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This paper investigates the effects of a global uncertainty shock in open economies and the role of country relative risk exposure in the transmission of the shock. We employ an Interacted VAR model to take the time-varying dimension of country relative risk exposure into account. Evidence of nonlinearities in the real effects of a global uncertainty shock is found. The reduction in real activity is larger when the country is more exposed to aggregate risk. These findings support recent theoretical contributions on the role of risk exposure in the transmission of uncertainty shocks.

Keywords: Global uncertainty shocks, Country relative riskiness, International analysis, Interacted VAR, Generalized Impulse Response Functions

JEL Codes: C32, E32, F41

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July 2016

Abstract

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1 Introduction

In recent years the role of uncertainty in driving business cycle fluctuations received a great deal of attention in policy debate (e.g., FOMC, 2008; Blanchard, 2009) and, since the seminal work of Bloom (2009), macroeconomic research has increasingly focused on the investigation of the mechanisms linking uncertainty to economic activity, as well as tried to empirically estimate its effects on the economy. It has been claimed that the increased level of macroeconomic uncertainty was one of the main causes of the Great Recession of 2008-2009 (e.g., Stock & Watson, 2012) and that heightened uncertainty also played an important role in the slow recovery that followed thereafter (e.g., Leduc & Liu, 2015). Moreover, Bloom et al. (2012) among others highlight the fact that uncertainty can also affect economic policy effectiveness. Indeed, in times of high uncertainty, agents may be cautious in responding to any stimulus, which can make policy interventions less effective. As a result, investigating which are the effects of uncertainty on economic activity became a central issue among policymakers, who are interested in understanding how to respond to the consequences of heightened uncertainty on the one hand, and whether policy interventions can reduce uncertainty itself on the other hand.

This paper empirically investigates the effects of global uncertainty shocks in open economies, by taking into account the role that different levels of country risk exposure might have in the transmission of the shock. We address the following questions: (i) which are the effects of a global uncertainty shock in an open economy and (ii) does countries' relative risk exposure play a role in the transmission the shock? To answer these questions, we perform a Structural Vector Autoregression (SVAR) analysis on a group of developed countries and take the U.S. as the benchmark to define our measure of relative riskiness.

More in details, we estimate an Interacted VAR (I-VAR) model and examine the dynamic responses of output and exchange rate to a global uncertainty shock. The I-VAR model allows to account for time variation in country relative riskiness and for the possible presence of nonlinearities in the transmission mechanism of global uncertainty shocks, through the computation of state conditional impulse response functions, where the state of the economy is defined by the level of risk exposure. This cannot be done in a linear framework, like a linear SVAR, since in that case the computed impulse response functions only capture the average response of the endogenous variables to the shock, without accounting for the possible presence of different regimes. An Interacted VAR model is a standard VAR augmented with an interaction term, which includes the variable that we want to shock and a conditioning variable that identifies the two states of the economy, that we think can be relevant for the transmission of the shock. This allows to get responses to the shock of interest conditionally on each of the two regimes we are interested in, and to account for the possible presence of nonlinear effects. Particularly, global uncertainty is the variable whose shocks we want to identify, whereas our conditioning variable is a measure of relative risk exposure.

As a measure of global uncertainty, we take the realized volatility of the MSCI World Index log returns, where the MSCI World Index is a stock market index that includes a collection of stocks of developed market countries. We employ interest rates to discriminate across countries' heterogeneous risk exposure in our empirical analysis. Taking the U.S. as the reference country, we consider the spread between each country's interbank rate and the Federal Funds rate (FFR) as our measure of relative riskiness. Following Gourio, Siemer, and Verdelhan (2013)'s two-country RBC model, we define a country as being in high risk regime when its interbank rate is lower than the FFR (negative spread), whereas we define the country in low risk regime when its interbank rate is higher than the FFR (positive spread). The spread reflects different levels of precautionary savings in the two countries. Indeed, the country which is more exposed to aggregate risk experiences a higher level of precautionary savings, which implies a higher demand for safe assets and hence a lower (risk-free) rate. On the other hand, a lower exposure to risk implies a lower level of precautionary savings for the country, and hence a higher interest rate, since the demand for risk-free assets would be lower.

An important feature of the specification of our I-VAR is that both variables in the interaction term are endogenously modeled, which implies that interest rate spreads are likely to react to a global uncertainty shock. This means that the economy can endogenously switch from one regime to the other within each horizon. Therefore, following Pellegrino (2014) and Caggiano, Castelnuovo, and Pellegrino (2015), dynamic responses of the endogenous variables to the uncertainty shock are computed as Generalized Impulse Response Functions (GIRFs) à la Koop, Pesaran, and Potter (1996). Indeed, through GIRFs the nonlinearity of the system is fully taken into account, because the responses of the endogenous variables will depend on the size and the sign of the shock, as well as on the initial conditions of the system and the future shocks.

Our main results can be summarized as follows. First, concerning question (i) on the effects of global uncertainty shocks in open economies, the dynamic responses of our variables of interest show that output negatively responds to the shock and exchange rate appreciates. The sign of the response of output is consistent with the main findings in the literature on uncertainty. Then, relative to question (ii) about the role of relative risk exposure in the transmission of the shock, we find that the level of countries' relative exposure to aggregate risk plays a relevant role in the transmission of a global uncertainty shock. Indeed, a global uncertainty shock generates a significant reduction in real activity when the economy is in high risk regime, whereas in low risk regime the response is generally not statistically different from zero. Moreover, the differences between the dynamic responses of output in the two regimes are statistically significant, meaning that the responses of output in high risk are estimated to be statistically larger than those in low risk. This results provide evidence for the presence of nonlinear effects in the transmission of global uncertainty shocks to economic activity. Further support to this evidence is provided by the results of an exercise in which we explore what happens when the two riskiness regimes become "extreme", i.e. when the distance in country relative risk exposure widens (meaning that interest rate spread increases in absolute value). Our main result is that, as the distance in countries' relative risk exposure increases, also the difference between the estimated responses in the two regimes increases. These findings support the theoretical model proposed by Gourio et al. (2013), where an increase in aggregate risk produces a larger decline in economic activity in the country which is more exposed to aggregate risk. Concerning exchange rate, we find that it appreciates on impact in response to a global uncertainty shock in both riskiness regimes, but we find little evidence in favor of the presence of nonlinearities in the transmission of the shock to the exchange rate, evidence which mainly comes from our exercise with "extreme" riskiness regimes.

