Essays on Economic Fluctuations in an Open Economy

Jørn Inge Halvorsen

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Although I still hold on to the view that my long-standing affection with the study of economic fluctuations is mainly the result of my own inherent interest in the subject. Further, I consider that interest to be decisive for the decision I made to move to Bergen to start at the Norwegian School of Economics and Business Adminstration (NHH) on a PhD program in economics. However, after starting on the program, and then be required to encounter the subject as a researcher meant that I came along a host of new and challenging situations. Looking back now, I can clearly see that many of these situations were helped dealt with due to much of the positive influence that I endured during my PhD.

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Part I

Overview

"The theme is that, after the explosion (in both the positive and negative meaning of the word) of the field in the 1970s, there has been enormous progress and substantial convergence. For a while – too long a while – the field looked like a battlefield. Researchers split in different directions, mostly ignoring each other, or else engaging in bitter fights and controversies. Over time however, largely because facts have a way of not going away, a largely shared vision both of fluctuations and of methodology has emerged."

Blanchard (2008) in "The State of Macro".

1 Introduction

1.1 Background

Early on in the introduction of a dissertation, it is common to provide the reader with a statement about its main topic. After that a description usually follows of the methodologies involved connected to the study of the topic. If I were to make a statement about the main topic of this dissertation, I would say it contains three essays all dealing with topics central to the study of aggregate economic fluctuations in an open economy.

Although the dissertation is united by the topic described, I believe it would be more helpful to the reader to actually know that the goal I set for my dissertation was more about acquiring good knowledge of some of the basic tools used in modern macroeconomics. In my opinion, a fruitful way of accomplishing this would be to apply some of the different tools on topics that are central within today's modern research program for the study of aggregate economic fluctuations in an open economy.

For the context described, one might be interested to know, compared to earlier influential directions, what are the real benefits of using a modern research program for the study of economic fluctuations. To be able to see such benefits clearly seems to rely very much on a willingness to adopt positivistic view on macroeconomics as a social science. In large, such a view is held by many macroeconomists who constantly refer to macroeconomics as a field that over time has *progressed* due to important improvements in its theoretical foundation and econometric methodology. Such improvements have been made possible largely due to the development over time of new mathematical and numerical methodologies.[1]

In assessing the present situation, numerous influential researchers, as affirmed in Blanchard (2008), Woodford (2008) and Chari, Kehoe, and McGrattan (2008), have taken the view that macroeconomics as a field has largely converged on the use of its methodology.[2] Within the methodolog-

[1]For an early discussion of the use of mathematical and numerical methodologies in macroeconomics, see Lucas (1980).

[2]The articles are all published in the first issue of American Economic Journal: Macroeconomics (2009), devoted especially to the topic convergence in macro.

ical framework, Woodford (2008) describes the current empirical research program on economic fluctuations to be about *"develop empirically validated quantitative models that can sensibly be used in counterfactual policy analysis."* For the implementation of such a research program, a set of complementary tools are involved. It is possible to distinguish the tools between those used for structural modeling and those used for empirical validation. For structural modeling, dynamic macroeconomic models (commonly referred to as dynamic stochastic general equilibrium (DSGE) models) are used. Given a structural model, empirical validation is done by using empirical tools (based on a minimal set of prior restrictions about the economy) to form facts which the structural model is expected to explain.

It is within such a research program, on issues mainly related to an open economy, that I have found it compelling to base my research. Before I give a summary of how the essays included here can be regarded to have contributed to such a research program, it is perhaps wise to first take a step back. More specifically, what I offer in the next section is an historical outline on how the shared vision on economic fluctuations, macroeconomic methodology and view on monetary policy, that is present in the current research program, came about. After the outline, I emphasize, within the program, three areas where major disagreement exists. The three areas form a natural backdrop for the summary of the essays given in the final section, since each essay seeks to make a specific contribution to a particular area of disagreement.

1.2 Convergence in vision and methodology

1.2.1 The Neo-Keynesian and Monetarist schools

In the 1960s and the early 1970s, macroeconomics as a field was divided mainly between the Neo-Keynesian (NK) and the Monetarist schools. Both schools, however, shared the view that interrupted changes in aggregate demand for goods could have a substantial effect on output and employment. The result was thought of as due to the presence of nominal rigidities which prevented self-equilibrating mechanisms, at least in the short run, of the economy to work. The disagreements were about the main causes for interrupted changes in aggregate demand. The NKs claimed that to a great extent such changes could be accounted for by disturbances in the form of erratic changes in agents' confidence, such as investors' "animal spirit". For the Monetarists, the disturbances could mainly be contributed to irregular changes in the money supply. In a theoretical Hicksian IS-LM model framework, the differences between the two schools could be illustrated by differences in interest elasticity between the IS-curve and the LM-curve.

On theories related to the open economy aspect of an economy, the overshooting hypothesis presented in Dornbusch (1976) was quickly accepted by many macroeconomists, and soon became a central building block in international macroeconomics. The central assumption here was the view that in the short run goods prices were sticky while financial variables, such as the exchange rate, could react instantaneously to other variables. This made it possible, within the theoretical framework provided by the the Neo-Keynesian (NK) and the Monetarist schools, to show that the nominal exchange rate could follow an unexpected increase in the interest rate by overshooting its long run equilibrium level.

In their attempts to use econometric tools in order to validate their theoretical ideas, the NK and the Monetarist schools opted for fundamentally different approaches. The NKs based their methodology on a probability approach to econometrics. Within such an enterprize, the aim was to develop large macro econometric models in order to provide an accurate description of the short run dynamics of the economic system. The models were founded on an equation-by-equation estimation approach, based somewhat loosely on economic theory, of the behavioral equations of the economy (e.g. consumption function, money demand, Philips curve etc.). The Monetarists in large found such an enterprize too ambitious, insisting that it was unlikely that the short run dynamics of a complex economic system could be given a reliable description within such a methodology. Instead, the Monetarists took a freer econometric approach by their use of short run and long run co-movements of aggregate time series in order to validate their narrative theory. [3]

The NK and the Monetarist schools used their positive theories together with empirical validation by means of offering normative policy advice. For the NKs this meant that they could regard their estimated econometric models as an acceptable place to start in order to evaluate the effect of monetary policy. For the Monetarists, their view of the complexity of the dynamics of the economic system combined with the strong long run empirical evi-

[3]Such form of empirical verification forms the basis of empirical evidence in Friedman and Schwartz (1963) "A Monetary History of the United States, 1867-1960".

dence for the quantity theory of money (see Friedman (1987)) let them hold on to Friedman (1960)'s main policy advice; namely that stabilization of economic fluctuations in practice would best be served by adopting a fixed percent growth rule for the money supply.

1.2.2 The New Classical school and Real Business Cycle Theory

The introduction in the 1970s and the early 1980s of the New Classical (NC) school and the real business cycle (RBC) theory led many macroeconomists to change their views on how to analyze economic fluctuations. For both directions, a microeconomic founded DSGE framework with a set of rigorous assumptions about the structure of the economy was deployed. The two most striking assumptions were the view of instantaneous market clearing, and, on the part of the agents in economy, endogenous expectations in line with the rational expectation hypothesis advocated in Muth (1961). The set of rigorous assumptions for the NC school implied, as shown in Lucas (1972), that only the unexpected part of the changes in money supply to have short run effects on real variables. In the RBC theory, money and other imperfections were left out of the model, making the equilibrating process of the model economy simply an optimal response to stochastic technology shocks.

The NC school spent little effort in trying to empirically validate their models, pointing rather to its theoretical coherence as a sign of strength. For the RBC theory, the calibration exercise within a DSGE framework was put forward as a new empirical tool. Calibration itself made it possible to use DSGE models to simulate the data generating process of the model economy, and as such was able to make theoretical models the centerpiece of empirical analysis. Kydland and Prescott (1996) argued that "matching moments" between the simulated and actual data was the right way to go, since theoretical business cycle models must be considered to be highly abstract and consequently would be rejected in a classical probability approach setting. In their pioneering work, Kydland and Prescott (1982) empirically validated their RBC model by pointing to the high degree of fit between the correlations from the simulated model and stylized facts of business cycles quarterly data from the postwar U.S. economy. The empirical validation of the RBC theory proved, however, in Backus, Kehoe, and Kydland (1992) to be much less successful for an open economy. In particular, strong discrepancies were found for output which in the data were more highly correlated across countries than consumption, while the business cycle model predicted the opposite.

The modeling approach of the NC school and the RBC theory implicitly implied critique, both in their approach to empirical validation and to their normative policy advice, of the NK and the Monetarist schools. For empirical validation, modeling rational expectations made it possible for Lucas (1976) to show that the NK estimation of behavior equation and Monetarist use of co-movements of aggregate time series in general would be incorrect since the coefficients on these equations would be variant to policy change. Apart from this, Sims (1980) provided his own critique of NK estimation methodology, arguing that unreasonable restrictions on a behavior equation could imply more unreasonable behavior implications for the system as a whole. Due to this, reliable information from an economic system should be obtained by simultaneous estimation by the use of a vector autoregressive (VAR) model.

On the position on how to conduct monetary policy, the NC school offered few clues since in their framework only the unexpected policy errors and unforeseen changes in policy were able to influence real output. The RBC theory argued that fluctuations in output to a great extent reflected an economy's optimal response that could be interpreted as a critique that earlier schools were mixing cycles with trends.

After the introduction of the NC school and the RBC theory, macroeconomists from different traditions of economic thoughts engaged themselves for a long period in bitter and stalled debates. A way to understand why this situation became so tense, is to look at the different theories I have outlined in light of the two positivistic principles used in Blanchard (2008) as determinants for the evolution of macroeconomics: (1) Facts have a way of forcing irrelevant theory out. (2) Good theory also has a way of eventually forcing bad theory out. At this point in time, the theories outlined could arguably be weakened by *one* of the two principles. On the one hand, the observed fact, which seems to have initiated the study of economic fluctuations as a field, namely the substantial effect changes in aggregate demand could have on output seemed much stronger than an economy based on the assumption of competitive markets as the NC school and the RBC theory would suggest. On the other hand, the NC school and the RBC theory offered a much stronger theoretical framework than the Neo-Keynesian (NK) and the Monetarist schools.

1.2.3 The New Neoclassical synthesis

In the last decade the development of a new class of DSGE models, referred to on many occasions as New Neoclassical Synthesis (NNS) models, have taken center stage in the study of economic fluctuations. The models seek to merge important elements from the previously outlined directions of economic thought. In the most basic version of an NNS model, the so-called New Keynesian model, imperfect competition and nominal rigidities are integrated into a intertemporal general equilibrium framework with rational expectations and technology shocks. The model offers many of the basic features that macroeconomists today seem to share. Namely that economic fluctuations can be caused by both changes in technology and monetary policy and that agents' expectations about the future could influence their present behavior.

For the empirical validation of the NNS models, the type of VAR model advocated in Sims (1980) has become the prime source of empirical evidence. The validation consists of comparing impulse response functions of an identified VAR (Structural (SVAR)) model with that of the model economy. Compared to the calibration approach advocated in Kydland and Prescott (1996), the SVAR approach has the advantage that the information from the impulse response functions will be based on the conditional correlations of the structural shocks rather than the unconditional correlations when using "matching moments". In the literature such an approach has been quite successful (see for instance Gali (1999) and Christiano, Eichenbaum, and

Evans (1999a)) in providing empirical support for NNS models; particulary for the closed economy version of the New Keynesian model.

In principle, the use of NNS models makes it easy for researchers to deliver policy advice. The reason is that the model's microeconomic foundation implies that optimal policy can be derived directly from the preferences from the private agents in the economy. Such a utility based approach has been extensively used in the analysis of monetary policy. As shown in Woodford (2003a), a general result is that the stabilization of goals which the agents find desirable can best be achieved if the central bank commit itself to a monetary policy rule. The gains from a commitment to a policy rule lies in the fact, as first stressed in Kydland and Prescott (1977), that it can be used to successfully steer the private sector's expectations. In the New Keynesian model (both in in its closed and under particular parameter values the small open economy version) the optimal monetary policy rule takes on a particularly simple form, since an interest rate rule with only domestic inflation targeting is shown to be able to close the welfare relevant output gap of the model (see e.g. Blanchard and Gali (2005) and Gali and Monacelli (2005)).

The rule-based monetary policy advice from the NNS models is in sharp contrast with NC school and the RBC-theory lack of advice. Viewed in comparison to the NK and the Monetarist schools, the NNS is different from the discretionary policy advice from the NK school while reminiscent of the monetarist's advice of a rule based fixed percentage growth rate in the money supply. However, for the NNS models, the rule can be explicitly derived from the model itself. Maybe as a result of this, the models have been a force in influencing central banks around the world, where in the last decade it has become common to adopt some type of an inflation-targeting regime.

1.3 Some of today's disagreements about vision and implementation of methodology

Although many macroeconomists today have accepted the NNS framework as a proper place to conduct further research; there are within the research program considerable disagreements related to specific features about its vision on fluctuations and on the appropriate use of its methodology. Since it is of specific interest for the essays included here, three areas of disagreements are now highlighted. Namely, what types of imperfections should be included in a standard NNS model, how should its open economy features be specified and caveats related to the use of SVAR as a tool to discriminate among competing models.

1.3.1 What types of imperfections to include?

On the issue of what types of imperfections to include, disagreements among macroeconomists can be related to the following question: Beyond the use of nominal rigidities and imperfect competition, what other types of imperfections matters in macro so that they deserve to be included in an standard NNS model?

In practice, the most noticeable differences on the approach to the issue seems today to be found between macroeconomists involved in practical policymaking at central banks and those working in academic institutions.[4] For macroeconomists at central banks, state-of-the-art DSGE models (based on a Bayesian estimation) with numerous imperfections (e.g. habit formation, backward indexation of prices and convex costs of changing investments) and many loosely defined structural shocks (e.g. shock to wage markups, price markups, exogenous spending and risk premium) are typically employed.[5] As shown for instance in Smets and Wouters (2007) and Christiano, Eichenbaum, and Evans (2005b), the inclusion of many imperfections and structural shocks is able to make such DSGE models fit the data very well.

It is important, though, to be aware of that data fitting itself by no means provides independent support for making a model useful for policy analysis. Provided that some of the imperfections and structural shocks included in the model are based on parameters with weak or no empirical support (i.e. free parameters), they will be open to the same criticism as put forward in Lucas (1976). As emphasized in Chari, Kehoe, and McGrattan (2008), the parameters and shocks of a DSGE model can only be regarded to be structural if they are invariant to policy change.

In essay 3 of the dissertation it is demonstrated that such type of criticism is relevant for the case of the exchange rate risk premium. Many open

[4]The source of the disagreements may not be so much due to fundamental differences in theoretical views, but rather something that has sprung out as a response to accommodate different needs: Works intended for the academic community typically requires a sound theoretical base. Consequently, the type of imperfections used need strong backing from microeconomic facts. For works used in the analysis of applied problems, the requirements are more about achieving results judged to be reasonable among policymakers.

[5]For instance the model used in Smets and Wouters (2007) contains 19 structural parameters and 17 parameters corresponding to the variances and the first order autocorrelation coefficients of the underlying shock processes.

economy DSGE models have today obtained empirically plausible results for the low degree of risk sharing among countries by modeling the risk premium as an exogenous stochastic process. However, when making the risk premium endogenous in a DSGE model, it is demonstrated here that such a variable is not invariant to monetary policy changes, and actually has a positive impact in enhancing the utility for the representative agent of a small open economy.

1.3.2 Open economy features of the New Keynesian model

The New Keynesian model offers many of the basic features that macroeconomists today seem to share regarding the closed economy. The theories are further strengthened by the empirical evidence that can be obtained from the use of a SVAR. For the open economy, though, such agreement is harder to come about. Specifically, the difficulties are related to the issue about the exchange rate response of monetary policy and on how should monetary policy operate in an open economy.

For the first issue, many SVAR studies have difficulties in finding empirical support for the traditional Dornbusch's overshooting hypothesis (see for e.g. Uhlig and Scholl (2005) and Faust and Rogers (2003)).[6] The lack of empirical support seems, as pointed out in Bjørnland (2006), to have been transmitted into uncertainty on how the exchange rate response to monetary policy should be specified, with researchers suggesting that theoretical models should be specified with delayed overshooting impact similar to what

[6] For SVAR studies exceptions are to be found in Bjørnland (2006, 2008) while Zettelmeyer (2004) and Kearns and Manners (2006) find such support for event studies.

is observed in many SVAR studies.

On the second issue on how monetary policy should operate in an open economy, many macroeconomists seem to share the view for the need also here of a monetary policy rule with an explicit inflation target. Though, there is little consensus about whether the exchange rate should also be included in such a rule and, if yes, how much of a interest rate response.[7] Even if the exchange rate is not included, it is shown in Taylor (2001) that the exchange rate in a monetary policy rule could lend itself to a strong *indirect* effect on the interest rate. Such indirect effect can be the consequence of a monetary policy rule based on forecasts on future variables or with a rational expectation model for the term term structure of the interest rate. In both cases, inertia in the monetary transmission mechanism (i.e. unexpected exchange rate movements work with a lag on inflation and output) will make the interest rate respond to exchange rate movements through the effect this variable has on the expectations of future output and inflation.

In essay 2 of the dissertation, the two issues discusses above are analyzed by the use of a SVAR for six open economies. By identifying the SVAR so that contemporaneous interdependence between monetary policy and the exchange rate is allowed for, the papers provides empirical support for the conventional overshooting hypothesis in all countries. Furthermore, the exchange rate seems to had a strong impact for monetary policy makers when setting interest rate.

[7] For some different views on this issue, see for instance Ball (1999), Svensson (2000), Clarida, Gali, and Gertler (2001) and Paoli (2007).

1.3.3 The ability of a SVAR model to provide empirical evidence

Though SVAR today has become the primary tool for discriminating among competing DSGE models, the ability of a SVAR model to provide such evidence has recently been questioned in a number of papers. The disagreements are primarily linked to the issue of whether an estimated VAR is able to reflect the reduced form dynamics of an economic system and the usefulness of the various identification schemes used in identifying a VAR.

On its ability to reflect the reduced form dynamics, Fernandez-Villaverde, Rubio-Ramirez, and Sargent (2005) show that a DSGE model will lend itself to a VAR representation only under specific conditions. In addition, even if this is satisfied, the VAR representation of a DSGE model may require an infinite number of lags which necessarily must be truncated by an estimated VAR based on a limited number of data.[8] According to Ravenna (2006), truncation can cause large errors due to estimation bias which can be further increased by the imposition of an identification scheme, even though the latter is based on correct identifying restrictions.

Regarding the identification schemes themselves, they are usually based on restrictions in the form of (contemporaneous) short run, long run (neutrality) or sign restrictions of the dynamic impact the structural shocks have on the model's variables. On the use of short run restrictions, many macroeconomists have argued that they are problematic since economic theory in general will have difficulties in justifying enough restrictions. According

[8] This case will arise when the true system follows a finite order VAR of n variables which is estimated by a VAR with $m < n$ variables.

to Faust and Leeper (1997) and Chari, Kehoe, and McGrattan (2007), a scheme based on long run neutrality restrictions will not hold exact since a VAR model will only be able to perform an approximate estimation of the economic system. For sign restrictions the problem is, as shown in Fry and Pagan (2005) and Paustian (2007a), linked to the fact that the weakness of information contained in such restrictions will make identification non-unique and as consequently inaccurate if not enough restrictions are enforced.

In essay 1 of the dissertation the problems with the various identification schemes are discussed and sought to be improved on. Specifically, the paper develops an identification scheme that combines the use of short run and sign restriction and argues for why it has the ability to mitigate the main problems associated with the identification scheme frequently used to identify a VAR.

1.3.4 Benefits of further progress

In light of the disagreements present in the NNS framework, a positivistic view can be taken relying on that further research will continue to generate improvements in both methodology and theoretical foundation with the positive implication of bridging the gap various areas of disagreements. In general, this could easily be transferred into better policies since the microfounded approach of the NNS models implies that less disagreements about its specification will automatically be transferred into less uncertainty when it comes to policy analysis.

For monetary policy, such a process could be of great importance for the practical implementation of a rule based monetary policy. This is due to that the full gain from commitment to a policy rule, as shown in Woodford (2003a), only will come about if the central bank is clear about its policy and the limits of its knowledge. With improved and more certain knowledge, a monetary policy could become more robust since optimal policy response can be articulated for more contingencies that an economy might face In the future, there is perhaps hope that this could make practical monetary policy more of a science and less of an art.[9]

1.4 Summmary

1.4.1 Essay 1: Combining short term and sign restrictions to identify a VAR. A useful approach

The purpose of the essay is to suggest the use of an identification scheme that will make it easier for a researcher to achieve reliable identification of a VAR model.

Usually, the identification of a VAR model is achieved by imposing a set of prior restrictions on an identification scheme. The set of prior restrictions is justified based on prior information reflecting the researcher's strong belief about the working of the economy, and often takes the form of either (contemporaneous) short run, long run (neutrality) or sign restrictions. However, such schemes have often been criticized either on the grounds that they are unreasonable or not numerous enough to achieve proper identification

In this paper, an identification scheme that combines the use of short run

[9]See Blanchard (2006) for an discussion of this issue.

and sign restrictions is developed, and it is argued for why such a scheme has the ability to mitigate the main problems associated with the identification scheme frequently used to identify a VAR.

1.4.2 Essay 2: How does monetary policy respond to exchange rate movements? New international evidence

With Hilde C. Bjørnland

The purpose of the essay is to analyze the interaction between monetary policy and the exchange rate for six open economies (Australia, Canada, New Zealand, Norway, Sweden and the UK), focusing in particular on how monetary policy has responded to exchange rate movements.

The analysis is carried out using a structural vector autoregressive (VAR) model that is identified using a combination of sign and short-run (zero) restrictions. Such restrictions have the ability to preserve the endogenous interaction between the interest rate and the exchange rate commonly observed in the market.

In all countries, the results suggest that the interest rate increases systematically in response to a shock that depreciates the exchange rate. Furthermore, we find the impact of monetary policy shocks on exchange rates to be non-trivial. In particular, following a contractionary monetary policy shock, the exchange rate appreciates on impact. The exchange rate then gradually depreciates back to baseline, broadly consistent with UIP. These results are in contrast to the results that have been found previously in the literature using recursive restrictions, or, pure sign restrictions, to identify the structural VARs.

1.4.3 Essay 3: Monetary Policy, Risk Premium and Portfolio Holdings in a Small Open Economy

With Michal Zdenek

The purpose of the essay is to make the risk premium and portfolio holdings endogenous in a New Keynesian dynamic general equilibrium model for an small open economy (SOE) and investigate the impact of monetary policy.

Two results stand out from our analysis: First, the risk premium serves as an allocative efficiency role since it provides clearing for the markets for nominal bonds which is used by the agents in order to provide hedging against consumption risk. Second, monetary policy improves a SOE's portfolio selection opportunities by adopting a policy of strict domestic inflation targeting.

Our main results are of interest since they contradict the commonly used policy argument that nominal exchange rate uncertainty and the risk premium have a negative impact on a country's welfare. Furthermore, the results question the validity of the approach of modeling the risk premium as an exogenous stochastic process as is commonly done in New Keynesian or NNS DSGE models.

Part II

Essays

2

Essay 1: Combining Short Term and Sign Restrictions to Identify a VAR. A Useful Approach

Abstract

Structural VAR models are an important tool in the analysis of economic fluctuations. Once identified, the VAR model can provide information of the dynamic quantitative impact that structural shocks have on economic variables. However, the identification schemes used to identify a VAR have recently been criticized either on the grounds that they are unreasonable, or not numerous enough to achieve proper identification. In this paper, I develop an identification scheme that combines the use of short run and sign restrictions and argue for why such a scheme may make it easier for a researcher to achieve identification. [1]

[1] I am grateful to Hilde C. Bjørnland, Gernot Doppelhofer, Dag Henning Jacobsen and conference participants at Conference on Computing in Economics and Finance (CEF) in Paris (2008) for constructive comments.

