact of Uncertainty on the Policy

	e_{t-1}	u_{t-1}	s_{1t-1}	s_{3t-1}	r_{t-1}	ε_t	v_t
Benchmark Model							
Rational Expectations	0.084	0.759	-0.222	-0.675	0.553	0.105	0.949
With Robustness	0.038	0.819	-0.23	-0.69	0.522	0.048	1.023
Sign of the Change	-	+	+	+	-	-	+

Note: The third row demonstrates how doubts about model uncertainty changes the coefficients of the rational expectations solution for the policy rate with a detection error probability of 20%. A positive change reflects more aggressive response of the robust policy.

To begin with, model uncertainty induces lower response to last period's interest rate; thus, the policymaker attaches less importance to the interest rate inertia. In addition, the robust rule induces caution for the supply shock but aggressive response for the demand shock. To understand this, one has to analyze the dynamics of the model in response to shocks under model uncertainty with the help of impulse response functions.

I also present the impact of model uncertainty for a discretionary policy maker in Table 3.4.

Table 3.4: The Impact of Uncertainty on the Policy under Discretion

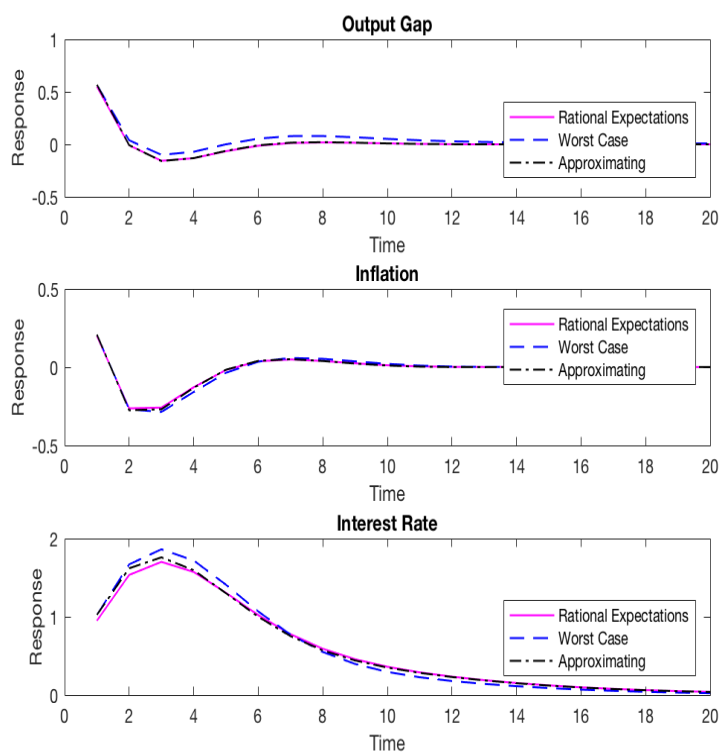
	e_{t-1}	u_{t-1}	ε_t	v_t	r_{t-1}
Benchmark Model					
Rational Expectations	0.308	0.964	0.385	1.205	0.396
With Robustness	0.292	1.072	0.365	1.34	0.435
Sign of the Change	–	+	–	+	+

Note: The third row demonstrates how doubts about model uncertainty changes the coefficients of the rational expectations solution for the policy rate with a detection error probability of 20%. A positive change reflects more aggressive response of the robust policy.

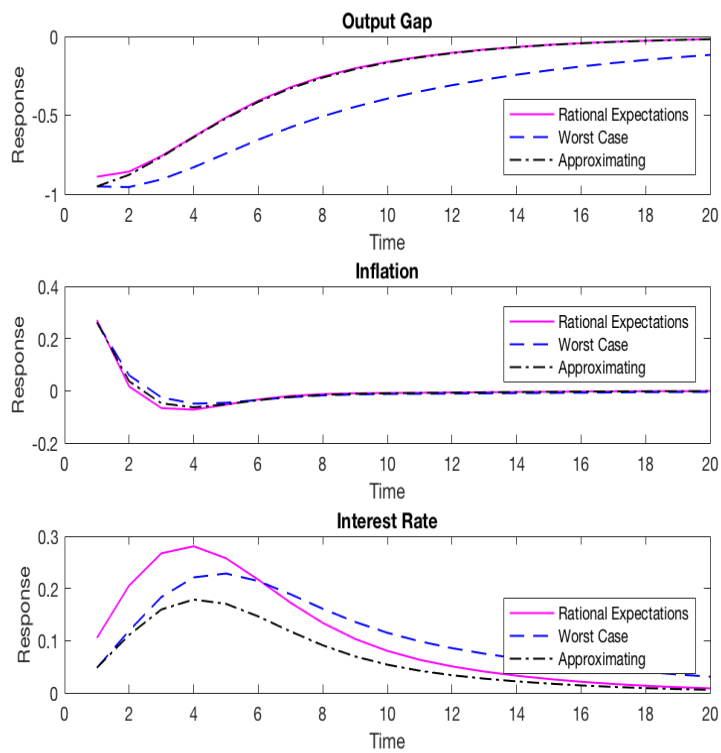
The results are similar with the findings for the commitment case such that concerns for model misspecification calls for attenuation for the policymaker under a supply shock; however policymaker becomes more aggressive when facing a demand shock.

Impulse Response Functions The impulse response functions for the output gap, inflation rate and the nominal interest rate, illustrated in Figure 3.1 show how model dynamics evolve.

In Figure 3.1a, one can find the responses to one standard deviation of a demand shock. Figure demonstrates the dynamics of the model for the standard rational expectations solution (the pink line), the approximating model (the



(a) Demand Shock



(b) Supply Shock

Figure 3.1: Impulse Responses of the Benchmark Model Under Uncertainty

black dashed line), and the dynamics under the worst-case (the blue dashed line).

For the benchmark specification, a demand shock has a direct impact on the output gap and the inflation rate. Both variables increase above their steady state values. The policymaker responds to the increase in the aggregate demand by raising the policy rate. This increase in the interest rate is gradual due to the impact of the policy on future expectations under commitment and the presence of interest rate in the objective function of the policymaker. As the central bank raises the interest rate the output gap and the inflation return to their steady state values. Moreover, model uncertainty makes the optimal policy more aggressive compared to the rational expectations case. When the economy faces a shock to aggregate demand, the monetary authority guards against model misspecification and formulates a policy that would work well under the worst possible outcome of the shock. Central bank not only increases the nominal interest rate to a higher level compared to the case under rational expectations but also keeps it that way for a longer time. Although the responses of output gap and inflation seem close with and without model uncertainty, it takes longer for inflation to go back to the steady state.

Figure 3.1b, report the responses of output gap, inflation and the nominal interest rate for a positive shock to the Phillips curve. A positive supply shock initially raises inflation rate above its steady state value. As a consequence, the policymaker sets the nominal interest rate high enough to keep the real interest rate positive so that she chooses a path for the output gap that keeps output below its potential for some periods. With credible commitment, the

central bank is able to influence private sector expectations of inflation with promises to keep the output gap negative in the future. As time passes, the inflation starts to fall, interest rate declines and output gap rises.

In the worst-case equilibrium, the impact of the supply shock dies out slower relative to the rational expectations case. First, inflation is more persistent. Second, the decline in the output gap is more pronounced initially and effect of the shock on the output gap becomes more persistent under model uncertainty. Finally, the initial response of the interest rate is the same as the responses under the worst-case model. However, what follows is a lower interest rate and the path converges to the rational expectations equilibrium.

The robust central bank fears that inflation responds less strongly to its disturbance. The response of the policymaker under the approximating model, when the fears of the monetary authority do not come true so distortions are not realized, becomes less aggressive (compared to the response under rational expectations) in order to control inflation.

Figure 3.2 shows the impulse responses under commitment and discretion with and without model misspecification for each shock. Although, monetary authority responds more to a demand shock, it takes longer for the output gap to return to the steady state. For the supply shock, nominal interest rate is above compared to the optimal behavior under rational expectations.

Under commitment, the monetary authority is able to stabilize the economy not only by decreasing the output gap (by adjusting the policy rate gradually) but also promising to keep output gap lower in the future. At the same time, with doubts about model misspecification, both the policymaker and

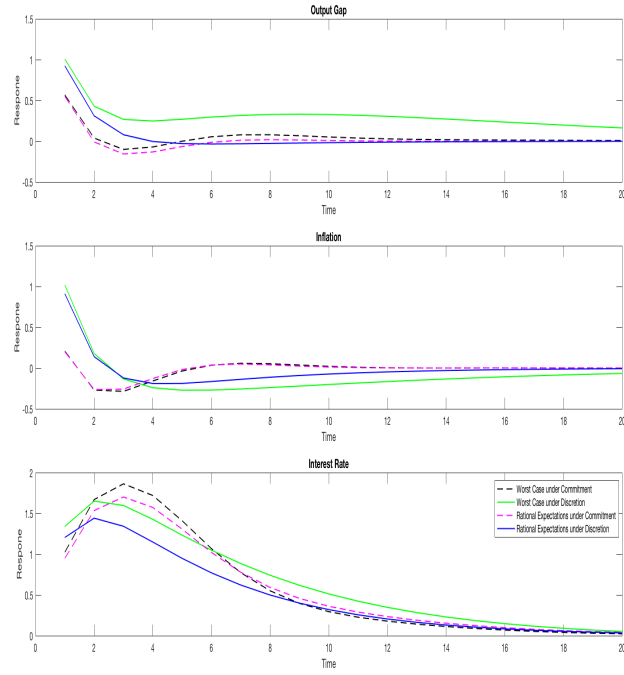
the private sector overestimate the impact of the shocks, which induces a more aggressive policy.

Under discretion, since policymaker is not able to control expectations regarding future variables, she adjusts the nominal rate sharply to control the effects of the shock immediately, allowing for high deviations of output and the inflation from the steady state in the initial periods. Also, neither the policymaker nor the fictitious evil agent can commit, there will be lower disturbances due to model misspecification compared to the commitment case.

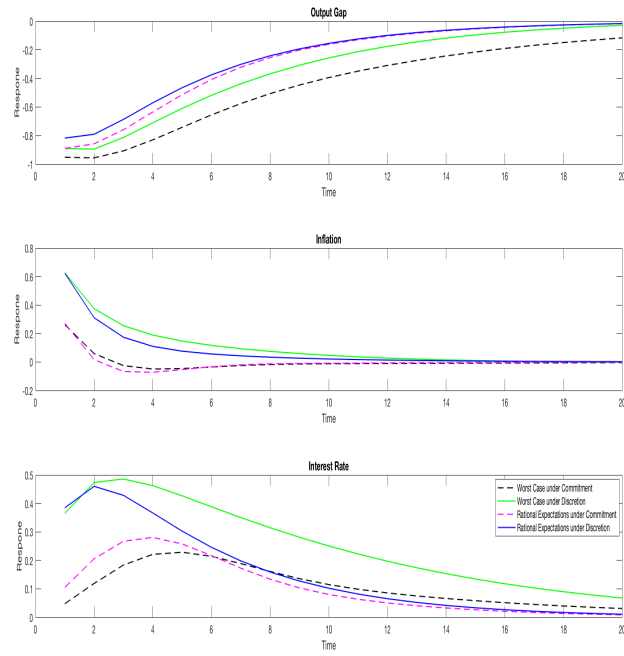
3.2.7 Comparison with the Literature

The results based on the benchmark New Keynesian model show that the response of a robust central bank depends on the type of shock.¹⁷ Cateau (2006) argues that different New Keynesian models imply different monetary policy transmission mechanisms; hence, uncertainty reveals varying responses depending on the model. Giordani and Söderlind (2004) stresses an aggressive behavior for the central bank in different specifications of Keynesian models under uncertainty. Clearly, responses to a supply shock above contradicts those of Giordani and Söderlind (2004). As first suggested by Dennis (2008), their algorithm for the approximating model is not valid. To clarify, Figure 3.3 presents a comparison the approximating equilibrium calculated by their algorithm as well. Although the dynamics for the rational expectations, the approximating model and the worst-case model are similar, the dynamics for the approximating equilibrium calculated with Giordani and Söderlind

¹⁷Model features also play a considerable role on the dynamics under model uncertainty. Section 3.3 elaborates more on this argument.



(a) Demand Shock



(b) Supply Shock

Figure 3.2: Benchmark Model- Commitment versus Discretion

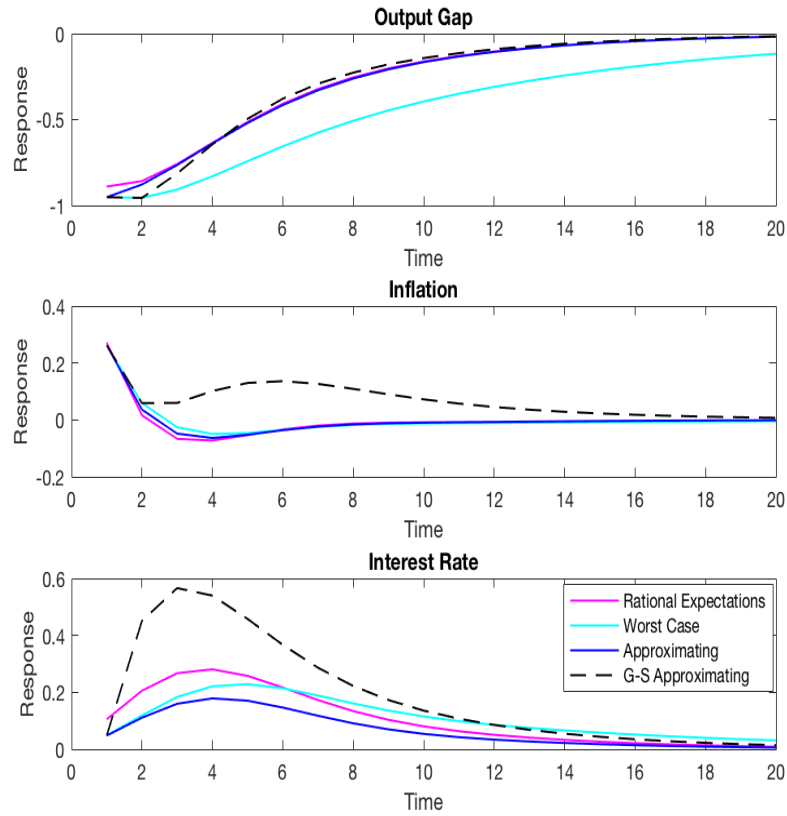


Figure 3.3: Comparison with Giordani and Söderlind (2004)

(2004)'s algorithm (G-S Approximating) are substantially different. Under G-S approximating equilibrium, the policymaker reacts more aggressively by increasing the interest rate too much, causing a fall in the output as much as in the worst-case. The response of the inflation to a supply shock under G-S approximating equilibrium does not fall below zero, which contradicts with optimal behavior in New Keynesian models under commitment.

3.3 Introducing Endogenous Persistence to the Model

In what follows, I present some extensions of the basic model.

3.3.1 Habit Formation in Consumption

The utility of the representative household now takes the form:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\eta}}{1+\eta} \right\} \quad (3.33)$$

where h is a parameter that controls the habit persistence.

Maximization of (3.33) subject to the intertemporal budget constraint (3.3)

yields the following first order conditions:

$$\begin{aligned} \frac{(C_t - hC_{t-1})^{-\sigma}}{P_t} &= \lambda_t \\ \left(\frac{L_t^\eta}{w_t P_t} \right) &= \lambda_t \\ \left(\frac{\lambda_t}{E_t \lambda_{t+1}} \right) &= \beta R_t \end{aligned} \quad (3.34)$$

Log-linearization of above optimality conditions, assuming the production side is as described in the benchmark model, yields the set of equilibrium conditions in Table 3.5.

Table 3.5: Consumption Habits

Phillips Curve	$\pi_t = \beta E_t \pi_{t+1} + \gamma_{11} y_t + \gamma_{12} y_{t-1} + e_t$
Hybrid IS Curve	$y_t = \gamma_8 y_{t-1} + \gamma_9 E_t y_{t+1} + \gamma_{10} (r_t - E_t \pi_{t+1}) + u_t$

where $\gamma_8 = \frac{h}{1+h}$, $\gamma_9 = \frac{1}{1+h}$, $\gamma_{10} = -\frac{(1-h)}{\sigma(1+h)}$, $\gamma_{11} = \frac{(1-\theta)(1-\beta\theta)}{\theta} \left[\left(\frac{\sigma}{1-h} + \frac{\alpha+\eta}{1-\alpha} \right) \right]$,
 $\gamma_{12} = -\frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{\sigma h}{1-h}$.

Including habit formation into the model adds a backward-looking component, i.e. y_{t-1} into the IS curve and the Phillips curve. Habit persistence parameter, h , also reflects the persistence in output dynamics.

Optimal Policy

Allowing for habit formation in consumption yields the following Lagrangian:

$$\begin{aligned} \min_{\{\pi_t, y_t, i_t\}_{t=0}^{\infty}} E_0^{RE} \sum_{t=0}^{\infty} \beta^t \{ & \left[\left(\frac{1}{2} \right) \pi_t^2 + \left(\frac{1}{2} \right) \lambda_y y_t^2 + \left(\frac{1}{2} \right) \lambda_r (r_t - r_{t-1})^2 \right] \\ & + s_{1t} (\pi_t - \beta \pi_{t+1} - \gamma_{11} y_t - \gamma_{12} y_{t-1} - e_t) \\ & + s_{3t} (y_t - \gamma_8 y_{t-1} - \gamma_9 y_{t+1} - \gamma_{10} (r_t - \pi_{t+1}) - u_t) \} \end{aligned} \quad (3.35)$$

which leads to the first-order necessary conditions stated below.

$$\begin{aligned} \pi_t + s_{1t} - s_{1t-1} + \frac{\gamma_{10}}{\beta} s_{3t-1} &= 0 \\ \lambda_y y_t - \gamma_{11} s_{1t} - \gamma_{12} \beta s_{1t+1} + s_{3t} - \gamma_8 \beta s_{3t+1} - \frac{\gamma_9}{\beta} s_{3t-1} &= 0 \\ \lambda_r (r_t - r_{t-1}) - \beta \lambda_r (r_{t+1} - r_t) - \gamma_{10} s_{3t} &= 0 \end{aligned} \quad (3.36)$$

at each date $t \geq 0$, with the initial conditions (3.10).

Considering habit formation in the New Keynesian model changes the structure of the economy in a way that makes the economy more persistence. Embedding model misspecification into the model, we aim to see how the behavior of the optimal monetary policy conduct acts together with the habit persistence. The Lagrangian under model uncertainty for the model with habit formation is written as:

$$\begin{aligned}
& \min_{\{v_{t+1}^e, v_{t+1}^u\}_{t=0}^\infty} \max_{\{\pi_t, y_t, r_t\}_{t=0}^\infty} E_t^{RC} \sum_{i=0}^\infty \beta^i \{ [(\frac{1}{2})\pi_{t+i}^2 + (\frac{1}{2})\lambda_y y_{t+i}^2 + (\frac{1}{2})\lambda_r (r_{t+i} - r_{t+i-1})^2 \\
& \quad - (\frac{1}{2})\beta\Theta([v_{t+i+1}^e]^2 + [v_{t+i+1}^u]^2)] \\
& \quad + s_{1t+i}(\pi_{t+i} - \beta\pi_{t+i+1} - \gamma_{11}y_{t+i} - \gamma_{12}y_{t+i-1} - e_{t+i}) \\
& \quad + s_{2t+i}(\rho_e e_{t+i-1} + [\epsilon_{t+i} + v_{t+i}^e] - e_{t+i}) \\
& \quad + s_{3t+i}(y_{t+i} - \gamma_8 y_{t+i-1} - \gamma_9 y_{t+i+1} - \gamma_{10}(r_{t+i} - \pi_{t+i+1}) - u_{t+i}) \\
& \quad + s_{4t+i}(\rho_u u_{t+i-1} + [v_{t+i} + v_{t+i}^u] - u_{t+i}) \} \quad (3.37)
\end{aligned}$$

One can obtain the first-order necessary conditions as:

$$\begin{aligned}
& \pi_t + s_{1t} - s_{1t-1} + \frac{\gamma_{10}}{\beta} s_{3t-1} = 0 \\
& \lambda_y y_t - \gamma_{11} s_{1t} - \beta \gamma_{12} s_{1t+1} + s_{3t} - \beta \gamma_8 s_{3t+1} - \frac{\gamma_9}{\beta} s_{3t-1} = 0 \\
& \lambda_r (r_t - r_{t-1}) - \beta \lambda_r (r_{t+1} - r_t) - \gamma_{10} s_{3t} = 0 \\
& -s_{1t} + \rho_e s_{2t} - \frac{1}{\beta} s_{2t-1} = 0 \\
& -s_{3t} + \rho_u s_{4t} - \frac{1}{\beta} s_{4t-1} = 0 \\
& -\beta \Theta v_{t+1}^e + s_{2t} = 0 \\
& -\beta \Theta v_{t+1}^u + s_{4t} = 0 \quad (3.38)
\end{aligned}$$

Optimal solution to the extremization problem is represented by the system of equations (3.38) with the structural equations under model misspecification as shown below:

$$\begin{aligned}
y_t &= \gamma_8 y_{t-1} + \gamma_9 E_t^{RC} y_{t+1} + \gamma_{10} (r_t - E_t^{RC} \pi_{t+1}) + u_t \\
u_t &= \rho_u u_{t-1} + [\epsilon_t + v_t^u] \\
\pi_t &= \beta E_t^{RC} \pi_{t+1} + \gamma_{11} y_t + \gamma_{12} y_{t-1} + e_t \\
e_t &= \rho_e e_{t-1} + [\epsilon_t + v_t^e]
\end{aligned} \tag{3.39}$$

3.3.2 Backward-looking Firms

When the aggregate price level is given by $P_t = \theta P_{t-1} + (1 - \theta) P_t^*$, the index of newly set prices are defined as

$$P_t^* = \omega P_t^b + (1 - \omega) P_t^f$$

where ω fraction of firms which have a chance to reoptimize their prices are backward-looking and set $P_t^b \equiv P_{t-1}^* + \Pi_{t-1}$ ¹⁸ and $(1 - \omega)$ fraction are forward-looking and choose profit maximizing price P_t^f . Households solve the problem in section 2.1. The resulting linearized equilibrium conditions are summarized in Table 3.6. Phillips curve has an additional component, π_{t-1} , due to backward-looking firms.