This paper contributes to the existing literature on uncertainty in several respects. We propose a multi-country analysis on the effects of global uncertainty shocks in open economies and investigate the role of countries' relative risk exposure in the transmission of the shock. As a measure of global uncertainty we propose the quarterly series of realized volatilities of the returns of the MSCI World Index.[1] Relative to Carrière-Swallow and Céspedes (2013), who also consider an open economy framework, we consider both the responses of economic activity and exchange rate to the shock.[2] To examine how different levels of country risk exposure affect the transmission of a global uncertainty shock, we employ a nonlinear model, specifically an Interacted VAR model, which allows to account for the presence of two different riskiness regimes in the economy and to compute state-conditional responses to the global uncertainty shock.

The structure of the paper is the following. Section 2 discusses the relation to the literature. Section 3 presents the empirical strategy and the data employed in the analysis. Section 4 describes the nonlinear model. Section 5 illustrates the results. Section 6 concludes.

2 Related literature

This paper mainly relates to macroeconomic research which investigates the role of uncertainty in driving business cycle fluctuations. A non-exclusive list of recent works includes Bloom (2009); Bloom et al. (2012); Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez, and Uribe (2011); Benigno et al. (2012). Bloom (2014) provides a survey of the main facts, issues and contributions related to uncertainty. A widely recognized result is that uncertainty shocks negatively affect economic activity by producing a fall in the levels of production and employment.

Theoretical contributions have emphasized two transmission channels for uncer-

[1]Related contributions investigating the effects of global uncertainty on economic activity, as Carrière-Swallow and Céspedes (2013) and Cesa-Bianchi, Pesaran, and Rebucci (2014) propose different measures. Carrière-Swallow and Céspedes measure global uncertainty shocks as strong increases in the VIX index, whereas Cesa-Bianchi et al. construct a quarterly measure of global uncertainty by using daily returns across 109 asset prices worldwide.

[2]Benigno, Benigno, and Nisticò (2012) investigate the relationship between uncertainty and the exchange rate employing an open economy VAR and examine the response of the exchange rate to changes in the volatility of nominal and real shocks. The measures of uncertainty they use are given by the time-varying volatilities of a monetary policy shock, an inflation-target shock and a productivity shock.

tainty to affect economic activity in closed economies. The first one relates to the idea of real options, for which high levels of uncertainty increase the option value of postponing investment decisions and hiring for firms, and durable consumption for households, particularly when the cost of reversing decisions is high. Then, a high level of uncertainty reduces the levels of investment, hiring and consumption, thus reducing economic activity (e.g., Bernanke, 1983; Bloom, 2009). The other channel examined in the literature focuses on risk aversion and risk premia. Arellano, Bai, and Kehoe (2012) and Christiano, Motto, and Rostagno (2014) among others emphasize how a higher level of uncertainty leads investors to ask for increasing risk premia to be compensated for higher risk. Higher uncertainty also increases the probability of default. As a consequence, uncertainty raises borrowing costs, which can reduce growth. Ilut and Schneider (2011) explore the confidence effect of uncertainty in models where agents have pessimistic beliefs and act as if the worst outcomes will occur, showing a behaviour known as "ambiguity aversion". Increasing uncertainty expands the range of possible outcomes, and makes the worst outcome worse, which can induce agents to reduce hiring and investment. In a third mechanism that relates to risk aversion, a rise in uncertainty can induce consumers to increase the level of precautionary savings, thus reducing consumption and economic activity in the short-run (Bansal & Yaron, 2004; Fernandez-Villaverde, Guerron-Quintana, Kuester, & Rubio-Ramirez, 2011; Leduc & Liu, 2015; Basu & Bundick, 2015).

Concerning open economies, recently Gourio et al. (2013) have proposed a two-country real business cycle model, to understand the effects of changes in aggregate risk on economic activity in small open economies, in the presence of heterogeneous country risk exposure. Aggregate risk, which Gourio et al. interpret as a global uncertainty shock, and heterogeneity in country risk exposure are the two key elements of this model.[3] Concerned with the effects of uncertainty shocks in open economies are also Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez,

[3]The key mechanism of the model is the following. Following an increase in the probability of an economic disaster, investment falls because of a reduction in capital holdings by firms, due to increasing risk premia. At the same time, output and employment reduce. Hence, an increase in disaster probability leads to a recession. The risk-free interest rate falls as the demand for safe assets rises (flight to quality effect) and equity prices drop. All these effects are stronger in the more risky country. Concerning the exchange rate, the currency of the most risky country appreciates in response to an increase in disaster probability.

and Uribe (2011), Benigno et al. (2012) and Carrière-Swallow and Céspedes (2013). Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez, and Uribe focus on the role played by changes in the volatility of the real exchange rate in the dynamics of business cycle fluctuations of emerging economies. Benigno et al. analyze the response of the exchange rate to shocks to the volatilities of a monetary policy shock, a shock to the inflation target and a productivity shock, in an open economy VAR framework.[4] Carrière-Swallow and Céspedes estimate the response of investment and private consumption to a global uncertainty shock in 40 countries in an open economy VAR. Global uncertainty shocks are measured as strong increases in the VIX index. Investigating the effects of global uncertainty shocks on economic activity is also the aim of Cesa-Bianchi et al. (2014), who estimate a Global VAR for 33 countries. A quarterly series for uncertainty is constructed using the realized volatilities of 109 asset prices worldwide.