2.1 Introduction

Much of the analysis of economic fluctuations today focuses on the development of empirically validated dynamic quantitative general equilibrium models. Within such a research program, a goal is to build structural dynamic stochastic general equilibrium (DSGE) models that are able to match moments in data. The moments may be correlation, standard deviation or impulse response functions. In such a context, information from the estimation of a vector autoregressive (VAR) model (where all variables are treated as endogenous) is considered useful since the estimated VAR model has the ability to reflect the complex equilibrium dynamics observed in a structural model.

A necessary requirement for the empirical validation is that the impulse response functions are derived from an identified VAR model. For this to be the case the VAR model must be converted from its reduced form representation to its structural VAR (SVAR) representation; thereby making impulse response functions measure the impact of the structural shocks of the economy. The information from the impulse response functions of the structural shocks is useful since it can be used as a selection criteria to choose among competing DSGE models, or for the estimation of a particular DSGE model's structural parameters.[2]

Usually, the identification of a VAR model is achieved by imposing a set of prior restrictions on an identification scheme. The set of prior restrictions

[2] Well known examples of verifying competing traditions of economic macroeconomic thought, which have stirred a lot of debate, are the inquiry in Gali (1999) of the response to hours from a technology shock and Christiano, Eichenbaum, and Evans (2005b) of the response to real variables from a monetary policy shock.

is justified based on prior information reflecting the researcher's strong belief about the working of the economy, and often takes the form of either (contemporaneous) short run, long run (neutrality) or sign restrictions.

However, although useful, each of these schemes is also problematic in its own right. The use of only short run restrictions may be problematic since economic theory in general could have a hard time justifying enough restrictions. A scheme based on long run neutrality restrictions will, according to Faust and Leeper (1997) and Chari, Kehoe, and McGrattan (2007), not hold exact since a VAR will only be able to perform an approximate estimation of the economic system. The latest identification scheme, based on the use of sign restrictions, has been criticized by Fry and Pagan (2005) and Paustian (2007a) on the grounds that the weakness of information contained in such restrictions will make identification non-unique and consequently inaccurate if not enough restrictions are enforced.

For this paper, I suggest an identification scheme that for many applications may make it easier for a researcher to achieve reliable identification of a VAR model. In particular, I develop an identification scheme that combines the use of short run and sign restrictions and argue that such a scheme will mitigate the main problems associated with the identification schemes frequently used to identify a VAR. The arguments are related to that such identification schemes will have the ability to incorporate all the types of prior information used in the earlier schemes. Such a property could be useful since it might be the case that a researcher has prior information of many types considered to be reliable. If this is the case, it will address the main problems associated with earlier schemes. The reason is linked to the fact that with other types of reliable prior information enforced, fewer short run restrictions and less numerous sign restrictions will be needed in order to achieve proper identification.

The three applications in the paper serve the purpose of illustrating the usefulness of the identification scheme. In the first application, I look at how a monetary policy shock and an exchange rate shock can be identified in a small open economy model. The prior view held is that both shocks have delayed effect on real variables, but immediate effect on the interest rate and the exchange rate. In the second application, a bank lending shock is identified. The prior view here is that this shock will have a positive immediate impact on real variables but not on inflation. For the final application I identify technology shock in Gali (1999). The prior view held is that the effect of technology shock on the level of productivity in the long run will be strong but inaccurately estimated.

The paper is organized as follows: In section 2.2, the main problems associated to the identification schemes commonly used to identify a VAR are reviewed. Section 2.3 develops and argues under which conditions an identification scheme that combines the use of short run and sign restrictions could be beneficial. Section 2.4 illustrates the use of such an identification based on two illustrative examples. Section 2.5 concludes.

2.2 Common approaches to the identification of a VAR

The earliest approach to identify a VAR, as used in Sims (1980), imposed on the identification scheme short run prior restrictions in a recursive form. The restrictions can be thought of as reflecting the contemporaneous relationship between the structural shocks and the variables in the VAR model. Later, it became popular to replace short run restrictions with long run neutrality restrictions. More recently, an identification approach known as sign restrictions, which is based on restricting the shape of the impulse response functions on the structural shocks, is widely being used.

In conjunction to the identification schemes mentioned, a great deal of criticisms have been raised over the years; each for its own particular reason. A major point in this paper is to argue that the criticisms for many applications can be mitigated if the researcher uses an identification scheme that combines the use of short run and sign restrictions. Before carrying out such an argument, I find it appropriate to start with setting up a general VAR and to review the main problems associated with the identification schemes commonly adopted in the literature.

2.2.1 The general VAR set up

The VAR model in matrix form (for simplicity ignoring any deterministic terms) can be expressed as

$$A(L)X_t = e_t, \text{ with } \Sigma_e = E(e_t e_t'), \tag{2.1}$$

where $A(L)$ is a (mxm) matrix polynomial in the lag operator L, $A(L) = \sum_{i=0}^{p} A_i L^i$ with $A_0 = I_m$. X_t is a $(mx1)$ vector of endogenous variables. e_t is the one step ahead prediction error which is assumed to be normally distributed with mean zero and a positive semidefinite covariance matrix Σ_e.

Given that $A(L)$ is invertible, the VAR model can be written in terms of its moving average (MA) representation:

$$X_t = B(L)e_t, \text{ with } B(L) = A(L)^{-1} \tag{2.2}$$

In the literature, the standard assumption is that the model contains m structural shocks ε_t which are uncorrelated to each other and related linearly to e_t.[3] If we normalize the structural shocks to have unit variance, we can write this relationship as

$$e_t = C\varepsilon_t, \text{ with } I_m = E(\varepsilon_t \varepsilon_t'). \tag{2.3}$$

The MA representation of the model can now be written in terms of its structural shocks as

$$X_t = D(L)\varepsilon_t, \tag{2.4}$$

where $D(L) = B(L)C$. This representation is the one we need in order to study the dynamic impact of structural shocks on the model's variables (e.g. in the form of impulse responses or variance decomposition). $B(L)$ can by found by the ordinary least square estimation of $A(L)$. However, for C

[3] The violation of this assumption, as shown in Cooly and Dwyer (1998), implies specification error that can can lead to very poor estimate of the impulse response functions.

the only restrictions used so far come from equation (2.1) and (2.3) which implies that

$$\Sigma_e = E(e_t e_t') = AE(\varepsilon_t \varepsilon_t')C' = CC'. \tag{2.5}$$

Since there are many different decompositions satisfying $CC' = \sum_e$, we do not have an unique MA representation in terms of the structural shocks. However, for two different decompositions, $\Sigma_e = CC'$ and $\Sigma_e = \tilde{C}\tilde{C}'$, it must be the case that $C = \tilde{C}Q$ with Q being an orthogonal matrix, i.e. $QQ' = I_m$. A property of this type of a matrix is that the columns $Q = [q_1, ..., q_m]$ are orthonormal which tells us that its vectors are mutually perpendicular, i.e. $< q_i, q_j >= 0$ for $i \neq j$, and of unit length, i.e. $||q_i||$=1. The setting represents the vantage point from which the standard identification schemes in the literature have developed.

2.2.2 Identification using short run restrictions

The identification scheme most commonly adopted is the one put forward in Sims (1980). In this scheme the prior restrictions are of a contemporaneous nature, restricting the short run interdependence among the variables in the system.[4] Such restrictions usually seek their justifications from informal reasoning. For instance, it is often claimed that monetary policy variables (as in Gali (1992)) will react contemporaneously to news in real variables, while it may take some time for monetary policy news to impact the real variables in the economy. The latter is due to the belief that unexpected changes in monetary policy must first work its way through the financial

[4]What is meant by short run will in practical applications be determined by the frequency of the data used in the estimation of the VAR model.

sector of the economy before being able to have any substantial impact on the real part of the economy.

To implement the identification scheme, the variables in X_t can be cast in a recursive contemporaneous order of determination. Technically, it implies selecting $\tilde{C} = C^c$ (i.e. the lower triangular matrix of the Cholesky decomposition) and $Q = I_m$. The identification scheme will now restrict the structural shocks in such a way so that the structural shock associated with the first variable is able to have an immediate impact on all the variables in the system, while the structural shock associated with the nth variable is only able to have a contemporaneous effect on the last n to m variables in the system. In total, in order to identify all the structural shocks of the model, the researcher must select $m(m-1)/2$ short run prior restrictions corresponding to the zero elements in the non-triangular part of C^c. For many cases, the need to identify all the structural shocks of the system may not be necessary . If this is the case, one can get away with the use of fewer zero restrictions since the identification of the n-th shock of the system will be invariant to the restrictions enforced on the first 1 to (n-1) variables in the system (see proposition 4.1 in Christiano, Eichenbaum, and Evans (1999b)).

An advantage of the identification scheme is that it has the ability to uniquely identify the structural shocks. However, it seems that for many applications it has been difficult to come up with sufficient reasonable justifications to uniquely identify the structural shocks. Cooley and Leroy (1985) demonstrate this point, arguing that contemporaneous prior information is hardly obtainable from general equilibrium models. Imposing wrong prior restrictions has the consequence that the SVAR model becomes misspecified. Canova and Pina (2003) show that wrong short run prior restrictions are able to substantially bias the results of the economy it seeks to identify.

2.2.3 Identification using long run restrictions

Another identification scheme commonly used is the one first put forward in Blanchard and Quah (1989). For this scheme, the prior information take the form of long run neutrality restrictions; restricting the long run impact the structural shocks have on the variables in the system. In comparison with short run restriction, such neutrality restrictions will for many cases be stronger grounded. This is because competing theoretical models in business cycle literature often share the same long run features. For instance, Blanchard and Quah (1989) identify demand shock on the grounds that it has no long run effect on the level of production. In Gali (1999), technology shock is identified on the grounds that it is the only shock that can have a permanent effect on the level of measured labor productivity.

In a similar vein to using short run restrictions, the recursive ordering of the variables will determine which structural shocks that will have a long run neutrality impact on the variables in the system. Consequently, when applying this identification scheme $m(m-1)/2$ zero restrictions in a triangular form must also be enforced in order to identify all the structural shocks in the system.[5] In this case, however, the restrictions must be enforced on the long run multipliers of $B(1)C$.

Even if the neutrality restrictions are well grounded, Faust and Leeper

[5] Also for this identification scheme, the identification of the n-th structural shocks will be invariant to the ordering of the earlier variables. As such, fewer long run restrictions need to be enforced if not all structural shocks are in need of identification.

(1997) and Chari, Kehoe, and McGrattan (2007) show that such an identification scheme could be problematic. The problem is linked to the fact that the long-run effect of structural shocks in general will be imprecisely estimated in finite samples. The imprecision occurs when the VAR model estimated is truncated so that the number of lags it has is lower than the true data generating process. Even though the estimated VAR model has the same number of lags as the true data generating process, the finite sample property of the time series data will, as Faust and Leeper (1997) argue, imply imprecise results since the estimation of $B(1)$ will not be exact. The problem will be especially severe if the sample size is small relative to the lag order of the true VAR model. Imprecise estimation of $B(1)$ is problematic since, by the imposition of the long run restrictions, the imprecision will be transferred into the estimate of the other parameters in the model making the estimation of the dynamic impact of structural shocks biased.

Though it would have no impact on solving the problem just raised, Gali (1992) shows that it is also possible to use an identification scheme that combines short run and long run restrictions. Technically, in order to identify all the structural shocks of the system it amounts to imposing together $m(m-1)/2$ prior restrictions on $B(1)C = 1$ and C. Potentially, given that the problems with using long run restrictions were not present, such a scheme could be beneficial since it makes prior information in the form of both short run and long run restrictions available.

2.2.4 Identification using sign restrictions

A more recent methodological innovation for identifying structural shocks in a VAR is the imposition of sign restrictions. The method was first put forward in Canova and de Nicolo (2002), Uhlig (2005) and Faust (1998), analyzing different questions. However, although the set up was different, they all amount to the same basic idea, namely, seek identification by restricting the shape of the impulse response functions.

Numerical methods are used to implement the method. The basic idea is to make candidate draws for C in order to compute the corresponding impulse response functions. Based on the draws from the computed impulse response functions, the impulse responses that satisfy the prior sign restriction are kept while the others are discarded. Technically, candidate draws for C can be collected by setting $\tilde{C} = C^c$ and to make draws based on a numerical process so that the orthogonal space for Q is searched in a systematic way.

A clear advantage of this approach, compared to the other identification approaches, is that such restrictions are robust since they contain very little information. Due to this, restrictions are readily available from economic theory, especially in the form of DSGE models. But using sign restrictions also implies one will not be able to uniquely identify the structural shocks. As Fry and Pagan (2005) and Paustian (2007b) pointed out, there could be many totally different structural shocks satisfying the sign restrictions. Due to this, meaning the results from the numerical process could imply highly inaccurate results for the impulse response functions.

A way of reducing this problem, as shown in Paustian (2007b), would be to go on to increase the number of sign restrictions. However, it is not clear whether achieving identification based on such type of prior information would be any more reliable than using the type of prior information associated with the restrictions used in the earlier identification schemes. In addition, enforcing a lot of sign restrictions could make the numerical procedure used for the identification extremely time consuming.

2.3 Identification combining the use of short run and sign restrictions

Compared to the identification approaches reviewed, an alternative choice would be to use an identification scheme that combines short run and sign restrictions. In this section, I argue for the applicability of such an identification scheme and show how it can be developed.

When confronted with the situation of identifying structural shocks in a VAR, a researcher could well be faced with prior information considered to be reliable in the form short term, long run and sign restrictions; though, neither numerous enough nor accurate enough to achieve reliable identification using some of the earlier identification schemes.

If it is the case that a researcher has at his disposal prior information considered to be reliable of different types, selecting among one of the earlier identification schemes would necessarily imply that not all prior information can be taken into account. For an identification scheme that combines the use of short run and sign restrictions, however, it will be possible to take into account prior information of all the different types. The incorporation of short run and sign restrictions can be done mainly as before. That is, place short run restrictions on the C matrix while for sign restrictions restrict the impulse response functions generated from different orthogonal draws. But for this scheme the draws must be made conditional on that the zero restrictions on the C matrix are satisfied. For long term neutrality restrictions, I suggest that the prior information should be be incorporated by forming sign restrictions in the shape of interval restrictions around zero on the impulse response functions at a distant horizon.

In total, such a set up will help to address the main problems associated with the identification schemes reviewed: Since one do not need to pick a full set of short run restrictions, the researcher has the opportunity of selecting only the most reliable ones. Implementing long run neutrality restrictions, by forming interval restriction around zero at a distant horizon, would better serve the fact that estimated VAR is only an approximate estimate of the economic system.[6] Concerning the use of pure sign restrictions, with the enforcement of the other types of prior information, one will have fewer opportunities for differences in structural shocks dynamics. Due to this, fewer sign restrictions are needed in order to avoid the problem of highly inaccurate results for the impulse response functions.

[6]It will of course here be a question how wide such an interval should be. I do not take a strong stand on the issue, but point to the fact that such an approach would be more robust than enforcing long run restrictions that must hold exactly. A way to analyze this issue would be to conduct simulated exercises. As shown in (preliminary) Vigfusson (2007), the power of identifying a VAR using long run restrictions is quite strong, which suggests that a relative small interval could be used to achieve proper identification.

2.3.1 Restricting the Gram-Schmidt process

The identification scheme proposed calls for a combination of the scheme used for short run restrictions with the one used for sign restrictions. A challenge that now needs to be addressed is to provide a general algorithm that can be used to implement such a scheme.

The general idea behind such an algorithm must be a numerical process (as when using sign restrictions) where draws are made such that the space of possible structural orthogonal shocks is searched in a systematic way. But now the numerical process must be restricted, so that it only searches systematically in the space of possible orthogonal shocks where the enforced short run zero restrictions are satisfied. Such a numerical process will produce restricted draws for Q^r, which can be used to calculate C^r and its corresponding impulse response functions which will be kept if they satisfy the enforced sign restrictions.

In the sign restriction approach used in Uhlig (2005), candidates for the impulse response functions of a specific structural shock are made by constructing an impulse vector in C based on normalized i.i.d. draws from the unit sphere from a vector in Q. If more than one type of structural shock needs to be identified, several normalized i.i.d. draws from different unit spheres in Q must be made. Since the matrix Q is assumed to be orthonormal, the unit spheres must be made orthogonal to each other. An algorithm that can be used to achieve this is the Gram-Schmidt process.[7]

For the identification scheme I suggest here there is a demand to provide

[7] Other algorithms exist, but the recursive property of the Gram-Schmidt process is useful for the purpose here, which is to restrict the space of orthogonal draws.

restricted orthonormal draws for Q^r, in order to calculate C^r. [8] I propose doing this using a Gram-Schmidt process linearly restricted so that the short run restrictions placed on C^r are satisfied. In general, one can accomplish this by adopting the following algorithm.

Algorithm: The restricted Gram-Schmidt process

1. Fix the matrix $\tilde{C}$, for instance by selecting $\tilde{C} = C^C$ (i.e. lower triangular matrix of the Cholesky).

2. For $m - 1$ of the impulse vectors of C enforce on the non-diagonal elements of the matrix between $< 0, \frac{m(m-1)}{2} - 1 >$ contemporaneous zero restrictions. The restricted impulse vectors $C^r = [\mathbf{c}_1^r, \mathbf{c}_2^r, ..., \mathbf{c}_m^r]$ should be ordered in increasing order with regard to the number of zero restrictions in each impulse vector.[9]

3. Restrict the vector $\mathbf{v}_i^r = [v_{1i}^r, v_{2i}^r, ..., v_{mi}^r]'$ so that it contains an unknown if it corresponds to a zero component in $\mathbf{c}_{m+1-i}^r$ otherwise set it equal to a normalized i.i.d. draw.

4. Making the vector orthogonal by recursively solving the restricted Gram-Schmidt process. The process does this by solving the following

[8] A thank to Gernot Doppelhoffer for pointing this out to me.

[9] The matrix C^r does only need to include as many vectors as the number of shocks desired to be identified. Though, they must be ordered from right to left the way specified here.

linear system of equations for its unknowns in $\mathbf{u}_i^r = [u_{1i}^r, u_{2i}^r, ..., u_{mi}^r]'$ and $\mathbf{v}_i^r$:

$$\mathbf{u}_i^r = \mathbf{v}_i^r - \sum_{j=1}^{i-1} proj_{\mathbf{u}_j^r}\mathbf{v}_i^r \text{ where the projection operator } proj_{\mathbf{u}_j^r}\mathbf{v}_i^r := \frac{< \mathbf{u}_j^r, \mathbf{v}_i^r >}{< \mathbf{u}_j^r, \mathbf{u}_j^r >}\mathbf{u}_j^r$$

Linearly restricted such that[10]

$$
\begin{aligned}
0 &= c_{11}^c u_{1i}^r & \text{if } c_{1,m+1-i}^r = 0\\
0 &= c_{21}^c u_{1i}^r + c_{22}^c u_{2i}^r & \text{if } c_{2,m+1-i}^r = 0\\
&...\\
0 &= c_{m,1}^c u_{1i}^r + c_{m2}^c u_{2i}^r + ... + c_{mm}^c u_{mi}^r & \text{if } c_{m,m+1-i}^r = 0
\end{aligned}
$$

$i = 1, 2, ..., m$

5. Make the vector of restricted draws $\mathbf{u}_i^r$ orthonormal by enforcing them to be of unit length:

$$\mathbf{q}_i^r = \frac{\mathbf{u}_i^r}{||\mathbf{u}_i^r||}$$

$i = 1, 2, ..., m.$

6. Repeat steps 3-5 until $n2$ restricted draws have been made.

For a given covariance matrix, the algorithm provides us with $n2$ restricted draws for $Q^r = [\mathbf{q}_m^r, \mathbf{q}_{m-1}^r, ..., \mathbf{q}_1^r]$. This can be used to calculate $C^r = A^c Q^r$,

[10]Initially we restrict by setting non-diagonal elements of $[\mathbf{c}_1^r, \mathbf{c}_2^r, ..., \mathbf{c}_m^r] = C^c[\mathbf{q}_1^r, \mathbf{q}_2^r, ..., \mathbf{q}_m^r]$ equal to zero. Since we can use the condition that $\mathbf{q}_i^r = \frac{\mathbf{u}_i^r}{||\mathbf{u}_i^r||}$, it is possible to arrive at the restricting equations given here.

now restricted so that short run zero restrictions are enforced.

In practical applications, the identification scheme would form a part of the estimation and inference procedure. It seems convenient to do this by integrating the scheme proposed into the Bayesian methodology used in Uhlig (2005). The numerical procedure would then start by making n_1 draws of the reduced form coefficients from the posterior of the estimated VAR. For each of these draws (based on the calculation of its covariance matrix) make n_2 draws based on the identification scheme suggested here. Calculate the impulse response functions and keep the draws satisfying the sign restrictions. The draws would then form the simulated data which can be used to calculate the percentiles of the impulse response functions.

2.4 Applications

In this section I present three applications. The applications are meant be illustrative of the usefulness of the identification scheme.

2.4.1 Application 1: Combining short run and sign restrictions

For this application, the variables included in the VAR are thought of as being representative of a small open economy. The variables are $X_t = [\mathrm{i}_t^*, \mathrm{y}_t, \pi_t, \mathrm{i}_t, \mathrm{re}_t]'$ where i_t^* and i_t is the foreign and domestic interest rate, while the other variables (denoted in log or log differences) are gross domestic product (gdp) y_t, inflation rate π_t and the real exchange rate re_t. Connected to the last two variables in the vector X_t are two structural shocks in the form of monetary policy shock and exchange rate shock. The data used for estimating the VAR model is from Norway in the period 1983Q1 to 2004Q4. A detailed analysis of the results for Norway and a host of other economies are provided in Bjørnland and Halvorsen (2008).

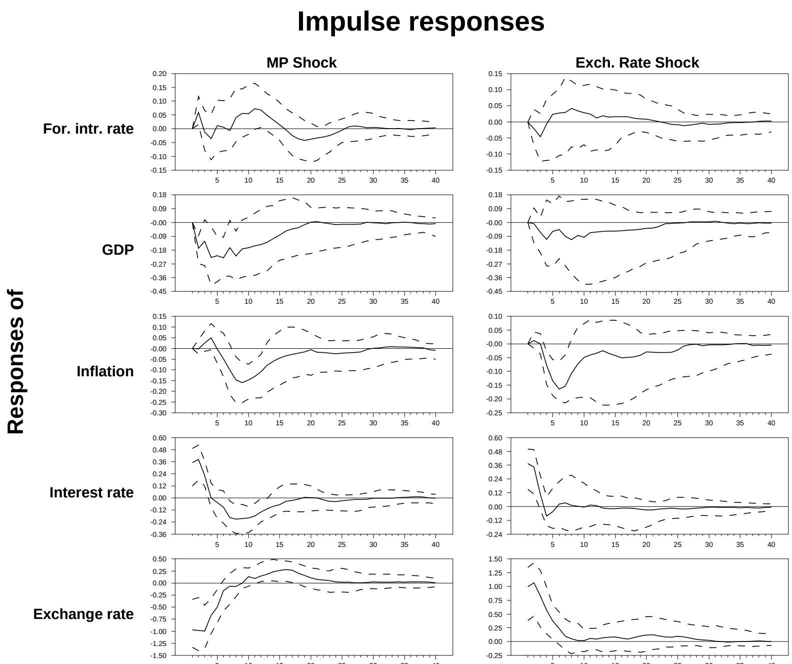


Figure 2.1: Estimated impulse responses with 16 and 84 percent error bands for monetary policy shock and exchange rate shock.