Table 3.6: Inflation Persistence

Hybrid Phillips Curve	$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda_B y_t + e_t$
IS Curve	$y_t = E_t y_{t+1} - \frac{1}{\sigma} (r_t - E_t \pi_{t+1}) + u_t$

where $\gamma_b = \frac{\omega}{\theta + \omega[1 - \theta(1 - \beta)]}$, $\gamma_f = \frac{\beta\theta}{\theta + \omega[1 - \theta(1 - \beta)]}$, and $\lambda_B = \frac{(1 - \omega)(1 - \theta)(1 - \beta\theta)}{\theta + \omega[1 - \theta(1 - \beta)]} \left(\frac{\alpha + \eta}{1 - \alpha} + \sigma \right)$.

¹⁸See Galí and Gertler (1999).

Optimal Policy

For the model with inflation persistence, I form the Lagrangian in a similar fashion as follows:

$$\begin{aligned}
\min_{\{\pi_t, y_t, i_t\}_{t=0}^{\infty}} E_0^{RE} \sum_{t=0}^{\infty} \beta^t \{ & [(\frac{1}{2})\pi_t^2 + (\frac{1}{2})\lambda_y y_t^2 + (\frac{1}{2})\lambda_r (r_t - r_{t-1})^2] \\
& + s_{1t}(\pi_t - \gamma_b \pi_{t-1} - \gamma_f \pi_{t+1} - \gamma_b y_t - e_t) \\
& + s_{3t}(y_t - y_{t+1} + \frac{1}{\sigma}(r_t - \pi_{t+1}) - u_t) \} \quad (3.40)
\end{aligned}$$

The first-order necessary conditions with respect to π_t , y_t and r_t are

$$\begin{aligned}
\pi_t + s_{1t} - \gamma_b \beta s_{1t+1} - \frac{\gamma_f}{\beta} s_{1t-1} - \frac{1}{\beta \sigma} s_{3t-1} &= 0 \\
\lambda_y y_t - \gamma_b s_{1t} + s_{3t} - \frac{1}{\beta} s_{3t-1} &= 0 \\
\lambda_r (r_t - r_{t-1}) - \beta \lambda_r (r_{t+1} - r_t) + \frac{1}{\sigma} s_{3t} &= 0 \quad (3.41)
\end{aligned}$$

Robustly optimal policy problem can be set as follows:

$$\begin{aligned}
\min_{\{v_{t+1}^e, v_{t+1}^u\}_{t=0}^{\infty}} \max_{\{\pi_t, y_t, r_t\}_{t=0}^{\infty}} E_t^{RC} \sum_{i=0}^{\infty} \beta^i \{ & [(\frac{1}{2})\pi_{t+i}^2 + (\frac{1}{2})\lambda_y y_{t+i}^2 + (\frac{1}{2})\lambda_r (r_{t+i} - r_{t+i-1})^2 \\
& - (\frac{1}{2})\beta \Theta([v_{t+i+1}^e]^2 + [v_{t+i+1}^u]^2)] \\
& + s_{1t+i}(\pi_{t+i} - \gamma_b \pi_{t+i-1} - \gamma_f \pi_{t+i+1} - \lambda_B y_{t+i} - e_{t+i}) \\
& + s_{2t+i}(\rho_e e_{t+i-1} + [\epsilon_{t+i} + v_{t+i}^e] - e_{t+i}) \\
& + s_{3t+i}(y_{t+i} - y_{t+i+1} + \frac{1}{\sigma}(r_{t+i} - \pi_{t+i+1}) - u_{t+i}) \\
& + s_{4t+i}(\rho_u u_{t+i-1} + [v_{t+i} + v_{t+i}^u] - e_{t+i}) \} \quad (3.42)
\end{aligned}$$

The first-order conditions with respect to π_t , y_t , r_t , v_{t+1}^e , and v_{t+1}^u for the

optimal commitment policy are:

$$\begin{aligned}
\pi_t + s_{1t} - \beta\gamma_b s_{1t+1} - \frac{\gamma_f}{\beta} s_{1t-1} - \frac{1}{\beta\sigma} s_{3t-1} &= 0 \\
\lambda_y y_t - \lambda_B s_{1t} + s_{3t} - \frac{1}{\beta} s_{3t-1} &= 0 \\
\lambda_r(r_t - r_{t-1}) - \beta\lambda_r(r_{t+1} - r_t) + \frac{1}{\sigma} s_{3t} &= 0 \\
-s_{1t} + \rho_e s_{2t} - \frac{1}{\beta} s_{2t-1} &= 0 \\
-s_{3t} + \rho_u s_{4t} - \frac{1}{\beta} s_{4t-1} &= 0 \\
-\beta\Theta v_{t+1}^e + s_{2t} &= 0 \\
-\beta\Theta v_{t+1}^u + s_{4t} &= 0
\end{aligned} \tag{3.43}$$

The solution for the optimal paths for π_t , y_t , r_t , v_{t+1}^e , v_{t+1}^u , s_{1t} , s_{2t} , s_{3t} , s_{4t} are represented by (3.43) and the model equations with distortions to shocks shown below.

$$\begin{aligned}
\pi_t &= \gamma_b \pi_{t-1} + \gamma_f E_t^{RC} \pi_{t+1} + \lambda_B y_t + e_t \\
e_t &= \rho_e e_{t-1} + [\epsilon_t + v_t^e] \\
y_t &= E_t^{RC} y_{t+1} - \frac{1}{\sigma} (r_t - E_t^{RC} \pi_{t+1}) + u_t \\
u_t &= \rho_u u_{t-1} + [v_t + v_t^u]
\end{aligned} \tag{3.44}$$

3.3.3 Habit Formation and Inflation Persistence

Maximization of the utility of the form:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\eta}}{1+\eta} \right\}$$

subject to the intertemporal budget constraint

$$P_t C_t + B_t \leq B_{t-1} R_{t-1} + P_t [w_t L_t] + \Phi_t$$

yields the following linearized dynamic equation for the determination of consumption:

$$c_t = \gamma_8 c_{t-1} + \gamma_9 E_t c_{t+1} + \gamma_{10} (r_t - E_t \pi_{t+1}) \quad (3.45)$$

Assuming some fraction of the firms reoptimizing their prices as backward-looking yields the following transition equation for the aggregate price setting as suggested by the model with inflation persistence:

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda z_t \quad (3.46)$$

where $\lambda = \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\theta+\omega[1-\theta(1-\beta)]}$, and z_t is the real marginal cost derived under the model with habit persistence. Linearized equilibrium dynamics of the model is shown in Table 3.7

Table 3.7: Inflation and Habit Persistence

Hybrid Phillips Curve	$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t \pi_{t+1} + \lambda_1 y_t + \lambda_2 y_{t-1} + e_t$
Hybrid IS Curve	$y_t = \gamma_8 y_{t-1} + \gamma_9 E_t y_{t+1} + \gamma_{10} (r_t - E_t \pi_{t+1}) + u_t$

where $\lambda_1 = \lambda(\frac{\alpha+\eta}{1-\alpha} + \frac{\sigma}{1-h})$, $\lambda_2 = -\lambda \frac{\sigma h}{1-h}$, and $\gamma_b, \gamma_f, \gamma_8, \gamma_9$ and γ_{10} are as defined above.

Optimal Policy

Finally, the Lagrangian for the model with both inflation persistence and habit persistence is written under commitment as follows:

$$\begin{aligned}
\min_{\{\pi_t, y_t, i_t\}_{t=0}^{\infty}} E_0^{RE} \sum_{t=0}^{\infty} \beta^t & \left\{ \left[\left(\frac{1}{2} \right) \pi_t^2 + \left(\frac{1}{2} \right) \lambda_y y_t^2 + \left(\frac{1}{2} \right) \lambda_r (r_t - r_{t-1})^2 \right] \right. \\
& + s_{1t} (\pi_t - \gamma_b \pi_{t-1} - \gamma_f \pi_{t+1} - \lambda_1 y_t - \lambda_2 y_{t-1} - e_t) \\
& \left. + s_{3t} (y_t - \gamma_8 y_{t-1} - \gamma_9 y_{t+1} + -\gamma_{10} (r_t - \pi_{t+1}) - u_t) \right\} \quad (3.47)
\end{aligned}$$

This leads to the first-order necessary conditions for the commitment problem as follows:

$$\begin{aligned}
\pi_t + s_{1t} - \gamma_b \beta s_{1t+1} - \frac{\gamma_f}{\beta} s_{1t-1} + \frac{\gamma_{10}}{\beta} s_{3t-1} &= 0 \\
\lambda_y y_t - \lambda_1 s_{1t} - \lambda_2 \beta s_{1t+1} + s_{3t} - \gamma_8 \beta s_{3t+1} - \frac{\gamma_9}{\beta} s_{3t-1} &= 0 \\
\lambda_r (r_t - r_{t-1}) - \beta \lambda_r (r_{t+1} - r_t) - \gamma_{10} s_{3t} &= 0 \quad (3.48)
\end{aligned}$$

at each date $t \geq 0$, with the initial conditions (3.10).

The optimal policy under rational expectations for the benchmark model is the solution $\{y_t, \pi_t, r_t, s_{1t}, s_{3t}\}$ to the system of first-order conditions (3.41) initial conditions (3.10) together with the IS and Phillips equations summarized in Table 3.7.

We set up the Lagrangian for robustly optimal policy as follows:

$$\begin{aligned}
\min_{\{v_{t+1}^e, v_{t+1}^u\}_{t=0}^\infty} \max_{\{\pi_t, y_t, r_t\}_{t=0}^\infty} E_t^{RC} \sum_{i=0}^\infty \beta^i \{ & \left[\left(\frac{1}{2} \right) \pi_{t+i}^2 + \left(\frac{1}{2} \right) \lambda_y y_{t+i}^2 + \left(\frac{1}{2} \right) \lambda_r (r_{t+i} - r_{t+i-1})^2 \right. \\
& \left. - \left(\frac{1}{2} \right) \beta \Theta([v_{t+i+1}^e]^2 + [v_{t+i+1}^u]^2) \right] \\
& + s_{1t+i} (\pi_{t+i} - \gamma_b \pi_{t+i-1} - \gamma_f \pi_{t+i+1} - \lambda_1 y_{t+i} - \lambda_2 y_{t+i-1} - e_{t+i}) \\
& + s_{2t+i} (\rho_e e_{t+i-1} + [\epsilon_{t+i} + v_{t+i}^e] - e_{t+i}) \\
& + s_{3t+i} (y_{t+i} - \gamma_8 y_{t+i-1} - \gamma_9 y_{t+i+1} - \gamma_{10} (r_{t+i} - \pi_{t+i+1}) - u_{t+i}) \\
& \left. + s_{4t+i} (\rho_u u_{t+i-1} + [v_{t+i} + v_{t+i}^u] - e_{t+i}) \right\} \quad (3.49)
\end{aligned}$$

The first-order conditions with respect to π_t , y_t , r_t , v_{t+1}^e , and v_{t+1}^u for the optimal commitment policy are:

$$\begin{aligned}
\pi_t + s_{1t} - \beta \gamma_b s_{1t+1} - \frac{\gamma_f}{\beta} s_{1t-1} + \frac{\gamma_{10}}{\beta} s_{3t-1} &= 0 \\
\lambda_y y_t - \lambda_1 s_{1t} - \beta \lambda_2 s_{1t+1} + s_{3t} - \beta \gamma_8 s_{3t+1} - \frac{\gamma_9}{\beta} s_{3t-1} &= 0 \\
\lambda_r (r_t - r_{t-1}) - \beta \lambda_r (r_{t+1} - r_t) - \gamma_{10} s_{3t} &= 0 \\
-s_{1t} + \rho_e s_{2t} - \frac{1}{\beta} s_{2t-1} &= 0 \\
-s_{3t} + \rho_u s_{4t} - \frac{1}{\beta} s_{4t-1} &= 0 \\
-\beta \Theta v_{t+1}^e + s_{2t} &= 0 \\
-\beta \Theta v_{t+1}^u + s_{4t} &= 0 \quad (3.50)
\end{aligned}$$

The solution for the optimal paths for π_t , y_t , r_t , v_{t+1}^e , v_{t+1}^u , s_{1t} , s_{2t} , s_{3t} , s_{4t} are given by (3.43) and the model equations with distortions to shocks shown below.

$$\begin{aligned}
y_t &= \gamma_8 y_{t-1} + \gamma_9 E_t^{RC} y_{t+1} + \gamma_{10} (r_t - E_t^{RC} \pi_{t+1}) + e_t \\
e_t &= \rho_e e_{t-1} + [\epsilon_t + v_t^e] \\
\pi_t &= \gamma_b \pi_{t-1} + \gamma_f E_t^{RC} \pi_{t+1} + \lambda_1 y_t + \lambda_2 y_{t-1} + u_t \\
u_t &= \rho_u u_{t-1} + [v_t + v_t^u]
\end{aligned} \tag{3.51}$$

3.3.4 Comparison with the Literature

With a concern for model uncertainty, the policymaker sets the policy rate that would work well under the worst possible model misspecification. Table 3.3 demonstrate robust optimal policy rule in comparison to the Ramsey solution without any concern for robustness under the calibrated values given in 3.2 and 3.8.

Table 3.8: Calibration

Parameter	Description	Values
Parameters specific to the model with habit		
h	Habit Persistence	0.6
Θ	Robustness Parameter	91
Parameters specific to the model with inflation persistence		
ω	the Fraction of Backward-looking Firms	0.25
Θ	Robustness Parameter	38
Parameters specific to the model with habit and inflation persistence		
Θ	Robustness Parameter	100

Given the current calibration of parameters, the concerns about model uncertainty always makes the policymaker attribute less importance to the nominal interest rate inertia, and respond aggressively to the demand shock for the extensions of the benchmark model. Although endogenous persistence in

Table 3.9: The Impact of Uncertainty on the Policy Rule

	e_{t-1}	u_{t-1}	s_{1t-1}	s_{3t-1}	r_{t-1}	ε_t	v_t	y_{t-1}	π_{t-1}
Benchmark Model									
Rational Expectations	0.084	0.759	-0.222	-0.675	0.553	0.105	0.949	–	–
With Robustness	0.038	0.819	-0.23	-0.69	0.522	0.048	1.023	–	–
Sign of the Change	-	+	+	+	-	-	+		
Habit Persistence									
Rational Expectations	0.247	2.399	-0.25	-0.215	0.617	0.309	2.999	0.187	–
With Robustness	0.278	2.821	-0.259	-0.212	0.556	0.348	3.526	0.204	–
Sign of the Change	+	+	+	-	-	+	+	+	
Inflation Persistence									
Rational Expectations	0.098	0.718	-0.165	-0.758	0.57	0.122	0.897	–	0.065
With Robustness	0.011	0.746	-0.17	-0.776	0.556	0.014	0.933	–	0.066
Sign of the Change	-	+	+	+	-	-	+		+
Habit and Inflation									
Rational Expectations	0.369	2.28	-0.175	-0.234	0.629	0.461	2.85	0.173	0.08
With Robustness	0.408	2.68	-0.18	-0.231	0.572	0.51	3.35	0.189	0.084
Sign of the Change	+	+	+	-	-	+	+	+	+

Note: The third row demonstrates how doubts about model uncertainty changes the coefficients of the rational expectations solution for the policy rate with a detection error probability of 20%. A positive change reflects more aggressive response of the robust policy.

inflation does not bring substantial difference, habit formation in consumption reverses the robust rule coefficient to the supply shock.

Recent studies present mixed results on whether robust control approach attenuates or aggravates the optimal policy rule as in this study. Leitemo and Söderström (2008b) work with a discretionary solution for the monetary policy and present more aggressively responses to supply shock but unaltered responses to demand shocks. In a small open economy, the results of Leitemo and Söderström (2008a) indicate that the impact of robustness concerns depends on the type of shock and the source of misspecification. Furthermore, Gerke and Hammermann (2016) introduces uncertainty in a New Keynesian model with financial intermediaries and imperfect interest rate pass-through from the nominal interest rate to the loan rate. They document that the response of the policy rate depends on the source of the shock. Dennis (2010)

working on a hybrid New Keynesian model similar to the ones in this paper shows that a discretionary central bank stabilizes inflation and consumption more tightly than the optimal policy under rational expectations.¹⁹

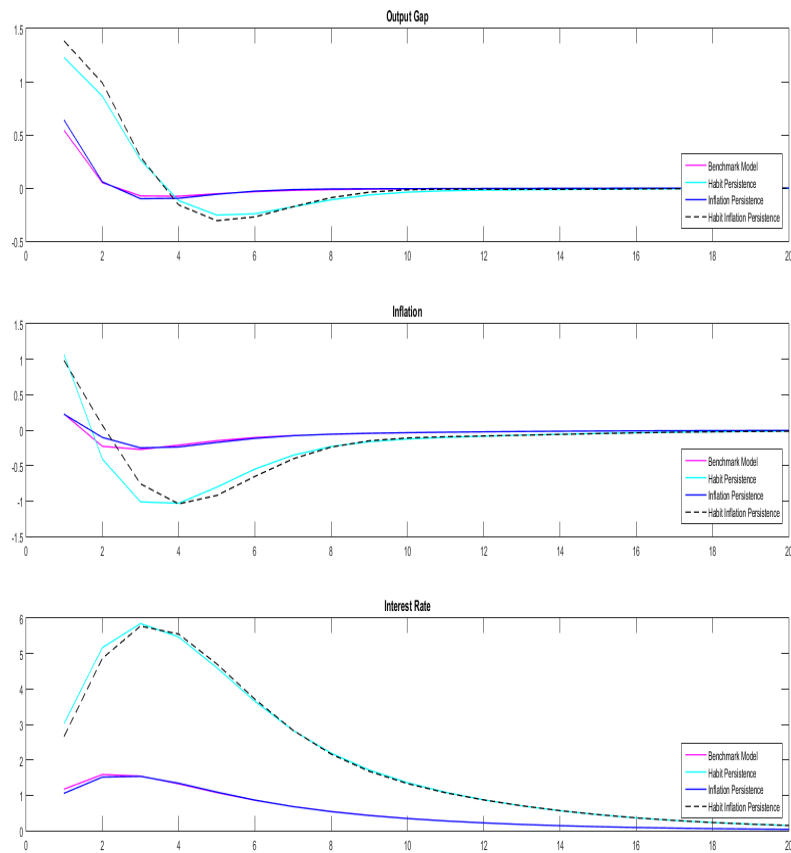
3.3.5 Impulse Responses

Rational Expectations: I first discuss the responses of the policy relevant variables under the assumption of rational expectations. This analysis is useful for understanding the intuition behind the properties and the amplification mechanism of each model. Figure 3.4a demonstrates the impulse responses for one standard deviation of a positive shock to the IS equation, i.e. a demand shock.