Other empirical contributions on the effects of uncertainty shocks on economic activity employ country-specific measures of uncertainty, especially those capturing uncertainty in the U.S.. Moreover, most of them are single-country studies investigating the effects of country-specific uncertainty shocks, and in some cases exploring the presence of spillover effects in other countries (e.g., Colombo, 2013). From a methodological perspective, most contributions employ linear models for the analysis and particularly linear Structural VARs (e.g., Bloom, 2009; Alexopoulos & Cohen, 2009; Mumtaz & Theodoridis, 2012; Baker, Bloom, & Davis, 2013). Nevertheless, more recent works also take into account the possibility for the state of the economy to have a role in the transmission of uncertainty shocks and investigate the issue through nonlinear models, that allow for regime switches.

Among them, Enders and Jones (2013) employ a Smooth Transition autoregressive model to explore the presence of asymmetric effects of uncertainty shocks on a number of macroeconomic variables. Bijsterbosch and Guérin (2013) propose a two-step procedure in which they identify episodes of high uncertainty in the U.S.,

[4] They find that the exchange rate appreciates in response to an increase in the volatility of the monetary and the inflation target shocks, and that it depreciates following an increase in the volatility of the productivity shock. They also develop a two-country open economy model in which the channel that links uncertainty and exchange rate is a hedging motive. The currency does not necessarily depreciates following an uncertainty shock. If the currency is relatively safer when the shock occurs, then heightened uncertainty may improve its hedging properties, leading to an appreciation.

through a Markov switching approach, and then regress several macroeconomic and financial variables on this high uncertainty indicator. Caggiano, Castelnuovo, and Groshenny (2014) employ a Smooth Transition VAR to estimate the response of unemployment to uncertainty shocks during recessions. Caggiano, Castelnuovo, and Nodari (2015) employ the same methodology to explore the asymmetric effects of uncertainty shocks over the business cycle and to analyze the effectiveness of the systematic part of monetary policy in dealing with the real effects of uncertainty shocks. Alessandri and Mumtaz (2014) investigate the role of financial markets conditions in the transmission of uncertainty shocks. Ricco, Callegari, and Cimadomo (2014) analyze the effects of fiscal policy shocks in the presence of fiscal policy uncertainty. Caggiano, Castelnuovo, and Pellegrino (2015) employ an Interacted VAR to investigate whether the effects of uncertainty shocks on economic activity are greater when the economy is at the Zero Lower Bound (ZLB).

3 Empirical strategy

This paper aims at answering two questions: (i) which are the effects of a global uncertainty shock in open economies and (ii) does countries' relative risk exposure play a role in the transmission the shock? To answer these questions, the empirical analysis is organized as follows. First, as a warm-up exercise, we explore the effects of global uncertainty in open economies, through the estimation of a linear VAR model for a group of eleven countries. To investigate whether countries' relative risk exposure does play a relevant role in the transmission of the shock, we employ a nonlinear specification and estimate an Interacted VAR model. Indeed, a nonlinear model such as an I-VAR allows to compute state-dependent impulse responses, i.e. responses of output and exchange rate conditional on the riskiness level of the economy. With respect to the sample of countries considered for the linear exercise, we perform the nonlinear analysis on a subsample of countries, where the selection criterion is given by the results of a linearity test. The nonlinear analysis will be limited to those countries for which the linearity test provides evidence in favour of the nonlinear specification, by rejecting the null hypothesis of a linear specification. Indeed, a nonlinear model would be misspecified if the true data generating process is linear.

3.1 Data

For our investigation we consider a group of eleven countries: Australia, Austria, Canada, Finland, France, Germany, Italy, Netherlands, Norway, Sweden and United Kingdom, which can all be considered as small open economies with respect to the U.S.. We employ quarterly data. The starting time for estimation changes across countries, depending on data availability,[5] whereas for all of them the estimation period ends in 2008Q2. The period starting in 2008Q3 and including the financial crisis and the subsequent Great Recession is excluded from the analysis. The reason for this choice is that, since the end of 2008, policy rate hit the zero lower bound (ZLB) in the U.S., as well as in most advanced economies thereafter, and as a consequence, interest rate spreads which captures countries' relative risk exposure in our analysis, stayed almost constant and very close to zero during the subsequent period. This might significantly affect the results of our analysis.[6]

Six variables are included in the specification. A measure of global uncertainty (VOL) is obtained as the 90-day realized volatility of the MSCI World Index log returns, computed as the standard deviations of daily returns over calendar quarters. The MSCI World Index ($MSCI$) is a stock market index that includes a collection of stocks of developed market countries. Since open economies are considered, we also include the spot bilateral nominal exchange rate of country i with respect to U.S. dollar (USD) ($S_{\$/i}$), measured as units of USD for one unit of foreign currency. Hence an increase in $S_{\$/i}$ means an appreciation of the currency of country i and a USD depreciation. We then include a consumer price index (CPI_i) as a measure of prices and gross domestic product (GDP_i) as a measure of economic activity. $SPREAD_i$ is the difference between country i overnight interbank rate and the Federal Funds rate, and it is the variable that captures countries' relative riskiness with respect to the U.S.. Macroeconomic data are taken from the Federal Reserve Bank of St. Louis FRED database, whereas we refer to Bloomberg for financial data.[7]

[5]Australia 1973Q1, Austria 1988Q1, Canada 1973Q1, Finland 1990Q1, France 1973Q1, Germany 1973Q1, Italy 1981Q1, Netherlands 1988Q1, Norway 1979Q1, Sweden 1973Q1, UK 1973Q1.

[6]The transmission of uncertainty shocks in the presence of the ZLB is explored in Caggiano, Castelnuovo, and Pellegrino (2015).

[7]We use GDP Implicit Price Deflator, Index 2010=100, Quarterly, Seasonally Adjusted (all countries but Sweden); Consumer Price Index All Items, Index 2010=100, Quarterly, Not

The model is estimated via OLS for each of the countries in our sample. We consider the U.S. as the reference country when defining relative riskiness. For this reason the U.S. enter the specification through the exchange rate, which is measured as units of USD for one unit of foreign currency, and interest rate spread, which is computed as the difference between each country's interbank rate and the FFR. All variables are taken in log-levels, with the exception of volatility and interest rate spreads, which are in levels. Equation-specific constants are included in both the linear and nonlinear specifications and the number of lags is selected via the Akaike Information Criterion (AIC).[8]

To identify the global uncertainty shock from the vector of reduced form residuals we employ short-run restrictions (Cholesky decomposition), with the endogenous variables ordered as follows: (i) stock market index, (ii) volatility, (iii) exchange rate, (iv) prices, (v) consumption, (vi) production, (vii) interest rate spread. Following Bloom (2009) we order the stock market index before volatility, in order to control for the impact of stock market levels and to focus on a volatility shock which is orthogonal to market levels. Results obtained from an identification scheme with uncertainty ordered last will be illustrated in the section of robustness checks.