In the VAR model, monetary policy shocks and exchange rate shocks are identified using a combination of short run and sign restrictions.[11] For the short run restrictions, we have enforced that both monetary policy shocks and exchange rate shocks have no short run impact (i.e. quarterly) on the

[11]In Bjørnland and Halvorsen (2008) the identification scheme is named a Cholesky-Sign decomposition. By setting in for the zero and sign restrictions in the algorithm presented here, one can confirm that such a scheme is a just a special case of the identification scheme presented here.

three first variables of the system. The zero restrictions on the first variable is based on the assumption that domestic variables in a small open economy do not influence foreign variables. For the next two variables, we take the commonly held view that monetary policy shock works with a lag on output and inflation due to the presence of some "outside-lag". Further, we find the zero restriction put on exchange rate shocks on inflation reasonable due to the presence of exchange rate pass-through. Concerning the use of sign restrictions, we have adopted only one restriction, namely the traditional Dornbusch overshooting hypothesis that a positive monetary policy shock must be met by an immediate appreciation of the real exchange rate.

The results of the impulse response functions for a monetary policy shock and an exchange rate shock are displayed in figure 2.1. With regard to a monetary policy shock, both GDP and inflation (with some price puzzle) have a mirrored hump shaped response. Such a response is commonly observed in the VAR literature. The shape of the response to the exchange rate is in line with the traditional Dornbusch's overshooting hypothesis. For an exchange rate shock, the strong but short lived response to domestic interest rate is noteworthy, in addition to the puzzling response to inflation.

In general, as documented extensively in Bjørnland and Halvorsen (2008), the identification scheme adopted here will, compared to a Cholesky identification scheme, deliver an exchange rate response in line with the traditional Dornbusch's overshooting hypothesis (i.e. no "exchange rate puzzle") and be able to account for a much stronger interaction between the monetary policy and the exchange rate.

2.4.2 Application 2: Combining short run and sign restrictions

For the second application, I let the variables in the VAR also to be representative of a small open economy, but now explicitly taking into account the financial sector. The variables are $X_t = [\pi_t, \mathrm{y}_{gap,t}, \mathrm{ph}_t, \mathrm{re}_t, \mathrm{i}_t, \mathrm{mix}_t]'$ where $\mathrm{y}_{gap,t}$ and ph_t (in logs) represent the output gap and the property price, respectively. The variable mix_t represents the total bank credit divided by total credit in the economy. The other variables are defined as in the first application.[12] The data used for estimating the VAR model is from Norway in the period 1988Q2 to 2008Q2.

For the VAR model, I am interested to identify how bank lending shocks transmit themselves through to the economy. [13] The inclusion of a mix variable in the VAR model can be considered to make the model particularly able to identify such type of shocks since changes in the variable can be thought as reflecting changes in the supply of credit to the economy and not demand (see for e.g. Kashyap, Stein, and Wilcox (1993) for a discussion about this issue). Still, the issue about identification must be resolved. Different from the assumption made in the first application for the identification of monetary policy shocks, bank lending shocks are, since they provide direct access to liquidity for the economy, likely to have a much faster impact on many of the variables in the system. This should call for an identification approach using fewer zero restrictions and more sign restrictions. Hence,

[12] To limit the size of the VAR, the foreign interest rate is for this application included as an exogenous variable.

[13] According to Bernanke and Blinder (1988), a bank lending channel could form a central part of the financial sector in an economy.

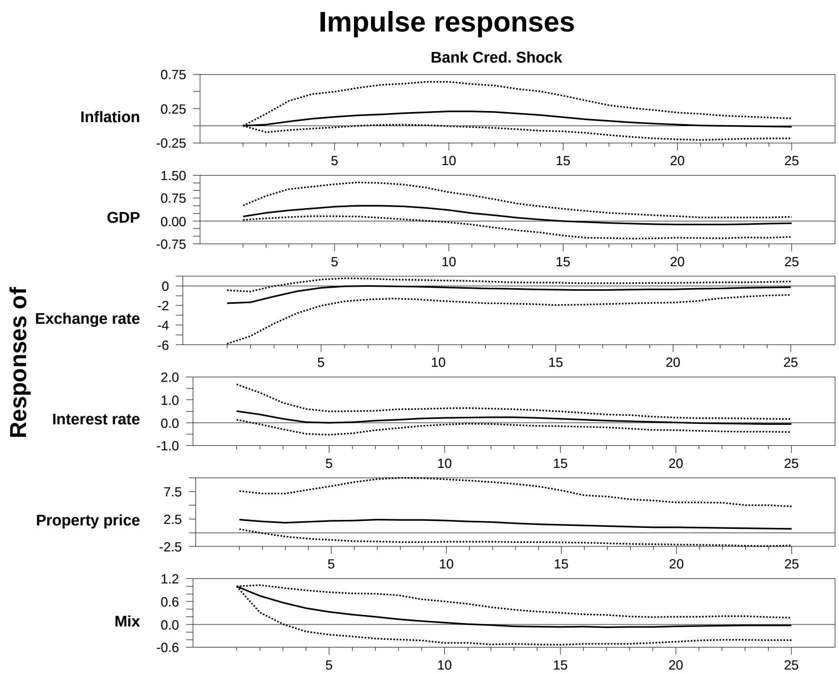


Figure 2.2: Estimated impulse responses with 16 and 84 percent error bands for bank lending shock with one basis point impact on the mix.

I do this by letting a positive bank lending shock to be restricted to have an immediate positive impact on the output gap and the property price. Further, I restrict the short term interest rate to increase and the exchange rate to appreciate. For the interest rate, the restriction is based on the view that increased supply of bank credit must be financed by increased demand for money from the money market which should increase the short term interest rate. Such an increase in the interest rate should also, in line with the traditional overshooting theory, to call for an immediate appreciation of the exchange rate. Finally, I place a zero restriction on inflation, justified by sluggishness of the firms in their price setting behavior.

The results for the impulse response functions for a bank lending shocks of one basis point on the mix are displayed in figure 2.2. In general, the shape of the response of such a shock on the output gap, inflation, property price, and the real exchange rate are similar to an expansionary monetary policy shock. The wide error band on the response to the property price implies that little information is obtained about how this variable react to a mix shock. For the interest response, the increase starting after about the fifth quarter reflects perhaps monetary policymakers delayed response to such a shock.

2.4.3 Application 3: Using long run interval restriction

In the final application, I let the VAR model take the bivariate specification used in Gali (1999). The two variables included in the VAR model are $X_t = [\Delta \mathrm{x}_t, \Delta \mathrm{n}_t]'$, where x_t denote the log of labor productivity and n_t the log of hours. For the two variables, structural shocks in the form of a technology shocks and non-technology shocks are associated. The VAR model is estimated on U.S. quarterly data for the period 1948:1-1994:1.

Proper identification of the bivariate model is of huge interest. This is linked to the fact that the impulse response functions can generate empirical evidence able to discriminate between the traditional New Keynesian (under non accommodating monetary policy) and real business cycle (RBC) models. The identification restriction enforced in Gali (1999) is the long run neutrality restriction that only technology shocks can have a permanent effect on the level of labor productivity.[14]

[14] Both the identifying restriction and other various issues related to the specification

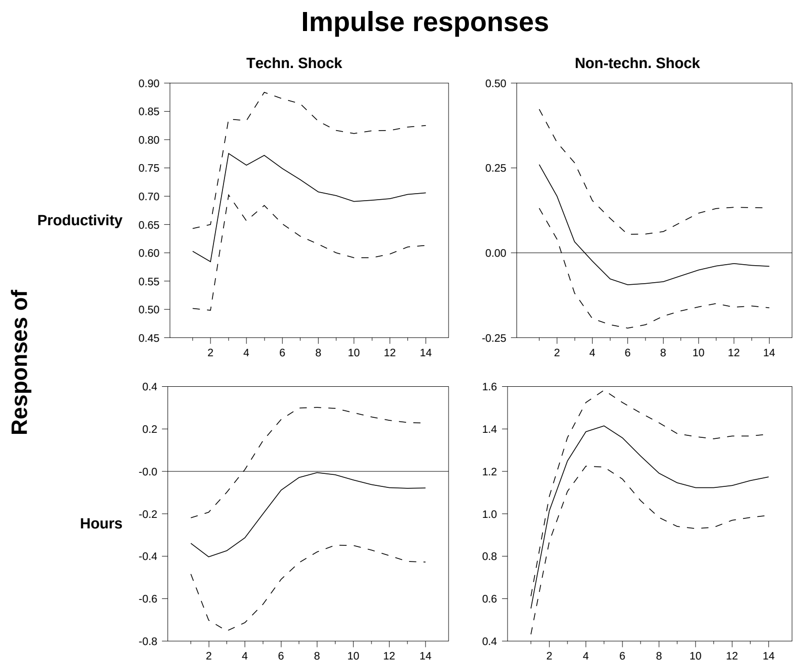


Figure 2.3: Estimated impulse responses with 16 and 84 percent error bands for monetary policy shock and exchange rate shock.

If one maintain the criticism against long run restrictions discussed earlier, namely that such restrictions will not hold exactly due to the approximate nature of the VAR. A more robust identifying restriction would be to replace the long run restriction with an interval restriction at the distant horizon. It is noteworthy that such an approach, in addition, will be able to mitigate some of the problems raised in Uhlig (2004), where it is claimed that other structural shocks than technology shock could influence the level of labor productivity in the long run. The restriction used here is that a non-technology shock, after two and half years (i.e. ten periods), can not

of the model have been discussed a lot in the literature ("the technology-hours debate"). See Gali and Rabanal (2004) for a survey related to some of these issues.

influence the level of labor productivity more than 0.20 (percent).

The distribution of impulse response functions by the use of such an interval restriction is displayed in figure 2.3. The figure confirms the main result in Gali (1999), namely that following a technology shock there is an immediate and significant decline in the use of hours. Such a result is the same as the response in a baseline New-Keynesian DSGE model with non-accommodating monetary policy, but at odds with the response from a traditional RBC model.

2.5 Conclusion

In this paper it is argued that using an identification scheme that combines the use short run and sign restrictions could provides the researcher with a more flexible and powerful way to identify a VAR. In particular, the arguments are related to the fact that the identification scheme proposed here can incorporate all the types of prior information used in the earlier schemes. For the empirical validation of DSGE models, such a result is of interest since an identified VAR can be used as a selection criteria to choose among competing DSGE models, and for the estimation of a particular DSGE model's structural parameters.

Within the scheme proposed, prior information in the form of short run and sign restrictions can be directly implemented. For the case of long run neutrality restrictions, I suggest that they should be implemented using sign restrictions in the form of an interval restriction around zero at a distant horizon. In total, such an approach will be able to mitigate the main problems associated to the identification schemes commonly used to identify a VAR: By not having to pick a full set of short run restrictions, the researcher has the opportunity to select among the most reliable ones. Interval restrictions would better serve the fact that estimated VAR is only an approximate estimate of the economic system. While for pure sign restrictions, with the enforcement of the other types of prior information, there will be less need to enforce numerous sign restrictions in order to obtain accurate results.

Thought it is difficult at this stage to say anything about the extent of the use of such a scheme. The paper provides three applications that clearly illustrates the use of such a scheme: In the first application, we see that achieving identification using a combination of short run and sign restrictions provided evidence of strong interaction between monetary policy and the exchange rate and a response to monetary policy shock consistent with Dornbusch's traditional overshooting hypothesis. In the second application, a bank lending shock is shown to cause interesting disruptions to the economy. In the final application, achieving identification using interval restriction did not change the main conclusion in Gali (1999), i.e that hours fall following a technology shock.

3

Essay 2: How does monetary policy respond to exchange rate movements? New international evidence

Joint with Hilde C. Bjørnland

Abstract

This paper analyzes how monetary policy responds to exchange rate movements in open economies, and pays particular attention to the two-way interaction between monetary policy and exchange rate movements. We address this issue using a structural VAR model that is identified using a combination of sign and short-term (zero) restrictions. Our suggested identification scheme allows for a simultaneous reaction between the variables that are observed to respond intraday to news (the interest rate and the exchange rate), but maintains the recursive order for the traditional macroeconomic variables (GDP and inflation). Doing so, we find strong interaction between monetary policy and exchange rate variation. In particular, monetary policy responds immediately (within the quarter) to an exchange rate shock. Furthermore, we find the impact of monetary policy shocks on exchange rates to be non-trivial, suggesting instant, rather than delayed, overshooting. These results are in contrast to what has been found previously in the literature. [1]

[1] We thank Gernot Doppelhofer, Mardi Dungey, Renee A. Fry, Christian Kascha, Jan Tore Klovland, Kai Leitemo, Krisztina Molnar, Øivind Anti Nilsen, Georg Rabl, Francesco Ravazzolo, and participants at the SOEGW 2008 conference in Toronto, the CFE 2008 conference in Neuchâtel, the MMF 2008 conference in London as well as seminar participants at the Norwegian School of Economics and Business Administration for their useful comments and suggestions. The authors thank the *Norwegian Financial Market Fund* under the Norwegian Research Council for financial support.

3.1 Introduction

In 2001, John B. Taylor wrote: *"An important and still unsettled issue for monetary policy in open economies is how much of an interest-rate reaction there should be to the exchange rate in a monetary regime of a flexible exchange rate, an inflation target, and a monetary policy rule."* (Taylor (2001)).

Eight years on, the issue still remains unsettled. Yet, several times a year, the board of an inflation-targeting central bank meets to analyze the development of a series of economic variables, including the exchange rate. For a small open economy, the exchange rate plays a crucial role in relation to monetary policy. It plays a significant part in the formulation of monetary policy (being an important influence on the overall level of demand and prices), and is itself also influenced by monetary policy. Understanding the role of the exchange rate in the transmission mechanism of monetary policy, as well as quantifying the appropriate interest rate reaction to exchange rate fluctuations, is therefore imperative to the implementation of an efficient monetary policy strategy.

This paper analyzes the interaction between monetary policy and the exchange rate in six open (inflation-targeting) countries, focusing in particular on how monetary policy has responded to exchange rate movements. We address this issue using a structural vector autoregressive (VAR) model that is identified using a combination of sign and short-run (zero) restrictions which preserves the endogenous interaction between the interest rate and the exchange rate commonly observed in the market. The novel feature of our approach is that, instead of the conventional view of using a recursive Cholesky ordering for all of the variables, or the more recent view of relying on only on pure sign restrictions, we combine the two approaches in an intuitive way. That is, we allow for a simultaneous reaction between the variables that are observed to respond intraday to news (the interest rate and the exchange rate), but maintain the Cholesky recursive order for the traditional macroeconomic variables that are observed to respond with delay to economic shocks (output, inflation etc.). Identified in this way, we believe the VAR approach is likely to give very useful information about monetary policy and exchange rate dynamics in the open economy that previous studies have been unable to recover.

Up to now, the standard approach for analyzing monetary policy responses has been to estimate interest rate rules like the simple Taylor rule. For the closed economies, Taylor rules are often estimated using a single equation framework that quantifies the actual interest rate response to observed changes in economic variables such as inflation and the output gap, see e.g. Taylor (1999) for an overview. For open economies, the Taylor rule is frequently augmented to also include the exchange rate. However, the commonly observed simultaneity between the interest rate and the exchange rate implies that the policy rule needs to be estimated simultaneously with a reaction function for the exchange rate. In most cases this is not trivial, and parameters often end up being insignificant.

More recently, Lubik and Schorfheide (2007) and Dong (2008) have instead favored a multivariate approach when estimating policy rules in the open economy. Using Bayesian estimation techniques and dynamic stochastic general equilibrium (DSGE) models, they estimate whether monetary policy responds to exchange rate movements. In contrast to the single equation approaches, both find that the interest rate increases systematically in all countries following an exchange rate depreciation. However, the degree of response varies with the assumption underlying the exchange rate behavior. While Lubik and Schorfheide (2007) find a modest interest rate response by assuming the exchange rate follows an exogenous AR process, Dong (2008) reports substantially more evidence using an endogenous specification for the exchange rate.

The focus of this paper will be to specify multivariate VARs to analyze policy reaction (operationalized through short-term interest rates) to shocks in the exchange rate. By investigating the impulse responses and variance decomposition of the policy instrument in response to the identified shocks, one can get an idea of how central banks use the instrument to reach their goals. While this is not the same as estimating interest rate rules, we believe that the information as to how the interest rates actually react to shocks to be equally interesting, and more to the point, in describing how central banks implement policy. Furthermore, the empirical results may be an important addition to the more theoretically driven structural model responses derived in Lubik and Schorfheide (2007) and Dong (2008), where the chosen exchange rate specification will influence the results. The paper therefore contributes with new empirical evidence, as well as providing a methodological contribution on how one can identify monetary policy and exchange rate shocks in the open economy.

The analysis is applied to six open economies with floating exchange rates: Australia, Canada, New Zealand, Norway, Sweden and the UK. In all countries, the results suggest that the interest rate increases systematically in response to a shock that depreciates the exchange rate. Furthermore, we find the impact of monetary policy shocks on exchange rates to be non-trivial. In particular, following a contractionary monetary policy shock, the exchange rate appreciates on impact. The exchange rate then gradually depreciates back to baseline, broadly consistent with UIP. These results are in contrast to the results that have been found previously in the literature using recursive restrictions, or, pure sign restrictions, to identify the structural VARs.

The paper is organized as follows. Section 2 motivates and presents our suggested identification scheme (the Cholesky-sign decomposition) that is used to identify the shocks. In Section 3 we present the empirical results and discuss robustness. Section 4 concludes.

3.2 Identifying monetary policy responses in the structural VAR model

Structural VAR models are increasingly being used as a method to analyze transmission mechanisms of monetary policy. Typically, the focus is on identifying the unsystematic monetary policy shocks and tracing out the effects of these shocks on various macroeconomic and financial variables.[2] However,

[2] See e.g. Sims (1980), Bernanke and Blinder (1992) and Christiano, Eichenbaum, and Evans (1999b, 2005a) for an analysis of the closed economy (i.e. the U.S.), Eichenbaum and Evans (1995) for an analysis of open economies and Bjørnland and Leitemo (2009) for an analysis of the stock market.

while the method has been successful in providing a consensus with regard to the effects of monetary policy in the closed economy, VAR studies of the open economy have provided several puzzles, in particular with regard to the effects on the exchange rate. For instance, following a contractionary monetary policy shock, the exchange rate is seen to depreciate, or if it appreciates, it does so for a prolonged period of up to three years, thereby giving a hump-shaped response that violates uncovered interest parity (UIP).[3]

A major challenge when analyzing monetary policy in the open economy, though, is how to identify the structural shocks when there is simultaneity between the interest rate and the exchange rate. Most of the traditional VAR studies of the open economies ignore this simultaneity, by placing recursive, contemporaneous restrictions on the interaction between monetary policy and the exchange rate. Typically, they either assume a lagged response in the systematic monetary policy setting to exchange rate news (see e.g. Eichenbaum and Evans (1995), Peersman and Smets (2003) and Lindé (2003)), or a lagged response in the exchange rate to monetary policy shocks (see e.g. Kim (2002)[4] and Mojon and Peersman (2003)). However, both restrictions are potentially wrong. The first as it prevents the policymaker from using all the current information when designing monetary policy. There is, however, no a priori reason for why the monetary policymakers should disregard news on the exchange rate among all available information when deciding the appropriate interest rate response. Further-

[3] In the literature, the first phenomenon has been referred to as the exchange rate puzzle, whereas the second is termed delayed overshooting (or forward discount puzzle), see Cushman and Zha (1997).

[4] For some of the countries Kim (2002) also experiments with the reverse restrictions, i.e. that monetary policy responds to the exchange rate with a lag.

more, the restriction is useless for the purpose of our study, which seeks to quantify this policy response. The second restriction is equally implausible, as it imposes strong restrictions on the flexibility of the exchange rate. Daily observations in the market, as well as formal empirical evidence using among others (non-VAR) event studies, typically suggest that the exchange rate responds instantaneously to news, including monetary policy shocks (see e.g. Bonser-Neal, Roley, and Sellon (1998), Zettelmeyer (2004) and Kearns and Manners (2006) among others).

The issue of identification has not gone unattended. In an early attempt to solve the puzzle, Cushman and Zha (1997) suggest that one should identify monetary policy shocks in a simultaneous environment, using a systems method of estimation. The paper analyzes Canada prior to the inflation targeting period (the analysis ends in 1993), and is distinct from our paper in that they specify a VAR model with tightly estimated equations for money demand, money supply and the exchange rate. Hence, monetary policy is identified through innovations in the money supply equation rather than through an interest rate equation as we do here. Nevertheless, the paper is relevant as it finds much more evidence of simultaneous responses for Canada than traditionally found in the literature.

More recently, Faust and Rogers (2003) have used sign restrictions to *test* the implications of the short-run (zero) restrictions commonly applied. Doing so they find that traditional VARs may have produced a numerically important bias in the estimate of the degree of interdependence. By relaxing the zero restrictions, they find that the exchange rate can appreciate on impact. However, their approach of relying of pure sign restriction can not *identify* the precise exchange rate responses to the monetary policy shocks, which could be immediate or delayed. To do so, one needs to apply additional restrictions, or, allow the sign restrictions imposed to be effective for a prolonged period. An example of the latter is found in Uhlig and Scholl (2005), where they impose sign restrictions for up to a year after the shocks. Doing so, however, they find no evidence of instant overshooting.

An obstacle with the approach of relying on pure sign restrictions when identifying a structural VAR model, is that the identification scheme will be non-unique. This has been emphasized by Fry and Pagan (2007), who show that due to the weakness of information contained in the sign restrictions, there will be many impulse responses that can satisfy each sign restriction. When a series of impulse responses are compatible with a particular restriction, identification will not be exact. Canova and Paustian (2007) and Paustian (2007a) have further shown that sign restrictions can only uniquely pin down the unconstrained impulse responses when the imposed restrictions are sufficiently numerous. Otherwise, the use of sign restrictions could lead to the identified shock being a hybrid of shocks, lacking clear economic interpretation.

In this paper we suggest combining sign and short-run (zero) restrictions (the Cholesky-Sign decomposition) to identify the VAR. In particular, we explicitly account for the interdependence between monetary policy and exchange rate movements within a VAR model by applying the following sign restriction: Following a contractionary monetary policy shock (that increases the interest rate), the exchange rate has to *fall* immediately (i.e. appreciate). Such a response is consistent with formal empirical evidence from among others the event studies cited above.[5] It seems therefore reasonable to assume that the restriction is uncontroversial. Note that in the periods following the initial response, the exchange rate is free to move in any direction. That is, we do not place any restrictions on whether the maximum response should be immediate or delayed. This way we can test for any evidence of delayed overshooting within our present framework. Finally, and at the core of this paper, by restricting the response in the exchange rate only, we leave the issue of how monetary policy responds to exchange rate movements open for testing.

Once allowing for a contemporaneous relationship between the interest rate and the exchange rate, the remaining VAR will be identified using standard recursive zero restrictions on the impact matrix of shocks that are commonly used in the closed economy literature, see e.g. Christiano, Eichenbaum, and Evans (1999b). That is, we identify a recursive structure between domestic macroeconomic variables and monetary policy, so that monetary policy can react to all shocks, but the macroeconomic variables (such as output and inflation) react with a lag to monetary policy shocks. These restrictions are less controversial, and studies identifying monetary policy without these restrictions have found qualitatively similar results: see for example Faust, Swanson, and Wright (2004). Furthermore, they provide for an unique identification with regard to pinning down the effects of monetary policy on the the various macroeconomic variables.

[5]It is also in line with results found in Bjørnland (2008), using instead long run (neutrality) restrictions to identify the VAR.

3.2.1 The Cholesky-sign identification scheme

The choice of variables included in the VAR model is based on small open economies with a New-Keynesian framework, such as described in Svensson (2000) and Clarida, Gali, and Gertler (2001). Formally, the variables to be included consist of $X_t = [i_t^*, y_t, \pi_t, i_t, re_t]'$, where i_t^* is the foreign short-term nominal interest rate, y_t is the log of real GDP, π_t, is the log of the price differential within a year, i_t the short-term nominal interest rate, and re_t the log of the country's real exchange rate.