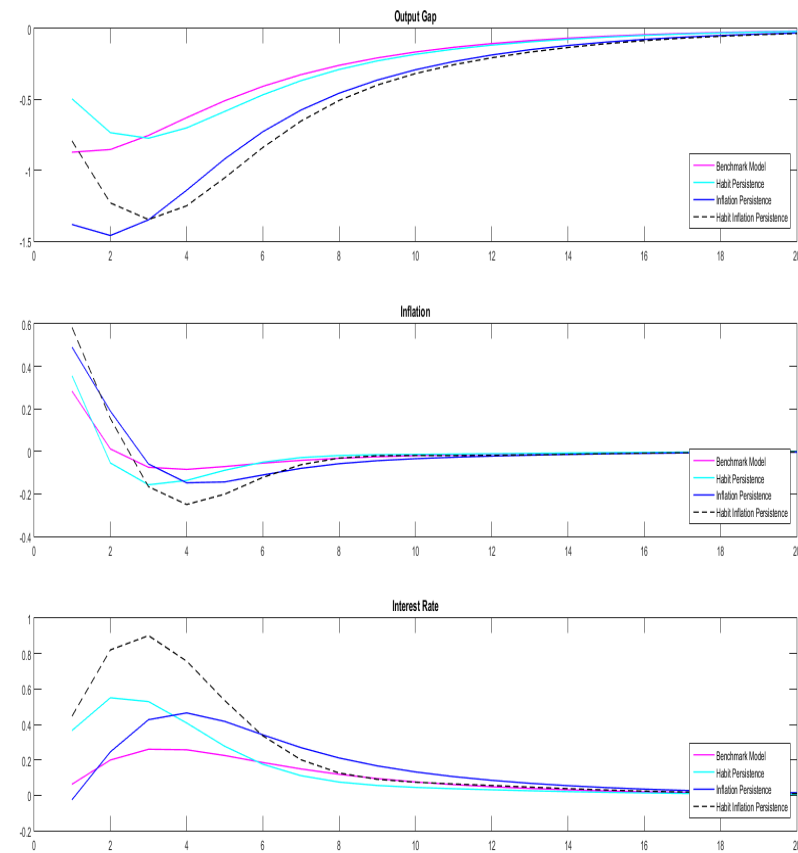
Allowing household utility to depend on both current consumption and on past consumption reflecting the habit persistence weakens the transmission of the policy rate on aggregate demand. Under a demand shock, since the initial rise in demand persists, optimal response of the policymaker is to rise the nominal interest rate substantially to keep the fluctuations in the output gap under control by allowing for a disinflationary process for the inflation rate. To put differently, a demand shock is expected to be more persistent due to the hybrid nature of the IS curve unless the central bank makes up for it by keeping the nominal interest rate high for longer compared to its response in the benchmark specification.²⁰

¹⁹Interested reader is referred to Kara (2004) for the cases in between discretion and commitment where the monetary authority can only partially commitment.

²⁰One can find impulse responses for different degrees of habit persistence in Appendix E. As the habit persistence parameter increases, the amplification mechanism deepens, and the effect of the shock becomes more persistent.



(a) Demand Shock



(b) Supply Shock

Figure 3.4: Impulse Responses under Rational Expectations

On the other hand, supposing that some fraction of the firms set prices indexed to past inflation rate adds a backward-looking component into the aggregate supply equation, which brings persistence in inflation. Intuitively, when the source of the shock is the demand side of the economy, the policymaker proposes a policy that would decrease the output and the inflation rate in the future. Letting persistence in inflation, by improving the transmission of interest rate on inflation works in favor of the policy of the monetary authority to bring output back to the steady state. Hence, less rise in the policy rate will be needed to offset the impact of the shock. Given the current calibration of the parameters, this channel is negligible and indexation to past inflation does not make a significant influence on model dynamics compared to the benchmark specification.

Furthermore, when the source of the shock comes from the supply side, the monetary authority finds it optimal to raise the nominal interest rate as a response to the initial increase in the inflation rate. However, the presence of habit formation lowers the effectiveness of monetary policy on the output gap, implying that the transmission mechanism of policy on the inflation rate weakens. Consumption habits calls for a stronger policy, i.e. higher interest rate associated with lower volatility in the output gap needed to stabilize the inflation rate.

Similarly, indexation to past inflation ensures stronger responses under a supply shock for the nominal rate, inflation rate and the output gap. More importantly, the policymaker continues to raise the interest rate gradually until the fifth quarter; although this reaction starts to die out in the third quarter in

the benchmark case. Due to the stronger reaction, output gap recovers faster and returns to its steady state at the same time with the benchmark.

Finally, inclusion of persistence in both the demand and the price setting shows almost identical dynamics to those under the model with habit formation with a demand shock. The figure shows that indexation does not interact with the habit persistence. These features only interact with each other with a supply shock. Nominal interest rate peaks at a level twice as much as the one with habit persistence alone.

Model Uncertainty: This part presents the impulse response functions for the output gap, inflation rate and the nominal interest rate under the worst case scenario, as well as under the approximating model together with the rational expectations responses.

The reaction of the policymaker to a demand shock always becomes stronger, i.e. more aggressive under in the presence of habit formation as shown in Figure 3.3.5. Since the monetary policy transmission on output weakens with habit persistence, the reaction of the policymaker has to be stronger. When coupled with specification doubts, in order to reassure the private sector and signal that it will stabilize the fluctuations in the output gap, the policymaker reacts more aggressively as habit persistence rises, while keeping the inflation below the steady state for some time.

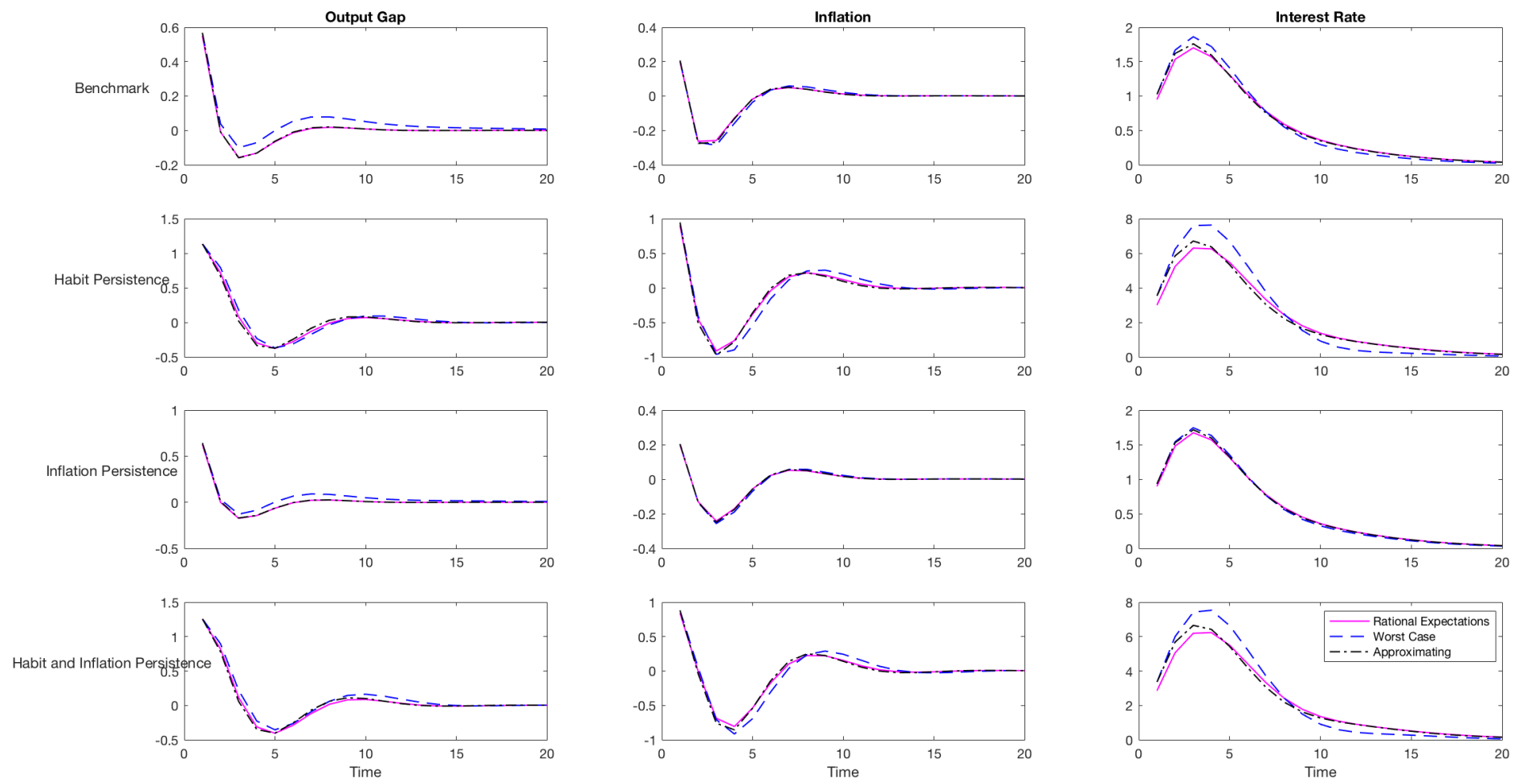


Figure 3.5: Impulse Responses for the Demand Shock

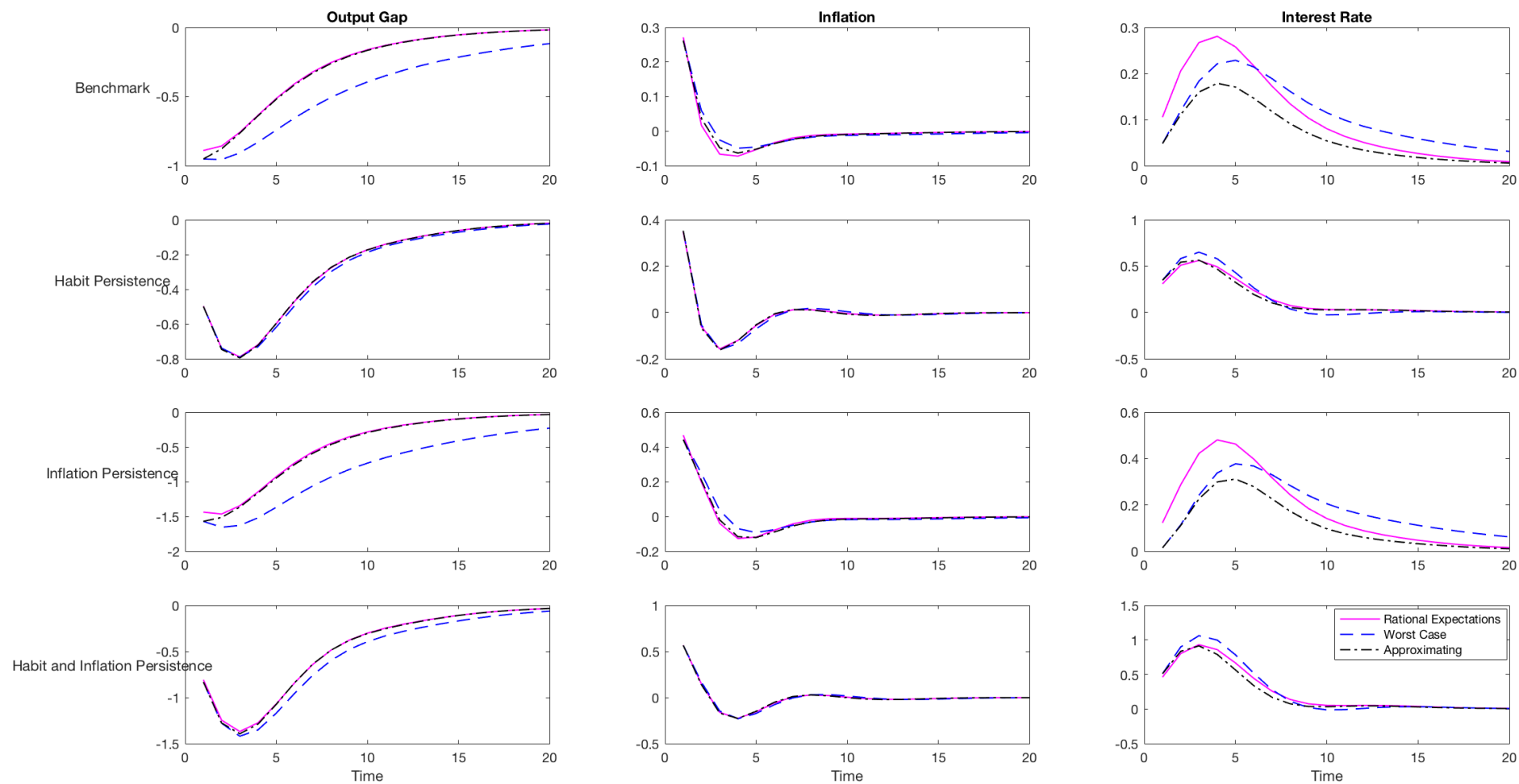


Figure 3.6: Impulse Responses for the Supply Shock

However, persistence in inflation smooths out the fluctuations in output, and partially dampens the impact of model uncertainty. The results show that a supply shock is more persistent under model uncertainty.

In response to a supply shock, indexation to past inflation does not change the impact of model uncertainty; habit formation in consumption eliminates -even reverses- the impact of uncertainty on the policy reaction. Although the difference is small, Figure 3.6 shows an aggressive monetary policy for the models with habits in consumption.

3.4 Conclusion

In this chapter, I aim to shed light on the impact of the concerns for model misspecification on the conduct of optimal policy and dynamics of the New Keynesian models. I discussed whether and how model uncertainty affects the amplification mechanism of the new Keynesian models with various features. I first derived a benchmark model with staggered price setting. Then, I present two extensions, namely habit formation in consumption, and intrinsic persistence in price setting.

Analyzing the optimal commitment policy, I compared the dynamics of the models under rational expectations to those under model uncertainty via robust control approach. I initially documented that allowing for model uncertainty makes the optimal policy always more aggressive under demand shock. This finding is robust to allowing for habit formation to past consumption. Habit formation generates persistence in the aggregate demand and deteriorates the ability of the central bank to affect the output gap so it calls for a

stronger response for the policy. An additional finding is that allowing for inflation persistence attenuates the effect of model uncertainty. I do not observe a substantial difference between the behaviors of a robust policymaker and the monetary authority acting under the assumption of rational expectations.

Last but not the least, a supply shock brings a cautious behavior for robust policymaker in the benchmark model. Adding indexation to past inflation changes neither the dynamics nor the magnitude under the approximating model. In all other specifications considered in this study, aggressive policy stance is a general feature of the New Keynesian models with a concern for robustness on the side of not only the policymaker but also the private agents.

CHAPTER 4

OPTIMAL MONETARY POLICY WITH A FEAR OF A CHANGING ECONOMIC STRUCTURE UNDER UNCERTAINTY

4.1 Introduction and Background

Awareness of the uncertainties regarding the structure of the economy might lead to shifts in the expectation formation of economic agents, and call for fundamental changes in the way policy is conducted. Certainty equivalence principle prescribes an optimal policy that is independent of (a specific form of) uncertainty given the expected values of all state variables. However, uncertainty might reveal itself in many different forms that might cause violations of certainty equivalence. Policy makers seek for policies that are robust across different (uncertain) states of the world, and optimality of the decision rules necessitates minimizing the impact of any type of uncertainty. How best to react uncertainty, depending on different forms, is widely studied by academics to provide guidance for policymakers.

When one deviates from the assumption of perfect knowledge in several

ways and acknowledges the possible uncertainties about the structure of the economy, the propagation of shocks hence implied policy suggestion could change substantially. For instance, although the literature on uncertainty has pioneered by Brainard (1967) with an advice on more cautious behavior for the policymaker when faced with ambiguity about parameters of the model, there may be fundamental uncertainties regarding which is the true data generating process. The monetary authority facing uncertainty regarding the model, or the exogenous disturbances might find it optimal to respond to fluctuations in the economy in a stronger manner. Therefore, introducing uncertainty into an otherwise standard New Keynesian model can improve the propagation of the shocks, the fit of the model with the data, and relieve the DSGE models from the criticism of several, unfounded shocks. Further providing a sound economic intuition, allowing model uncertainty can improve the reliability of the policy suggestions derived from the model.

A general form of uncertainty is when the policymaker faces general *model uncertainty*. When the policymaker can put a structure on the model uncertainty, she can assign prior probabilities to possible different views of the economy. To design a robust policy across competing models, a policymaker first computes economic losses implied by optimal policy prescribed by each model. And she minimizes average expected loss across models, in which the policymaker assigns larger weights for most likely model and smaller weights for least likely model. Hence, she utilizes Bayesian model averaging to insure against undesirable outcomes (as in Levin et al. (2003)). A robust policy under structured model uncertainty is set to work well across alternative models.

On the other extreme, the policymaker might face unstructured uncertainty when she cannot assign probabilities to alternative models of the economy. In this case, policymaker has a reference model of the economy; however, she has doubts about her model and thinks that her model can only approximate the structure of the economy. To accommodate potential model misspecification, she considers a set of alternative models that are difficult to distinguish from her reference model. Decision-making under robust control can be interpreted as a dynamic game between the policymaker and the nature. In this game, the nature, or the hypothetical evil agent forms the worst-case strategy that would deteriorate the performance of the policymaker as bad as possible, and the policy maker designs the best decision rule given the decision of the nature. Hence, a robust policymaker seeks for a min-max solution to the policy problem. This type of uncertainty is additive and reflected as additional disturbances, which can feed back on state variables, in the additive shock processes. As opposed to structured model uncertainty,¹ robust control approach relies on designing optimal policy that would work on the worst possible outcome irrespective of how likely this outcome might be. Hence, in the case of designing robust policy under unstructured uncertainty, policymaker has to set a prior judgment on the worst-case outcome depending on how much she is concerned about model misspecification. Hansen and Sargent (2008) suggest interpreting possible deviations from policymaker's reference models as a collection of the likelihood ratios whose relative entropies with respect to the reference model are bounded by the policymaker's desired degree of robustness.²

¹See Kara (2002); Giannoni (2002) for examples of a comparison of structured and unstructured model uncertainty.

²Chapter 3 of the thesis elaborates more on calibrating the desire for robustness using

On modeling uncertainty, this chapter explicitly relies on the robust control literature as suggested by Hansen and Sargent (2008) in general equilibrium models.³

Henceforth, I will use the term *risk* as suggested by Hansen and Sargent (2008) for the type of unknowns that the economic agents can quantify. I will allow the risk to be represented by the possibility of the economy shifting between two different models. Accordingly, this chapter combines both the uncertainty caused by model specification doubts of the monetary authority and the risk of weakening transmission of monetary policy on the real economy.

When the primary monetary policy tool is constrained by the zero bound, lowering it further to produce further stimulus has not been an option. Especially when a negative shock to aggregate demand hits the economy, the recession might become persistent if the central bank cannot do any policy.

Several models predict the possibility of a long-lasting liquidity trap when monetary authorities rely exclusively on the short-term nominal interest rate as their policy instrument (which is constrained from below). Eggertsson and Woodford (2003) is a widely-cited example of how an exogenous fundamental shock drives the economy into a liquidity trap. Other stand of the literature relies on the property of self-fulfilling expectations as drivers of the trap. When economic agents expect the situation to worsen as long as the recession persists, the existence of the lower bound has the potential to produce a self-fulfilling crisis due to pessimistic expectations.⁴

detection error probabilities.

³Hansen and Sargent (2001), Gilboa and Schmeidler (1989), Epstein and Schneider (2003), Klibanoff et al. (2005), Maccheroni et al. (2006) and Strzalecki (2011) are examples of earlier decision-theoretical studies.

⁴Benhabib et al. (2001*b,a*, 2002) shows the existence of multiple equilibria consistent

In contrast to the predictions of standard models, recent crisis experience has proven that central banks can further stimulate the economy even if the short-term nominal rate has reached zero. To begin with, the policy rate can go below zero. Euro area, Denmark, Sweden, Switzerland and Japan are examples of countries which decline the interest rate modestly below zero starting from 2012. The idea is to encourage cash holdings rather than keeping assets paying negative rates.