Measuring uncertainty. Concerning our proxy for global uncertainty, measures of implied volatility like the VIX index are usually preferred as proxies for uncertainty in the literature, because they are forward-looking variables and capture market expectations. Nevertheless, realized volatilities of stock market returns are considered as a good approximation and are largely used when measures of implied volatility are not available (e.g., Bloom, 2009), in that they generally show

Seasonally Adjusted (Sweden); Gross Domestic Product by Expenditure in Constant Prices: Total Gross Domestic Product, Index 2010=1, Quarterly, Seasonally Adjusted; Gross Domestic Product by Expenditure in Constant Prices: Private Final Consumption Expenditure, Index 2010=1, Quarterly, Seasonally Adjusted; US Dollar to National Currency Spot Exchange Rate, US Dollar per National Currency Units, Quarterly, Not Seasonally Adjusted; Immediate Rates: Less than 24 Hours: London Clearing Banks Rate, Percent, Quarterly, Not Seasonally Adjusted (UK); Immediate Rates: Less than 24 Hours: Central Bank Rates, Percent, Quarterly, Not Seasonally Adjusted (Austria, Finland); Immediate Rates: Less than 24 Hours: Call Money/Interbank Rate, Percent, Quarterly, Not Seasonally Adjusted (France, Germany, Sweden); 3-Month or 90-Day Rates and Yields: Interbank Rates, Percent, Quarterly, Not Seasonally Adjusted; Effective Federal Funds Rate, Percent, Monthly, Not Seasonally Adjusted.

[8]For some countries we also include a deterministic trend: Austria, Finland, Netherlands, Norway, Sweden for the linear VAR specification; Norway and Sweden for the I-VAR.

a high degree of correlation with measures of implied volatility. Also in our case correlation between the realized volatility of the MSCI index returns and the VIX is equal to 0.83. Moreover, in Gourio et al. (2013) a change in disaster probability is proxied by a change in equity market volatility, when they empirically test the key mechanism of their model. Indeed they find that there is a high degree of correlation between equity implied volatility and the risk of large drops in equity prices in the United States, which is consistent with their model. Hence they interpret shocks to equity realized volatility as shocks to disaster probability, thus linking their work to the literature on uncertainty. Figure 1 plots the quarterly time series of our measure of global uncertainty. The series displays large spikes at all major economic and political shocks in the recent history at a worldwide level, like the OPEC oil-price shocks in 1973 and 1978, the two Gulf wars in 1990 and 2003, the Asian crisis in 1997 and the 9/11 terrorist attack in 2001, when uncertainty appears to largely increase.[9]

3.2 A linear SVAR exercise

As a warm-up exercise to assess the responses of output and exchange rate to a global uncertainty shock, we estimate a linear SVAR model for each of the countries in our sample. A common SVAR representation is the following:

$$\mathbf{A}_0\mathbf{y}_t = \sum_{\ell=1}^{k} \mathbf{A}_\ell \mathbf{y}_{t-\ell} + \mathbf{u}_t$$

where $\mathbf{y}_t = [MSCI\ VOL\ S_{\$/i}\ CPI_i\ GDP_i\ SPREAD_i]'$ is the vector of endogenous variables, $\mathbf{A}_0$ is the matrix that captures the contemporaneous relations among the variables, $\mathbf{A}_\ell$ is the $q \times q$ matrix of autoregressive coefficients up to lag k and $\mathbf{u}_t$ is the vector of structural shocks.

Figures 3 and 4 plot impulse responses of exchange rate and GDP to a one-

[9] The spikes are identified following the procedure in Bloom (2009). We take the HP detrended ($\lambda = 129,600$) series of the 30-day realized volatility of the MSCI World Index log returns, computed as the standard deviations of daily returns over calendar months, and assign a value of one to the observations that correspond to a value of shock-market volatility more than 1.65 standard deviations above the HP detrended mean. Among the events selected by this procedure, we only keep those that we define as global shocks.

standard deviation global uncertainty shock, along with 68% confidence bands, for each of the countries in our sample. Some regularities across countries can be noticed in the responses of both variables. Concerning the exchange rate, it responds to the shock by significantly appreciating on impact in all countries but Australia, Austria and Canada (fig. 3). The response of GDP is often not statistically different from zero on impact, but then turns significantly negative some quarters after the shock in the cases of Australia, Canada, Finland, France, Germany, Italy, Norway, Sweden and UK (fig. 4). Austria and Netherlands are the only two exceptions, and display a significant positive response. As a general conclusion for this linear part of the analysis, we have that in most countries exchange rate appreciates on impact and output reduces in response to a global uncertainty shock. This last finding is in line with the main results in the literature on uncertainty.

We now move to the core part of our empirical analysis, where we employ an Interacted VAR to evaluate whether the level of countries' risk exposure plays a relevant role in the transmission of a global uncertainty shock. Indeed, impulse responses computed from the linear model just allow to evaluate average responses of the endogenous variables to the shock, whereas we want to account for time variation in countries' relative riskiness and consider the possible presence of different states of the economy in our empirical specification.