The five variables can be estimated jointly in the reduced form VAR(p), which in matrix form (ignoring any deterministic terms) can be expressed as

$$A(L)X_t = e_t, \text{ with } \Sigma_e = E(e_t e_t'), \tag{3.1}$$

$A(L)$ is here a $(5x5)$ matrix polynomial in the lag operator L, $A(L) = \sum_{i=0}^{p} A_i L^i$ with $A_0 = I_5$. e_t is the one step ahead prediction error which is assumed to be normally distributed with a positive semidefinite covariance matrix Σ_e. Given that $A(L)$ is invertible, the VAR model can also be written in terms of its moving average (MA) representation:

$$X_t = B(L)e_t, \tag{3.2}$$

where $B(L) = A(L)^{-1}$.

We assume that the error term e_t is linearly related to a vector of five independent structural shocks specified as $\varepsilon_t = [\varepsilon_t^{i^*}, \varepsilon_t^{y}, \varepsilon_t^{\pi}, \varepsilon_t^{mp}, \varepsilon_t^{ex}]'$. It is common to loosely identify $\varepsilon_t^{i^*}$ as foreign interest rate shocks, ε_t^{y} as output shocks and ε_t^{π} as inflation shocks (or cost-push shocks). For the latter two shocks (the main focus of this paper), ε_t^{mp} represents monetary policy shocks and ε_t^{ex} refers to real exchange rate shocks. If we normalize the structural shocks to have unit variance, the relationship between the error term and structural shocks can be written as

$$e_t = A\varepsilon_t, \text{ with } I_5 = E(\varepsilon_t \varepsilon_t'). \tag{3.3}$$

By substituting for equation (3.3) into (3.2), the model can be written in the form of a structural MA-representation

$$X_t = C(L)\varepsilon_t, \tag{3.4}$$

where $C(L) = B(L)A$. In order to derive the impulse responses and the variance decomposition, the matrix A needs to be identified. So far the only restriction on A comes from equation (3.3) that implies

$$\Sigma_e = E(e_t e_t') = AE(\varepsilon_t \varepsilon_t')A' = AA'. \tag{3.5}$$

There are, however, many different decompositions satisfying $AA' = \sum_e$, hence we do not have a unique MA representation in terms of the structural shocks. We know, however, that for two different decompositions, $\Sigma_e = AA'$ and $\Sigma_e = \tilde{A}\tilde{A}'$, it must be the case that $A = \tilde{A}Q$ with Q being an orthogonal matrix, i.e. $QQ' = I_5$. A property of this type of matrix is that the columns $Q = [q_1, ..., q_5]$ are orthonormal which tells us that its vectors are mutually perpendicular, i.e. $< q_i, q_j >= 0$ for $i \neq j$, and of unit length, i.e. $||q_i||$=1.

For the case of our small open economy model, we will identify the matrix A by using a combination of a Cholesky and sign identification approach. Technically, it amounts to partitioning the matrix X_t into two blocks of variables where the relationship among the structural shocks of the first block is cast in a recursive order while for the second block, a contemporaneous relationship among the structural shocks is allowed for. For our model, the two blocks are specified to be $X_{1t} = [i_t^*, y_t, \pi_t]'$ and $X_{2t} = [i_t, re_t]'$. If we select $\tilde{A} = A^c$, where A^c is equal to the lower triangular product of the Cholesky decomposition, one can verify that the block structure forces Q to be restricted to Q_r such that the relationship between the error term and the structural shock now can be written as

$$A\varepsilon_t = A^c Q_r \varepsilon_t = \begin{pmatrix} a_{11}^c & 0 & 0 & 0 & 0 \\ a_{21}^c & a_{22}^c & 0 & 0 & 0 \\ a_{31}^c & a_{32}^c & a_{32}^c & 0 & 0 \\ a_{41}^c & a_{42}^c & a_{43}^c & a_{44}^c & 0 \\ a_{51}^c & a_{52}^c & a_{53}^c & a_{54}^c & a_{55}^c \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \cos(\theta) & -\sin(\theta) \\ 0 & 0 & 0 & \sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} \varepsilon_t^{i^*} \\ \varepsilon_t^{y} \\ \varepsilon_t^{\pi} \\ \varepsilon_t^{mp} \\ \varepsilon_t^{ex} \end{pmatrix}$$

From this setup one should note that the zero elements on the fourth and fifth column of Q_r together with the multiplication of the Cholesky decomposition imply that monetary policy shocks and exchange rate shocks will be restricted so that they have a non-immediate (zero contemporaneous) impact on the variables belonging in X_{1t}. For monetary policy shocks we find this to be appropriate since it represents the conventional view used in the closed economy literature (Christiano, Eichenbaum, and Evans (1999b)), namely that monetary policy can react immediately to macroeconomic variables (such as output and inflation), while such a relationship does not exist the other way around (i.e. macroeconomic variables react with a lag to policy shocks).[6] Similar assumptions pertain to the exchange rate shocks: The exchange rate can react immediately to all shocks, but due to nominal rigidities, there is a slow process of exchange rate pass through to macroeconomic variables. Regarding the ordering of the first three variables, we will show that the effects of the monetary policy shocks (or the exchange rate shocks) will be invariant to how these variables are ordered. This follows from a generalization of proposition 4.1 in Christiano, Eichenbaum, and Evans (1999b), and is discussed further in the robustness section below.

For our second block of variables, we allow for contemporaneous interactions between the interest rate and the exchange rate. By varying the value of θ around the unit circle $(0, 2\pi)$, all potential contemporaneous relationships can be traced out. To identify the monetary policy shocks, we then impose one sign restriction, namely the conditional overshooting hypothesis that a monetary contraction will be met by an immediate appreciation of the real exchange rate.[7]

3.2.2 Estimation and inference

To estimate the model, we adopt a Bayesian approach. As shown in Uhlig (2005), such an approach is computationally simple and allows for a concep-

[6]Having the foreign interest rate in the recursive block should neither be controversial, since shocks to the domestic variables in a small open economy are usually assumed to have little or no influence on foreign variables, at least on impact.

[7]Note that, due to the mutually perpendicular property of $Q_r(\theta)$, this restriction implies that an unexpected appreciation of the exchange rate must have an immediate non-positive impact on the interest rate.

tually clean way of drawing error bands for the statistics of interest (such as impulse responses and variance decomposition). The prior for our reduced form coefficients and covariance matrix is chosen to be non-informative. We let θ have a uniform prior specified as $U(0, 2\pi)$.

Within this setting the first three shocks of our VAR model will be identified using the Cholesky decomposition based only on draws from the posterior VAR. For the last two shocks, however, a sign restriction approach must be implemented as in Uhlig (2005). That is, for each of the draw from the VAR posterior we make a uniform draw for θ, calculate the impulse responses and check whether our sign restriction is satisfied. If this is the case, we keep the draw; otherwise the draw is discarded. Error bands are then calculated based on all the draws that are accepted. The number of accepted draws from the posterior is set to be 1000.

3.3 Empirical results using Cholesky-sign identification

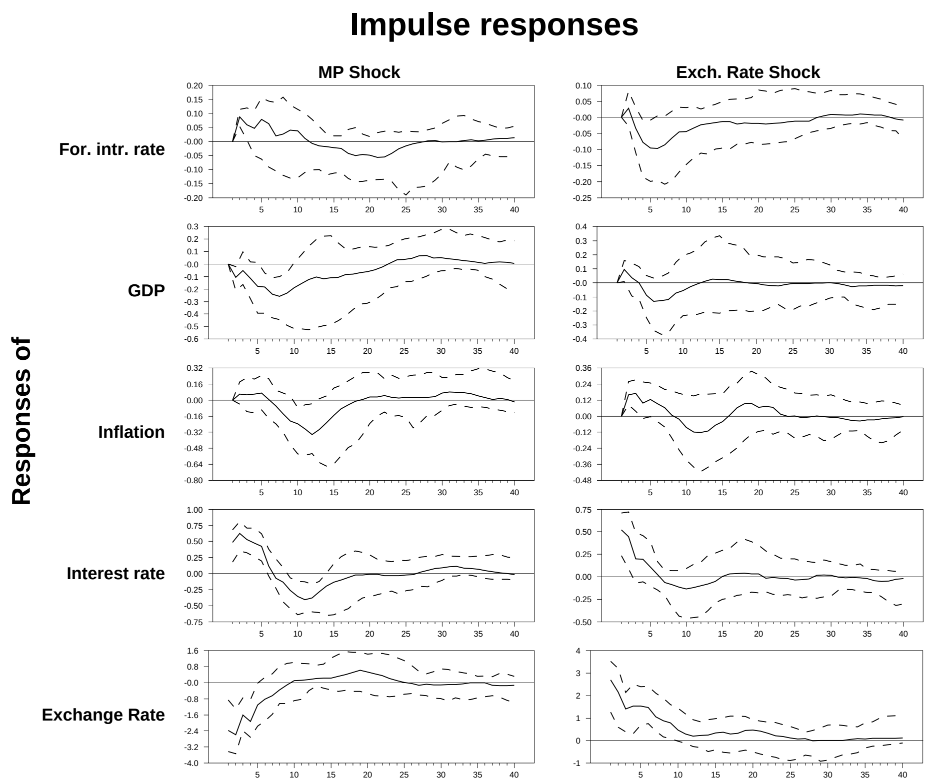
The model is estimated for six countries: Australia, Canada, New Zealand, Norway, Sweden and the UK, using quarterly data from 1983Q1 to 2004Q4 (see the appendix). Using an earlier starting period will make it hard to identify a stable monetary policy regime, as monetary policy prior to 1983 has undergone important structural changes and unusual operating procedures (see Bagliano and Favero (1998) and Clarida, Gali, and Gertler (2000)).

Consistent with most other related studies, the variables, with the exception of prices, are specified in levels. Rather than including prices, we include a measure of inflation, calculated as annual changes in the CPI. We have chosen to focus on annual inflation as it is a direct measure of the monetary policy target in inflation-targeting countries. One may argue (Giordani (2004)) that with the theoretical model of Svensson (1997) as a data-generating process, rather than including output in levels, one should either include the output gap in the VAR, or the output gap along with the trend level of output. However, as pointed out by Lindé (2003), a practical point that Giordani does not address is how to compute trend output (thereby also the output gap). To overcome this issue, we therefore instead follow Lindé (2003) and include a linear trend in the VAR along with output in levels. In that way we try to address this problem by modelling the trend implicit in the VAR. However, as will be seen in the robustness section below, excluding the trend does not change the main results. We choose four lags for all countries. Again, we will show that results are robust to alternative lag orders.

3.3.1 The effects of monetary policy shocks

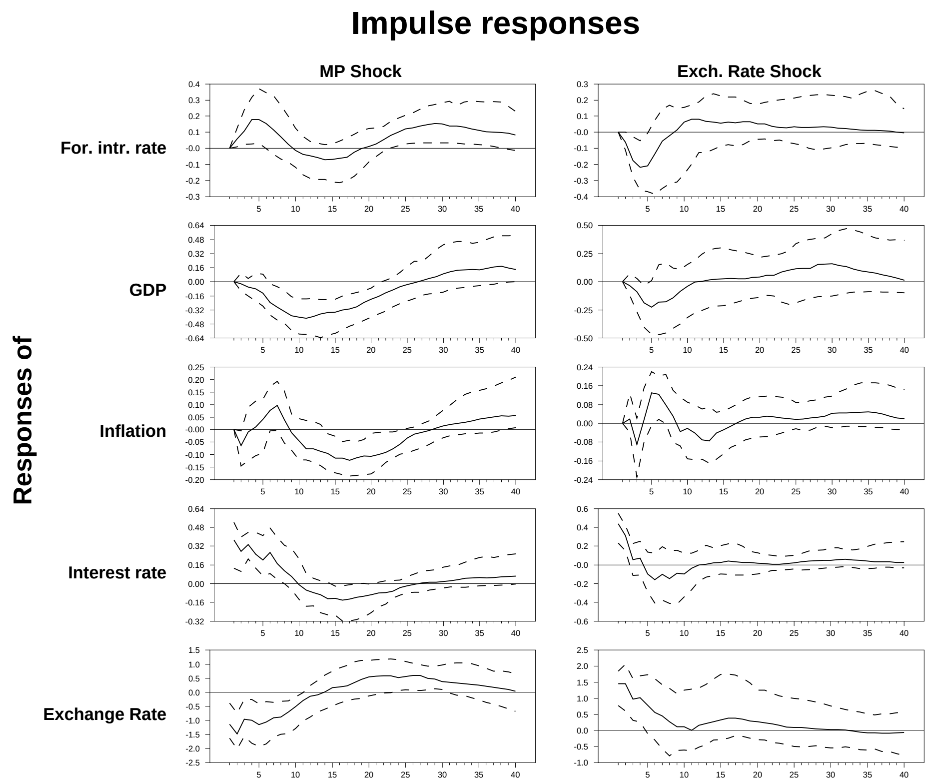
Figures 1-6 show, for each of the six countries: Australia, Canada, New Zealand, Norway, Sweden and the UK respectively, the effect of the monetary policy shock (in the left column) on all five variables and the effect of an exchange rate shock (in the right column) on the same variables, using the Cholesky-sign identification scheme. The solid line represents the median response of the error bands for the impulse responses, while the dotted lines are the 16 and 84 percentiles. Before analyzing the systematic monetary policy response to exchange rate shocks, we discuss the effects of the unsystematic monetary policy shocks on all macroeconomic variables (left column).

Figure 3.1: Australia: The response to monetary policy shocks and exchange rate shocks



The figures suggest that a contractionary monetary policy shock (that increases the interest rate temporarily) has the usual effects identified in other international studies. In particular, output falls gradually for 1-2 years before the effects essentially die out. The effect on inflation is also eventually negative as expected and reaches its minimum after 2-3 years. However, for some countries, and in particular the UK, there is some evidence that

Figure 3.2: Canada: The response to monetary policy shocks and exchange rate shocks

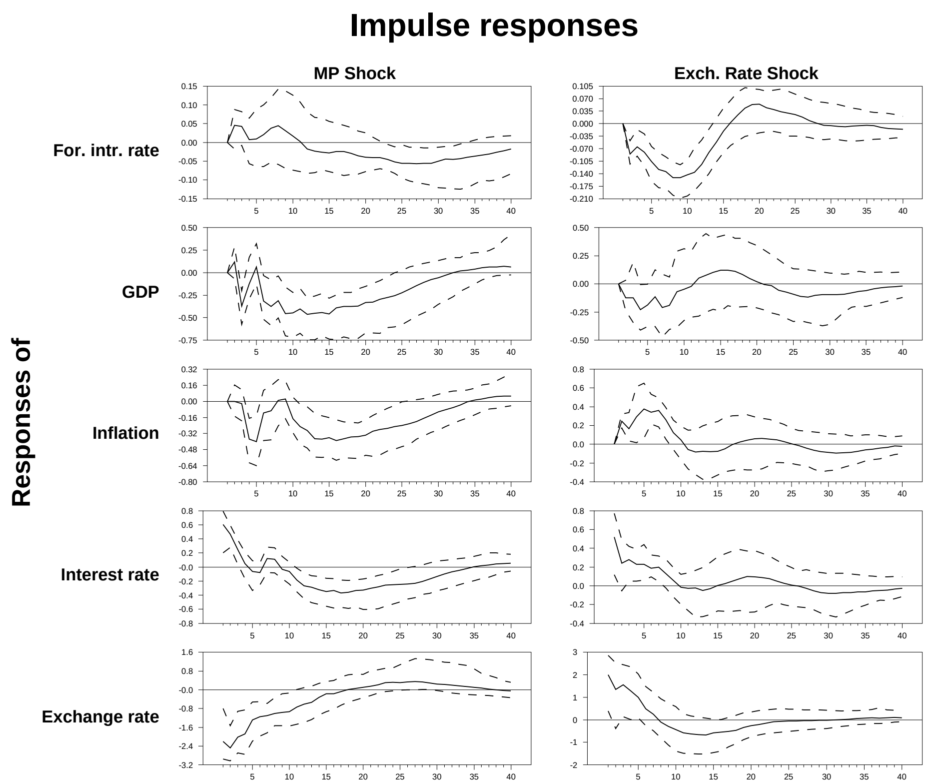


consumer prices increase initially, commonly referred to as the price puzzle.[8] Though, in most cases, this initial response is not significant.

There is a high degree of interest-rate inertia in the model, in the sense that a monetary policy shock is only offset by a gradual reduction in the interest rate. The interest rate response is consistent with what has become known as good monetary policy conduct (see Woodford (2003b)). In partic-

[8]The puzzle has often been explained by a cost channel of the interest rate, where part of the increase in firms' borrowing costs is offset by an increase in prices (Ravenna and Walsh (2006) and Chowdhury, Hoffmann, and Schabert (2006)).

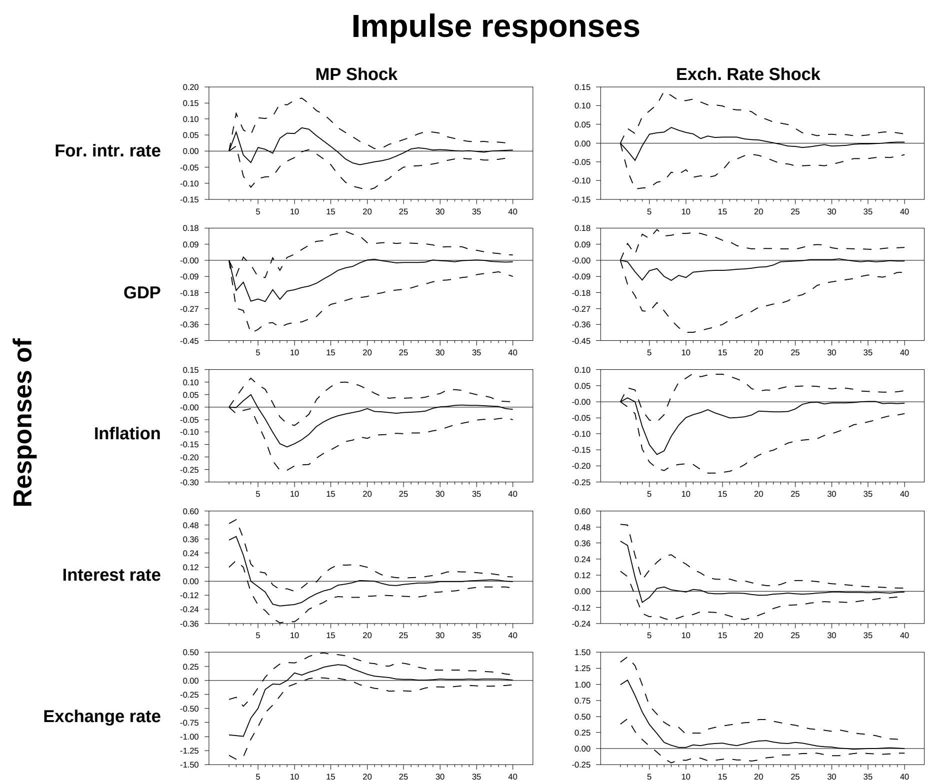
Figure 3.3: New Zealand: The response to monetary policy shocks and exchange rate shocks



ular, interest-rate inertia is known to let the policymaker smooth the effects of policy over time by affecting private-sector expectations. Moreover, the reversal of the interest rate stance is consistent with the policymaker trying to offset the adverse effects of the initial policy deviation from the systematic part of policy.

Regarding the exchange rate, the figures show that in all countries the exchange rate appreciates on impact (as assumed). However, the response is far from trivial. The median response indicates that the exchange rate

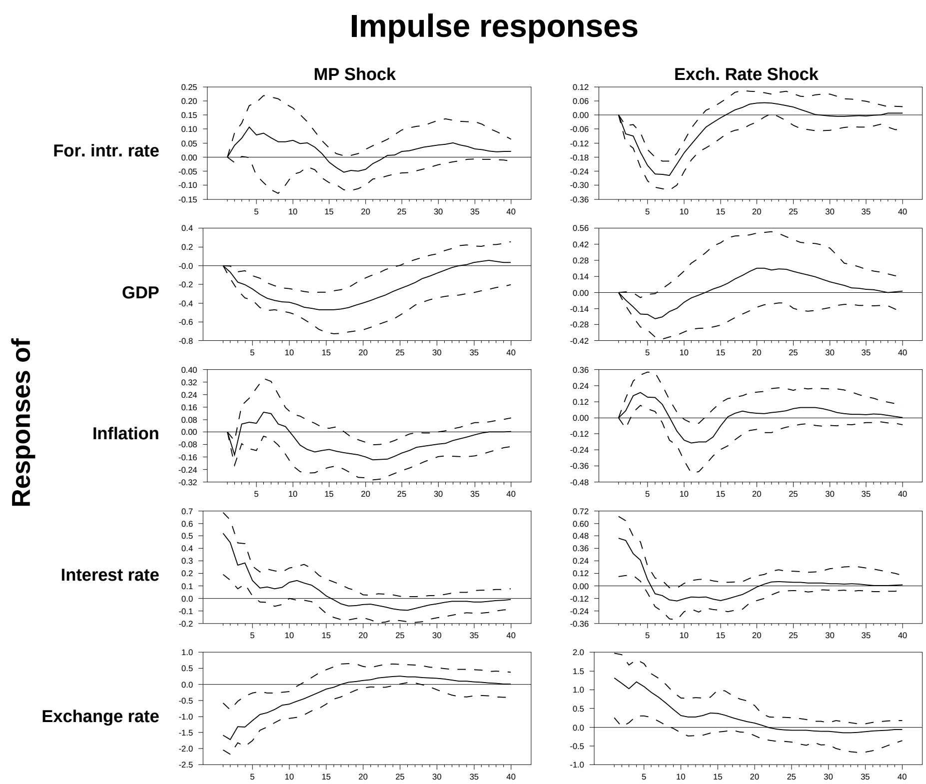
Figure 3.4: Norway: The response to monetary policy shocks and exchange rate shocks



may fall by approximately 2.5-4 percent, following (a normalized) one percentage point increase in the interest rate. Furthermore, following the initial effect, the exchange rate thereafter gradually depreciates back to baseline, consistent with the Dornbusch overshooting hypothesis. In most cases, the maximum effect is felt initially, or at most, delayed by one quarter. This seems to be a robust feature of the data, as indicated by the 16-84 percentiles error band around the median responses.