Moreover, central banks have developed unconventional policy tools such as forward-guidance, i.e. promises for future policy actions and asset purchase programs, i. e. quantitative easing as a substitute for the short rate to influence the economy by affecting long-term interest rates.⁵

Though, monetary policy can theoretically stimulate aggregate spending, and hence inflation, through unconventional channels; the ability of the central bank to effect the private sector expectations is the key in the effectiveness of these policies. For instance, forming inflationary expectations by promising to keep the policy rate low -by increasing the inflation target even after the zero bound is no longer binding can reduce the duration of a liquidity trap (Eggertsson and Woodford, 2003, 2004).

Theoretically, these unconventional tools can work as a substitute to the short rate; however, empirical evidence casts a suspicion on the implications of the models. Several studies suggest that these are not as powerful as the normal time monetary policy in stimulating the economy. Although, monetary

with rational expectations due to the zero lower bound. Mertens and Ravn (2014) studies how a sudden loss in confidence can produce multiple equilibria in a New Keynesian model.

⁵Central banks have continued to use these unconventional tools when the zero lower bound is no longer binding to complement normal time policy.

authority has access to unconventional tools such as forward-guidance and asset purchase programs to effect real economy, these tools are proven not to work well in practice. Filardo and Hofmann (2014) empirically show that the ability of forward guidance policies in affecting market expectations has declined over time. Contributions by Giannoni et al. (2016) and McKay et al. (2016) are theoretical (and empirical) demonstrations in this direction.

Only two decades ago, the concept of a *liquidity trap* has been evaluated as an academic curiosity. Large declines in aggregate output have been seen as extreme tail events. Models used to estimate the frequency of this negative tail risk are misleading as they mostly rely on data from U.S. postwar period. Williams (2014) document that long-lasting and deep recessions are not as rare as the models predict. On the other hand, a binding zero lower bound has become a relevant problem in practice only when the interest rates are low to begin with. Central banks' low inflation targets together with declining long run real interest rates are to blame as they account for low nominal rates. Policymakers' ability to reverse economic downturns has been restricted by a binding zero lower bound in most advanced countries with a target level of inflation close to two percent. Studies on how to prevent the crisis stress the potential role for higher inflation targets as they can provide more room for nominal rate reductions in the first place.⁶

Whether weakening of monetary policy transmission is due to different data generating process or increasing pessimism is both academically and practically relevant. This chapter aims to study optimal monetary policy design in a

⁶Billi (2011), Coibion et al. (2012), and Ball (2014) dissect the impact of increasing the inflation target in reducing the costs of zero lower bound periods.

changing economic structure. To model a possible weakening of monetary policy subject to an effective lower bound on nominal interest rate, I allow elasticity of substitution to vary across different states of the economy.

In an environment where the central bank is not able to use its conventional instrument, she has to rely on alternative channels. Although, theoretically, the monetary authority has other unconventional tools such as forward guidance and asset purchase programs to effect real economy, these tools are proven not to work well in practice as discussed above. Hence, alternating states of the economy where monetary authority is forced to switch to unconventional tools is similar to the economic environment in this study especially when unconventional tools do not work as the usual one.

Further, by allowing the nominal interest rate to fall below zero, I aim to abstract from model complexity of switching to unconventional tools. The idea is using the policy rate as a shadow rate in the place of unconventional tools to summarize the overall stance of monetary policy -yet in a less effective manner. Wu and Zhang (2017) present an elegant description of modeling the shadow rate in a New Keynesian model from microfoundations. As discussed in this study, the idea is to use the short rate as the shadow rate during normal times. They also find out that the negative shadow rate summarizes unconventional monetary policy when the zero lower bound binds.

I examine the link between time-varying fear of model uncertainty and changing effectiveness of monetary policy. To capture the idea that monetary policy responds endogenously to possible different states of the economy, I utilize the regime switching approach. Earlier contributions to the literature

relies on Markov switching processes for different states so they treat regime changes as exogenous. A novel contribution by Davig and Leeper (2008) allows for systematic responses of the decision makers to possible changes in economic structure. I utilize the approach developed by Barthélemy and Marx (2017) which also allows for endogenous or state-dependent transition probabilities in the spirit of Davig and Leeper (2008).

I also utilize piecewise linear perturbation technique which is extensively-used in the literature on occasionally binding constraints. I present the results of this methodology as a benchmark ignoring the expectations channel of the possibility of a future regime change. By providing a comparison with the regime switching structure, I focus on the expectation formation effects of the possibility of alternating regimes.

The aim of this study is to analyze the optimal commitment behavior of a central bank facing uncertainty regarding the structural equations governing the economy and becomes pessimistic under an effective lower bound on nominal interest rate; and how the policy recommendation changes if the central bank has a time-varying concern for robustness regarding model uncertainty when the transmission mechanism of the monetary policy weakens.

When there is a possibility that monetary policy transmission mechanism will not work as usual, the optimal response of the monetary authority is to respond aggressively to a negative demand shock in order to reduce the probability of switching to the second regime. This result is due to the expectations channel inherent in regime switching structure.

Even in normal circumstances, optimal policy becomes more active when

a deterioration of monetary transmission mechanism is highly possible.

4.2 Model

I use a standard New Keynesian model in which the representative household chooses consumption, leisure, money and bond holdings to maximize its additively separable utility function subject to a budget constraint. Firms operate under monopolistic competition and prices are sticky in the spirit of Calvo (1983) which leads to the following New Keynesian Phillips equation.⁷

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + e_t \quad (4.1)$$

where π_t is the inflation rate, y_t is the output gap, and e_t is the cost-push shock which follows an $AR(1)$ process as follows:

$$e_t = \rho_e e_{t-1} + \epsilon_t, \quad \epsilon_t \sim N(0, 1), \quad |\rho_e| < 1 \quad (4.2)$$

The output gap is described by the following IS equation:

$$y_t = E_t y_{t+1} - \Omega(r_t - E_t \pi_{t+1}) + u_t \quad (4.3)$$

where u_t denotes for the demand shock (or preference shock) which follows a stationary $AR(1)$ process:

$$u_t = \rho_u u_{t-1} + v_t, \quad v_t \sim N(0, 1), \quad |\rho_u| < 1 \quad (4.4)$$

⁷Derivations of the model can be found in the appendix.

The central bank minimizes the following quadratic loss function⁸

$$\max_{\{r_t\}_{t=0}^{\infty}} E_t \sum_{t=t_0}^{\infty} \beta^t \{[\pi_t^2 + \lambda_y y_t^2 + \lambda_r (\Delta r_t)^2]\} \quad (4.5)$$

In the analysis, I distinguish two different regimes ($s_t = N, W$): i) normal regime (N) in which monetary policy transmission mechanism works as usual, and ii) a weak regime (W) in which monetary policy transmission weakens. Here, I describe the regime switching as a change in the sensitivity of the economy to policy rate, and IS equation varies depending on the two regimes as follows:

$$\Omega_{s_t} = \begin{cases} \Omega_N & \text{if } s_t = N \\ \Omega_W & \text{if } s_t = W \end{cases} \quad (4.6)$$

where the real interest-rate elasticity of output (intertemporal substitution effects in consumption) is higher in the normal regime, i.e. $\Omega_N > \Omega_W$.

This possible change in the structure of the economy is reflected on the monetary policy as follows.

In the first regime, decision makers trust their model and do not worry about model uncertainty, yet in the second regime, decision makers guard against possible model misspecification. Hence, this structure provides a basis for time-varying uncertainty aversion. This type of unstructured uncertainty is modeled à la Hansen and Sargent (2008).

⁸A discussion on this type of an ad-hoc loss function can be found in Chapter 3 of the thesis.

$$z_{t+1} = \begin{cases} Az_t + Br_t + C\epsilon_{t+1} & \text{if } s_t = N \\ Az_t + Br_t + C(\epsilon_{t+1} + v_{t+1}) & \text{if } s_t = W \end{cases} \quad (4.7)$$

The problem of the central bank is also modified according to the state of the economy as follows:

$$\min_{\{v_{t+1}^e, v_{t+1}^u\}_{t=0}^{\infty}} \max_{\{\pi_t, y_t, r_t\}_{t=0}^{\infty}} E_t \sum_{t=t_0}^{\infty} \beta^t \{[\pi_t^2 + \lambda_y y_t^2 + \lambda_r (r_t - r_{t-1})^2]\} \quad (4.8)$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + e_t \quad (4.9)$$

$$e_t = \rho_e e_{t-1} + [\epsilon_t + v_t^e] \quad (4.10)$$

$$y_t = E_t y_{t+1} - \Omega(r_t - E_t \pi_{t+1}) + u_t \quad (4.11)$$

$$u_t = \rho_u u_{t-1} + [v_t + v_t^u] \quad (4.12)$$

$$E_t \sum_{\tau=0}^{\infty} \{[v_{t+\tau}^e]^2 + [v_{t+\tau}^u]^2\} \leq \eta_0 \quad (4.13)$$

where η_0 represents the bound on the amount of misspecification v_{t+1} . When the policymaker is not concerned about model misspecification, $\eta_0 = 0$ so the constraint (4.13) binds for $s_t = N$.

4.2.1 Solution Methods via Deterministic Switching versus Regime Switching

To capture the impact of time-varying nature of the key parameters, I first consider two different cases, namely *deterministic switch*, and *regime switch*. Change of regimes is a deterministic switch, in the terminology of Goldfeld and Quandt (1973), when it depends on an observable variable with a threshold.

In other words, the switching mechanism is determined and triggered by this threshold. The latter is the case when the transition of the system between two states of the economy is controlled by a transition matrix.

To obtain model solutions, I use two different methodologies: i) a piecewise linear solution method, and ii) a regime switching approach.

Although this chapter is mainly interested in accounting for expectational effects due to the possibility of a future regime change, I exploit the discreet configuration of piecewise linear solution. The simplicity of the method provides a natural benchmark by excluding any form of forward-looking behavior on an alternative regime. When compared with the resulting dynamics from regime switching, piecewise linear solution brings out the expectations channel inherent in regime switching structure.

Jung et al. (2005) is the first to propose a piecewise linear solution method to apply occasionally binding constraints. A widely-cited work by Eggertsson and Woodford (2003) generalizes their method for a stochastic environment where the economy alternates between two states conditional on exogenously determined values of the natural interest rate. Guerrieri and Iacoviello (2015) extended the solution method, and proposed a Occbin toolkit that implements the codes in Dynare. I use this toolkit to illustrate how the dynamics of the model changes when a threshold interest rate is introduced in the model.

Piecewise linear solution considers model with occasionally binding constraints as a model with multiple regimes. The method requires linearizing the model under each regime around the non-stochastic steady state of the first regime. When the constraint does not bind, the linearized model without

the constraint determines the state of the economy. In addition, when the constraint binds (in response to a shock), a future time period in which the constraint does not bind is chosen and the model is solved backwards to obtain the sequence of policy functions consistent with the constraint binding in the current period.

This methodology is criticized by not accounting for the risk of the constraint binding in the future in response to unanticipated shocks (Binning and Maih, 2016). Here, agents are unaware of the possibility that the constraint might bind until it actually binds. However, the drawback of this methodology becomes a virtue and serves well for the purposes of this study.

Here, the regimes are determined by a threshold interest rate as follows:

$$s_t = \begin{cases} N \text{ (Normal Regime)} & \text{if } r_t > r^* \\ W \text{ (Weak Regime)} & \text{if } r_t \leq r^* \end{cases} \quad (4.14)$$

To take into account the possibility of future switches, I adopt the endogenous regime switching structure proposed by Barthélemy and Marx (2017) in the spirit of Davig and Leeper (2008).

The probability to remain in regime $j \in \{N, W\}$ is

$$Pr(s_t = j | s_{t-1} = j, z_{t-1}, u_t) = p_{jj} + \lambda_{jj}g(z_{t-1}, u_t) \quad (4.15)$$

where p_{jj} is the steady state level of the probability of remaining in regime j , λ_{jj} is the sensitivity of transition probabilities to a function ($g(\cdot)$) of the vector of endogenous variables, z , and multi-dimensional stochastic process,

u_t . Hence, the transition probability is allowed to depend on the information available at time $t - 1$, i.e. past endogenous variables, and/or current shocks for $\lambda_{jj} \neq 0$. Accordingly, the probability of regime shift is

$$\Pr(s_t = i | s_{t-1} = j, z_{t-1}, u_t) = p_{ji} \equiv 1 - (p_{jj} + \lambda_{jj}g(z_{t-1}, u_t)) \quad (4.16)$$

I also analyze constant transition probabilities, the case where $\lambda_{jj} = 0$ as a special case. Then the state evolves exogenously according to the following transition matrix:

$$P = \begin{pmatrix} p_N & 1 - p_W \\ 1 - p_N & p_W \end{pmatrix} \quad (4.17)$$

where $p_j = \Pr(s_t = i | s_{t-1} = j)$, $j \in \{N, W\}$.

When $\lambda_{jj} \neq 0$, the transition probabilities are endogenous. Then, the probability to remain in a particular regime is assumed to follow:

$$\Pr(s_t = N | s_{t-1} = N, r_{t-1}) = p_N - (p_{jj} + \lambda_{jj}g(r_{t-1} - r^N)) \quad (4.18)$$

$$\Pr(s_t = W | s_{t-1} = W) = p_W \quad (4.19)$$

where r^N represents the interest rate threshold for entering the second regime.

4.3 Results

Table 4.1 summarizes the calibration. Under this calibration, this section provides a comparison of the results obtained under different solution methods.

Table 4.1: Calibration

Parameter	Description	Values
β	Discount Factor	0.99
Ω_N	Elasticity of Intertemporal Substitution	0.5
Ω_W	Elasticity of Intertemporal Substitution	0.2
κ	Slope of the Phillips Relation	0.75
λ_y	Weight of the output gap in loss function	0.25
λ_r	Weight of the interest rate in loss function	0.1
Θ_W	Robustness Parameter in Weak Regime	22

4.3.1 Piecewise Linear Solution

By using the piecewise linear solution, impulse response functions are represented as a combination of the two regimes: the first regime in which the constraint is never binding, and the second regime in which the constraint is binding all the time.

Figure 4.1 demonstrates the dynamics of the economy in response to two unforeseen demand shocks. All results are reported in percentage values. In period 5, the economy is hit by a positive demand shock. Both the output gap and inflation rate increase above their steady-state values. Monetary authority responds by increasing its instrument gradually acknowledging the impact of her actions on expectations on future values of the variables under commitment and the interest rate inertia in her objective function. For positive rates of nominal interest rate, the economy stays in the first regime in which monetary policy transmission works efficiently. Hence, the dynamics implied by the piecewise linear and the linear models overlap. In the sequent 20 years, the impact of the shock dissipates and the economy returns back to the zero

inflation steady state.

In period 25, the economy experiences an unexpected negative demand shock which is symmetric (around the steady-state) to the first shock in magnitude. Since a negative shock to demand necessitates decreasing the policy rate below its steady state, linear and piecewise linear solutions differs substantially. Piecewise linear solution shows how the economy switches to the second regime in which transmission mechanism of monetary policy weakens and the central bank becomes pessimistic about her model. Both the change in the structure of the economy and the uncertainty aversion of the central bank reduce the policy rate well below the one in the linear model. Further, output gap and inflation rate fluctuates more under the piecewise linear model.

Piecewise linear solution shows that output falls by almost 4% when agents perceive the constraint to bind forever. This creates an approximately 5% annual inflation. Since the monetary policy transmission weakens for low values of the policy rate, central bank has to react by decreasing the policy rate by more than 60 basis points.

4.3.2 Regime Switching

Under regime switching, the impulse responses are generated conditional on a specific regime. Agents form their decisions by internalizing the possibility that the economy can switch to the other regime. However, ex post, the economy stays in the current regime over the impulse response period. Hence, the dynamics of the model is affected by other regime through the expectations formation effects.

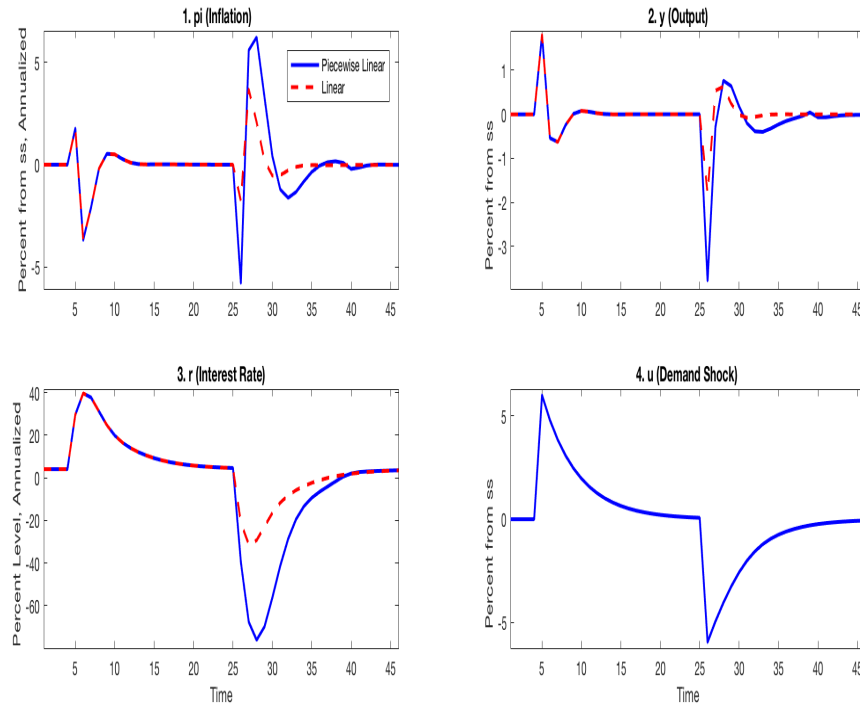


Figure 4.1: Impulse Responses for Piecewise Linear Solution-Demand Shock

I distinguish two cases depending whether the transition probabilities are exogenous or endogenous.

I consider $p_N = 0.90$, $p_W = 0.80$ to represent conditional probability of remaining in regimes N and W for the exogenous case. These probabilities also serve as the steady state values of the probabilities in the endogenous switching model.

Exogenous Transition Probabilities

The economy is assumed to start in the normal regime where monetary policy transmission works effectively. Figure 4.2 plots the impulse response functions in response to a negative demand shock conditional on staying in the same regime. That is to say, economic agents forms their expectations by taking into account the possibility of switching to the weak regime with a constant

exogenous probability. The differences from the deterministic switch is sub-

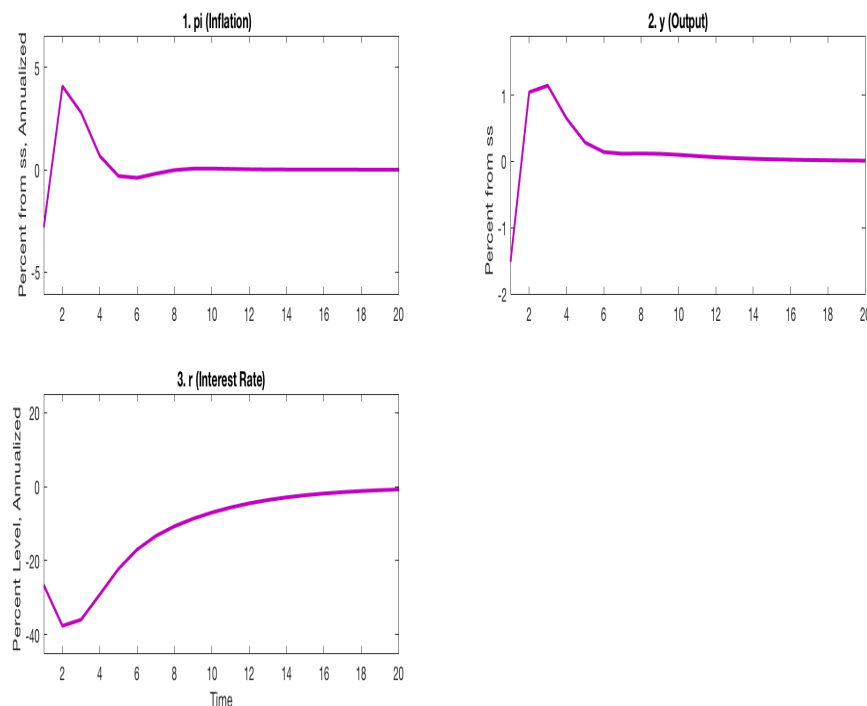


Figure 4.2: Impulse Responses with exogenous transition probabilities

stantial. Since the monetary authority now internalizes the possibility of a future weakening of the policy transmission, her response to the shock becomes 2 times stronger. Central bank lowers the policy instrument by 40 basis points (in comparison to the 20 basis point decline in the linear model) to avoid the inconvenience even before it happens.