4 Relative riskiness and Interacted VARs

4.1 Measuring countries' relative risk exposure

First, to investigate whether countries' relative exposure to risk does have a role in the transmission of global uncertainty shocks, a measure of relative riskiness is needed. Following Gourio et al. (2013), we employ interest rates to discriminate across countries' heterogeneous risk exposure in the empirical analysis that follows. Taking the U.S. as our reference country, we consider the spread between each country's interbank rate and the Federal Funds rate (FFR) as our measure of relative risk exposure. Indeed, movements in interest rate spreads are generally thought to deliver important signals about the evolution of economic activity, a view that is supported by a large literature on the predictive content of yield spreads. The idea is that fluctuations in spreads may reflect the quality of borrowers' balance sheets, on which their access to external finance depends, as well as shifts in the availability of funds provided by financial intermediaries. In both cases, movements in interest rate spreads may signal an increase in the cost of credit and/or a reduction in the supply of credit, which can cause a reduction in spending and production (see Gilchrist & Zakrajsek, 2012).

More in details, for each country in our sample, when the interbank-FFR spread is positive, then the interbank rate is higher than the FFR and we define the country as less risky than the U.S., whereas when the spread is negative, the interbank rate is lower than the FFR and the country is defined as more risky than the U.S..

The way in which the two riskiness regimes are identified refers once again to one of the results in Gourio et al.'model. Indeed, as a result of model calibration, the high interest rate country has the lower exposure to disaster risk, whereas the low interest rate country is the more exposed to aggregate risk. The explanation for this result refers to different levels of precautionary savings in the two countries. A higher exposure to disaster risk would imply a higher level of precautionary savings, which means a higher demand for safe assets and hence a lower (risk-free) interest rate. On the other hand, a lower exposure to disaster risk would imply a lower level of precautionary savings and hence a higher interest rate, since the demand for risk-free assets would be lower. According to this view, the interbank rate spreads that we use as a measure of relative riskiness would reflect the relative availability of risk-free assets in the two countries, which in turn depends on the level of precautionary savings, being the level of precautionary savings related to the perceived economic strength of the country, i.e. on the level of exposure to economic risk.[10]

Figure 2 shows the evolution over time of interest rate spreads for each of

[10]Rates on Treasury bills are generally used as a proxy for the risk-free rate. For the present analysis, we employ interbank rate spreads rather than sovereign spreads, because longer series are available. However, interbank and sovereign spreads display a high degree of correlation. For the same reason, we use the FFR, for which a longer series is available, rather than interbank rates for the U.S.. Also in this case, the degree of correlation between FFR and U.S. interbank rates is very high, almost equal to one.

the countries in our sample. Time variation is an important dimension of this cross-country relationship, and it clearly emerges from the plots. Heterogeneity can be noticed across two dimensions. On the one hand, each country oscillates between low and high risk, displaying both positive and negative spreads over time (being zero the threshold that separates the two riskiness regimes according to our definition). On the other hand, the plots also show a high degree of variability in risk exposure across countries.

4.2 Interacted VARs

To evaluate the role of risk exposure in the transmission of global uncertainty shocks, we employ a nonlinear approach, and particularly consider an Interacted VAR model, following Pellegrino (2014) and Caggiano, Castelnuovo, and Pellegrino (2015). An I-VAR is a standard VAR augmented with an interaction term, which includes the variable that we want to shock and the conditioning variable that identifies the two regimes we are interested in. This allows us to get responses to our shock of interest conditionally on the state of the economy which we think can be relevant for the transmission of the shock. In this framework, we can define two regimes for each country, a high risk regime and a low risk one relative to the U.S., depending on whether the interest rate spread is below or above zero, and compute state-dependent impulse response functions, in order to evaluate whether different levels of relative risk exposure do have an influence on the transmission of a global uncertainty shock.

Interacted VAR models have been recently introduced in macroeconomic studies. A panel I-VAR has been proposed by Towbin and Weber (2011) to analyze how the transmission of external shocks in open economies is influenced by the exchange rate regime, the level of foreign currency debt and by the import structure. Sá, Towbin, and Wieladek (2014) also use a panel I-VAR to explore how the mortgage-market characteristics influence the way in which shocks to capital inflows impact the housing market in a group of OECD countries. Lanau and Wieladek (2012) employ the same methodology to examine the relationship between financial regulation and the current account, whereas Nickel and Tudyka (2013) investigate the impact of fiscal policy at different levels of government debt. Aastveit, Natvik, and Sola

(2013) employ an I-VAR to investigate the effectiveness of monetary policy shocks in low and high uncertainty regimes. A similar issue is analyzed in Pellegrino (2014), who adds an important novelty in that the variables entering the interaction term are fully endogenous in the model, whereas they were treated as exogenous in previous works. This requires to compute Generalized Impulse Response functions (GIRFs) à la Koop et al. (1996) to take the time-varying behaviour of the system into account. Caggiano, Castelnuovo, and Pellegrino (2015) employ the same methodology as Pellegrino (2014) to address the issue of the impact of uncertainty shocks at the Zero Lower Bound (ZLB). In this paper we follow Pellegrino (2014) and Caggiano, Castelnuovo, and Pellegrino (2015) by making the interaction term with which we augment our VAR fully endogenous and then by computing GIRFs to recover the state-dependent responses.

In this context, the use of an I-VAR model has several advantages with respect to alternative nonlinear specifications, such as Smooth-Transition VARs, Time-Varying-Parameters VARs, Nonlinear Local Projections and Threshold VARs. STVARs are computationally more intensive than I-VARs and require calibrating the slope parameter in the transition function, which regulates the smoothness of the transition between regimes and affects the probability of being in one regime or the other. Such a calibration is not needed for estimating an I-VAR. Also TVP-VARs are computationally more demanding than I-VARs, and moreover require setting priors for estimation. Nonlinear Local Projections instead do not allow to endogenously model the conditioning variable and hence do not allow for endogenous switches from one regime to another, which is an essential feature in our specification, where both variables in the interaction term are endogenously modeled. T-VARs could offer an interesting alternative to I-VARs in this setting, since a T–VAR model is not computationally intensive and allows to model sudden regime changes like the ones we are considering. Moreover, in a T-VAR the threshold that defines the two states of the economy can be endogenously estimated. Nevertheless, a T-VAR does not allow for endogenous regime switches, whereas an I-VAR model does, and only allows for the computation of conditionally linear impulse response functions, rather than GIRFs.