Hence, we find no evidence of delay overshooting that has often been

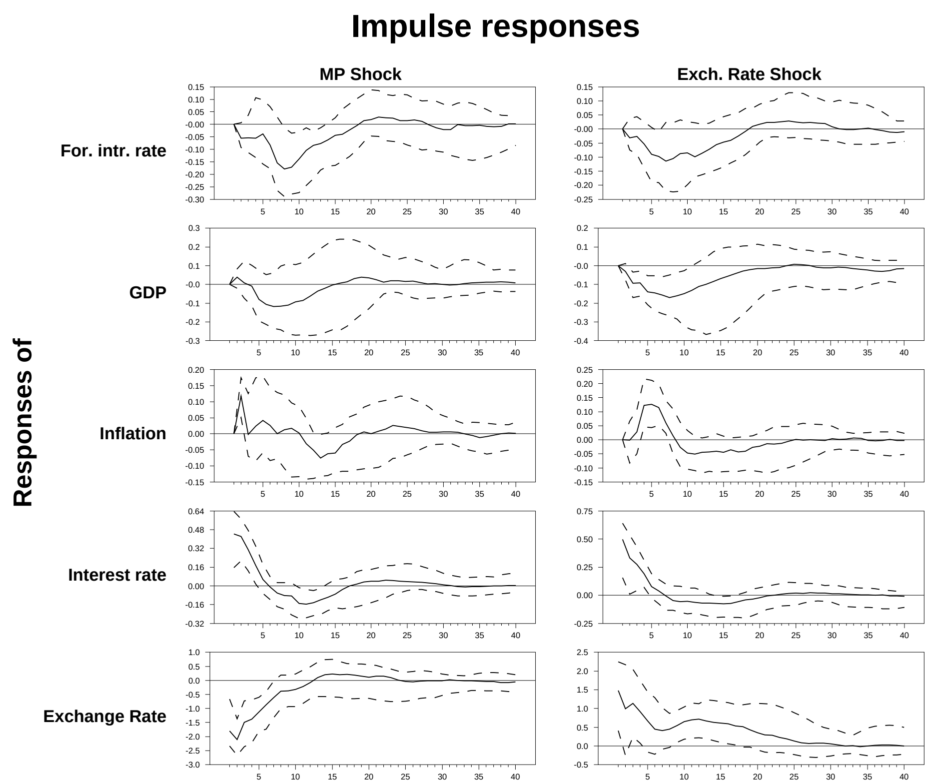
Figure 3.5: Sweden: The response to monetary policy shocks and exchange rate shocks



found in open economy VAR applications identified using recursive restrictions. Instead, our results are consistent with main conclusion from Faust and Rogers (2003) which, using sign restrictions only, could not rule out that there was an early peak in the exchange rate following a monetary policy shock.[9] However, whereas they could not determine whether the maximum

[9]In contrast, Uhlig and Scholl (2005) find no evidence of overshooting, also using sign restrictions. However, by restricting, among others, domestic prices from rising (thereby avoiding "price puzzle" by construction), they find instead puzzling responses in the other variables, as real output rises and the real exchange rate depreciates on impact following a contractionary monetary policy shock. These impulse responses are hard to interpret as all resulting from a *contractionary* monetary shock, making us question whether the

Figure 3.6: UK: The response to monetary policy shocks and exchange rate shocks



response was immediate or delayed, our results suggest the maximum response to be within a quarter. This result of instant overshooting is also consistent with findings in Bjørnland (2006, 2008) and Cushman and Zha (1997), using either long-run (neutrality) restrictions or a structural approach to identify the VARs. Finally, the magnitude of the response found here is consistent with (non-VAR) event studies that measure the immediate response of the exchange rate to shocks associated with particular policy

identified shocks could be a hybrid of shocks, lacking clear economic interpretations.

actions. For instance, Zettelmeyer (2004) analyzing Australia, Canada and New Zealand using daily data, finds that a one percentage point increase in the interest rate will appreciate the exchange rate on impact by 2-3 percent. Kearns and Manners (2006) using intraday data for the same three countries plus the UK find similar results, although the magnitude of the effects of the shocks is somewhat smaller. Hence, we feel confident to conclude that by allowing the interest rate and the exchange rate to respond simultaneously to news, the exchange rate behaves closer to economic theory than previous VAR studies have reported.

3.3.2 Does monetary policy respond to exchange rate shocks?

Having examined the response in the variables to a (unsystematic) monetary policy shock, we now turn to address the core question in this paper, namely how does the instrument of monetary policy, i.e. the interest rate, react to an exchange rate shock (right column)?

All the figures 1-6 emphasize that following an exchange rate shock that depreciates (increase) the real exchange rate by one percent, interest rates increase by 20-40 basis points. In all countries, the maximum interest rate response is immediate and then dies quickly out, within a year or so. Hence, if the central banks respond to an exchange rate shock, they do so mainly within a year. Failing to account for this interaction will therefore probably bias all other results.

Interestingly, the interest rate response could be (indirectly) related to the effect of the exchange rate on inflation, which increases temporarily in most countries. Output, on the other hand, responds very little at first, but as the monetary contraction intensifies, it starts to fall. Eventually monetary policy is eased, and output returns to equilibrium.

Are these results plausible? Much of the theoretical research to date indicates that monetary policy rules that react directly to the exchange rate (in addition to inflation and output) do not work much better in stabilizing inflation and real output than policy rules that do not react to the exchange rate (see Taylor (2001) and the references stated therein).[10] However, Taylor (2001) also points out that although there may be no evidence that the central bank follows a policy rule with a direct exchange rate effect, theory still suggests that there may be strong *indirect* effects of exchange rates on interest rates.

Such indirect effect can be the consequence of a monetary policy rule based on forecasts on future variables or with a rational expectation model for the term term structure of the interest rate. In both cases, inertia in the monetary transmission mechanism (i.e. unexpected exchange rate movements work with a lag on inflation and output) will make the interest rate respond to exchange rate movements through the effect this variable has on the expectations of future output and inflation. Consistent with this, some inflation-targeting central banks have argued that they specifically look at the exchange rate to assess to what extent it will impact on import prices and hence the inflation forecast, see e.g. Heikensten (1998) on Sveriges

[10]For instance, normative studies like Ball (1999) finds that although a depreciation of the exchange rate of 1 percent would call for an immediate interest rate response of 37 basis points, the effect would be partially offset by 15 basis points the period after. Similar responses are also suggested in Svensson (2000), but there the response is totally offset the next period.

Riksbank.[11]

Hence, central banks may want to respond to real exchange rate movements in order to smooth international relative price fluctuations that could affect their international competitiveness and have an effect on aggregate demand for domestic goods, which is consistent with what we found here. This is also the inherent feature of the recent work by Lubik and Schorfheide (2007), which using a DSGE model finds that in two of the four countries they examine (Canada and the UK), the central banks include the exchange rate in their policy rules. Using a similar model, but allowing the exchange rate to be endogenously determined, Dong (2008) finds larger responses, as measured by the marginal likelihood values. Now the Reserve Bank of Australia, the Bank of Canada and the Bank of England have all responded to real exchange rate movements in the past.

To sum up. To the extent that we can interpret our responses as systematic responses, we have found clear evidences of strong and simultaneous reactions between monetary policy and the exchange rate, similar in magnitude to those that were found in Dong (2008) and somewhat larger than those that were found in Lubik and Schorfheide (2007).

Finally, we examine the quantified contribution of the different shocks to the variance in the interest rate at different horizons. That is, Table 1 displays for each country the variance decomposition of the interest rate

[11] Heikensten (1998) writes (p.1): In this context I should like to elaborate on the Riksbank's appraisal of the Swedish krona... The Riksbank does not target the krona's exchange rate. But as one of the factors behind inflation, the exchange rate is important for monetary policy in a flexible exchange rate regime. A considerable period with a weak exchange rate might lead to a forecast rate of inflation that exceeds the target, in which case the Riksbank has to respond in order to meet this target.

with respect to the (median) effect of the different shocks. We focus on the effect on impact, after four quarters and after eight quarters. The table demonstrates that the exchange rate explains a large share (34-47 percent) of the variation in the interest rate on impact. In fact, in four of the countries, Australia, Canada, Norway and the UK, the exchange rate shocks are the most important shocks for explaining the variation in the interest rate on impact. However, the contribution of these shocks thereafter quickly dies out, so that after one year, the exchange rate shocks explain close to 20 percent of the interest rate variation in all countries but Sweden and the UK, where it contributes with 30 percent. However, after two years, the contribution has declined to 15-25 percent in all countries. These results are consistent with Lubik and Schorfheide (2007) and Dong (2008), who found that the exchange rate played an important role in the monetary policy setting in countries such as Canada and the UK (but less so in New Zealand). Interestingly, the countries that respond the most are all resource-intensive countries, where the export sector plays a large role in the economy.

Hence, we can conclude that the interest rate responds systematically to exchange rate shocks. However, as suggested above, this does not necessarily imply that the exchange rate has an independent role in the monetary policy rule, other than indirectly as a leading indicator for variables such as inflation. The magnitude of the response, however, indicates that the exchange rate is an important variable in the interest rate determination. Furthermore, accounting for this interaction may be important when identifying monetary policy in open economies. In particular, VAR studies that assume a lagged response in (the systematic) monetary policy setting to exchange rate news would most likely underestimate the monetary policy responses, as well as underestimate the role of the exchange rate in the the monetary policy transmission. This issue is explored further in the next section.

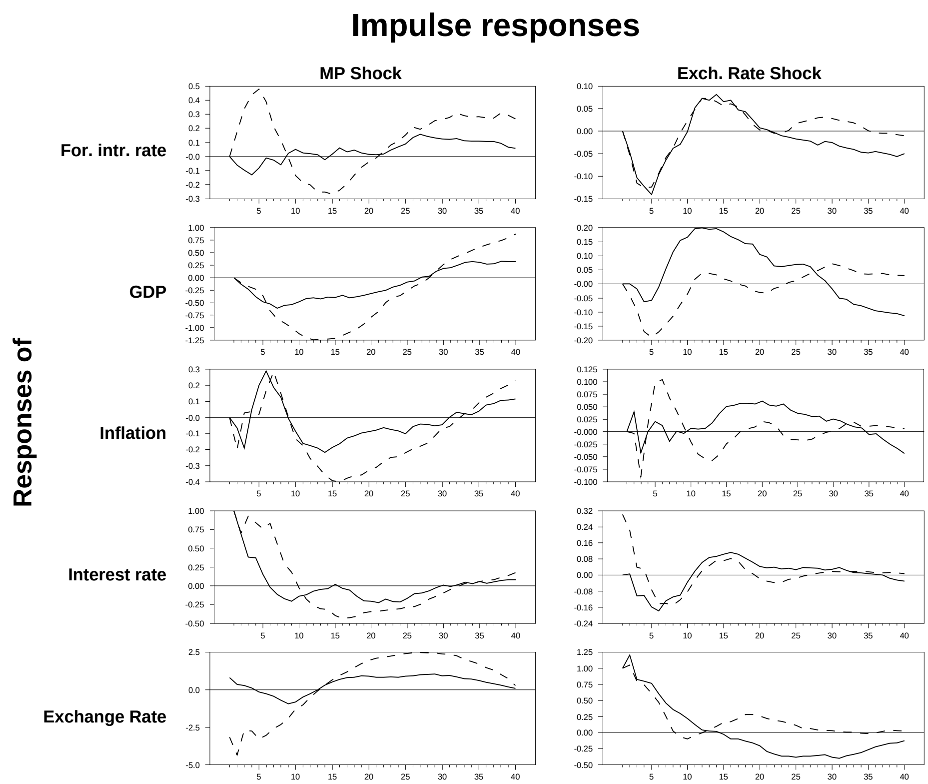
3.3.3 Comparing Cholesky-sign with Cholesky identification

If monetary policy reacts immediately to exchange rate shocks and the exchange rate reacts on impact to monetary policy shock, then one would expect the interaction between interest rates and exchange rates to be important when identifying the various shocks. Below we examine the implications of our restrictions versus a pure Cholesky decomposition where we restrict the interest rate to respond to exchange rate shocks with a lag.

Figures 7 gives a comparison of the recursive Cholesky identification and our suggested Cholesky-sign restriction for Canada. The results for the other countries are very similar and can be obtained on request. Note that solid line is the impulse responses found using the Cholesky decomposition with the exchange rate now ordered below the interest rate, while the dotted line is the median response following our suggested Cholesky-sign decomposition. For ease of exposition, the effect of the monetary policy shock (left column) is normalized to increase the interest rate by one percentage point initially, while the exchange rate shock (right column) is normalized to increase (depreciate) the exchange rate by one percent initially.

Starting with the effects of a monetary policy shock (left columns). The figure demonstrates that when monetary policy is identified using the traditional recursive Cholesky identification, there is virtually no exchange rate

Figure 3.7: Canada: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign



response to a monetary policy shock.[12] Recall that to obtain these responses, we have restricted the interest rate from responding initially to exchange rate shocks. However, since our suggested Cholesky-sign identification found exactly the opposite, i.e. monetary policy will react immediately to exchange rate shocks, one could expect the interaction between interest rates and exchange rates to be important when identifying monetary policy shocks.

[12]Similar results are also found for Australia, Canada, Norway and the UK, while for the remaining two countries (New Zealand and Sweden), the exchange rate responds on impact, but shows evidence of delay overshooting

Failing to account for this interaction may therefore likely have biased the results.

The right column, mapping out the effects of the exchange rate shocks, illustrates this. The figures suggest that when the recursive Cholesky identification is used, the interest rate does not respond to an exchange rate shock, even after a year. Hence, whereas the Cholesky-sign identification has uncovered a clear interaction between the interest rate and the exchange rate, the conventional Cholesky identification would fail to recover any simultaneity between the interest rate and the exchange rate. This is important, as many researchers would argue that by restricting the policy response from responding by one period only, one can still allow possible monetary policy reactions to the exchange rate, but with a lag. However, as suggested from the figures above, the policy reaction will in most cases be severely underestimated.

Finally, note also that when the Cholesky identification is used, the effect of the monetary policy shock on the remaining variables will also be underestimated, suggesting less of an inflation and output response relative to the median response found using the Cholesky-sign identification. Hence, accounting for an interaction between monetary policy and the exchange rate is imperative not only for estimating the systematic response in the interest rate to exchange rate shocks, but also for establishing the role of the exchange rate in the monetary policy transmission.

3.3.4 Robustness

Below we check robustness of our results by performing the following alterations to the: (i) model specification, (ii) lags, (iii) order of variables in the Cholesky decomposition, (iv) additional variables, (v) exogenous variables and (vi) sample stability. In more detail, we first examine two alterative model specifications. We estimate the model in levels but without the trend and we check robustness to the lag order, using two instead of four lags in the estimated VAR. We then test robustness to the order of variables in the recursive (Cholesky) block. That is, we reverse the order of the first three variables, so that inflation is ordered above output which is ordered above the foreign interest rate. Now output and inflation will respond with a lag to both domestic and foreign monetary policy. Next we check robustness to the inclusion of an oil price. An objection to our set up is that many of the countries examined are net oil exporters (in particular Canada, Norway and the UK). By including the oil price, we can examine if oil is an important contributor to exchange rate variations. To save on the degrees of freedom, we let the oil price be exogenous to the VAR (since these are small countries with little effect on oil prices), although allowing it to enter as an endogenous variable provides about the same results. We then check robustness to how we have included the foreign interest rate. Since the countries in our sample are small open economies, they have little effect (if any at all) on the foreign interest rate. We can therefore allow the foreign interest to be exogenous to the VAR. Finally, we re-estimate the model from 1988, using all variables. The period after 1988 is considered to be a more stable monetary policy regime, with more countries adopting inflation-targeting as a monetary policy strategy. Due to the relatively short sample, we let GDP, inflation, interest rates and exchange rate be endogenous (using two lags in the VAR), while the foreign interest rate and oil prices are included as exogenous variables.

Figures 8-13 in Appendix A graph the impulse responses from the robustness exercises respectively. The results are illustrated for Canada, but similar findings can be obtained for the other countries at request. Clearly the main results are robust to these changes. In particular, the interdependence between monetary policy and exchange rate fluctuations remains intact. The main changes are found when we remove the trend from the analysis, as now the effect of monetary policy on output is more persistent than in the basic case. However, this is not surprising as the relevant measure in the central bank's reaction function is the output gap, and not the level of output.

Regarding the test of the ordering of the first three variables, the results remain unchanged. This is interesting, as it suggests that the order of the variables in the recursive block does not play any role. This follows from a generalization of the well known findings in Christiano, Eichenbaum, and Evans (1999b). There, proposition 4.1 states that when the monetary policy variable (the interest rate) is ordered last in a Cholesky ordering, the responses to the monetary policy shock will be invariant to the ordering of the variables above the interest rate. Instead, the ordering of the variables above the policy equation becomes a computational convenience with no bite. The real bite here is the short-term (zero) restriction that the first three variables in the VAR do not respond contemporaneously to a monetary policy shock. The same argument will hold for the exchange rate shock since the first three variables do not respond contemporaneously to this shock either.

3.4 Conclusions

Empirical evidence using intraday data has shown that exchange rates react immediately to news, including news about monetary policy. If monetary policy also reacts quickly to surprise changes in the exchange rate, one would expect the interaction between interest rates and exchange rates to be important in applied analysis of monetary policy.

This paper has demonstrated that monetary policy and exchange rate interaction matter. By estimating VAR models that are identified using a combination of sign and short-term (zero) restrictions (the Cholesky-sign identification), we have analyzed how monetary policy has responded to exchange rate movements in six open economies. Our suggested identification preserves the contemporaneous interaction between the interest rate and the exchange rate, without extensively deviating from the established literature of identifying a monetary policy shock as an exogenous shock to an interest rate reaction function.

The novel feature of such an approach is that, instead of the conventional view of using a recursive Cholesky ordering for all of the variables, or the more recent view of relying on only pure sign restrictions, we combine the two approaches in an intuitive way. That is, we allow for a simultaneous reaction between the variables that are observed to respond intraday to news (the interest rate and the exchange rate), but maintain the Cholesky recursive order for the traditional macroeconomic variables that are observed to respond with delay (output, inflation etc.) to economic shocks.

Doing so, we find great interaction between monetary policy and the exchange rate. In particular, an exchange rate shock that depreciates the exchange rate by one percent, increases the interest rate on impact (within a quarter) by 20-40 basis points. Furthermore, we find the impact of monetary policy shocks on exchange rates to be non-trivial and consistent with Dornbusch overshooting. In particular, a contractionary monetary policy shock that increases the interest rate by one percentage point, appreciates the exchange rate on impact by 2.5-4 percent. The exchange rate thereafter gradually depreciates back to baseline, broadly consistent with UIP. These results are in contrast to what has been found previously in the literature using recursive restrictions, or, pure sign restrictions, to identify the structural VARs.

Table 3.1: Variance decomposition of the interest rate, 1, 4 and 8 quarter horizon

Shocks	Monetary policy shock	Exchange rate shock	Other shocks
AUSTRALIA			
1-step	0.44	0.47	0.09
4-step	0.45	0.22	0.33
8-step	0.30	0.14	0.56
CANADA			
1-step	0.30	0.41	0.29
4-step	0.21	0.15	0.64
8-step	0.19	0.18	0.63
NEW ZEALAND			
1-step	0.42	0.38	0.20
4-step	0.25	0.19	0.56
8-step	0.16	0.16	0.68
NORWAY			
1-step	0.33	0.39	0.28
4-step	0.22	0.18	0.60
8-step	0.17	0.13	0.70
SWEDEN			
1-step	0.50	0.34	0.16
4-step	0.34	0.33	0.33
8-step	0.22	0.24	0.54
UNITED KINGDOM			
1-step	0.34	0.42	0.24
4-step	0.36	0.32	0.32
8-step	0.29	0.23	0.48

3.5 Appendix

3.5.1 Data sources

All data are taken from the OECD database, except the Fed Funds rate that is taken from Eco Win. GDP and inflation are seasonally adjusted (s.a.) by the official sources, the remaining series are unadjusted. The following data series are used:

(π_t) Inflation, measured as annual changes in the consumer price index (CPI).

(y_t) Log real GDP, deflated by the official sources.

(re_t) [CCRETT01.IXOB.Q] Log of the real effective exchange rate, measured against a basket of trading partners. The exchange rate is specified so that an increase implies depreciation.

(i_t) [IR3TBB01.ST.Q] Three month domestic interest rate.

(i_t^*) Trade-weighted foreign interest rate. For Canada and the UK, the foreign interest rate is represented by the Federal Funds rate, as the US comprises more than 80 percent of the foreign trade weight. For Australia, New Zealand, Norway and Sweden, the foreign interest is an weighted average of the interest rate in the major trading partners, source: Reserve Bank of Australia (http://www.rba.gov.au/), Reserve Bank of New Zealand (http://www.rbnz.govt.nz/), Norges Bank (http://www.norges-bank.no) and Sveriges Riksbank (http://www.riksbank.com/) respectively.