Endogenous Transition Probabilities

As opposed to the previous case, Figure 4.3 shows the impulse responses for the inflation, output gap, and the nominal interest rate when agents consider endogenous transition probabilities in the formation of expectations. I allow the transition to depend on the interest rate decisions of the policymaker. To be specific, the probability of staying in the first regime increases with the

nominal interest rate. The higher the interest rate the lower the probability to switch to the weak regime in which the monetary policy does not work as usual. Compared to the piecewise linear solution, central banks reaction is

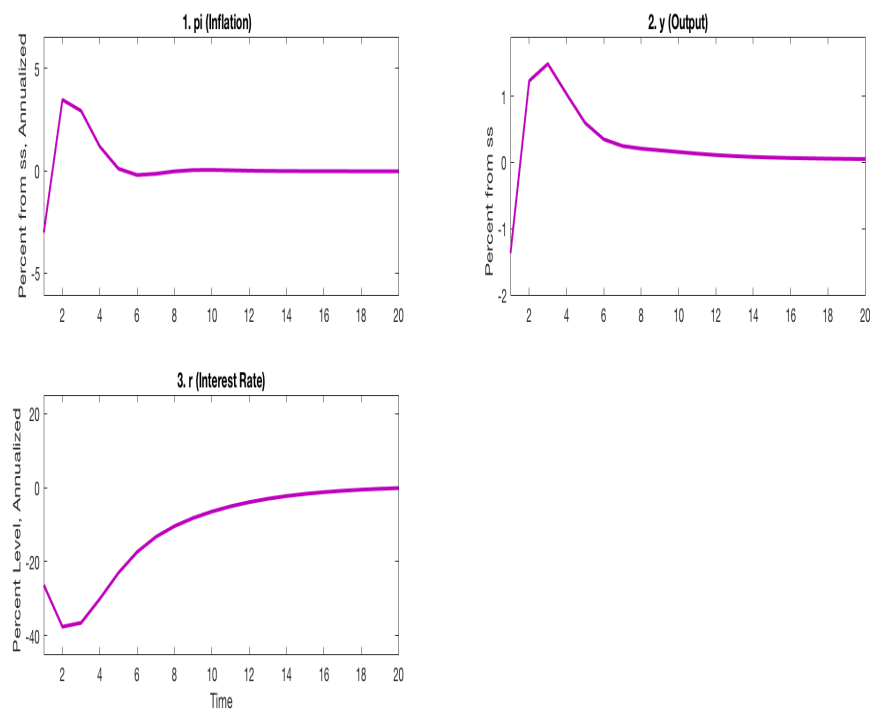


Figure 4.3: Impulse Responses with endogenous transition probabilities

more aggressive to prevent the economy from switching to the weak regime. Resulting impulse responses are similar to the ones for the case where regime switch is triggered by constant transition probabilities. As pointed out by Barthélemy and Marx (2017), this result is due to steady state being constant over regimes.

4.4 Discussion of Policy Implications and Future Work

This chapter combines both risk and uncertainty by allowing the possibility of the economy shifting between these two different models, as well as time-varying model specification doubts of the monetary authority.

In this chapter, I first allow for regime-dependent elasticity of substitution as a short-cut to model a possible weakening of monetary policy subject to an effective lower bound on nominal interest rate. In an environment where the central bank is not able to use its conventional instrument, she has to rely on alternative channels. Although, theoretically, the monetary authority has other unconventional tools such as forward-guidance and asset purchase programs to effect the real economy, these tools are proven not to work uniformly well in practice. Hence, alternating states of the economy where monetary authority is forced to switch to unconventional tools is similar to the economic environment in this study especially when unconventional tools do not work as the standard policy tool.

To stress the role of expectations of regime switching structure, I utilize the deterministic switch as a natural framework excluding this channel. I use the resulting dynamics of the model economy as a benchmark to assess the implications of forward-looking nature inherent in regime switches.

The results of this chapter first demonstrate that weakening of the monetary policy transmission mechanism calls for stronger policy actions in response to shocks. When agents acknowledge this possible future change in the eco-

conomic structure, optimal policy becomes more active even in normal times.

When there is a possibility that monetary policy transmission mechanism will not work as usual, the optimal response of the monetary authority is to respond aggressively to a negative demand shock in order to reduce the probability to switch to the second regime. This result is because of the expectations channel inherent in regime switching structure. The model where the regime switching probabilities endogenously depend on the policy instrument confirms the results.

This chapter shows the importance of model uncertainty and risks about future effectiveness of the monetary policy in a standard New Keynesian model. The findings has important implications for more detailed descriptions of the real world including several frictions.

A natural follow-up work will be studying a model allowing for positive steady-state inflation. In an environment where a positive inflation target for the monetary authority is justified, the risk of future obstacles to policymaking might involve in aggressive policy stance even in normal times. Policymaker might guard against future unfavorable output costs by increasing the inflation target.

CHAPTER 5

MEASURING THE IMPACT OF MONETARY POLICY ON ASSET PRICES IN TURKEY

5.1 Introduction

“It is crucial for central banks to obtain reliable estimates of the reaction of asset prices to monetary policy. However, there are two major difficulties in the measurement of this. First, while the asset prices are affected by the monetary policy decisions, the policy rate may also respond to changes in the asset prices. Second, some common factors, such as macroeconomic outlook and changes in risk preferences, can simultaneously affect both policy decisions and asset prices. In the literature, to overcome these problems, the most commonly adopted estimation method is the event study (ES) approach.¹ Rigobon and Sack (2004) (henceforth, RS) develop the heteroscedasticity-based generalized method of moments (GMM) estimation technique as an alternative to the ES

This work is published in Economics Letters, Volume 114, Issue 1, January 2012, Pages 29-31, as a joint work with Murat Duran, Pınar Özlü, and Deren Ünalımsı.

¹For two notable examples using the ES approach, see Kuttner (2001) and Gürkaynak et al. (2005).

approach. This technique is considered more reliable as it is valid under much weaker assumptions.

Studies using the heteroscedasticity-based estimation technique are very limited for emerging markets.² This study estimates the response of asset prices to monetary policy in Turkey, using the heteroscedasticity-based GMM. The impact of monetary policy on longer-term interest rates is found to be positive and diminishes with maturity for maturities longer than 9 months. Surprisingly, the policy rate has little effect on the foreign exchange value of the Turkish lira. Finally, an increase in the policy rate leads to a decline in the stock prices, where monetary policy has the greatest impact on the share prices of the financial sector firms.

5.2 Methodology

The dynamics of the short-term interest rate and asset prices are as follows:

$$\Delta i_t = \beta \Delta s_t + \gamma z_t + \varepsilon_t \quad (5.1)$$

$$\Delta s_t = \alpha \Delta i_t + z_t + \eta_t \quad (5.2)$$

where Δi_t is the change in the policy rate, Δs_t is the change in the asset price, and z_t is a vector of exogenous variables which affect both i_t and s_t . In our setup, following RS, z_t is taken as an unobservable common factor. The variable ε_t is the monetary policy shock and η_t is the asset price shock. The shocks

²See Rezessy (2005), (Guimarães and Soares Gonçalves, 2007) and Duran et al. (2010), which is a parallel study on the Turkish stock market. For examples on developed countries, see (Rigobon and Sack, 2004), Bohl et al. (2008), Kholodilin et al. (2009).

ε_t and η_t are assumed to be serially uncorrelated and to be uncorrelated with each other and with the common shock z_t . In this paper, the parameter of interest is α , which measures the impact of a change in the policy rate, Δi_t , on the change in the asset price, Δs_t . The ES approach estimates only Equation (5.2) and uses the asset price changes directly after the announcement of the monetary policy committee (MPC) decision. The ES approach implicitly assumes that, in the limit, the variance of the policy shock becomes infinitely large relative to the variances of other shocks on policy dates.

The heteroscedasticity-based identification technique suggested by RS does not require such a strong assumption. In this approach, we only need to observe a rise in the variance of the policy shock when the MPC decision is announced, while the variances of other shocks remain constant, given that the parameters α , β and γ are stable. Since the GMM technique requires weaker assumptions, it can give more reliable estimates than the ES approach. Two subsamples are essential to implement the GMM technique. P stands for the policy dates (days when the MPC decisions are announced) and N stands for the non-policy dates (days immediately preceding the policy days). This method uses a comparison of the covariance matrices of the variables on the policy and the non-policy dates, denoted by Ω_P and Ω_N . The difference in the covariance matrices is as follows:

$$\Delta\Omega = \Omega_P - \Omega_N = \frac{(\sigma_\varepsilon^P - \sigma_\varepsilon^N)}{(1 - \alpha\beta)^2} \begin{bmatrix} 1 & \alpha \\ \alpha & \alpha^2 \end{bmatrix} \quad (5.3)$$

As in RS, we denote $\lambda = \frac{(\sigma_\varepsilon^P - \sigma_\varepsilon^N)}{(1 - \alpha\beta)^2}$. There are two parameters to be estimated,

namely; α , the parameter of interest, and λ , a measure of the degree of heteroscedasticity that is present in the data. There are three moment conditions and two parameters to estimate. Therefore, overidentification restrictions enable us to test the model as a whole.

5.2.1 Data

Market interest rates are the yields on government bonds traded in the Istanbul Stock Exchange (ISE) secondary market. We use yield curve implied rates calculated using daily ISE data for various maturities. The policy rate is proxied by the yield on government bonds with one-month maturity. We take stock indices ISE All, ISE 100, ISE 30 and the indices of the manufacturing, services, trade, financial and IT sectors. The market rates are constructed as the daily changes of the interest rates in basis points while the stock indices and the exchange rates are in daily percentage changes. The sample covers the January 2005-December 2009 period with 60 policy decisions.³

5.2.2 Empirical Results

The estimates for the parameter α using both the ES approach and the heteroscedasticity-based GMM method are reported in Table 5.1.⁴ According to the GMM method, which is theoretically more reliable, yields on the government bonds with maturities ranging from 6 to 36 months respond to the change in the short term interest rate significantly and in the same direction.

³Long-term yields are unavailable before 2005.

⁴See Aktaş et al. (2009) for an earlier version of ES results.

Table 5.1: Estimation Results

	$\hat{\alpha}_{ES}$		$\hat{\alpha}_{GMM}$		$\hat{\lambda}_{GMM}$	
Yields on Government Bonds						
6 months	0.731***	(0.085)	1.050***	(0.061)	0.116***	(0.012)
9 months	1.092***	(0.120)	1.769***	(0.143)	0.119***	(0.011)
12 months	1.005***	(0.117)	1.382***	(0.178)	0.105***	(0.013)
15 months	0.866***	(0.110)	0.915***	(0.215)	0.089***	(0.019)
18 months	0.770***	(0.110)	0.696***	(0.193)	0.084***	(0.022)
Benchmark Rate	0.724***	(0.112)	0.623***	(0.172)	0.085***	(0.024)
21 months	0.716***	(0.113)	0.611***	(0.168)	0.085***	(0.024)
24 months	0.687***	(0.115)	0.558***	(0.161)	0.085***	(0.025)
27 months	0.670***	(0.115)	0.502***	(0.172)	0.083***	(0.025)
30 months	0.659***	(0.114)	0.447**	(0.189)	0.081***	(0.025)
33 months	0.648***	(0.112)	0.411**	(0.197)	0.078***	(0.025)
36 months	0.637***	(0.110)	0.399**	(0.198)	0.076***	(0.025)
Exchange Rates						
TRL/USD	-0.224	(0.315)	-0.511	(0.438)	0.092***	(0.032)
TRL/EUR	-0.516*	(0.333)	-0.997***	(0.394)	0.088***	(0.031)
Stock Indices						
ISE All	-2.760***	(0.754)	-3.385***	(0.914)	0.101***	(0.032)
ISE 100	-2.856***	(0.775)	-3.445***	(0.942)	0.099***	(0.031)
ISE 30	-2.928***	(0.828)	-3.503***	(0.976)	0.100***	(0.032)
Industry	-2.258***	(0.704)	-2.762***	(0.818)	0.097***	(0.032)
Services	-2.104***	(0.640)	-2.634***	(0.817)	0.101***	(0.032)
Trade	-1.347**	(0.676)	-1.433	(0.931)	0.097***	(0.034)
Financial	-3.233***	(0.895)	-3.982***	(1.050)	0.102***	(0.031)
IT	-1.778**	(0.785)	-2.433**	(1.131)	0.076***	(0.030)

Notes: The standard errors are in parentheses. The maturity of the benchmark rate is around 20.4 months. GMM over-identification test has a $\chi^2(1)$ distribution. $F_{1,59}$ distribution is used for the Hausman-type biasedness test.

* Indicate the significance levels at 10% level.

** Indicate the significance levels at 5% level.

*** Indicate the significance levels at 1% level.

Table 5.2: Diagnostic Tests

	OIR Test	GMM vs. ES
Yields on Government Bonds		
6 months	0.215	29.054***
9 months	0.292	76.854***
12 months	0.052	7.957***
15 months	0.027	0.071
18 months	0.109	0.217
Benchmark Rate	0.113	0.610
21 months	0.111	0.721
24 months	0.115	1.307
27 months	0.169	1.742
30 months	0.312	1.982
33 months	0.559	2.139
36 months	0.857	2.090
Exchange Rates		
TRL/USD	0.744	0.895
TRL/EUR	0.909	5.194***
Stock Indices		
ISE All	0.091	1.468
ISE 100	0.053	1.209
ISE 30	0.065	1.232
Industry	0.017	1.460
Services	0.140	1.093
Trade	0.138	0.018
Financial	0.155	1.864
IT	1.379	0.646

Notes: The standard errors are in parentheses. The maturity of the benchmark rate is around 20.4 months. GMM over-identification test has a $\chi^2(1)$ distribution. $F_{1,59}$ distribution is used for the Hausman-type biasedness test.

* Indicate the significance levels at 10% level.

** Indicate the significance levels at 5% level.

*** Indicate the significance levels at 1% level.

Monetary policy changes do not have a large impact either on the US dollar rate or on the euro rate. Even though the effect of the policy changes on the euro rate is found to be statistically significant, the estimated coefficient (0.997 in absolute value) is small in magnitude, suggesting that an increase in the unanticipated component of the policy rate would only cause a minor appreciation against the euro. It is important to note that the estimated responses of exchange rates under the heteroscedasticity-based identification method, while still small, are larger (in absolute value) than the corresponding estimates under the ES approach.

The responses of various stock indices to a rise in the short term rate are significant and negative. While the ISE Financials give the largest response, the least response is given by the trade sector under the ISE Services. According to the GMM estimates, a 25 basis points increase in the short-term interest rate decreases ISE All Shares by 0.85%, ISE Financials by 0.99%, ISE Industrials by 0.69%, ISE Services by 0.65%, and ISE IT by 0.61%.

The diagnostics for the estimates are reported in Table 5.2. The results of the tests confirm that the assumptions of the GMM method are more reliable. The fact that λ is significant suggests that the increase in the volatility of the policy rate is sufficiently large for GMM estimation. The over-identification test results, reported in the fifth column, do not point to model misspecification. The difference between the ES and the heteroscedasticity-based GMM likely reflects a bias in the ES estimates. The potential biasedness of the event-study estimates compared to the GMM method is tested and reported in the last column. For interest rates with 6 to 12 months maturity, the ES estimates

are found to be statistically biased. On the other hand, longer-term interest rates do not exhibit significant bias. The ES approach is found to be biased in estimating the response of the euro rate as well. The empirical results for the stock indices suggest that the ES estimates are not statistically biased compared to the GMM estimates.

5.3 Conclusion

This study estimates the impact of monetary policy on asset prices in Turkey using the heteroscedasticity-based GMM technique suggested by Rigobon and Sack (2004), which takes into account both the simultaneity and the omitted variables problems. The empirical results show that increases in the policy rate lead to a decline in stock prices, rises in government bond yields with longer maturities, and an economically insignificant appreciation of the domestic currency. We compare the results with the more widely applied event study method and find that the event study gives biased results in measuring the responses of short-term bond yields and the Turkish lira/euro exchange rate. We show that monetary policy transmission in Turkey, an emerging market and a small open economy, works very similarly to that in advanced economies.”

REFERENCES

- Aktaş, Z., Alp, H., Gürkaynak, R. S., Kesriyeli, M. and Orak, M. (2009), ‘Türkiye’de para politikasının aktarımı: Para politikasının mali piyasalara etkisi’, *İktisat İşletme ve Finans* **24**(278), 9–24.
URL: <http://www.iif.com.tr/index.php/iif/article/view/iif.2009.278.6047>
- Andrade, P. and Bihan, H. L. (2013), ‘Inattentive professional forecasters’, *Journal of Monetary Economics* **60**(8), 967 – 982.
URL: <http://www.sciencedirect.com/science/article/pii/S0304393213001190>
- Ang, A., Bekaert, G. and Wei, M. (2007), ‘Do macro variables, asset markets, or surveys forecast inflation better?’, *Journal of Monetary Economics* **54**(4), 1163–1212.
URL: <https://ideas.repec.org/a/eee/moneco/v54y2007i4p1163-1212.html>
- Armantier, O., Bruine de Bruin, W., Topa, G., van der Klaauw, W. and Zafar, B. (2015), ‘Inflation expectations and behaviour: Do survey respondents act on their beliefs?’, *International Economic Review* **56**(2), 505–536.
URL: <http://dx.doi.org/10.1111/iere.12113>
- Ball, L. M. (2014), The Case for a Long-Run Inflation Target of Four Percent, IMF Working Papers 14/92, International Monetary Fund.
URL: <https://ideas.repec.org/p/imf/imfwpa/14-92.html>
- Barthélemy, J. and Marx, M. (2017), ‘Solving endogenous regime switching models’, *Journal of Economic Dynamics and Control* **77**, 1 – 25.
URL: <http://www.sciencedirect.com/science/article/pii/S0165188917300192>
- Benhabib, J., Schmitt-Grohe, S. and Uribe, M. (2001a), ‘Monetary Policy and Multiple Equilibria’, *American Economic Review* **91**(1), 167–186.
URL: <https://ideas.repec.org/a/aea/aecrev/v91y2001i1p167-186.html>
- Benhabib, J., Schmitt-Grohe, S. and Uribe, M. (2001b), ‘The Perils of Taylor Rules’, *Journal of Economic Theory* **96**(1-2), 40–69.
URL: <https://ideas.repec.org/a/eee/jetheo/v96y2001i1-2p40-69.html>
- Benhabib, J., Schmitt-Grohe, S. and Uribe, M. (2002), ‘Avoiding Liquidity Traps’, *Journal of Political Economy* **110**(3), 535–563.
URL: <https://ideas.repec.org/a/ucp/jpolec/v110y2002i3p535-563.html>

- Berger, H., Ehrmann, M. and Fratzscher, M. (2006), Forecasting ECB Monetary Policy; Accuracy is (Still) a Matter of Geography, IMF Working Papers 06-41, International Monetary Fund.
URL: <https://ideas.repec.org/p/imf/imfwpa/06-41.html>
- Berger, H., Ehrmann, M. and Fratzscher, M. (2008), Geography or skills: what explains Fed Wachters' forecast accuracy of US monetary policy?, Discussion Papers 2008-11, Free University Berlin, School of Business & Economics.
URL: <https://ideas.repec.org/p/zbw/fubsbe/200811.html>
- Bhandari, A., Borovička, J. and Ho, P. (2016), Identifying Ambiguity Shocks in Business Cycle Models Using Survey Data, NBER Working Papers 22225, National Bureau of Economic Research, Inc.
URL: <https://ideas.repec.org/p/nbr/nberwo/22225.html>
- Billi, R. M. (2011), 'Optimal Inflation for the US Economy', *American Economic Journal: Macroeconomics* **3**(3), 29–52.
URL: <https://ideas.repec.org/a/aea/aejmac/v3y2011i3p29-52.html>
- Binning, A. and Maih, J. (2016), Forecast uncertainty in the neighborhood of the effective lower bound: How much asymmetry should we expect?, Working Paper 2016-13, Norges Bank.
URL: <https://ideas.repec.org/p/bno/worpaper/2016-13.html>
- Bohl, M. T., Siklos, P. L. and Sondermann, D. (2008), 'European Stock Markets and the ECB's Monetary Policy Surprises', *International Finance* **11**(2), 117–130.
URL: <https://ideas.repec.org/a/bla/intfin/v11y2008i2p117-130.html>
- Brainard, W. C. (1967), 'Uncertainty and the effectiveness of policy', *The American Economic Review* **57**(2), 411–425.
URL: <http://www.jstor.org/stable/1821642>
- Calvo, G. A. (1983), 'Staggered prices in a utility-maximizing framework', *Journal of Monetary Economics* **12**(3), 383 – 398.
URL: <http://www.sciencedirect.com/science/article/pii/0304393283900600>
- Cateau, G. (2006), Guarding Against Large Policy Errors under Model Uncertainty, Staff Working Papers 06-13, Bank of Canada.
URL: <https://ideas.repec.org/p/bca/bocawp/06-13.html>
- Cavallo, A., Cruces, G. and Perez-Truglia, R. (2017), 'Inflation expectations, learning, and supermarket prices: Evidence from survey experiments', *American Economic Journal: Macroeconomics* **9**(3), 1–35.
URL: <http://www.aeaweb.org/articles?id=10.1257/mac.20150147>
- Celasun, O., Gelos, R. G. and Prati, A. (2004), 'Obstacles to disinflation: what is the role of fiscal expectations?', *Economic Policy* **19**(40), 441–481.
URL: <https://ideas.repec.org/a/bla/ecpoli/v19y2004i40p441-481.html>