Our I-VAR model has the following representation:

$$\mathbf{y}_t = \mu + \sum_{\ell=1}^{k} \mathbf{A}_\ell \mathbf{y_{t-\ell}} + \sum_{\ell=1}^{k} \mathbf{c}_\ell (VOL_{t-\ell} \times IR_{t-\ell}) + \mathbf{u}_t$$

where $\mathbf{y}_t$ is the $q \times 1$ vector of explanatory variables, μ is the $q \times 1$ vector of intercepts, $\mathbf{A}_\ell$ is the $q \times q$ matrix of autoregressive coefficients up to lag k and $\mathbf{u}_t \sim \mathcal{N}(\mathbf{0}, \mathbf{\Sigma})$ is the $q \times 1$ vector of residuals, whose covariance matrix is $\mathbf{\Sigma}$. $(VOL_{t-\ell} \times IR_{t-\ell})$ is the interaction term, which includes our measure of global uncertainty (VOL) and the difference between the interbank rate of each country and the FFR ($SPREAD$), as our measure of country relative riskiness. Indeed, global uncertainty is the variable whose shocks we want to identify, whereas interest rate spread is the conditioning variable that defines the two states of low and high risk. $\mathbf{c}_\ell$ is the $q \times 1$ vector of coefficients. The same number of lags is imposed for the linear part and the interaction term.

Evidence in favour of nonlinear specification. Since a nonlinear model would be misspecified if the true data generating process is linear, we perform a linearity test to provide evidence in favour of the nonlinear specification. For this reason, the nonlinear part of the analysis will be performed only for those countries for which the test provides such an evidence. Since the linear VAR and the I-VAR are nested models, it is possible to use a likelihood ratio test for the null hypothesis of a linear specification against the alternative of an I-VAR model. We employ the following test statistic:

$$LR = T \left(ln \,|\, \tilde{\mathbf{\Sigma}}^{\mathbf{r}}_{\mathbf{u}} \,| - ln \,|\, \tilde{\mathbf{\Sigma}}_{\mathbf{u}} \,| \right)$$

where T is the sample size; $|\, \tilde{\mathbf{\Sigma}}^{\mathbf{r}}_{\mathbf{u}} \,|$ is the determinant of the estimated variance covariance matrix of the residuals in the linear VAR (restricted model), whereas $|\, \tilde{\mathbf{\Sigma}}_{\mathbf{u}} \,|$ is the estimated variance covariance matrix of the residuals in the I-VAR specification (unrestricted model); ln is the natural logarithm operator. The optimal number of lags is selected for the linear model through the AIC and is then imposed also to the nonlinear specification.

Under the null hypothesis of linearity, the test statistic has an asymptotic Chisquared distribution, the number of degrees of freedom being the difference between the number of coefficients estimated under the alternative and the number of coefficients estimated under the null hypothesis, that is the number of restrictions between the two specifications.[11] Table 1 shows the results of the test. The null hypothesis of a linear VAR model is rejected for six out of eleven countries: Australia, Germany, Netherlands and Norway (at 5% significance level), Canada (1% significance level) and Sweden (10% significance level). Therefore, the nonlinear part of the analysis will only consider these countries. The null hypothesis of a linear specification cannot be rejected for Austria, Finland, France, Italy and the United Kingdom.

Table 1: LR-test results

Country	**LR**	**p-value**
Australia	16.2197	0.0126
Austria	9.8241	0.1323
Canada	20.1593	0.0026
Finland	9.2098	0.1621
France	3.2595	0.7756
Germany	15.4709	0.0169
Italy	5.2204	0.5159
Netherlands	13.2060	0.0399
Norway	13.2547	0.0392
Sweden	11.8363	0.0657
UK	6.8959	0.3306

Notes: In red are the results which are not statistically significant.

[11]Since the same number of lags is imposed for the linear part and the interaction term, and since the two models are estimated with the same number of lags, the number of restrictions is given by the product between the number of endogenous variables and the selected number of lags.

4.3 Generalized Impulse Response Functions

Most I-VARs used in the literature employ interaction terms which include variables that are not endogenously modeled. This implies that the dynamic responses of the endogenous variables to a shock in a given state are conditionally linear for a given value of the interaction variables. An important feature of the specification of our I-VAR is that both variables in the interaction term are endogenously modeled. This implies that interest rate spreads are likely to react to a global uncertainty shock, meaning that the economy can endogenously switch from one regime to the other within each horizon, as pointed out in Caggiano, Castelnuovo, and Pellegrino (2015).

Hence, following Pellegrino (2014) and Caggiano, Castelnuovo, and Pellegrino (2015), the dynamic responses of the endogenous variables to a global uncertainty shock are computed as Generalized Impulse Response Functions (GIRFs) à la Koop et al. (1996), but working with orthogonalized shocks as in Kilian and Vigfusson (2011), so that we can talk of a global uncertainty shock. Through GIRFs we can fully take the nonlinearity of the system into account, since the dynamic responses of the endogenous variables will depend on the size and the sign of the shock as well as on the initial conditions of the system. Following Koop et al. (1996), the $GIRF_{\mathbf{y}}(h, \delta, \omega_{t-1})$ of the vector of endogenous variables $\mathbf{y}_t$, h periods ahead, for a given initial condition $\omega_{t-1} = \{\mathbf{y}_{t-1}, \ldots, \mathbf{y}_{t-k}\}$, k being the number of lags in the I-VAR, and a structural shock hitting at time t, δ, can be expressed as follows:

$$GIRF_{\mathbf{y}}(h, \delta, \omega_{t-1}) = E[\mathbf{y}_{t+h} \,|\, \delta, \omega_{t-1}] - E[\mathbf{y}_{t+h} \,|\, \omega_{t-1}]$$

where $E[\cdot]$ is the expectation operator and $h = 0, 1, \ldots, H$ indicates the horizons for which the GIRF is computed.[12]

[12]Details on the algorithm used to compute state-conditional GIRFS are provided in the Appendix.