3.5.2 Robustness

Figure 3.8: Australia: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

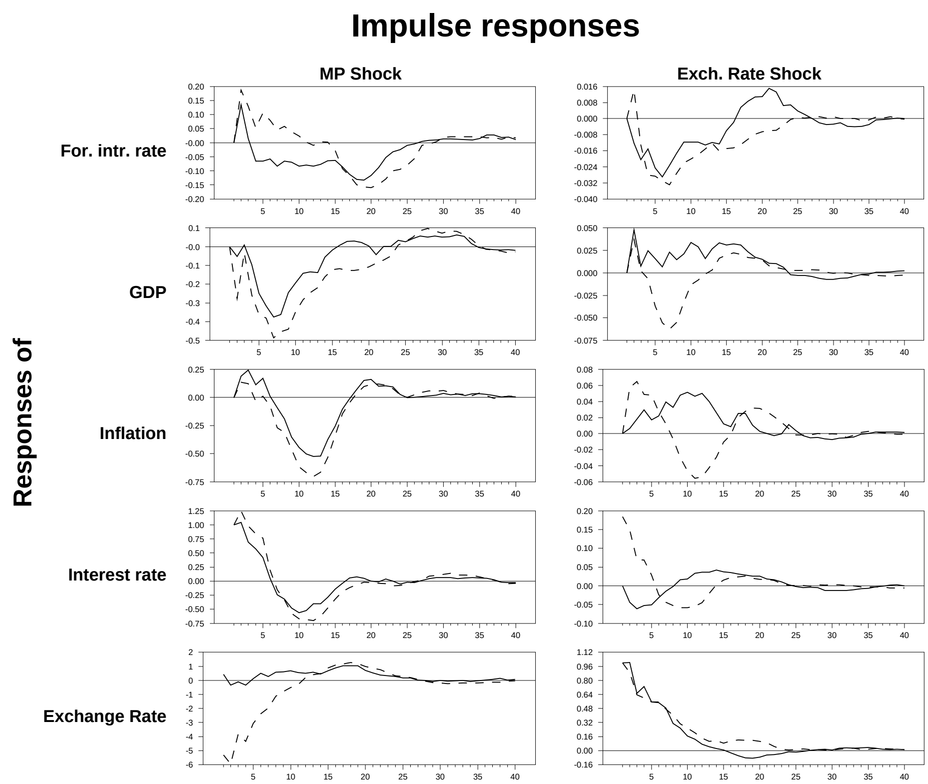


Figure 3.9: Norway: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

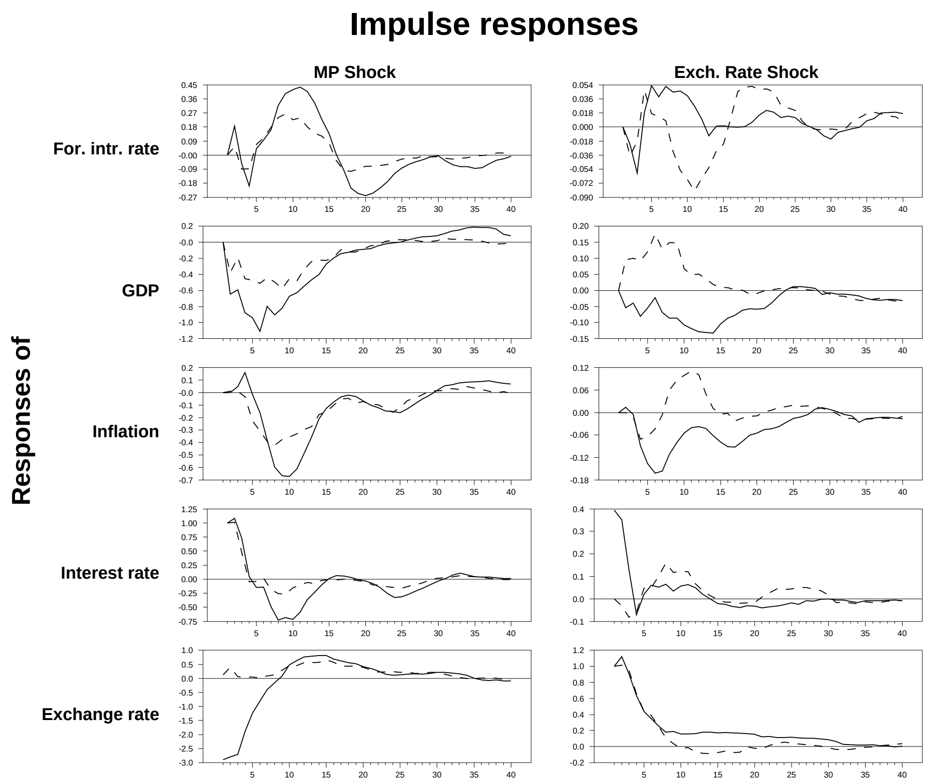


Figure 3.10: New Zealand: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

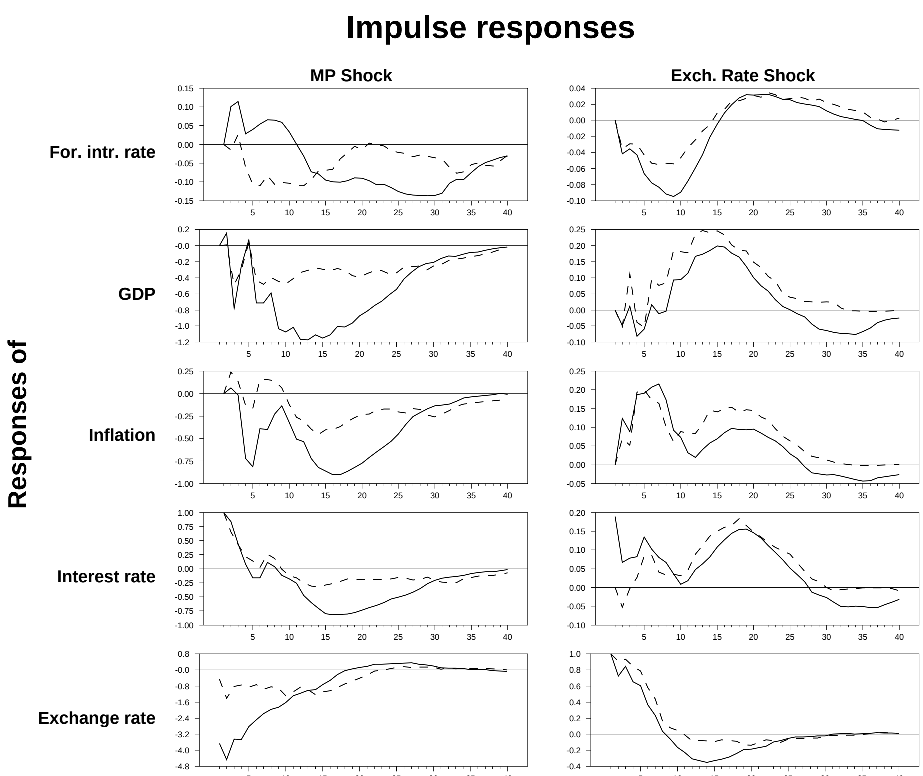


Figure 3.11: Sweden: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

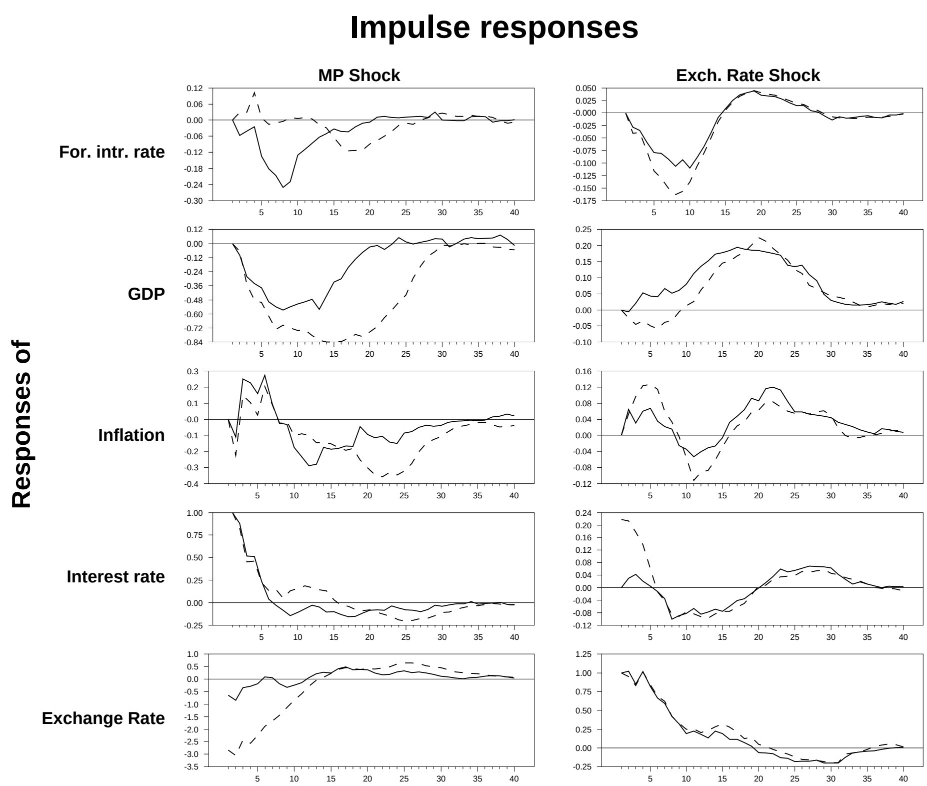


Figure 3.12: UK: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

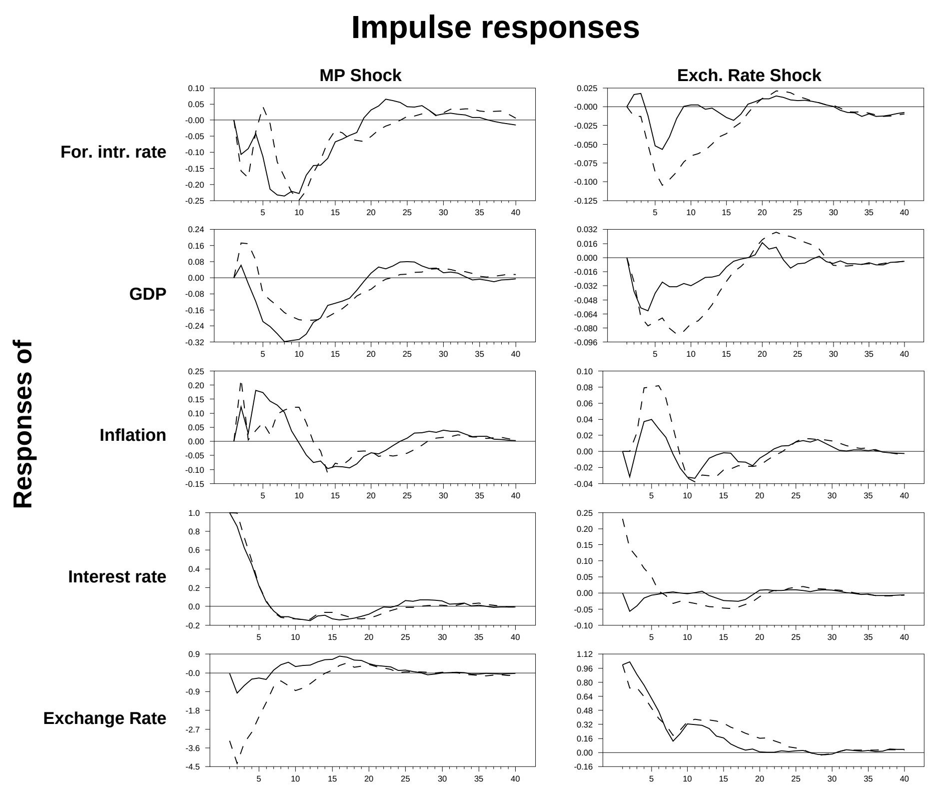


Figure 3.13: Canada: The response to monetary policy shocks and exchange rate shocks; Robustness: Model without trend

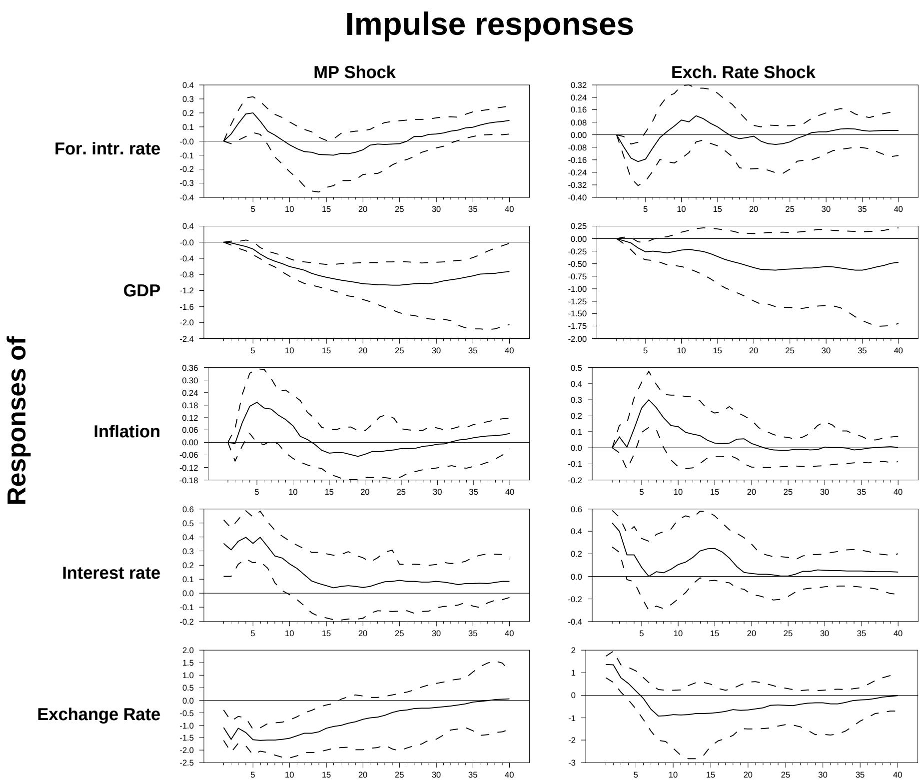


Figure 3.14: Canada: The response to monetary policy shocks and exchange rate shocks; Robustness: Model with 2 lags

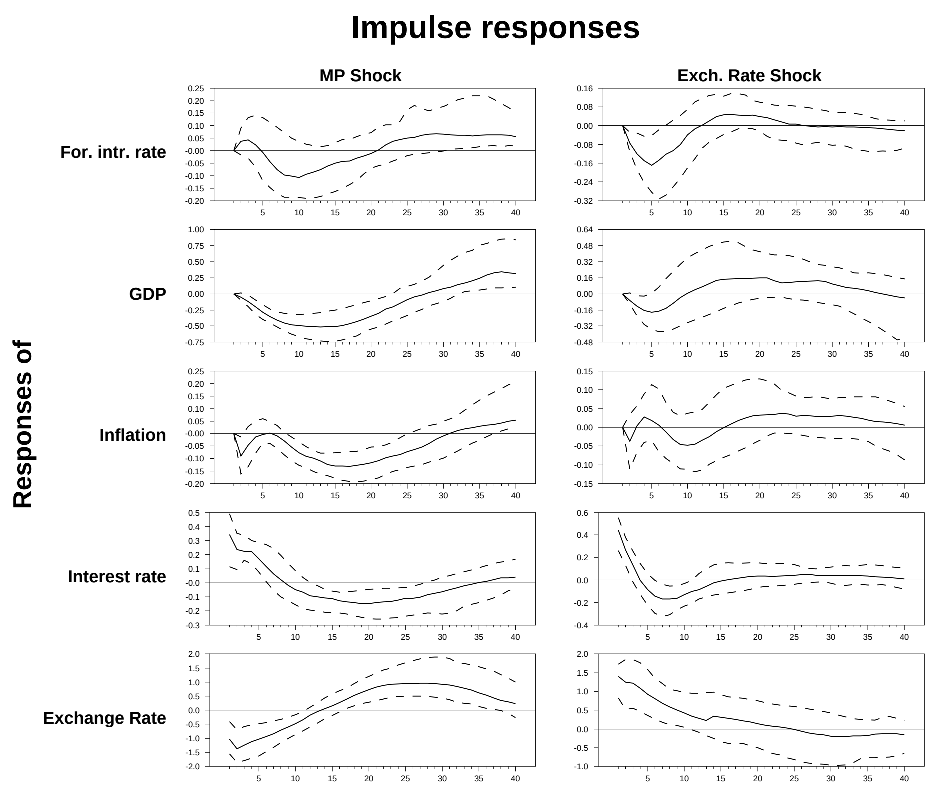
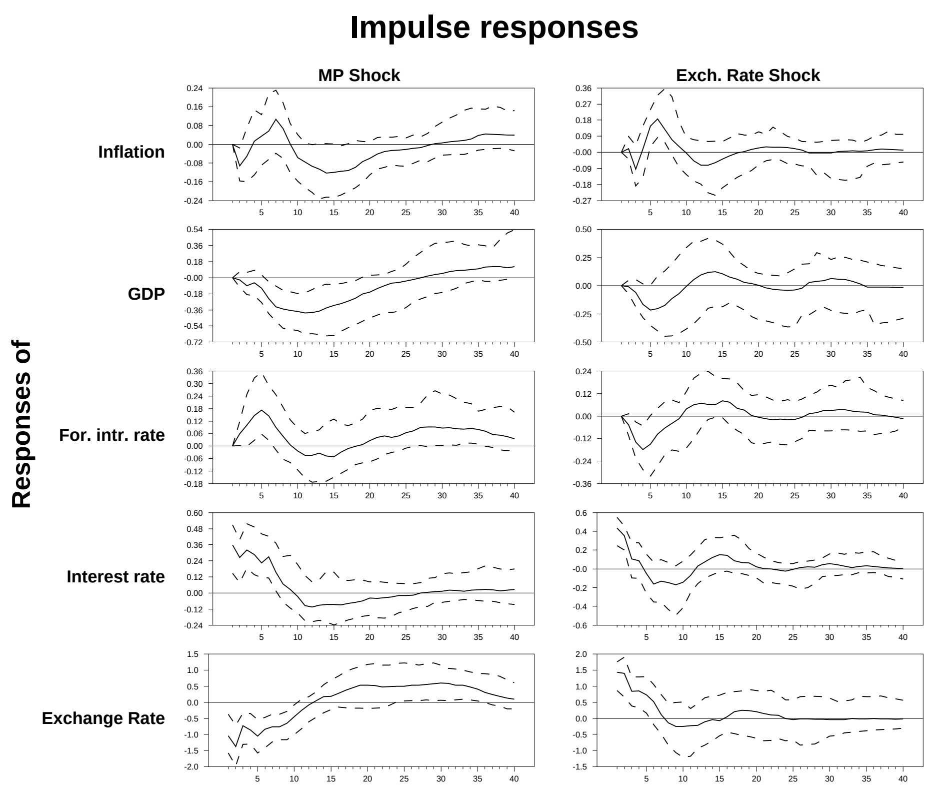


Figure 3.15: Canada: The response to monetary policy shocks and exchange rate shocks; Robustness: Alternative recursive order



4

Essay 3: Monetary Policy, Risk Premium and Portfolio Holdings in a Small Open Economy

Joint with Michal Zdenek

Abstract

In both the policy debate concerned with the desirability of a monetary union and in the dynamic macroeconomic theory, exchange rate risk premium and nominal exchange rate uncertainty are perceived to have negative welfare effects. For the policy debate, arguments linked to the theory of optimal currency areas are often referred to, while in modern macroeconomic literature it is common to model the risk premium as an exogenous stochastic process. In this paper, we make the risk premium and portfolio holdings endogenous in a dynamic general equilibrium model of an small open economy and investigate the impact of monetary policy. Our results challenge the conventional view of the risk premium and nominal exchange rate uncertainty as factors that are distorting portfolio decisions of the agents in an small open economy. [1]

[1]We are grateful to Hilde C. Bjørnland, Øystein Thøgersen, Mikhail Golosov and participants at NHH Macro Workshop for constructive comments.

4.1 Introduction

A fundamental policy question for a small open economy (SOE) is what kind of monetary policy regime it should adopt. Reflecting policy makers uncertainty about this issue, most countries have over time practiced various versions of fixed and floating exchange rate regimes. More recently, the policy question for many countries seems to have limited itself to a question of whether to have an independent inflation target, or to form a part of a monetary union.

The analysis of whether a country should join a monetary union naturally attracts a lot of attention, both from policymakers and researchers. A clear understanding of the welfare results that arise from such a decision is the focus of interest. In the policy debate, welfare results from the literature related to the theory of optimal currency areas (OCA) typically still have a strong influence. Researchers today, however, derive welfare results from the dynamic stochastic general equilibrium (DSGE) models using a fully micro-founded utility approach.

The welfare results from OCA theory are to some extent in line with those derived from DSGE models when it comes to the ability of monetary policy to bring the economy to its natural equilibrium level. In the theory of OCA, this result is achieved by a discretionary policy in a IS-LM framework.[2] Gali and Monacelli (2005) show that a somewhat similar result is obtained in a DSGE framework for the case of a New Keynesian model of a SOE. In this case, the implementation of a domestic inflation targeting rule will

[2] This was first highlighted in the pioneering work by Mundell (1961), McKinnon (1963) and Kenen (1969)

make the economy replicate its flexible price equilibrium.[3]

On the other hand, it is harder to bring together the welfare results from OCA theory with those from DSGE models when it comes to how monetary policy affects a country's portfolio selection opportunities. The policy debate seems to be particularly influenced by the theoretical analysis provided in Mundell (1973) and Baldwin (1989). In Mundell (1973), exchange rate uncertainty occurs outside a monetary union due to discretionary monetary policy. The presence of exchange rate uncertainty implies that consumption risk sharing through international capital market is limited because of market incompleteness. Consequently, asymmetric productivity shocks need to be absorbed mostly within the individual national economy. In Baldwin (1989), it is proposed that savings could have a stronger impact on growth of European economy than what typically is estimated. Baldwin (1989) forms the basis of the Emerson, Gros, and Italianer (1992) report 'One Market, One Money', where it is argued that the elimination of exchange rate uncertainty and the risk premium in a monetary union would lower the real interest rate which would imply more savings and thereby higher economic growth.

In the literature on the welfare analysis of a SOE using DSGE models, the ability of monetary policy to affect a country's portfolio selection opportunities has typically been ignored. An exception is Devereux and Sutherland (2007b) for the case of two symmetric open economies. The main reason for

[3] However, in the case of imperfect substitution between domestic and foreign goods, a flexible price equilibrium will not replicate first best output. As shown in Paoli (2009), this implies that the nominal exchange rate should also be included in the optimal monetary policy rule.

this omission is that the standard solution techniques do not allow optimizing agents to take into account information about the risk characteristics of their asset holdings. The lack of information implies indeterminacy. Specifically, starting from the same initial condition there exists a continuum of equilibria which all converge to a steady state. In Gali and Monacelli (2005), determinacy is achieved by making the rather strong assumption of a complete asset markets at the international level with its implication of full risk sharing.[4] In order to achieve, at least empirically, more realistic results many of today's state-of-the-art DSGE models (see for instance Smets and Wouters (2007) or Adolfson, Laseen, Linde, and Svensson (2008)) follow Kollmann (2002) in specifying the risk premium as an exogenous stochastic process. Using a DSGE model for the Swedish economy, Söderström (2008) argues that the risk premium shock has to a large extent induced inefficient volatility in the economy, pointing to that the benefits of joining monetary union could be substantial.

The contribution of this paper is to analyze how monetary policy affects a SOE's portfolio selection opportunities. We base our analysis on a version of a sticky price SOE model as in Gali and Monacelli (2005). We extend the model by making the risk premium and portfolio holdings endogenous in the case of an incomplete asset markets structure and study welfare results of monetary policy. Our approach makes use of the solution method for equilibrium portfolio holdings advocated in Devereux and Sutherland (2006). This method allows for portfolio holdings to be determined in a DSGE framework

[4]This assumption is at odds with the data. Crucini (1999) provides evidence that risk-sharing across countries is rather limited.

based on information about the assets' risk characteristics in the form of the variance of the stochastic shocks of the model.

Two results stand out from our analysis: First, the risk premium serves an allocative efficiency role since it provides clearing for the markets for nominal bonds which is used by the agents in order to obtain hedging against consumption risk. Second, monetary policy improves a SOE's portfolio selection opportunities by adopting a policy of strict domestic inflation targeting. The later result is similar to what is obtained for the study of two symmetric open economies in Devereux and Sutherland (2007b). However, in our case we show that monetary policy is also able to affect the level of the risk premium. Moreover, we show that the risk premium is not invariant to policy changes. Our results are of interest since they contradict the commonly used policy argument that nominal exchange rate uncertainty and the risk premium have a negative impact on a country's welfare. Furthermore, the results question the validity of the approach of modeling the risk premium as an exogenous stochastic process as is commonly done in New Keynesian DSGE models.

The rest of the paper is organized as follows: Section 4.2 presents the small open economy model. Section 4.3 adapts the solution method developed in Devereux and Sutherland (2006) for the portfolio holdings and the risk premium in the SOE. Section 4.4 provides a welfare analysis of portfolio holdings and studies the impact of monetary policy. Section 4.5 concludes. Derivations and technical details are given in the appendix.

4.2 The small open economy model

In this section a small open economy model is set-up. The model is a version of the New Keynesian model introduced in Gali and Monacelli (2005) with simplifying assumption about the homogeneity of the world economy. We allow for endogenous portfolio choice in an incomplete asset markets environment using the solution technique developed in Devereux and Sutherland (2006).

The world economy is modeled as a continuum of infinitesimally small open economies represented on the unit interval. Since each economy is of zero measure, its policy decisions have no impact on the rest of the world. We distinguish between the 'home' country, which in our environment refers to a single SOE, and the remaining 'foreign' economies which together make up the world economy. For all the SOE economies, we assume identical preferences, technology and market structure. We further assume that the productivity shocks for the 'home' open economy are uncorrelated with those of the 'foreign' economy. The financial market structure is represented by a 'home' nominal bond and 'foreign' nominal bond markets.

4.2.1 Households

The SOE is populated by a representative household maximizing expected discounted lifetime utility. It obtains utility from consumption and disutility from the labor effort. The specific utility function takes the form

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1-\varphi}}{1-\varphi} \right), \tag{4.1}$$

where β is the household's subjective discount rate satisfying $0 < \beta < 1$, σ is coefficient of relative risk aversion and φ denotes Frisch elasticity of labor supply. C_t is the composite consumption index defined across all home and foreign goods, and N_t denotes hours of labor.

The consumption index is defined by

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} (C_{H,t})^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} (C_{F,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} , \tag{4.2}$$

where $C_{H,t}$ and $C_{F,t}$ are indices of consumption of home and foreign produced goods, $0 < \alpha < 1$ is an (inverse) measure of the degree of home bias in consumption and η is the elasticity of substitution between home and foreign produced goods. The home country aggregate consumer price index is

$$P_t = \left[(1-\alpha)(P_{H,t})^{1-\eta} + \alpha(P_{F,t})^{1-\eta} \right]^{\frac{1}{1-\eta}} . \tag{4.3}$$

where $P_{H,t}$ and $P_{F,t}$ are the price indices of home and foreign produced goods respectively.