- Chari, V. V., Kehoe, P. J. and McGrattan, E. R. (2009), ‘New keynesian models: Not yet useful for policy analysis’, *American Economic Journal: Macroeconomics* **1**(1), 242–66.
URL: <http://www.aeaweb.org/articles?id=10.1257/mac.1.1.242>
- Ciccarelli, M. and Mojon, B. (2010), ‘Global inflation’, *The Review of Economics and Statistics* **92**(3), 524–535.
URL: <http://dx.doi.org/10.1162/REST-a-00008>
- Coibion, O. and Gorodnichenko, Y. (2012), ‘What can survey forecasts tell us about information rigidities?’, *Journal of Political Economy* **120**(1), 116–159.
URL: <http://www.jstor.org/stable/10.1086/665662>
- Coibion, O. and Gorodnichenko, Y. (2015), ‘Information rigidity and the expectations formation process: A simple framework and new facts’, *American Economic Review* **105**(8), 2644–78.
URL: <http://www.aeaweb.org/articles?id=10.1257/aer.20110306>
- Coibion, O., Gorodnichenko, Y. and Wieland, J. (2012), ‘The optimal inflation rate in new keynesian models: Should central banks raise their inflation targets in light of the zero lower bound?’, *The Review of Economic Studies* **79**(4), 1371–1406.
URL: + <http://dx.doi.org/10.1093/restud/rds013>
- Croushore, D. (2010), ‘An evaluation of inflation forecasts from surveys using real-time data’, *The B.E. Journal of Macroeconomics* **10**(1), 1–32.
URL: <http://EconPapers.repec.org/RePEc:bjp:bejmac:v:10:y:2010:i:1:n:10>
- D’Acunto, F., Hoang, D. and Weber, M. (2015), Inflation Expectations and Consumption Expenditure, 2015 Meeting Papers 1266, Society for Economic Dynamics.
URL: <https://ideas.repec.org/p/red/sed015/1266.html>
- Davig, T. and Gürkaynak, R. S. (2015), ‘Is Optimal Monetary Policy Always Optimal?’, *International Journal of Central Banking* **11**(4), 353–382.
URL: <https://ideas.repec.org/a/ijc/ijcjou/y2015q4a11.html>
- Davig, T. and Leeper, E. M. (2008), Endogenous Monetary Policy Regime Change, in ‘NBER International Seminar on Macroeconomics 2006’, NBER Chapters, National Bureau of Economic Research, Inc, pp. 345–391.
URL: <https://ideas.repec.org/h/nbr/nberch/7039.html>
- Debortoli, D., Kim, J., Linde, J. and Nunes, R. (2016), Designing a Simple Loss Function for the Fed: Does the Dual Mandate Make Sense?, Discussion Paper Series 1601, Institute of Economic Research, Korea University.
URL: <https://ideas.repec.org/p/iek/wpaper/1601.html>
- Dennis, R. (2008), ‘Robust control with commitment: A modification to hansen-sargent’, *Journal of Economic Dynamics and Control* **32**(7), 2061 – 2084.
URL: <http://www.sciencedirect.com/science/article/pii/S0165188907001911>

- Dennis, R. (2010), ‘How robustness can lower the cost of discretion’, *Journal of Monetary Economics* **57**(6), 653 – 667.
URL: <http://www.sciencedirect.com/science/article/pii/S0304393210000656>
- Duran, M., Gürkaynak, R., Özlü, P. and Ünalmış, D. (2010), TCMB Faiz Kararlarının Piyasa Faizleri Ve Hisse Senedi Piyasaları Üzerine Etkisi, CBT Research Notes in Economics 1008, Research and Monetary Policy Department, Central Bank of the Republic of Turkey.
URL: <https://ideas.repec.org/p/tcb/econot/1008.html>
- Edge, R. M. (2003), A utility-based welfare criterion in a model with endogenous capital accumulation, Finance and Economics Discussion Series 2003-66, Board of Governors of the Federal Reserve System (U.S.).
URL: <https://ideas.repec.org/p/fip/fedgfe/2003-66.html>
- Edge, R. M., Gürkaynak, R. S., Reis, R. and Sims, C. A. (2010), ‘How useful are estimated dsge model forecasts for central bankers? [with comments and discussion]’, *Brookings Papers on Economic Activity* pp. 209–259.
URL: <http://www.jstor.org/stable/41012847>
- Eggertsson, G. B. and Woodford, M. (2003), ‘The Zero Bound on Interest Rates and Optimal Monetary Policy’, *Brookings Papers on Economic Activity* **34**(1), 139–235.
URL: <https://ideas.repec.org/a/bin/bpeajo/v34y2003i2003-1p139-235.html>
- Eggertsson, G. B. and Woodford, M. (2004), ‘Policy options in a liquidity trap’, *The American Economic Review* **94**(2), 76–79.
URL: <http://www.jstor.org/stable/3592860>
- Epstein, L. G. and Schneider, M. (2003), ‘Recursive multiple-priors’, *Journal of Economic Theory* **113**(1), 1 – 31.
URL: <http://www.sciencedirect.com/science/article/pii/S0022053103000978>
- Evans, G. and Honkapohja, S. (2001), *Learning and Expectations in Macroeconomics*, Princeton University Press.
URL: <https://books.google.com.tr/books?id=A7rWCwAAQBAJhl=tr>
- Evans, G. W. and Honkapohja, S. (2009), Expectations, Learning and Monetary Policy: An Overview of Recent Research, in K. Schmidt-Hebbel, C. E. Walsh, N. L. S. Editor) and K. S.-H. (Series, eds, ‘Monetary Policy under Uncertainty and Learning’, Vol. 13 of *Central Banking, Analysis, and Economic Policies Book Series*, Central Bank of Chile, chapter 2, pp. 027–076.
URL: <https://ideas.repec.org/h/chb/bcchsb/v13c02pp027-076.html>
- Faust, J. and Wright, J. H. (2013), Forecasting inflation, in ‘Handbook of Economic Forecasting’, Vol. 2A, Elsevier, chapter 1, pp. 2–56.
URL: <http://EconPapers.repec.org/RePEc:eee:ecofch:2-2>
- Fernández-Villaverde, J. (2009), The econometrics of dsge models, Working Paper 14677, National Bureau of Economic Research.
URL: <http://www.nber.org/papers/w14677>

- Fernández-Villaverde, J. and Rubio-Ramírez, J. F. (2006), ‘A baseline dsge model’.
URL: http://economics.sas.upenn.edu/jesusfv/benchmark_DSGE.pdf
- Filardo, A. and Hofmann, B. (2014), ‘Forward guidance at the zero lower bound’, *BIS Quarterly Review*.
URL: <https://ideas.repec.org/a/bis/bisqtr/1403f.html>
- Fuhrer, J. C. (2012), Real expectations: replacing rational expectations with survey expectations in dynamic macro models, Working Papers 12-19, Federal Reserve Bank of Boston.
URL: <https://ideas.repec.org/p/fip/fedbwp/12-19.html>
- Gabaix, X. (2016), Behavioral Macroeconomics Via Sparse Dynamic Programming, NBER Working Papers 21848, National Bureau of Economic Research, Inc.
URL: <https://ideas.repec.org/p/nbr/nberwo/21848.html>
- Galí, J. (2015), *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework and Its Applications*, Princeton University Press.
URL: https://books.google.com.tr/books?id=_1CUBgAAQBAJ
- Galí, J. and Gertler, M. (1999), ‘Inflation dynamics: A structural econometric analysis’, *Journal of Monetary Economics* **44**(2), 195–222.
URL: <https://ideas.repec.org/a/eee/moneco/v44y1999i2p195-222.html>
- Galí, J., Gertler, M. and David Lopez-Salido, J. (2005), ‘Robustness of the estimates of the hybrid New Keynesian Phillips curve’, *Journal of Monetary Economics* **52**(6), 1107–1118.
URL: <https://ideas.repec.org/a/eee/moneco/v52y2005i6p1107-1118.html>
- Gerke, R. and Hammermann, F. (2016), ‘Robust monetary policy in a new keynesian model with imperfect interest rate pass-through’, *Macroeconomic Dynamics* **20**(6), 1504–1526.
- Giannoni, M. P. (2002), ‘Does model uncertainty justify caution? robust optimal monetary policy in a forward- looking model’, *Macroeconomic Dynamics* **6**(1), 111–144.
- Gilboa, I. and Schmeidler, D. (1989), ‘Maxmin expected utility with non-unique prior’, *Journal of Mathematical Economics* **18**(2), 141 – 153.
URL: <http://www.sciencedirect.com/science/article/pii/0304406889900189>
- Giordani, P. and Söderlind, P. (2004), ‘Solution of macromodels with hansen-sargent robust policies: some extensions’, *Journal of Economic Dynamics and Control* **28**(12), 2367–2397.
URL: <http://www.sciencedirect.com/science/article/pii/S0165188904000028>
- Goldfeld, S. and Quandt, R. (1973), The Estimation of Structural Shifts by Switching Regressions, in ‘Annals of Economic and Social Measurement,

Volume 2, number 4', NBER Chapters, National Bureau of Economic Research, Inc, pp. 475–485.

URL: <https://ideas.repec.org/h/nbr/nberch/9938.html>

Guerrieri, L. and Iacoviello, M. (2015), 'OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily', *Journal of Monetary Economics* **70**(C), 22–38.

URL: <https://ideas.repec.org/a/eee/moneco/v70y2015icp22-38.html>

Guimarães, B. and Soares Gonçalves, C. E. (2007), Monetary Policy, Default Risk and the Exchange Rate, CEPR Discussion Papers 6501, C.E.P.R. Discussion Papers.

URL: <https://ideas.repec.org/p/cpr/ceprdp/6501.html>

Gürkaynak, R. S., Sack, B. and Swanson, E. (2005), 'Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements', *International Journal of Central Banking* **1**(1).

URL: <https://ideas.repec.org/a/ijc/ijcjou/y2005q2a2.html>

Hansen, L. P. and Sargent, T. J. (2001), 'Acknowledging misspecification in macroeconomic theory', *Review of Economic Dynamics* **4**(3), 519 – 535.

URL: <http://www.sciencedirect.com/science/article/pii/S1094202501901322>

Hansen, L. P. and Sargent, T. J. (2008), *Robustness*, Princeton University Press.

URL: <https://ideas.repec.org/h/pup/chapts/8535-1.html>

Jung, T., Teranishi, Y. and Watanabe, T. (2005), 'Optimal monetary policy at the zero-interest-rate bound', *Journal of Money, Credit and Banking* **37**(5), 813–835.

URL: <http://www.jstor.org/stable/3839148>

Kabukçuoğlu, A. and Martínez-García, E. (2016), Inflation as a global phenomenon - some implications for policy analysis and forecasting, Globalization and Monetary Policy Institute Working Paper 261, Federal Reserve Bank of Dallas.

URL: <https://ideas.repec.org/p/fip/feddgw/261.html>

Kara, A. H. (2002), Robust Targeting Rules for Monetary Policy, Discussion Papers 0208, Research and Monetary Policy Department, Central Bank of the Republic of Turkey.

URL: <https://ideas.repec.org/p/tcb/dpaper/0208.html>

Kara, A. H. (2004), 'Optimal Monetary Policy, Commitment, and Imperfect Credibility', *Central Bank Review* **4**(1), 31–66.

URL: <https://ideas.repec.org/a/tcb/cebare/v4y2004i1p31-66.html>

Kearns, J. (2016), Global inflation forecasts, BIS Working Papers 582, Bank for International Settlements.

URL: <http://www.bis.org/publ/work582.pdf>

- Kholodilin, K., Montagnoli, A., Napolitano, O. and Siliverstovs, B. (2009), ‘Assessing the impact of the ecb’s monetary policy on the stock markets: A sectoral view’, *Economics Letters* **105**(3), 211–213.
URL: <http://www.sciencedirect.com/science/article/pii/S016517650900250X>
- Klibanoff, P., Marinacci, M. and Mukerji, S. (2005), ‘A smooth model of decision making under ambiguity’, *Econometrica* **73**(6), 1849–1892.
- Kuttner, K. N. (2001), ‘Monetary policy surprises and interest rates: Evidence from the fed funds futures market’, *Journal of Monetary Economics* **47**(3), 523–544.
URL: <http://www.sciencedirect.com/science/article/pii/S0304393201000551>
- Leitemo, K. and Söderström, U. (2008a), ‘Robust monetary policy in a small open economy’, *Journal of Economic Dynamics and Control* **32**(10), 3218–3252.
URL: <http://www.sciencedirect.com/science/article/pii/S016518890800016X>
- Leitemo, K. and Söderström, U. (2008b), ‘Robust monetary policy in the new keynesian framework’, *Macroeconomic Dynamics* **12**(S1), 126–135.
- Leith, C., Moldovan, I. and Rossi, R. (2012), ‘Optimal monetary policy in a new keynesian model with habits in consumption’, *Review of Economic Dynamics* **15**(3), 416–435.
URL: <http://www.sciencedirect.com/science/article/pii/S109420251200018X>
- Levin, A., Wieland, V. and Williams, J. C. (2003), ‘The performance of forecast-based monetary policy rules under model uncertainty’, *The American Economic Review* **93**(3), 622–645.
URL: <http://www.jstor.org/stable/3132109>
- Maccheroni, F., Marinacci, M. and Rustichini, A. (2006), ‘Ambiguity Aversion, Robustness, and the Variational Representation of Preferences’, *Econometrica* **74**(6), 1447–1498.
URL: <https://ideas.repec.org/a/ecm/emetrp/v74y2006i6p1447-1498.html>
- Maćkowiak, B. and Wiederholt, M. (2009), ‘Optimal sticky prices under rational inattention’, *American Economic Review* **99**(3), 769–803.
URL: <http://www.aeaweb.org/articles?id=10.1257/aer.99.3.769>
- Maćkowiak, B. and Wiederholt, M. (2015), ‘Business cycle dynamics under rational inattention’, *The Review of Economic Studies* **82**(4), 1502.
URL: <http://dx.doi.org/10.1093/restud/rdv027>
- Malmendier, U. and Nagel, S. (2016), ‘Learning from inflation experiences’, *The Quarterly Journal of Economics* **131**(1), 53.
URL: <http://dx.doi.org/10.1093/qje/qjv037>
- Mankiw, N. G. and Reis, R. (2002), ‘Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve’, *The Quarterly Journal of Economics* **117**(4), 1295–1328.
URL: <https://ideas.repec.org/a/oup/qjecon/v117y2002i4p1295-1328..html>

- Mertens, K. R. S. M. and Ravn, M. O. (2014), ‘Fiscal Policy in an Expectations-Driven Liquidity Trap’, *Review of Economic Studies* **81**(4), 1637–1667.
URL: <https://ideas.repec.org/a/oup/restud/v81y2014i4p637-1667.html>
- Piazzesi, M. and Schneider, M. (2008), Bond positions, expectations, and the yield curve, Working Paper, Federal Reserve Bank of Atlanta 2008-2, Atlanta, GA.
URL: <http://hdl.handle.net/10419/70745>
- Reis, R. (2006), ‘Inattentive producers’, *The Review of Economic Studies* **73**(3), 793.
URL: <http://dx.doi.org/10.1111/j.1467-937X.2006.00396.x>
- Rezessy, A. (2005), Estimating the immediate impact of monetary policy shocks on the exchange rate and other asset prices in Hungary, MNB Occasional Papers 2005/38, Magyar Nemzeti Bank (Central Bank of Hungary).
URL: <https://ideas.repec.org/p/mnb/opaper/2005-38.html>
- Rigobon, R. and Sack, B. (2004), ‘The impact of monetary policy on asset prices’, *Journal of Monetary Economics* **51**(8), 1553–1575.
URL: <http://www.sciencedirect.com/science/article/pii/S0304393204001138>
- Rotemberg, J. J. and Woodford, M. (1998), An optimization-based econometric framework for the evaluation of monetary policy: Expanded version, Working Paper 233, National Bureau of Economic Research.
URL: <http://www.nber.org/papers/t0233>
- Sims, C. A. (2003), ‘Implications of rational inattention’, *Journal of Monetary Economics* **50**(3), 665 – 690. Swiss National Bank/Study Center Gerzensee Conference on Monetary Policy under Incomplete Information.
URL: <http://www.sciencedirect.com/science/article/pii/S0304393203000291>
- Smets, F. and Wouters, R. (2007), ‘Shocks and frictions in us business cycles: A bayesian dsge approach’, *American Economic Review* **97**(3), 586–606.
URL: <http://www.aeaweb.org/articles?id=10.1257/aer.97.3.586>
- Strzalecki, T. (2011), ‘Axiomatic foundations of multiplier preferences’, *Econometrica* **79**(1), 47–73.
URL: <http://www.jstor.org/stable/41057437>
- Svensson, L. E. (2010), Inflation Targeting, in B. M. Friedman and M. Woodford, eds, ‘Handbook of Monetary Economics’, Vol. 3 of *Handbook of Monetary Economics*, Elsevier, chapter 22, pp. 1237–1302.
URL: <https://ideas.repec.org/h/eee/monchp/3-22.html>
- Walsh, C. E. (2004), ‘Robustly optimal instrument rules and robust control: An equivalence result’, *Journal of Money, Credit and Banking* **36**(6), 1105–1113.
URL: <http://www.jstor.org/stable/3839103>

Williams, J. C. (2014), ‘Monetary Policy at the Zero Lower Bound: Putting Theory Into Practice’, *Hutchins Center Working Paper No. 2*.

URL: <https://www.brookings.edu/wp-content/uploads/2016/06/16-monetary-policy-zero-lower-bound-williams.pdf>

Woodford, M. (2003), Imperfect Common Knowledge and the Effects of Monetary Policy, *in* ‘Knowledge, Information, and Expectations in Modern Macroeconomics: In Honor of Edmund S. Phelps’, Princeton University Press, Princeton, ed. by Philippe Aghion, Roman Frydman, Joseph Stiglitz, and Michael Woodford, pp. 25–28.

URL: <https://ideas.repec.org/p/nbr/nberwo/8673.html>

Woodford, M. (2011), *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton University Press.

URL: <https://books.google.com.tr/books?id=8AlrisNOOpYC>

Wu, J. C. and Zhang, J. (2017), A shadow rate New Keynesian model, 2017 Meeting Papers 11, Society for Economic Dynamics.

URL: <https://ideas.repec.org/p/red/sed017/11.html>

APPENDICES

A Data Appendix

Principal Component Analysis

Each national inflation rate can be written as a linear combination of a common factor and a unique factor as follows:

$$\pi_t^i = \gamma_1^i c_t + \epsilon_t^i \quad (4)$$

where π_t^i denotes for the inflation rate in home country i , in month t , and c_t represents the first common factor.

The first common factor from the regression equation (4) is interpreted as the global inflation rate that the forecasters experience.