5 Results

5.1 Nonlinear model: Baseline specification

Figures 5 and 7 plot the impulse responses of exchange rate and GDP to a one-standard deviation global uncertainty shock, computed from the estimation of the I-VAR model, along with 68% confidence bands, for high (red line) an low risk (blue line) regimes, for each of the countries in our sample. Figures 6 and 8 document the differences between the point estimates of the impulse responses computed in the two states, which are obtained by subtracting the response under low risk state from the response under high risk state. 68% confidence bands resulting from the empirical distribution of such differences are plotted.

Concerning the exchange rate (fig. 5), it significantly appreciates on impact in response to the shock in both states of the economy, for all countries except for Australia and Canada. For these two countries, responses are not statistically significant in neither of riskiness regime, except for low risk regime in Canada, where exchange rate significantly appreciates some quarters after the shock. For all countries whose currencies display a significant response to the shock, response in low risk state seems to be larger than that in high risk state, but the differences in point estimates (fig. 6) show that this difference is only marginally statistically significant. Moreover, the pattern followed by the two responses is very similar. Hence, we do not find significant evidence of nonlinearities driven by relative riskiness in the transmission of global uncertainty shocks to exchange rates.

For what concerns real activity (fig. 7), a global uncertainty shock generates a significant reduction in output when the country is in high risk state, in the cases of Germany, Norway and Sweden. The response of Australia is only marginally statistically different from zero. In low risk state, the responses of GDP are generally not statistically different from zero. Differences in the point estimates of responses in the two states confirm that the response in high risk state is significantly larger than that in low risk state, for all countries for which the response in high risk state is significantly negative (Germany, Norway and Sweden, fig. 8). Hence, state-conditional impulse responses of GDP obtained from the estimation of our nonlinear specification provide evidence in favour of the presence of nonlinearities in the transmission of global uncertainty shocks. Particularly, the level of relative risk exposure, as captured by short-term interest rate spreads, seems to play a significant role in the transmission of global uncertainty shocks to economic activity.

The results obtained for real activity also support the predictions of Gourio et al. (2013)'s model, about the effects of changes in aggregate risk on the economy in the presence of heterogeneous country risk exposure. Indeed, according to their model, the same increase in disaster probability has more negative effects on economic activity in the country which is more exposed to aggregate risk, by producing a larger reduction in investment and output. The estimated impulse response functions for some of the countries in our sample point in the same direction, since the response of output is estimated to be significantly more negative when the country is more exposed to risk. On the other hand, Gourio et al.'s model predicts that the currency of the more risky country appreciates in response to an increase in disaster probability, whereas our results do not display statistical difference between the responses in the two regimes.[13] Hence, our findings do not provide supporting evidence to these predictions, because currencies appreciate in response to a global uncertainty shock in both riskiness states, and the two responses are estimated to be statistically the same.

These results are confirmed by the patterns that emerge in figures 9 and 10, which report the dynamic responses of exchange rate and output respectively, for each initial condition within each regime. Dynamic responses of both exchange rate and output display a large variability both across and within regimes. However, a clear distinction between the two regimes can be noticed for the response of output. This distinction less clearly emerges when we look at the responses of exchange rate.

[13]In Gourio et al.'s theoretical framework, the response of the exchange rate is driven by consumption. Indeed, the exchange rate reflects the relative value of current and future consumption in the two countries, and since the more risky country expects a larger decline in consumption growth than the less risky one, its marginal utility of consumption rises more and its currency appreciates.

5.2 "Very high" and "very low" risk regimes

So far, we have explored the presence of nonlinear effects and the role of countries' relative risk exposure in the transmission of global uncertainty shocks in open economies. Our main finding is that a global uncertainty shock has larger negative effects on economic activity when the country is relatively more risky. In order to further investigate the issue, we ask which are the effects of a global uncertainty shock when the distance in relative risk exposure among countries widens, that is when the spread between short term interest rates increases in absolute value. This analysis is performed through the identification of two subsets of initial conditions, associated with different levels of the interest rate spread. We define as "very high"/"very low" risk regime initial conditions in which the value of the conditioning variable, namely interest rate spread, is below/above two standard deviations from the mean. Then, for each of these two subsets of initial conditions we recompute GIRFs.

Figures 11 and 12 show the GIRFs computed for the two extreme regimes and the differences in the point estimates of responses for both output and exchange rate, for each country in our sample.[14] Relative to our baseline results, the displayed impulse responses support our main findings for what concerns output, whereas they provide some evidence in favor of nonlinearities in the transmission of global uncertainty shocks to the exchange rate. Indeed, as the distance in the level of relative risk exposure increases, also the distance in the estimated impulse responses widens, thus reinforcing the idea that relative riskiness plays a relevant role in the transmission of global uncertainty shocks.

Particularly, concerning the response of the exchange rate (fig. 11), it can be noticed that the distance between the responses in the two "extreme" regimes is generally larger than the one observed in our baseline results. Further support is provided by the differences in the point estimates, which are now larger than the ones displayed in the baseline case. Moreover, for Canada, Germany and Sweden responses in the two regimes display different patterns. For what concerns output (fig. 12), the response of economic activity becomes more negative and persistent as the level of riskiness increases, in the cases of Germany, Norway and Sweden,

[14] Differences in the point estimates are computed as $(GIRF_{very\,high\,risk} - GIRF_{very\,low\,risk})$.

consistently with our previous findings. This result is supported once again by the differences in point estimates, which in the case of Germany are estimated to be larger than in our baseline case. Some marginal evidence in the same direction also emerges for Australia, whereas we do not find any evidence in this sense for Canada.

To summarize the main results for this part of the analysis, it is worth noticing that estimated responses to a global uncertainty shock of both exchange rate and output are sensitive to the level of relative riskiness. Indeed, responses are generally stronger as the regime becomes more "extreme", i.e. as countries become more distant in terms of their level of risk exposure. This findings provide supporting evidence to the main result of our I-VAR analysis, that cross-country differences in risk exposure are important in explaining the effects of a global uncertainty shock in open economies.