For a given level of consumption, the domestic household's demand for home and foreign consumption goods is given as [5]

$$C_{H,t} = (1-\alpha) \left(\frac{P_{H,t}}{P_t} \right)^{-\eta} C_t \text{ ; } C_{F,t} = \alpha \left(\frac{P_{F,t}}{P_t} \right)^{-\eta} C_t \tag{4.4}$$

For given demand functions, the representative household of the home coun-

[5] Home and foreign aggregate demand function is used to further determine demand for domestic differentiated good $C_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon} C_{H,t}$, for country i demand for foreign consumptions goods $C_{i,t} = \left(\frac{P_{i,t}}{P_{F,t}} \right)^{-\gamma} C_{F,t}$ and for country i demand for foreign differentiated good $C_{i,t}(j) = \left(\frac{P_{i,t}(j)}{P_{i,t}} \right)^{-\epsilon} C_{i,t}$.

try faces a budget constraint of the form

$$P_t C_t + W_{t+1} \leqq w_t N_t + \Pi_t + P_t(r_{H,t}\Xi_{H,t-1} + r_{F,t}\Xi_{F,t-1}) \qquad (4.5)$$

where w_t denotes the nominal wage, Π_t is the total profit generated by monopolistically competitive home country firms,[6] $r_{H,t}$ represents period t real rate of return on home assets and $\Xi_{H,t}$ denotes home country household's holdings of domestic assets at period t. Similarly, $r_{F,t}$ and $\Xi_{F,t}$ for foreign assets. W_t is the net value of nominal wealth of the home household and is defined as

$$W_t = P_t(\Xi_{H,t-1} + \Xi_{F,t-1}). \qquad (4.6)$$

Real rates of return on home ($r_{H,t}$) and foreign ($r_{F,t}$) assets are defined as

$$r_{H,t} = R_{H,t}\frac{P_{t-1}}{P_t} \;\; ; \;\; r_{F,t} = R_{F,t}\frac{P^*_{t-1}}{P^*_t} \qquad (4.7)$$

where P^*_t is the aggregate price level for the foreign economy and $R_{H,t}$, $R_{F,t}$ denote respectively nominal rates of return on domestic and foreign assets.

The representative agent's utility maximization problem yields standard optimality conditions. The intratemporal condition for consumption-leisure tradeoff is characterized by

$$N_t^{\varphi} C_t^{\sigma} = \frac{w_t}{P_t}. \qquad (4.8)$$

[6]We assume that the home country consumer is the default owner of the home firms and hence receives all monopoly profits.

The stochastic Euler equation is given as

$$C_t^{-\sigma} = \beta E_t(C_{t+1}^{-\sigma} r_{F,t+1}). \tag{4.9}$$

Finally, optimal portfolio choice implies

$$E_t C_{t+1}^{-\sigma}(r_{H,t+1} - r_{F,t+1}) = 0. \tag{4.10}$$

4.2.2 Firms

All goods markets are characterized by monopolistic competition. A typical firm produces one differentiated final good and all the firms have access to identical technology. The production function is given as

$$Y_t(j) = A_t N_t(j), \tag{4.11}$$

where $Y_t(j)$ is the output produced by a firm j in a period t, and A_t is the productivity level which follows an AR(1) process given by

$$\log A_t = \rho_a \log A_{t-1} + e_t \tag{4.12}$$

where $0 < \rho_a < 1$ and e_t is an i.i.d. productivity shock with $E_{t-1}[e_t] = 0$ and $Var[e_t] = \sigma_e^2$.

Profit maximizing firms are assumed to set nominal prices according to a Calvo rule: In each period, only a fraction $1-\theta$ of randomly selected firms is able to set new prices, hence $\theta \in [0, 1]$ is an index of price stickiness.[7]

[7] See Calvo (1983) for more details on a firm's optimal price setting strategy.

All prices are set in terms of producer's currency. For the firms that are allowed to reset their prices in period t the optimization problem will be to maximize the present value of expected discounted future profit stream

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ Q_{t,t+k} \left[Y_{t+k}^d \left(\overline{P}_{H,t} - MC_{t+k}^N \right) \right] \right\} \tag{4.13}$$

subject to the sequence of demand constraints

$$Y_{t+k}^d \leq \left(\frac{\overline{P}_{H,t}}{\overline{P}_{t+k}} \right)^{-\epsilon} \left(C_{H,t+k} + \int_o^1 C_{H,t+k}^i di \right) \tag{4.14}$$

where $Q_{t,t+k} \equiv \beta^k (\frac{C_{t+k}}{C_t})^{-\sigma} (\frac{P_t}{P_{t+k}})$ is the stochastic discount factor and MC_{t+k}^N denotes the nominal marginal cost. The first order condition for price setting is given by

$$\sum_{k=0}^{\infty} \theta^k E_t \left[Q_{t,t+k} Y_{t+k} \left(\overline{P}_{H,t} - \frac{\epsilon}{1-\epsilon} MC_{t+k}^n \right) \right] = 0. \tag{4.15}$$

The solution for $\overline{P}_{H,t}$ is given as

$$\overline{P}_{H,t} = \left(\frac{\epsilon}{1-\epsilon} \right) \frac{E_t \sum_{k=0}^{\infty} \beta^k Q_{t,t+k} Y_{t+k} MC_{t+k}^n}{E_t \sum_{k=0}^{\infty} \beta^k Q_{t,t+k} Y_{t+k}} \tag{4.16}$$

Finally, the dynamics of the domestic price index is characterized by the following expression.

$$P_{H,t} = \left[\theta P_{H,t-1}^{1-\epsilon} + (1-\theta) \overline{P}_{H,t}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}. \tag{4.17}$$

4.2.3 Monetary policy

The nominal interest rate is determined by a simple rule which is subject to stochastic financial markets shocks

$$R_{H,t+1} = \beta^{-1} \left(\frac{P_{H,t}}{P_{H,t-1}} \right)^{\zeta} \exp(m_t) \tag{4.18}$$

where m_t is i.i.d. stochastic financial shocks assumed to be outside the direct control of the monetary authority with $E_{t-1}[m_t] = 0$ and $Var[e_t] = \sigma_m^2$. From this equation, we see that monetary policy determines the nominal rate of return on domestic bonds as a function of the last period's producer price inflation rate. The parameter ζ represents the stance of monetary policy.

4.2.4 The world economy

We assume that all the foreign countries share the same AR(1) technological process with perfectly correlated productivity shocks. The foreign countries' productivity shocks are, however, uncorrelated with productivity shocks of the home country. Foreign countries have common monetary policy (i.e. form a monetary union), implying that only one foreign nominal bond is issued in the world economy. Further, in order to simplify our analysis, stochastic stochastic financial shocks play no role in the world economy.

4.2.5 Domestic market clearing conditions

In order to close the model, we need to impose market clearing conditions for the domestic labor market, the final goods market and the asset market.

For the domestic labor market, the representative household labor supply must equal domestic aggregate labor demand

$$N_t = \int_0^1 N_t(i) di \tag{4.19}$$

The domestic goods market clearing condition for the differentiated good j requires that the supply of the good must be equal to the sum of the demands from the domestic economy and that of the foreign economies

$$Y_t(j) = C_{H,t}(j) + \int_0^1 C^i_{H,t}(j) di \text{ for all } j \in (0,1) \tag{4.20}$$

Where the aggregate production level is determined by the following CES aggregator:

$$Y_t \equiv \left[Y_t(j)^{\frac{1-\epsilon}{\epsilon}} \right]^{\frac{\epsilon}{1-\epsilon}} \tag{4.21}$$

Finally, market clearing condition for the domestic asset market requires

$$\Xi_{H,t} + \Xi^*_{H,t} = 0 \tag{4.22}$$

4.3 Solving the model

In general, the model from section 4.2 does not have any analytical solution. A common approach to dealing with this issue is to derive the solution of the DSGE model using a first-order (log) linear approximation of the equilibrium conditions around its deterministic steady state.

A standard solution approach, however, will involve two important complications for the portfolio decision problem. First, the equilibrium portfolio will be indeterminate in a first-order linear approximation. The indeterminacy follows as the agents' portfolio decision is here entirely determined by the information given by the first moments of the stochastic shocks. Second, in a deterministic steady state, all portfolio allocations can be regarded as valid equilibria. Hence, a set of possible approximation points will be available.

In general these two complications can be overcome. For the first issue, using a higher-order approximation will make the portfolio decision determinate since the risk characteristics of the assets in the form of higher moments will be considered. For the second issue, as pointed out in Judd and Guu (2001), from the set of deterministic steady state portfolio allocations the bifurcation point can be selected as a point of approximation. The bifurcation point represents the unique optimal portfolio allocation when the stochastic noise of the economy becomes arbitrarily small, and consequently will serve as a reasonable approximation point.

By making use of these two results, Devereux and Sutherland (2006) develop a general solution methodology that allows for determining asset holdings for standard DSGE models. In their methodology, the optimal portfolio is obtained by a combination of second-order approximation to the *portfolio equilibrium conditions* with a first-order approximation to the solution of the *non-portfolio equilibrium conditions*. In this approach, the equilibrium portfolio conditions will only feature cross-products of the endogenous variables, implying that a second-order *accurate* solution can be derived using only first-order approximation of the non-portfolio equilibrium conditions (see Lombardo and Sutherland (2007)). By applying this results, we can determine the solution of the *steady state* portfolio holdings in a two-step procedure: First, solve the model taking the first-order approximation of the non-portfolio equilibrium conditions. Second, extract from this solution the cross products of the variables needed to solve the portfolio equilibrium conditions.[8]

4.3.1 The deterministic steady state

As the approximation point for the non-portfolio equilibrium conditions we choose a symmetric deterministic steady state. Thus, we have (bar over a variable denotes its steady state value) $\overline{W} = 0$, $\overline{Y} = \overline{C}$, $\overline{P}_{H,t} = \overline{P}_{F,t} = \overline{P}$, $\overline{r}_H = \overline{r}_F = \frac{1}{\beta}$, $\Rightarrow \overline{r}_x = 0$, $\overline{\Xi} \equiv \overline{\Xi}_H = -\overline{\Xi}_F$.

4.3.2 The log-linearized version of the small open economy model

Non-portfolio part

A reduced form system for the endogenous variables[9] $\hat{W}_t, \hat{C}_t, \hat{Y}_t^*, \hat{\chi}_t, \pi_{H,t}, \pi_{F,t}^*, \hat{r}_{x,t}$ of the first-order log-linear approximation of the equilibrium conditions can

[8] We must use the steady state portfolio holdings since this is the only variable that will appear when using a first-order approximation of the non-portfolio equilibrium conditions. To study dynamic asset holdings, one must combine a third-order approximation to the portfolio equilibrium conditions with a second-order approximation to the solution of the non-portfolio equilibrium conditions (see Devereux and Sutherland (2007a)).

[9] Hat denotes percentage deviation from the steady state value.

be written as follows (for derivations, see appendix 4.6.1) [10]

$$\sigma(E_t\hat{C}_{t+1} - \hat{C}_t) = \sigma(E_t\hat{Y}^*_{t+1} - \hat{Y}^*_t) + (1-\alpha)(E_t\hat{\chi}_{t+1} - \hat{\chi}_t) + O(\epsilon^2) \quad (4.23)$$

$$\hat{W}_{t+1} = \frac{1}{\beta}\hat{W}_t + \tilde{\Xi}\hat{r}_{x,t+1} - \alpha\hat{\chi}_t + \hat{Y}_t - \hat{C}_t + O(\epsilon^2) \quad (4.24)$$

$$\hat{Y}_t = (1-\alpha)\hat{C}_t + \alpha\hat{Y}^*_t + \eta(1-\alpha)\alpha\hat{\chi}_t + \gamma\alpha\hat{\chi}_t + O(\epsilon^2) \quad (4.25)$$

$$\pi_{H,t} = \beta E_t\pi_{H,t+1} + \lambda\left[\varphi\hat{N}_t + \sigma\hat{C}_t + \alpha\hat{\chi}_t - \hat{A}_t - \mu\right] + O(\epsilon^2) \quad (4.26)$$

$$\sigma(E_t\hat{C}_{t+1} - \hat{C}_t) + E_t\pi_{H,t+1} + \alpha(E_t\hat{\chi}_{t+1} - \hat{\chi}_t) = \zeta\pi_{H,t} + m_t + O(\epsilon^2) \quad (4.27)$$

$$\pi^*_{F,t} = \beta E_t\pi^*_{F,t+1} + \lambda\left[\varphi\hat{N}^*_t + \sigma\hat{Y}^*_t - \hat{A}^*_t - \mu\right] + O(\epsilon^2) \quad (4.28)$$

$$\sigma(E_t\hat{Y}^*_{t+1} - \hat{Y}^*_t) + E_t\pi^*_{F,t+1} = \zeta^*\pi^*_{F,t} + O(\epsilon^2) \quad (4.29)$$

$$\hat{r}_{x,t+1} = -(S_{t+1} - E_tS_{t+1}) + O(\epsilon^2) \quad (4.30)$$

where $\tilde{\Xi} = \frac{\overline{\Xi}}{\beta\overline{Y}}$, bilateral terms of trade are defined as $\hat{\chi}_t \equiv \hat{P}_{F,t} - \hat{P}_{H,t} \equiv \hat{P}^*_{F,t} + \hat{S}_t - \hat{P}_{H,t}$ and S_t is the nominal exchange rate.

Portfolio part

The second-order log-linear approximation of the portfolio equilibrium conditions can be combined so that in equilibrium the following equations must hold (for derivation, see appendix 4.6.2):

$$\mathtt{Cov}_t\left[(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \frac{\hat{Q}_{t+1}}{\sigma}), (\hat{r}_{x,t+1})\right] = 0 + O(\epsilon^3) \quad (4.31)$$

[10] Note, the term $O(\epsilon^{n+1})$ captures all the terms of higher order than n.

$$E_t(\hat{r}_{x,t+1}) = -\frac{1}{2}\left[\texttt{Var}_t(\hat{r}^2_{1,t+1}) - \texttt{Var}_t(\hat{r}^2_{2,t+1})\right] + \sigma\frac{1}{2}\texttt{Cov}_t\left[(\hat{C}_{t+1} + \hat{Y}^*_{t+1} + \frac{\hat{Q}_{t+1}}{\sigma}), (\hat{r}_{x,t+1})\right] + O(\epsilon^3) \tag{4.32}$$

4.3.3 The steady state portfolio holdings and the risk premium

Subsection (4.3.2) and (4.3.3) provide the necessary information to implement Devereux and Sutherland (2006)'s two-step procedure. The procedure will help us to determine the steady state portfolio holdings of nominal assets and the exchange rate risk premium in the SOE.

Step 1: The non-portfolio part

In order to find the solution to the non-portfolio part of the model, we need to fit the reduced form system of equations to the following first order state space representation

$$A_1\begin{bmatrix} s_{t+1} \\ E_t c_{t+1} \end{bmatrix} = A_2\begin{bmatrix} s_t \\ c_t \end{bmatrix} + A_3 x_t + B\xi_t + O(\epsilon^2) \tag{4.33}$$

$$x_t = Nx_{t-1} + \varepsilon_t \text{ where } \Sigma = E(\varepsilon_t \varepsilon_t')$$

We start doing this by replacing $\tilde{\Xi}\hat{r}_{x,t+1}$ with ξ_{t+1}, where ξ_{t+1} is a zero mean i.i.d. random variable. The coefficient matrices $A1$, $A2$, $A3$, B and N

in the state space representation will be specified by setting

$$
\begin{aligned}
s_t' &= \left[\hat{W}_t\right] \\
c_t' &= \left[\hat{C}_t, \hat{\chi}_t, \hat{Y}_t^*, \pi_{H,t}, \pi_{F,t}^*, \hat{r}_{x,t}\right] \\
x_t' &= \left[\hat{M}_t, \hat{A}_t, \hat{A}_t^*,\right] \\
\varepsilon_t' &= [m_t, e_t, e_t^*,] \\
N &= \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \\
\Sigma &= \begin{bmatrix} \sigma_m^2 & 0 & 0 \\ 0 & \sigma_a^2 & 0 \\ 0 & 0 & \sigma_{a^*}^2 \end{bmatrix}
\end{aligned}
$$

For the parameters of our model, we use the following calibration values:

Parameter	**Calibration Value**
β	0,99
α	0,5
γ	1,5
θ	0,5
ζ	2
η	1,5
σ	1
φ	0

The model will have the first order state space solution of the following form

$$s_{t+1} = T_1 x_t + T_2 s_t + T_3 \xi_t + O(\epsilon^2) \tag{4.34}$$

$$c_t = P_1 x_t + P_2 s_t + P_3 \xi_t + O(\epsilon^2) \tag{4.35}$$

Step 2: Portfolio part

From the first order state space solution, we extract the following variables [11]

$$\hat{r}_{x,t+1} = R_1 \xi + R_2 \varepsilon + O(\epsilon^2) \tag{4.36}$$

$$(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \hat{Q}_{t+1}) = D_1 \xi + D_2 \varepsilon + D_3 \mathbf{X} + O(\epsilon^2) \tag{4.37}$$

$$(\hat{C}_{t+1} + \hat{Y}^*_{t+1} + \hat{Q}_{t+1}) = F_1 \xi + F_2 \varepsilon + F_3 \mathbf{X} + O(\epsilon^2) \tag{4.38}$$

(4.36) and (4.37) can be used to find the steady state portfolio holdings of domestic nominal bonds (for derivation, see appendix 4.6.3)[12]

$$\tilde{\Xi} = \left[R_2 \Sigma D_2' R_1' - D_1 R_2 \Sigma R_2' \right]^{-1} R_2 \Sigma D_2' + O(\epsilon^3) \tag{4.39}$$

(4.36) and (4.38) together with the solution in (4.39) can be used to find the steady state exchange rate risk premium (for derivation, see appendix

[11] We can drop the time subscript since a non-time varying covariance matrix Σ will make the conditional one-period-ahead second moments solution of the model non-time varying (see property 4 in Devereux and Sutherland (2006)).

[12] Note that if we let $\Sigma = C\Sigma_0$ and let $C \to 0$ (i.e. we get infinitesimally small noise) the value of $\overline{\Xi}$ will be arbitrarily close to a deterministic steady state that represents a bifurcation point. Hence, this will be consistent with using the deterministic steady state as an approximation point for the non-portfolio variables.

4.6.3)

$$\overline{rp} = \frac{1}{2}\tilde{R}_2 \Sigma \tilde{F}_2{}' + O(\epsilon^3) \tag{4.40}$$

where $\tilde{R}_2 \equiv \left(1 - R_1 \tilde{\Xi}\right)^{-1} R_2$ and $\tilde{F}_2 \equiv F_1 \tilde{\Xi} \tilde{R}_2 + F_2$

4.4 Welfare analysis of portfolio holdings

4.4.1 Partial equilibrium analysis of portfolio holdings

Before we start analyzing the steady state portfolio holdings and the exchange rate risk premium in general equilibrium, it is useful to obtain some intuition by first performing an analysis of portfolio holdings in a partial equilibrium setting. We start this by extracting the domestic consumption and real excess return from the state space solution (see appendix (4.6.4)):[13]

$$\hat{C}_t = -0.25 m_t + 0.71 e_t + 0.29 e_t^* + 0.010 \tilde{\Xi} r_{x,t} + O(\epsilon^2) \tag{4.41}$$

$$\hat{r}_{x,t} = 0.75 m_t - 0.57 e_t + 0.57 e_t^* + 0.020 \tilde{\Xi} r_{x,t} + O(\epsilon^2) \tag{4.42}$$

For the convenience of our analysis, suppose initially that the portfolio share of domestic bond to GDP is zero, i.e. $\tilde{\Xi} = 0$. From (4.41), we can see that in response to a interest rate shock of one percentage point the consumption index will be reduced by 0.25. To be able to hedge against this effect, the household has incentives to obtain a portfolio holdings that will generate a positive income stream to offset the impact that the interest

[13]Note, we have used the steady state value of wealth by setting $\hat{W}_t = 0$

rate shock has on consumption. From (4.42) we have that the interest rate shock will cause an immediate appreciation so that the excess return on domestic nominal bonds will increase by a factor of 0.75. Consequently, to insure against consumption risk, gross portfolio holdings are required to take a long position in domestic nominal bonds financed by a short position in foreign nominal bonds. However, since the level of portfolio holdings also influences the terms of trade, an additional effect from changes in portfolio holdings on the real excess return will take place. In total, it will be the case that a complete hedge against a productivity shock requires a positive share in home nominal bonds proportional to $0.25 \cdot 0.75/(0.25 \cdot 0.75 + 0.75^2)$. The first term in the denominator adjusts for the influence from the terms of trade, while the remaining part of the expression represents the immediate effect of the interest rate shock on real excess return. To obtain the optimal portfolio holdings, the expression must be scaled by a proportionality factor of $1/0.01$. This reflects the fact that the pay-off from a one-period bond is only transitory and consequently needs to be magnified in order to generate an income stream that can offset the immediate impact that a structural shock have on consumption.

By applying similar type of reasoning, a domestic productivity shock can be fully hedged by a positive portfolio holdings proportional to $0.71 \cdot 0.57/(2 \cdot 0.71 \cdot 0.57 + 0.57^2)$. However, for a foreign productivity shock, the portfolio holding will in general be indeterminate.[14]

[14]The explanation for this is that to hedge against the direct impact of this shock a negative domestic portfolio holding is demanded. But since a negative portfolio holding will reduce the effect a foreign productivity shock impact has on the real excess return, it will reduce the initial impact of hedging. In general, increased demand for domestic bonds will not be able to catch up with this latter effect making the portfolio holdings

Suppose now a setting in which the household faces all the uncorrelated structural shocks simultaneously. The optimal portfolio holdings will be affected by the relative variance of each of the different structural shocks. In particular, when the variance of one of the structural shocks increases relatively to the other structural shocks, the optimal portfolio shares will move towards the portfolio holdings required to fully hedge against that shock.[15] The intuition is that increased variance of a shock will make the variance of consumption more exposed to the shock. Hence, the household is provided with incentives to adjust its portfolio holdings to hedge more against it.

4.4.2 General equilibrium portfolio holdings and the risk premium

If the world economy consisted of risk neutral agents the portfolio demands (discussed in the previous subsection) from SOE would always be met. This would be the case since foreign agents then would be willing to absorb all the risk. However, we have assumed that foreign agents are risk averse. Further, since our SOE setting differs from the analysis for two symmetric open economies, the portfolio demands from the foreign agents would not be the same as the demand from the SOE. Hence, since changes in expected real excess return (i.e. risk premium) provides incentives for changes in

---

indeterminate.

[15]This can be shown by setting the exchange rate risk premium equal to zero in the portfolio selection equation (4.72) in the appendix. Then insert for equation (4.41) and (4.42) in the remaining expression, solve for the portfolio holdings which gives $\frac{1}{0.010}\frac{0.25\cdot 0.75\sigma_m^2+0.71\cdot 0.57\sigma_a^2-0.29\cdot 0.57\sigma_{a*}^2}{2(0.25\cdot 0.75\sigma_m^2+0.71\cdot 0.57\sigma_a^2)+0.75\sigma_m^2+0.57^2\sigma_a^2}$.

portfolio demand it also serves an allocative efficiency role since it provides market clearing for nominal bonds. In other words it provides an optimal trade-off between risk (variance) and expected return (mean) for the SOE.

This implies that the general equilibrium portfolio holdings from the solution to our model can be expressed as

$$\tilde{\Xi} = \frac{\overbrace{(0.19\sigma_m^2 + 0.41\sigma_a^2 + 0.41\sigma_{a^*}^2)}^{A}}{0.010\left[\underbrace{2(0.19\sigma_m^2 + 0.41\sigma_a^2 + 0.41\sigma_{a^*}^2)}_{B} + \underbrace{(0.56\sigma_m^2 + 0.33\sigma_a^2 + 0.33\sigma_{a^*}^2)}_{C}\right]} \tag{4.43}$$

The risk premium becomes

$$\overline{rp} = 0.5\left[p'\underbrace{\left(-0.19\sigma_m^2 - 0.41\sigma_a^2 + 0.73\sigma_{a^*}^2\right)}_{D} + p''\underbrace{\left(0.56\sigma_m^2 + 0.33\sigma_a^2 + 0.33\sigma_{a^*}^2\right)}_{E}\right] \tag{4.44}$$

where $p' \equiv (1 - 0.010\tilde{\Xi})^{-1}$ and $p'' \equiv p'^2 0.010\tilde{\Xi}$ represent two scaling factors.

As such, the uncovered interest rate parity (UIP) can be expressed as

$$R_{H,t} - R^*_{W,t} + \overline{rp} = E_t(\hat{S}_{t+1} - \hat{S}_t) + O(\epsilon^3) \tag{4.45}$$

In the expression for domestic nominal bonds (4.43), the term in the numerator (labeled as A) together with the term in the denominator (labeled as C), scaled by the proportionality factor 1/0.01, determine the equilibrium level of domestic nominal bond holdings given that bond holdings do not influence the terms of trade. However, since the share of domestic nominal bonds also influences the terms of trade, the equilibrium level of domestic nominal bond holdings must be adjusted by the term in the denominator (labeled as B).