Calculation of the orthogonal variables

We obtain the measures of alternative global inflation rates orthogonal to each other by utilizing the following system of equations:

$$\begin{aligned} \pi_t^{World} &= \gamma_1 \pi_t^{EA} + \epsilon_t^{World} \\ \pi_t^{Developed} &= \gamma_2 \pi_t^{EA} + \gamma_3 \epsilon_t^{World} + \epsilon_t^{Developed} \\ \pi_t^{Global} &= \gamma_4 \pi_t^{EA} + \gamma_5 \epsilon_t^{World} + \gamma_6 \epsilon_t^{Developed} + \epsilon_t^{Global} \\ \pi_t^{Home} &= \gamma_7 \pi_t^{EA} + \gamma_8 \epsilon_t^{World} + \gamma_9 \epsilon_t^{Developed} + \gamma_{10} \epsilon_t^{Global} + \epsilon_t^{Home} \end{aligned} \quad (5)$$

where π_t^{EA} , π_t^{World} , $\pi_t^{Developed}$, π_t^{Global} , and π_t^{Home} are inflation rates for euro area, world, developed economies and home country of the forecaster respectively. Here, ϵ_t^{World} denotes for the world inflation net of EA inflation, $\epsilon_t^{Developed}$ is the inflation rate for developed economies net of EA inflation and the world inflation, ϵ_t^{Global} is the global factor net of the inflation rates for EA, world and developed economies, and ϵ_t^{Home} represents the net home inflation rate purified from the inflation rates for developed economies, EA and the world.



B Model Derivation

A Simple New Keynesian Model with Sticky Prices

Household's problem:

$$\begin{aligned} \mathcal{L} = E_t \sum_{t=0}^{\infty} \beta^t \{ & \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\eta}}{1+\eta} \\ & + \lambda_t(-B_t - P_t C_t + B_{t-1} R_{t-1} + P_t w_t L_t + T_t + \Phi_t) \} \end{aligned} \quad (6)$$

with the first-order conditions:

$$\frac{\partial \mathcal{L}}{\partial C_t} = 0 \Rightarrow \frac{C_t^{-\sigma}}{P_t} = \lambda_t \quad (7)$$

$$\frac{\partial \mathcal{L}}{\partial L_t} = 0 \Rightarrow \frac{L_t^\eta}{w_t P_t} = \lambda_t \quad (8)$$

$$\frac{\partial \mathcal{L}}{\partial B_t} = 0 \Rightarrow \frac{\lambda_t}{E_t \lambda_{t+1}} = \beta R_t \quad (9)$$

Equation (7) together with equation (8) yields:

$$w_t = L_t^\eta C_t^\sigma \quad (10)$$

(10) in log-linearized form (using $w_t = z_t F_L = z_t(1-\alpha)L_t^{-\alpha} = z_t(1-\alpha)\frac{Y_t}{L_t}$) is:

$$\begin{aligned} \eta \hat{L}_t + \sigma \hat{C}_t &= \hat{z}_t + \hat{Y}_t - L_t \\ \hat{z}_t &= \sigma \hat{C}_t + (1+\eta) \hat{L}_t - \hat{Y}_t \end{aligned} \quad (11)$$

Equation (7) together with equation (9) gives:

$$\begin{aligned} \frac{\lambda_t}{E_t \lambda_{t+1}} &= \frac{C_t^{-\sigma}/P_t}{E_t C_{t+1}^{-\sigma}/P_{t+1}} = \beta R_t \\ \Rightarrow C_t^{-\sigma} &= \beta E_t [C_{t+1}^{-\sigma} R_t \frac{P_t}{P_{t+1}}] \end{aligned} \quad (12)$$

Equation (12) is written in log-linearized form as:

$$-\sigma \hat{C}_t = -\sigma E_t \hat{C}_{t+1} + \hat{R}_t - E_t \hat{\Pi}_{t+1} \quad (13)$$

Goods market clearing condition $Y_t = C_t$ in log-linearized form is:

$$\hat{Y}_t = \hat{C}_t \quad (14)$$

Using equation (14) in (13) gives the IS relation as follows:

$$\sigma \hat{Y}_t = \sigma E_t \hat{Y}_{t+1} - \hat{R}_t + E_t \hat{\Pi}_{t+1} \quad (15)$$

Inserting equation (14) in (11) yields:

$$\hat{z}_t = \sigma \hat{Y}_t + (1 + \eta) \frac{\hat{Y}_t}{(1 - \alpha)} - \hat{Y}_t = \left(\frac{1 + \eta}{1 - \alpha} - (1 - \sigma) \right) \hat{Y}_t \quad (16)$$

By substituting equations (14) and (16) in the New Keynesian Phillips curve, one obtains:

$$\hat{\Pi}_t = \beta E_t \hat{\Pi}_{t+1} + \frac{(1 - \theta)(1 - \beta\theta)}{\theta} \left(\frac{1 + \eta}{1 - \alpha} - (1 - \sigma) \right) \hat{Y}_t \quad (17)$$

A New Keynesian Model with Sticky Prices and Habit Formation in Consumption

Household's problem:

$$\begin{aligned} \mathcal{L} = E_t \sum_{t=0}^{\infty} \beta^t \{ & \frac{(C_t - hC_{t-1})^{1-\sigma}}{1 - \sigma} - \frac{L_t^{1+\eta}}{1 + \eta} \\ & + \lambda_t(-B_t - P_t C_t + B_{t-1} R_{t-1} + P_t w_t L_t + T_t + \Phi_t) \} \end{aligned} \quad (18)$$

with the first-order conditions:

$$\frac{\partial \mathcal{L}}{\partial C_t} = 0 \Rightarrow \frac{(C_t - hC_{t-1})^{-\sigma}}{P_t} = \lambda_t \quad (19)$$

$$\frac{\partial \mathcal{L}}{\partial L_t} = 0 \Rightarrow \frac{L_t^\eta}{w_t P_t} = \lambda_t \quad (20)$$

$$\frac{\partial \mathcal{L}}{\partial B_t} = 0 \Rightarrow \frac{\lambda_t}{E_t \lambda_{t+1}} = \beta R_t \quad (21)$$

Equation (19) together with equation (20) yields:

$$w_t = L_t^\eta (C_t - hC_{t-1})^\sigma \quad (22)$$

Log-linearizing gives:

$$\begin{aligned} \frac{\sigma}{1-h}(\hat{C}_t - \hat{C}_{t-1}) + \eta \hat{L}_t &= \hat{z}_t + \hat{Y}_t - \hat{L}_t \\ \Rightarrow \hat{z}_t &= \frac{\sigma}{1-h}(\hat{C}_t - \hat{C}_{t-1}) + (1+\eta)\hat{L}_t - \hat{Y}_t \end{aligned} \quad (23)$$

Equation (19) together with equation (21) yields:

$$\begin{aligned} \frac{(C_t - hC_{t-1})^{-\sigma}}{E_t(C_{t+1} - hC_t)^{-\sigma}} &= \beta R_t \frac{P_t}{P_{t+1}} \\ \Rightarrow C_t^{-\sigma} &= \beta E_t[C_{t+1}^{-\sigma} R_t \frac{P_t}{P_{t+1}}] \end{aligned} \quad (24)$$

One log-linearizes (24) as follows:

$$(\hat{C}_t - \hat{C}_{t-1}) = E_t(\hat{C}_{t+1} - \hat{C}_t) - \frac{1-h}{\sigma} [\hat{R}_t - E_t \hat{\Pi}_{t+1}] \quad (25)$$

in terms of habit-adjusted consumption or rearranges as follows:

$$\hat{C}_t = \frac{h}{1+h} \hat{C}_{t-1} + \frac{1}{1+h} E_t \hat{C}_{t+1} - \frac{1-h}{\sigma(1+h)} (\hat{R}_t - E_t \hat{\Pi}_{t+1}) \quad (26)$$

Inserting the goods market equilibrium condition gives the IS equation:

$$\hat{Y}_t = \frac{h}{1+h} \hat{Y}_{t-1} + \frac{1}{1+h} E_t \hat{Y}_{t+1} - \frac{1-h}{\sigma(1+h)} (\hat{R}_t - E_t \hat{\Pi}_{t+1}) \quad (27)$$

From equation (23), we have

$$\hat{z}_t = \frac{\sigma}{1-h} (\hat{Y}_t - \hat{Y}_{t-1}) + (1+\eta) \frac{\hat{Y}_t}{(1-\alpha)} - \hat{Y}_t \quad (28)$$

I use equation (28) to obtain the Phillips relation as follows:

$$\begin{aligned} \hat{\Pi}_t &= \beta E_t \hat{\Pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta} \hat{z}_t \\ \Rightarrow \hat{\Pi}_t &= \beta E_t \hat{\Pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta} \left[\frac{\sigma}{1-h} (\hat{Y}_t - \hat{Y}_{t-1}) + \frac{\alpha+\eta}{1-\alpha} \hat{Y}_t \right] \\ \Rightarrow \hat{\Pi}_t &= \beta E_t \hat{\Pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta} \left[\left(\frac{\sigma}{1-h} + \frac{\alpha+\eta}{1-\alpha} \right) \hat{Y}_t - \frac{\sigma h}{1-h} \hat{Y}_{t-1} \right] \end{aligned} \quad (29)$$

A New Keynesian Model with Sticky Prices and Backward-looking Firms

As in Galí and Gertler (1999), Phillips curve has an additional component, π_{t-1} , due to backward-looking firms.

$$\begin{aligned} \hat{\Pi}_t &= \frac{\omega}{\theta + \omega[1 - \theta(1 - \beta)]} \hat{\Pi}_{t-1} + \frac{\beta\theta}{\theta + \omega[1 - \theta(1 - \beta)]} E_t \hat{\Pi}_{t+1} \\ &\quad + \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\theta + \omega[1 - \theta(1 - \beta)]} \hat{z}_t \end{aligned} \quad (30)$$

Inserting the marginal cost (16) yields:

$$\begin{aligned} \pi_t &= \frac{\omega}{\theta + \omega[1 - \theta(1 - \beta)]} \pi_{t-1} + \frac{\beta\theta}{\theta + \omega[1 - \theta(1 - \beta)]} E_t \pi_{t+1} \\ &\quad + \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\theta + \omega[1 - \theta(1 - \beta)]} \left(\frac{1+\eta}{1-\alpha} - (1-\sigma) \right) \hat{Y}_t \end{aligned} \quad (31)$$

A New Keynesian Model with Sticky Prices, Consumption Habits and Backward-looking Firms

As suggested by the model with consumption habits, I obtain a hybrid IS curve which represents the behavior of the output gap as follows:

$$\hat{Y}_t = \frac{h}{1+h} \hat{Y}_{t-1} + \frac{1}{1+h} E_t \hat{Y}_{t+1} - \frac{1-h}{\sigma(1+h)} (\hat{R}_t - E_t \hat{\Pi}_{t+1}) \quad (32)$$

The real marginal cost is:

$$\begin{aligned} \hat{z}_t &= \frac{\sigma}{1-h} (\hat{Y}_t - \hat{Y}_{t-1}) + (1+\eta) \frac{\hat{Y}_t}{(1-\alpha)} - \hat{Y}_t \\ \Rightarrow \hat{z}_t &= \left[\left(\frac{\sigma}{1-h} + \frac{\alpha+\eta}{1-\alpha} \right) \hat{Y}_t - \frac{\sigma h}{1-h} \hat{Y}_{t-1} \right] \end{aligned} \quad (33)$$

Using equation (33) in the Phillips relation suggested by the model with backward-looking firms yields:

$$\begin{aligned} \hat{\Pi}_t &= \frac{\omega}{\theta + \omega[1 - \theta(1 - \beta)]} \hat{\Pi}_{t-1} + \frac{\beta\theta}{\theta + \omega[1 - \theta(1 - \beta)]} E_t \hat{\Pi}_{t+1} \\ &\quad + \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\theta + \omega[1 - \theta(1 - \beta)]} \hat{z}_t \\ \Rightarrow \hat{\Pi}_t &= \frac{\omega}{\theta + \omega[1 - \theta(1 - \beta)]} \hat{\Pi}_{t-1} + \frac{\beta\theta}{\theta + \omega[1 - \theta(1 - \beta)]} E_t \hat{\Pi}_{t+1} \\ &\quad + \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\theta + \omega[1 - \theta(1 - \beta)]} \left[\left(\frac{\sigma}{1-h} + \frac{\alpha+\eta}{1-\alpha} \right) \hat{Y}_t - \frac{\sigma h}{1-h} \hat{Y}_{t-1} \right] \end{aligned} \quad (34)$$

C Solution Algorithm for the Approximating Equilibrium

The approximating equilibrium represents the dynamics of the economy under robust decision-making by the policymaker and the private agents. To form the approximating equilibrium, one needs the equilibrium dynamics under the worst-case model. The worst-case model can be represented by the following linear law of motion

$$\begin{bmatrix} x_{t+1} \\ E_t y_{t+1} \end{bmatrix} = A \begin{bmatrix} x_t \\ y_t \end{bmatrix} + B u_t + C(\varepsilon_{t+1} + v_{t+1}), \quad C = \begin{bmatrix} C_1 \\ 0 \end{bmatrix} \quad (35)$$

where x_t and y_t represent n_1 predetermined and n_2 the forward-looking variables respectively. u_t is the control variable of the policymaker. The predetermined variables has shocks ε_{t+1} ($n_1 \times 1$ vector with zero mean and identity covariance matrix). v_{t+1} is $n_1 \times 1$ vector of misspecification which is the control variables of the hypothetical evil agent. The misspecification is bounded as

$$E_0 \sum_{\tau=0}^{\infty} \beta^{\tau+1} v'_{t+1} v_{t+1}^u \leq \eta_0, \quad \eta_0 > 0 \quad (36)$$

The policymaker and the evil agent share the following linear quadratic problem ⁵

$$\min_{\{u_t\}} \max_{\{v_{t+1}\}} E_0 \sum_{t=0}^{\infty} \beta^t [z'_t Q z_t + u'_t R u_t + 2z'_t U u_t - 2\beta \Theta v'_{t+1} v_{t+1}] \quad (37)$$

subject to

$$z_{t+1} = A z_t + B u_t + C(\varepsilon_{t+1} + v_{t+1}), \quad (38)$$

⁵This is the representation of the multiplier version of the Stackelberg problem defined in the text.

where $z'_t = (x'_t \quad y'_t)$ is the vector of all endogenous variables ⁶

The problem can be written in the standard state-space form by defining

$$R^* = \begin{bmatrix} R & 0 \\ 0 & -\beta\Theta I \end{bmatrix}, u_t^* = \begin{bmatrix} u_t \\ v_{t+1} \end{bmatrix}, B^* = \begin{bmatrix} B & C \end{bmatrix}, \text{ and } U^* = \begin{bmatrix} U & 0 \end{bmatrix} \text{ as follows:}$$

$$\min_{\{u_t\}} \max_{\{v_{t+1}\}} E_0 \sum_{t=0}^{\infty} \beta^t [z'_t Q z_t + u_t'^* R^* u_t^* + 2z'_t U^* z_t] \quad (39)$$

subject to

$$z_{t+1} = A z_t + B^* u_t^* + C(\varepsilon_{t+1} + v_{t+1}), \quad (40)$$

In the worst-case equilibrium, Giordani and Söderlind (2004) shows how to write the evolution of the state variables, the forward-looking variables and the decision rules as follows:

$$\begin{bmatrix} x_{t+1} \\ \lambda_{t+1} \end{bmatrix} = M \begin{bmatrix} x_t \\ \lambda_t \end{bmatrix} + C \varepsilon_{t+1}, \quad (41)$$

$$\begin{bmatrix} y_t \\ u_t^* \end{bmatrix} = N \begin{bmatrix} x_t \\ \lambda_t \end{bmatrix}, \quad (42)$$

$$\begin{bmatrix} u_t \\ v_{t+1} \end{bmatrix} = \begin{bmatrix} N_2 \\ N_3 \end{bmatrix} P^{-1} \begin{bmatrix} x_t \\ y_t \end{bmatrix} = \begin{bmatrix} -F_u \\ -F_v \end{bmatrix} P^{-1} \begin{bmatrix} x_t \\ \lambda_t \end{bmatrix} \quad (43)$$

where λ_t is $n_2 \times 1$ vector of shadow prices of the forward-looking variables with $\lambda_0 = 0$. $M = P(A - BF_u - CF_v)P^{-1}$, $P = \begin{bmatrix} I & 0 \\ & N_1 \end{bmatrix}$ implying

⁶The control problem under rational expectations corresponds to the case where $\Theta = 0$ (so the maximization is irrelevant) and there is no misspecification, i.e. $v_{t+1} = 0$ in equation (38).

$$\begin{bmatrix} x_t \\ y_t \end{bmatrix} = P \begin{bmatrix} x_t \\ \lambda_t \end{bmatrix}$$

The worst-case model in terms of the state variables is shown below:

$$x_{t+1} = M_{11}x_t + M_{12}\lambda_t + C_1\varepsilon_{t+1} \quad (44)$$

$$\lambda_{t+1} = M_{21}x_t + M_{22}\lambda_t \quad (45)$$

$$y_t = H_{21}x_t + H_{22}\lambda_t \quad (46)$$

$$u_t = F_{u11}x_t + F_{u12}\lambda_t \quad (47)$$

$$v_{t+1} = F_{v11}x_t + F_{v12}\lambda_t \quad (48)$$

where $M = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}$, $\begin{bmatrix} F_{u11} & F_{u21} \end{bmatrix} \equiv -F_u P^{-1}$, and $\begin{bmatrix} F_{v11} & F_{v21} \end{bmatrix} \equiv -F_v P^{-1}$.

To obtain the approximating model, I first eliminate the worst-case distortions by equating F_{v11} and F_{v12} to zero in equation (48). Note that the state variables evolve according to the following equation in the absence of distortions:

$$x_{t+1} = A_{11}x_t + A_{21}y_t + B_1u_t + C_1\varepsilon_{t+1} \quad (49)$$

Inserting equations (47) and (48) into (49) yields

$$x_{t+1} = A_{11}x_t + A_{21}[H_{21}x_t + H_{22}\lambda_t] + B_1[F_{u11}x_t + F_{u12}\lambda_t] + C_1\varepsilon_{t+1} \quad (50)$$

The approximating equilibrium is summarized by equations (46)-(48) and (50). I calculate the matrices, and implement the procedure using Dynare.

D State-space representation of New Keynesian models

A convenient representation of a New Keynesian model is given by the following set of difference equations:

$$z_{t+1} = Az_t + Br_t + \varepsilon_{t+1} \quad (51)$$

where z_t is the state vector, defining each period the state space. A is a matrix that represent the structural coefficients of the economy. B is a vector capturing the impact of the choice of the policymaker. ε_{t+1} is a vector of shocks that drive the system. Since the variance covariance matrix is diagonal, individual shocks can be treated as structural shocks.

Structural equations of the model can be represented in the following state-space form in terms of predetermined and forward-looking variables as follows:

$$\begin{bmatrix} z_{1,t+1} \\ E_t z_{2,t+1} \end{bmatrix} = A \begin{bmatrix} z_{1,t} \\ z_{2,t} \end{bmatrix} + Br_t + \begin{bmatrix} \varepsilon_{t+1} \\ 0 \end{bmatrix}$$

where

$$z_t = \begin{bmatrix} z_{1,t} \\ z_{2,t} \end{bmatrix}$$

Optimization problem of the central bank is as follows:

$$J_0 = E_0 \sum_{t=0}^{\infty} \beta^t \begin{bmatrix} z'_t & r'_t \end{bmatrix} \begin{bmatrix} Q & U \\ U' & R \end{bmatrix} \begin{bmatrix} z_t \\ r_t \end{bmatrix}$$

Benchmark Model

For the specification of the model explained in text and derived from micro-foundations in the previous section, we have:

$$z_{1,t} = \begin{bmatrix} e_t \\ u_t \end{bmatrix}, z_{2,t} = \begin{bmatrix} \pi_t \\ y_t \end{bmatrix}, \varepsilon_t = \begin{bmatrix} \epsilon_{\pi_t} \\ \epsilon_{y_t} \end{bmatrix}$$

where $z_{1,t}$ and $z_{2,t}$ denote for the vectors of predetermined and forward-looking variables respectively.

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \beta & 0 \\ 0 & 0 & \frac{1}{\sigma} & 1 \end{bmatrix} \begin{bmatrix} e_{t+1} \\ u_{t+1} \\ E_t \pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \begin{bmatrix} \rho_e & 0 & 0 & 0 \\ 0 & \rho_u & 0 & 0 \\ -1 & 0 & 1 & -\Omega \\ 0 & -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} e_t \\ u_t \\ \pi_t \\ y_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{\sigma} \end{bmatrix} r_t + \begin{bmatrix} \sigma_1 & 0 \\ 0 & \sigma_2 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \epsilon_{\pi,t+1} \\ \epsilon_{y,t+1} \end{bmatrix}$$

with the variances of the two shocks are $\sigma_1 = \sigma_2 = 1$

Model with Habit Formation in Consumption

In this case, we have an additional state variable, namely y_{t-1} . Hence, we have:

$$z_{1,t} = \begin{bmatrix} e_t \\ u_t \\ y_{t-1} \end{bmatrix}, z_{2,t} = \begin{bmatrix} \pi_t \\ y_t \end{bmatrix}, \varepsilon_t = \begin{bmatrix} \epsilon_{\pi_t} \\ \epsilon_{y_t} \end{bmatrix}$$

To incorporate a lagged dependent variable as an additional state variable, we use the fact that

$$y_{t+1} = E_t y_{t+1} + u_{t+1}$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \beta & 0 \\ 0 & 0 & 0 & -\gamma_{10} & \gamma_9 \end{bmatrix} \begin{bmatrix} e_{t+1} \\ u_{t+1} \\ y_t \\ E_t \pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \begin{bmatrix} \rho_e & 0 & 0 & 0 & 0 \\ 0 & \rho_u & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & -\gamma_{12} & 1 & -\gamma_{11} \\ 0 & -1 & -\gamma_8 & 0 & 1 \end{bmatrix} \begin{bmatrix} e_t \\ u_t \\ y_{t-1} \\ \pi_t \\ y_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -\gamma_{10} \end{bmatrix} r_t +$$

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \epsilon_{\pi,t+1} \\ \epsilon_{y,t+1} \end{bmatrix}$$

Model with Inflation Persistence

In this case, we have an additional state variable, namely π_{t-1} . Hence, we have:

$$z_{1,t} = \begin{bmatrix} e_t \\ u_t \\ \pi_{t-1} \end{bmatrix}, z_{2,t} = \begin{bmatrix} \pi_t \\ y_t \end{bmatrix}, \varepsilon_t = \begin{bmatrix} \epsilon_{\pi_t} \\ \epsilon_{y_t} \end{bmatrix}$$

To incorporate a lagged dependent variable as an additional state variable, we use the fact that

$$\pi_{t+1} = E_t \pi_{t+1} + e_{t+1}$$

implying

$$\pi_t = \pi_t$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \gamma_f & 0 \\ 0 & 0 & 0 & \frac{1}{\sigma} & 1 \end{bmatrix} \begin{bmatrix} e_{t+1} \\ u_{t+1} \\ \pi_t \\ E_t \pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \begin{bmatrix} \rho_e & 0 & 0 & 0 & 0 \\ 0 & \rho_u & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ -1 & 0 & -\gamma_b & 1 & -\lambda_B \\ 0 & -1 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} e_t \\ u_t \\ \pi_{t-1} \\ \pi_t \\ y_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \frac{1}{\sigma} \end{bmatrix} r_t +$$

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \epsilon_{\pi,t+1} \\ \epsilon_{y,t+1} \end{bmatrix}$$

Model with Habit and Inflation Persistence

In this case, we have two additional state variables, namely y_{t-1} and π_{t-1} . Hence, we have:

$$z_{1,t} = \begin{bmatrix} e_t \\ u_t \\ y_{t-1} \\ \pi_{t-1} \end{bmatrix}, z_{2,t} = \begin{bmatrix} \pi_t \\ y_t \end{bmatrix}, \varepsilon_t = \begin{bmatrix} \epsilon_{\pi_t} \\ \epsilon_{y_t} \end{bmatrix}$$

To incorporate a lagged dependent variable as an additional state variable, we use the fact that

$$y_{t+1} = E_t y_{t+1} + u_{t+1}$$

, and

$$\pi_{t+1} = E_t \pi_{t+1} + e_{t+1}$$

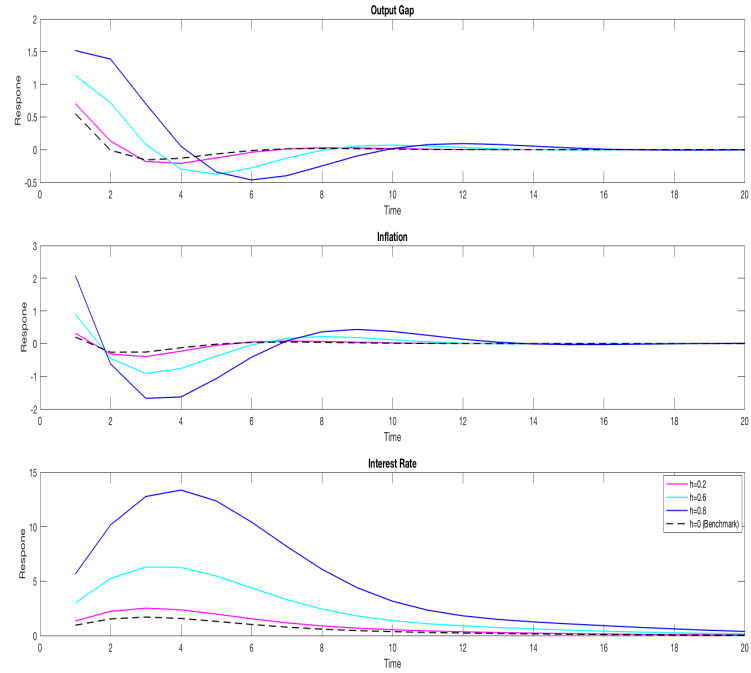
$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & \gamma_f & 0 \\ 0 & 0 & 0 & 0 & -\gamma_{10} & \gamma_9 \end{bmatrix} \begin{bmatrix} e_{t+1} \\ u_{t+1} \\ \pi_t \\ y_t \\ E_t \pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \begin{bmatrix} \rho_e & 0 & 0 & 0 & 0 & 0 \\ 0 & \rho_u & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & -\gamma_b & -\lambda_2 & 1 & -\lambda_1 \\ 0 & -1 & 0 & -\gamma_8 & 0 & 1 \end{bmatrix} \begin{bmatrix} e_t \\ u_t \\ \pi_{t-1} \\ y_{t-1} \\ \pi_t \\ y_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ -\gamma_{10} \end{bmatrix} r_t +$$

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \epsilon_{\pi,t+1} \\ \epsilon_{y,t+1} \end{bmatrix}$$

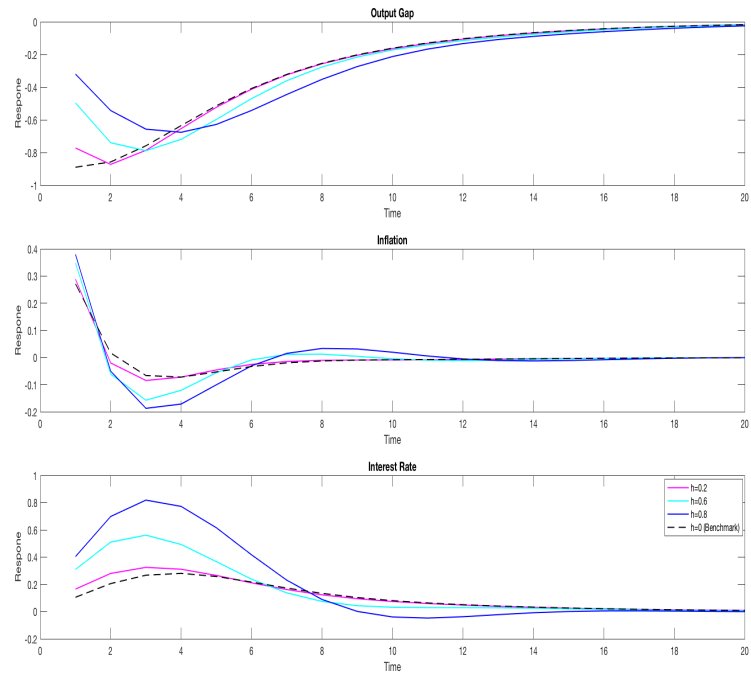
E Robustness to Calibration

This section shows the dynamics of the model under varying degrees of habit persistence and inflation persistence parameters. While calculating the worst-case model, I use the robustness parameter associated with a detection error probability of 20%.



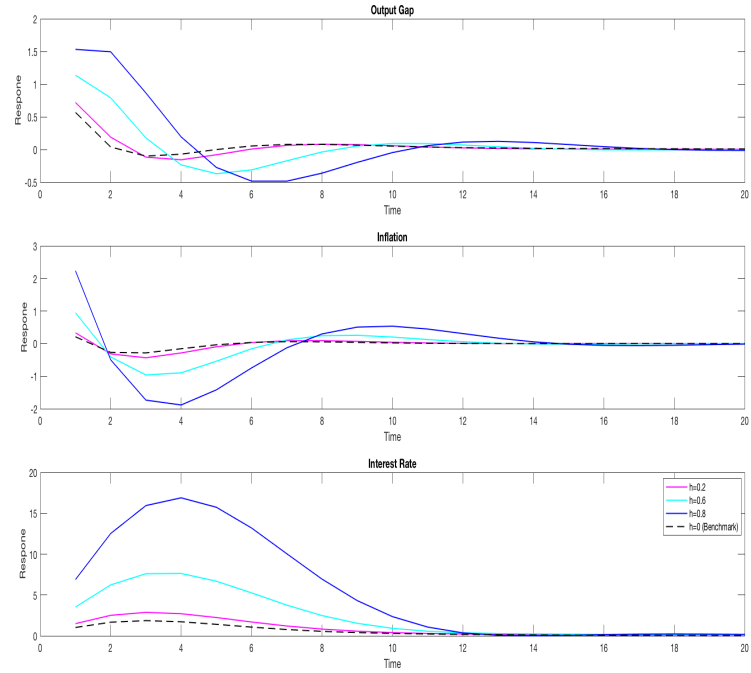


(a) Demand Shock

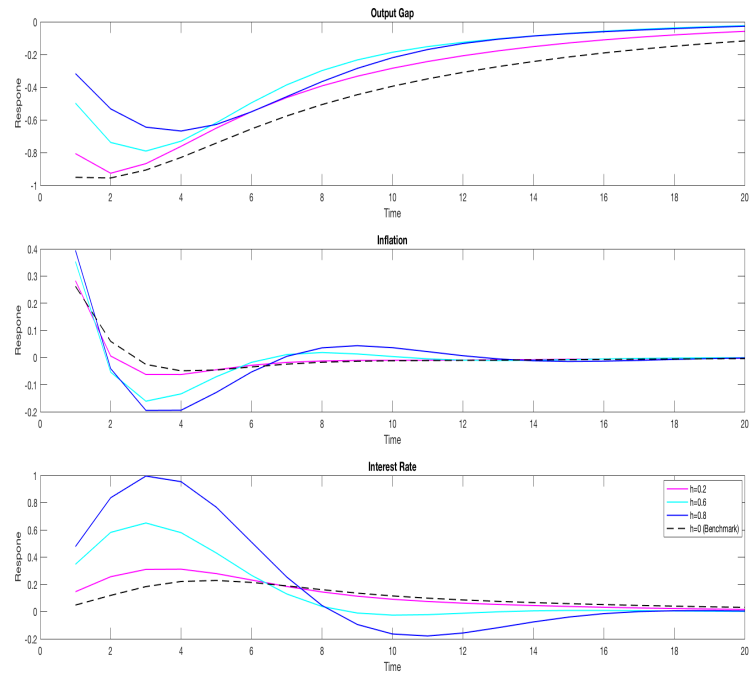


(b) Supply Shock

Figure 1: Degree of Habit Persistence Under Rational Expectations

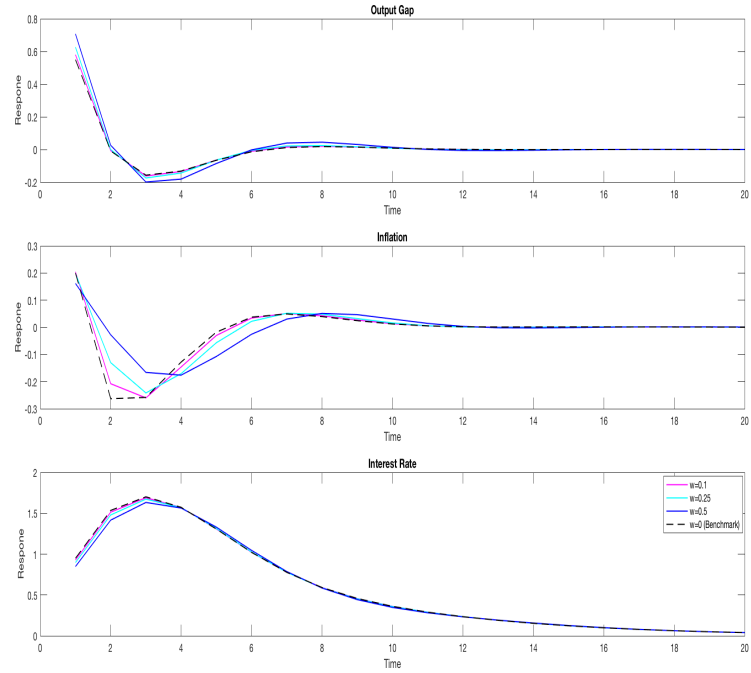


(a) Demand Shock

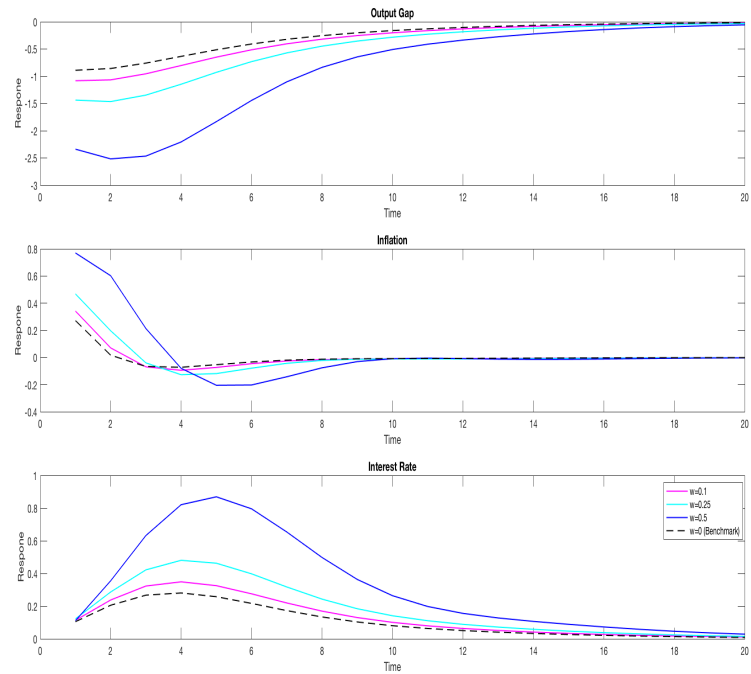


(b) Supply Shock

Figure 2: Degree of Habit Persistence Under Uncertainty

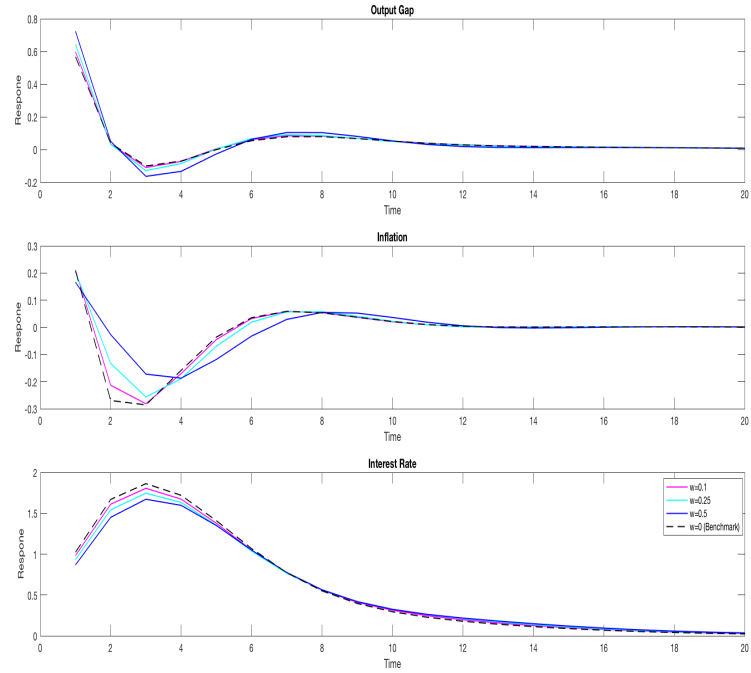


(a) Demand Shock

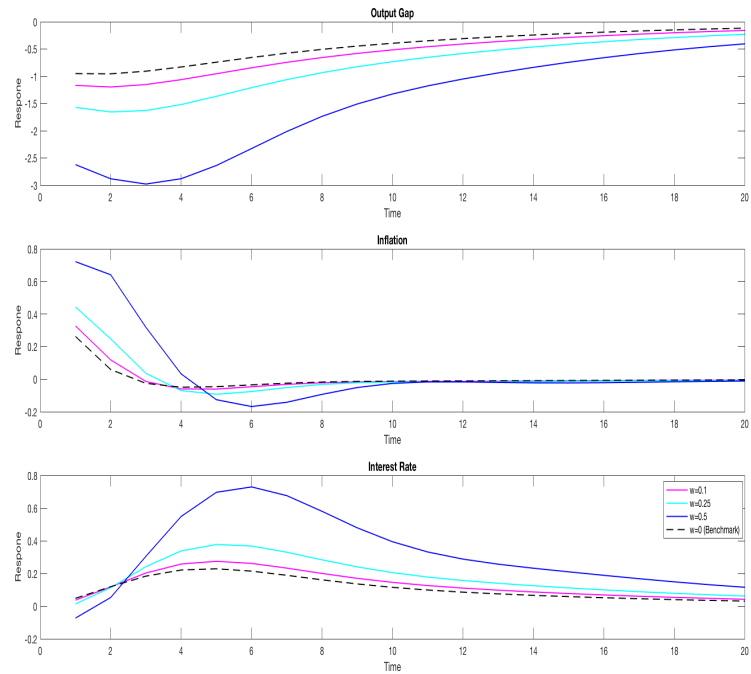


(b) Supply Shock

Figure 3: Degree of Inflation Persistence Under Rational Expectations



(a) Demand Shock



(b) Supply Shock

Figure 4: Degree of Inflation Persistence Under Model Uncertainty

F Solution Algorithms for Deterministic Switch versus Regime Switch

Following explains the solution algorithms both for piecewise linear and the regime switching approaches. Both methods are implemented using Matlab and Dynare.

Piecewise Linear Solution

The piecewise linear solution is represented two sets of linearized equations for the reference regime where the constraint does not bind (Equation (52)), and for the second regime where the constraint binds (53)).

$$A_0 z_{t+1} + A_1 z_t + A_2 z_{t-1} + A_3 \varepsilon_t = 0 \quad (52)$$

$$A_0^* z_{t+1} + A_1^* z_t + A_2^* z_{t-1} + D^* + A_3^* \varepsilon_t = 0 \quad (53)$$

where A_j , A_j^* for $j = 0, 1, 2, 3$ are system matrices, z_t is a vector of endogenous variables, ε_t is a vector of shocks, and D^* is a vector which arises since the system (53) is linearized around the steady-state in normal times, i.e. (52).

Solving the system backwards for a series of time-varying policy functions gives the following set of policy functions:

$$z_t = P_t z_{t-1} + R_t + Q_1 \varepsilon_1 \quad \text{for} \quad t = 1 \quad (54)$$

$$z_t = P_t z_{t-1} + R_t \quad \forall t \geq 2 \quad (55)$$

The algorithm of Guerrieri and Iacoviello (2015) is based on the approach of guess-and-verify. Assuming an initial value of z_0 , a shock ε_1 is realized which causes the constraint binds. Hence, one guesses that Equation (53) summarizes

the economy at time $t=1$. Accordingly, the solution for $t > 2$ is given by

$$z_t = P_t z_{t-1} Q_2 \varepsilon_2 \quad (56)$$

When there are no further expected shocks, one has $E_2 z_2 = P z_1$, implying

$$A_0^* P z_1 + A_1^* z_0 + D^* = 0 \quad (57)$$

One can obtain the decision rule for z_1 as

$$z_1 = P_1 z_0 + R_1 + Q_1 \varepsilon_1 \quad (58)$$

where $Q_1 = -(A_0^* P_2 + A_1^*)^{-1} \varepsilon$

Endogenous Regime Switch

To allow for endogenous transition probabilities, I use the methodology of Barthélemy and Marx (2017) which relies on perturbation techniques. They use functional iteration method to obtain the solution of a fix-point problem, through successive approximations of the solution.