In the expression for the risk premium (4.44), the first term inside the bracket (p'D) represents the one period ahead covariance between home and abroad consumption and the real excess return, not taking into account the income effect the portfolio holdings has on consumption. The expression in the parenthesis (labeled as D) gives the covariance effect given that nominal bonds do not influence the terms of trade. The scaling factor p' adjusts for the fact that the covariance is influenced by the effect that the bond holdings have on the terms of trade.

The next term in the bracket (p"E) captures the one period ahead covariance between the income effect of portfolio holdings on consumption and real excess return for the SOE household.[16] The expression in the parenthesis (labeled as E) gives the variance of real excess return given that nominal bonds do not influence the terms of trade. The scaling factor p'' adjusts for the effect the level of bond holding has both on the terms of trade and the income effect of portfolio holdings.

The results demonstrated here question the arguments typically used in the policy debate, namely that nominal exchange rate uncertainty and the presence of a risk premium distort the optimal decisions made by the agents

[16]The implicit assumption in the model of non-discrimination among foreign agents, implies that there will be no such effect from abroad since bonds supplied by the home economy will be divided equally among foreign agents.

in the financial markets. Instead, our analysis implies that financial markets under a floating exchange rate regime allow the household to adjust its gross portfolio holdings so that an additional income stream is obtained, having a positive impact on the expected utility.

4.4.3 Monetary policy influence

A policy of strict inflation targeting is implemented by letting $\zeta \to \infty$ in the inflation targeting rule. In general, this will imply that the SOE economy will replicate its flexible price equilibrium (see for instance, Gali and Monacelli (2005)), and thereby making interest rate shocks to have no influence on the economy and on the equilibrium portfolio decision. For the analysis of two symmetric open economies provided in Devereux and Sutherland (2007b), it is shown that the elimination of the interest rate shocks in the economy will enhance the degree of international risk sharing. The result is due to the fact that, without the presence of interest rate shock, the agents can concentrate their gross nominal portfolio holdings towards the elimination of country specific productivity shocks. In our case, the elimination of interest rate shocks will also improve the insurance opportunities against consumption risk in the SOE. The intuition behind this result is the following: The SOE household will, since hedging against an interest rate shocks calls for a positive nominal bond holdings (see section 4.4.1), decrease its demand for home nominal bonds. However, since monetary policy in the SOE has no effects on the world economy, demand for domestic nominal bonds from the world economy would remain unchanged. Together this implies an increase in the equilibrium risk premium, for the market clearing conditions to be satisfied.

The equilibrium portfolio holdings can be expressed as[17]

$$\tilde{\Xi} = \frac{(0.41\sigma_a^2 + 0.41\sigma_{a^*}^2)}{0.010\left[2(0.41\sigma_a^2 + 0.41\sigma_{a^*}^2) + (0.33\sigma_a^2 + 0.33\sigma_{a^*}^2)\right]} \tag{4.46}$$

while the risk premium now becomes

$$\overline{rp} = 0.5\left[p'\left(-0.41\sigma_a^2 + 0.73\sigma_{a^*}^2\right) + p''\left(0.33\sigma_a^2 + 0.33\sigma_{a^*}^2\right)\right] \tag{4.47}$$

The property that the risk premium is not invariant to the degree of interest rate response to inflation is at odds with the practice of many of today's state-of-the-art DSGE models, (see for instance Smets and Wouters (2007) or Adolfson, Laseen, Linde, and Svensson (2008)) in which the risk premium is specified as an exogenous stochastic process. As pointed out in Chari, Kehoe, and McGrattan (2008), this reduced form specification of the risk premium has a strong positive impact on the ability of the model in Smets and Wouters (2007) to fit the aggregate data. This is due to that variability of the shock to the risk premium is relatively large compared to the other structural shocks specified in the model.

However, the inclusion of an exogenous shock with the impact of improved aggregate data fit does not itself enhance the reliability of a model for the purpose of policy analysis. In general an accurate structural model (i.e. without free parameters) is needed for the evaluation of policy effects.

[17] The fact that the change in monetary policy shown here does not have any impact for the effect a domestic productivity shock has on consumption and the terms of trade is just a result of the calibration values we have selected, made purely to illustrate the main argument of this section. In general, this will not be the case.

According to Chari, Kehoe, and McGrattan (2008), this implies for the structural shocks that they must satisfy: (1) Invariability with respect to the policy interventions; (2) the structural shocks must be easily interpretable, in a sense that it is clear whether shock should be accommodated (good shock) or offset (bad shock). The results of our analysis prove that the risk premium is not invariant to policy changes and is efficient with respect the portfolio selection opportunities of the representative agent. Consequently, the approach of modeling risk premium as an exogenous random variable violates both the stated criteria.

4.4.4 Robustness

The specification of our model and the calibration values we use represent a simplification of an economic system. Much of the simplification was made in order to clearly illustrate our main results. Still,the allocative efficiency role of the risk premium and the property that monetary policy will influence the level of the risk premium will be valid under general parameter values and in a more general framework of the model.

In fact, it is well known that in a standard setup with a perfect capital market, deviation from the uncovered interest parity can occur either due to departure from risk neutrality or from rational expectations or from both. In our model, we have departed from risk neutrality but not from rational expectations. If we depart from rational expectations, agents portfolio holdings could of course be instrumental in deteriorating their risk sharing opportunities. In that case modeling the risk premium as an exogenous stochastic process could serve as a useful approximation. In a real world economy it is perhaps the combination of departure both from risk neutrality and rational expectations that is most relevant. In such light our analysis delivers an important message, namely that to be able to judge how nominal exchange uncertainty contributes to a country's welfare one must know how much the risk premium serves an efficient allocative role and how much can be considered to be caused by behavior that deviates from rational expectations.

4.5 Conclusion

In this paper we have analyzed the welfare effects of monetary policy, for the case of a SOE with endogenous portfolio choice and incomplete asset markets. We demonstrated that under a floating exchange rate regime with a monetary policy rule, the risk premium serves an allocative efficiency role, since it provides market clearing for nominal bonds used by the household to obtain an optimal trade-off between risk and return. Further, in line with previous research, the positive welfare effect of portfolio holdings is improved by the adoption of a strict domestic inflation targeting rule. Moreover, in our model monetary policy would also impact the level of the risk premium.

We have argued that our results are of interest both from a policy perspective and in relation to macroeconomic modeling of an open economy. Our findings call into question the conventional notion from the policy debate that nominal exchange rate uncertainty and the risk premium having negative impact on a country's welfare. Our results also challenge the common approach of today's state-of-the-art DSGE models to model the risk premium as an exogenous stochastic process.

4.6 Appendix

4.6.1 Non-portfolio equations

The solution of the non-portfolio part of the model is based on a log-linear first order approximation of the equilibrium conditions of the model.

Household

For the consumption-leisure trade of equation (4.8) this gives us

$$\varphi \hat{N}_t + \sigma \hat{C}_t = \hat{w}_t - \hat{P}_t \tag{4.48}$$

The intertemporal Euler equation (4.9) is

$$\sigma \hat{C}_t = \sigma E_t \left[\hat{C}_{t+1} - \hat{r}_{F,t+1} \right] + O(\epsilon^2) \tag{4.49}$$

The portfolio selection condition (4.10) can be expressed as

$$E_t \left[\hat{r}_{H,t+1} - \hat{r}_{F,t+1} \right] \equiv E_t \hat{r}_{x,t+1} = 0 + O(\epsilon^2) \tag{4.50}$$

The budget constraint equation (4.5) of the representative household becomes

$$\hat{W}_{t+1} = \frac{1}{\beta} \hat{W}_t + \frac{\bar{\Xi}}{\beta \bar{Y}} \hat{r}_{x,t+1} + \hat{P}_{H,t} + \hat{Y}_t - \hat{P}_t - \hat{C}_t + O(\epsilon^2) \tag{4.51}$$

Where $\hat{W}_t \equiv \frac{W_t}{\bar{Y}}$.

Firms

Combining equation (4.16) and (4.17) makes it possible to arrive at

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \lambda \left[(\hat{w}_t - \hat{P}_{H,t} - \hat{A}_t) - \mu \right] + O(\epsilon^2) \tag{4.52}$$

Where $\mu \equiv \frac{1-\epsilon}{\epsilon}$ and $\lambda \equiv \frac{(1-\theta)(1-\theta\beta)}{\theta}$.

Monetary policy

The monetary policy rule (4.18) is given as

$$\hat{R}_{H,t+1} = \zeta(\hat{P}_{H,t} - \hat{P}_{H,t-1}) + m_t \tag{4.53}$$

The world economy

By using the market clearing condition for the world economy that $\hat{C}_t^* = \hat{Y}_t^*$, the Euler equation for the world economy can be expressed as

$$\sigma \hat{Y}_t^* = \sigma E_t \left[\hat{Y}_{t+1}^* - \hat{r}_{F,t+1} + \hat{Q}_{t+1} - \hat{Q}_t \right] + O(\epsilon^2) \tag{4.54}$$

Domestic market clearing conditions

Inserting (4.11) into (4.19) and then approximating gives

$$\hat{Y}_t = \hat{A}_t + \hat{N}_t + O(\epsilon^2) \tag{4.55}$$

While inserting the domestic demand and foreign demand conditions into (4.20) and using the aggregator (4.21) implies that we can write

$$\hat{Y}_t = (1-\alpha)\hat{C}_t + \alpha \hat{Y}_t^* - \eta(1-\alpha)(\hat{P}_{H,t} - \hat{P}_t) - \gamma\alpha(\hat{P}_{H,t} - S_t - \hat{P}_{F,t}^*) + O(\epsilon^2) \tag{4.56}$$

Definitions and identities

To put our model in a simple reduced form specification, we will need to make use of some steady state identities and definitions.

For the terms of trade, $\hat{\chi}_t$, we have

$$\hat{\chi}_t = \hat{P}_{F,t} - \hat{P}_{H,t} = \hat{P}^*_{F,t} + \hat{S}_t - \hat{P}_{H,t} \tag{4.57}$$

While for the real exchange rate

$$\hat{Q}_t = \hat{P}^*_{F,t} + \hat{S}_t - \hat{P}_t \tag{4.58}$$

The real domestic rate of return

$$\hat{r}_{H,t} = \hat{R}_{H,t} + \hat{P}_{t-1} - \hat{P}_t \tag{4.59}$$

Domestic inflation

$$\pi_{H,t} = \hat{P}_{H,t} - \hat{P}_{H,t-1} \tag{4.60}$$

The aggregate consumer price index is approximated as

$$\hat{P}_t = (1-\alpha)\hat{P}_{H,t} + \alpha\hat{P}_{F,t} + O(\epsilon^2) = \hat{P}_{H,t} + \alpha(\hat{P}_{F,t} - \hat{P}_{H,t}) + O(\epsilon^2) \tag{4.61}$$

Using (4.57) to substitute for $(\hat{P}_{F,t} - \hat{P}_{H,t})$ in (4.61) gives

$$\hat{P}_t = \hat{P}_{H,t} + \alpha\hat{\chi}_t + O(\epsilon^2) \tag{4.62}$$

Inserting for $\hat{S}_t$ from (4.57) into (4.58) and substitute for $(\hat{P}_t - \hat{P}_{H,t})$ from

(4.62) implies that the relationship between the real exchange rate and the terms of trade can be expressed as

$$\hat{Q}_t = (1-\alpha)\hat{\chi}_t + O(\epsilon^2) \tag{4.63}$$

Reduced form

For the capital market condition, we can combine (4.49) with (4.54) and then insert for the terms of trade from (4.63):

$$\sigma(E_t C_{t+1} - C_t) = \sigma(E_t \hat{Y}^*_{t+1} + \hat{Y}^*_t) + (1-\alpha)(E_t \hat{\chi}_{t+1} - \hat{\chi}_t) + O(\epsilon^2) \tag{4.64}$$

For the budget constraint, substituting for $(\hat{P}_t - \hat{P}_{H,t})$ from (4.62) into (4.51) gives

$$\hat{W}_{t+1} = \frac{1}{\beta}\hat{W}_t + \frac{\bar{\Xi}}{\beta\bar{Y}}\hat{r}_{x,t+1} - \alpha\hat{\chi}_t + \hat{Y}_t - \hat{C}_t + O(\epsilon^2) \tag{4.65}$$

By substituting (4.62) into (4.56), the home market clearing condition can be written as

$$\hat{Y}_t = (1-\alpha)\hat{C}_t + \alpha\hat{Y}^*_t + \eta(1-\alpha)\alpha\hat{\chi}_t + \gamma\alpha\hat{\chi}_t + O(\epsilon^2) \tag{4.66}$$

For home inflation, we can substitute (4.48) and (4.62) into (4.52):

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \lambda\left[\varphi\hat{N}_t + \sigma\hat{C}_t + \alpha\hat{\chi}_t - \hat{A}_t - \mu\right] + O(\epsilon^2) \tag{4.67}$$

For the home monetary rule (4.53), we substitute for (4.59) and then for (4.49), (4.60) and (4.57). Taking the conditional expectation based on information from period t makes it possible to express

$$\sigma(E_t\hat{C}_{t+1} - \hat{C}_t) + E_t\pi_{H,t+1} + \alpha(E_t\hat{\chi}_{t+1} - \hat{\chi}_t) = \zeta\pi_{H,t} + m_t + O(\epsilon^2) \quad (4.68)$$

For the world economy, world inflation $\pi^*_{F,t}$ is given as

$$\pi^*_{F,t} = \beta E_t\pi^*_{F,t+1} + \lambda\left[\varphi\hat{N}^*_t + \sigma\hat{Y}^*_t - \hat{A}^*_t - \mu\right] + O(\epsilon^2) \quad (4.69)$$

While the monetary policy is stated as

$$\sigma(E_t\hat{Y}^*_{t+1} - \hat{Y}^*_t) + E_t\pi^*_{F,t+1} = \zeta^*\pi^*_{F,t} + O(\epsilon^2) \quad (4.70)$$

Real excess return on home nominal bonds is given as the negative of the one period ahead unexpected change in the nominal exchange rate.[18] Using (4.57) to substitute for the nominal exchange rate, this can also be expressed as the negative of the unexpected change in domestic prices and in the terms of trade plus the unexpected changes in the foreign price level:

$$\begin{aligned}\hat{r}_{x,t+1} &= -(S_{t+1} - E_tS_{t+1}) + O(\epsilon^2) \\ &= -\left[(\hat{P}_{t+1} - E_t\hat{P}_{t+1}) - (\hat{P}^*_{t+1} - E_t\hat{P}^*_{t+1})\right] - [\hat{\tau}_{t+1} - E_{t+1}\hat{\tau}_{t+1}] + O(\epsilon^2)\end{aligned} \quad (4.71)$$

4.6.2 Portfolio equations

The solution of the portfolio part of the model is based on a log-linear second order approximation of the portfolio equilibrium conditions.

[18] In general, this expression will depend only on the exogenous i.i.d. process of the model, see property 6 in Devereux and Sutherland (2006)

Home economy portfolio selection equation (4.10) then becomes

$$E_t\left[\hat{r}_{x,t+1}+\frac{1}{2}\hat{r}^2_{x,t+1}-\sigma\hat{C}_{t+1}\hat{r}_{x,t+1}\right]=0+O(\epsilon^3) \tag{4.72}$$

While for a generic foreign economy i we have

$$E_t\left[\hat{r}_{x,t+1}+\frac{1}{2}\hat{r}^2_{x,t+1}-\sigma\hat{C}^{i,*}_{t+1}\hat{r}_{x,t+1}-\hat{Q}_{i,t+1}\hat{r}_{x,t+1}\right]=0+O(\epsilon^3) \tag{4.73}$$

By combining equation (4.72) with (4.73) and integrating implies we can express portfolio equilibrium condition as

$$E_t\left[(\hat{C}_{t+1}-\int_0^1\hat{C}^{i,*}_{t+1}di-\int_0^1\frac{\hat{Q}_{i,t+1}}{\sigma}di)\hat{r}_{x,t+1}\right]=0+O(\epsilon^3) \tag{4.74}$$

$$\begin{aligned}E_t(r_{x,t+1})=&-\frac{1}{2}\left[E_t(\hat{r}^2_{1,t+1})-E_t(\hat{r}^2_{2,t+1})\right]\\&+\sigma\frac{1}{2}E_t\left[(\hat{C}_{t+1}-\int_0^1\hat{C}^{i,*}_{t+1}di-\int_0^1\frac{\hat{Q}_{i,t+1}}{\sigma}di)\hat{r}_{x,t+1}\right]+O(\epsilon^3)\end{aligned} \tag{4.75}$$

Since we for the world economy must have that $\hat{Y}^*_t=\int_0^1\hat{C}^{i,*}_t di$ and $\hat{Q}_{t+1}=\int_0^1\hat{Q}_{i,t+1}di$, we can substitute the two conditions into the expressions above:

$$E_t\left[(\hat{C}_{t+1}-\hat{Y}^*_{t+1}-\frac{\hat{Q}_{t+1}}{\sigma})\hat{r}_{x,t+1}\right]=0+O(\epsilon^3) \tag{4.76}$$

$$\begin{aligned}E_t(\hat{r}_{x,t+1})=&-\frac{1}{2}\left[E_t(\hat{r}^2_{1,t+1})-E_t(\hat{r}^2_{2,t+1})\right]\\&+\sigma\frac{1}{2}E_t\left[(\hat{C}_{t+1}+\hat{Y}^*_{t+1}+\frac{\hat{Q}_{t+1}}{\sigma})\hat{r}_{x,t+1}\right]+O(\epsilon^3)\end{aligned} \tag{4.77}$$

If we use the fact that for a first order approximation $E_t[\hat{r}_{x,t+1}] = 0$, the last two equations can also be expressed as

$$\texttt{Cov}_t\left[(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \frac{\hat{Q}_{t+1}}{\sigma}), (\hat{r}_{x,t+1})\right] = 0 + O(\epsilon^3) \tag{4.78}$$

$$E_t(\hat{r}_{x,t+1}) = -\frac{1}{2}\left[\texttt{Var}_t(\hat{r}_{1,t+1}) - \texttt{Var}_t(\hat{r}_{2,t+1})\right] \\ + \sigma\frac{1}{2}\texttt{Cov}_t\left[(\hat{C}_{t+1} + \hat{Y}^*_{t+1} + \frac{\hat{Q}_{t+1}}{\sigma}), (\hat{r}_{x,t+1})\right] + O(\epsilon^3) \tag{4.79}$$

4.6.3 Determination of portfolio holdings and expected excess return

Portfolio

Extracting from the state space solution

$$\hat{r}_{x,t+1} = R_1\xi + R_2\varepsilon + O(\epsilon^2) \tag{4.80}$$

$$(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \frac{\hat{Q}_{t+1}}{\sigma}) = D_1\xi + D_2\varepsilon + D_3\mathbf{X} + O(\epsilon^2) \tag{4.81}$$

Inserting for $\xi = \tilde{\Xi} r_{x,t+1}$ in the two expressions above gives

$$\hat{r}_{x,t+1} = R_1\tilde{\Xi} r_{x,t+1} + R_2\varepsilon + O(\epsilon^2) \tag{4.82}$$

$$(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \frac{\hat{Q}_{t+1}}{\sigma}) = D_1\tilde{\Xi} r_{x,t+1} + D_2\varepsilon + D_3\mathbf{X} + O(\epsilon^2) \tag{4.83}$$

Solving for $r_{x,t+1}$ and $(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \frac{\hat{Q}_{t+1}}{\sigma})$ gives

$$\hat{r}_{x,t+1} = (1 - R_1\tilde{\Xi})^{-1}R_2\epsilon + O(\epsilon^2) = \tilde{R}_2\epsilon + O(\epsilon^2) \tag{4.84}$$

$$(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \frac{\hat{Q}_{t+1}}{\sigma}) = D_1\tilde{\Xi}\tilde{R}_2\epsilon + D_2\epsilon + D_3\mathbf{X} = \tilde{D}_2\epsilon + D_3\mathbf{X} + O(\epsilon^2) \tag{4.85}$$

Inserting (4.84) and (4.85) into the portfolio equilibrium condition (4.74) and applying the property that $E_t(\epsilon\mathbf{X}) = 0$ implies

$$E_t\left[(\hat{C}_{t+1} - \hat{Y}^*_{t+1} - \frac{\hat{Q}_{t+1}}{\sigma})(\hat{r}_{x,t+1})\right] = E_t[(\tilde{R}_2\epsilon)(\tilde{D}_2\epsilon)'] = \tilde{R}_2\Sigma\tilde{D}_2' = 0 + O(\epsilon^3) \tag{4.86}$$

Inserting for $\tilde{R}_2$ and $\tilde{D}_2$ and solving for the steady state portfolio:

$$\tilde{\Xi} = \left[R_2\Sigma D_2'R_1' - D_1R_2'\Sigma R_2\right]^{-1} R_2\Sigma D_2' + O(\epsilon^3) \tag{4.87}$$

Expected excess return

Extracting from the state space solution

$$(\hat{C}_{t+1} + \hat{Y}^*_{t+1} + \frac{\hat{Q}_{t+1}}{\sigma}) = F_1\xi + F_2\varepsilon + F_3\mathbf{X} + O(\epsilon^2) \tag{4.88}$$

Inserting for $\xi = \tilde{\Xi}r_{x,t+1}$ in the expression above

$$(\hat{C}_{t+1} + \hat{Y}^*_{t+1} + \frac{\hat{Q}_{t+1}}{\sigma}) = F_1\tilde{\Xi}r_{x,t+1} + F_2\varepsilon + F_3\mathbf{X} + O(\epsilon^2) \tag{4.89}$$

$$(\hat{C}_{t+1} + \hat{Y}^*_{t+1} + \frac{\hat{Q}_{t+1}}{\sigma}) = F_1\tilde{\Xi}\tilde{R}_2\epsilon + F_2\epsilon + F_3\mathbf{X} = \tilde{F}_2\epsilon + F_3\mathbf{X} + O(\epsilon^2) \tag{4.90}$$

So the approximated steady state risk premium $\overline{rp}$ can be calculated as [19]

$$\overline{rp} = E_t(\hat{r}_{1,t+1}) + \mathrm{Var}_t(\hat{r}_{1,t+1}) - (E_t(\hat{r}_{2,t+1}) + \mathrm{Var}_t(\hat{r}_{2,t+1})) = \sigma \frac{1}{2} \tilde{R}_2 \Sigma \tilde{F}_2{}' + O(\epsilon^3) \tag{4.91}$$

4.6.4 State space solution for the portfolio variables

$$\begin{bmatrix} \hat{C}_t \\ \hat{C}_t^* \\ \hat{\tau}_t \\ \pi_{H,t} \\ \hat{r}_{x,t} \end{bmatrix} = \begin{bmatrix} 0.010 \\ 0 \\ -0.020 \\ 0 \\ 0.020 \end{bmatrix} \tilde{\Xi} r_{x,t} + \begin{bmatrix} -0.2488 & 0.7143 & 0.2857 \\ 0 & 0 & 1.0000 \\ -0.4975 & 0.5714 & -0.5714 \\ -0.2512 & 0 & 0 \\ 0.7487 & -0.5714 & 0.5714 \end{bmatrix} \begin{bmatrix} \hat{m}_t \\ \hat{A}_t \\ \hat{A}_t^* \end{bmatrix} \tag{4.92}$$

[19] Note, we use the fact that $X_{\%} \equiv \frac{X_t - \overline{X}}{\overline{X}} \approx \hat{X}_t + \frac{1}{2}\hat{X}_t^2 + O(\epsilon^3)$. Consequently, $E(X_{\%,t}) \approx E(\hat{X}_t) + \frac{1}{2}\mathrm{Var}(\hat{X}_t) + O(\epsilon^3)$

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