5.3 Consumption, external sector and financial flows

The results shown so far lead to the conclusion that following a global uncertainty shock economic activity reduces and the exchange rate appreciates. Moreover, countries' relative risk exposure seems to play a relevant role in the transmission of the shock, with significant nonlinearities arising especially in the effects on output. The channels through which a global uncertainty shock may affect the dynamics of exchange rate and economic activity are diverse. Here we examine three of them, that we think to be especially relevant: consumption, the external sector and financial flows.

First, in Gourio et al. (2013)'s theoretical model the response of exchange rate is driven by consumption. Indeed, the exchange rate reflects the relative value of current and future consumption in the two countries, and because the more risky country expects a larger decline in consumption growth than the less risky one, following a global uncertainty shock, then its marginal utility of consumption rises more and its currency appreciates. For this reason we estimate a specification of our model where we include consumption as an endogenous variable, ordered before output. Then, given that we examine an open economy framework, movements in the external sector may play a relevant role in the transmission of global uncertainty shocks. Hence, we estimate an alternative specification in which we include net exports ordered before output, in the vector of endogenous variables. Finally, international financial flows may be particularly helpful in explaining the dynamics of the exchange rate in response to the shock. For instance, heightened global uncertainty could in principle activate a flight to quality mechanism, with money leaving high risk countries and flowing towards less risky ones. This would affect foreign currency availability on currency markets and hence the exchange rate. Therefore, we propose a third alternative specification of our I-VAR, where a measure of financial flows is included, ordered after uncertainty and before the exchange rate.[15]

Figures 13-30 show the GIRFs obtained from these three alternative estimations and the differences in the point estimates, along with 68% confidence bands. Figures 13-18 refer to the specification including consumption. Our baseline results are confirmed for both output and exchange rate. The response of output is significantly more negative when the country is in high risk, whereas the exchange rate responds to the shock in a very similar way in both regimes.[16] Concerning consumption (fig. 17-18), we find heterogenous responses across countries and across regimes. For Australia and Canada, the response of consumption is not statistically significant in either regime. For Germany, Netherlands and Sweden, consumption positively responds to the shock in low risk, whereas the response is not significant in high risk. Finally, consumption significantly negatively responds in both regimes in the case of Norway, and the response in high risk is marginally larger than that in low risk.

[15]As a measure of consumption we use Gross Domestic Product by Expenditure in Constant Prices: Private Final Consumption Expenditure, Index 2010 = 1, Quarterly, Seasonally Adjusted. Net exports are computed as the difference between Gross Domestic Product by Expenditure in Constant Prices: Export of Goods and Services, Index 2010 = 1, Quarterly, Seasonally Adjusted and Gross Domestic Product by Expenditure in Constant Prices: Less: Imports of Goods and Services, Index 2010 = 1, Quarterly, Seasonally Adjusted. As a measure of financial flows we employ the Capital Accounts and Financial Accounts: Total Balance Including Change in Reserve Assets (US dollars, quarterly, not seasonally adjusted). The series of financial flows are only available since 1982Q1 for Sweden, 1990Q1 for Canada and 1994Q1 for Norway. All series are from Federal Reserve Bank of St. Louis (FRED) database.

[16]Canada is the only country for which we find different patterns in the responses of the exchange rate in high and low risk. Indeed in low risk, the currency appreciate some quarters after the shock, whereas the response in high risk is not statistically different form zero. In our baseline estimation we find exactly the same result.

Figures 19-24 refer to the specification including net exports. Once again, estimated responses are perfectly in line with our baseline results, for both output and exchange rate. The response of output is significantly more negative when the country is in high risk, whereas the exchange rate responds to the shock in a very similar way in both regimes.[17] Concerning the response of net exports (fig. 23-24), as a general result we find that net exports negatively respond, which implies that either export decreases or both import and export decrease, and the response in low risk is larger than that in high risk, as confirmed by the differences in the point estimates for all countries but Norway.

Finally, figures 25-30 refer to the specification including financial flows. Also in this case, the main findings coming the baseline estimation are still there. Concerning the response of financial flows (fig. 29-30), it does not emerge a common pattern. For Australia and Sweden financial flows positively respond to the shock, and in the case of Australia the response in high risk is larger than that in low risk. In the case of Germany, financial flows fall on impact and then suddenly raise some quarters after the shock in low risk, whereas the response is not statistically significant in high risk. For Netherlands, neither response is statistically different from zero.[18]

As a general result, these exercises aiming at exploring the channels through which a global uncertainty shock affects output and exchange rates confirm the main results coming from our baseline I-VAR estimation.

5.4 Robustness checks

Robustness of our results is tested through a series of perturbations of the baseline specification. We consider (i) uncertainty ordered last; (ii) an uncertainty shock dummy; (iii) the role of country-specific uncertainty; (iv) the role of financial shocks; (v) the role played by the size of the shock. Figures 31-50 illustrate the results.

[17]Once again, Canada is the only country for which we find different patterns in the responses of the exchange rate in high and low risk, as in our baseline results.

[18]For the part of the analysis including financial flows, results for Canada and Norway are not displayed. Indeed, the short available series for financial flows make our results unreliable.

Uncertainty ordered last. Employing a recursive ordering VAR with the uncertainty measure ordered first, as we do, is a commonly used strategy to identify structural uncertainty shocks in the empirical literature on uncertainty (e.g., Bloom, 2009; Alexopoulos & Cohen, 2009; Mumtaz & Theodoridis, 2012).[19] Using this identification scheme implies that uncertainty shocks can immediately affect exchange rate, prices, output and interest rate spread, whereas stock market volatility does not immediately react to the other shocks in the model, except for the shock to stock market levels. Since we consider a measure of global uncertainty, whereas all other variables but stock market index are country-specific, this seems to be a reasonable assumption, in the sense that it is plausible to assume that a global measure does not immediately react to country-specific shocks, while the converse, with country-specific variables immediately responding to a global shock seems more reasonable.

Nevertheless, a shortcoming of Cholesky decomposition is that results might depend on the particular ordering of endogenous variables. For this reason, among robustness checks we also consider the case in which uncertainty is ordered last. This allows to remove the possible effects of other shocks from the estimated effects of the global uncertainty shock we are interested in. Figures 31-34 show the estimated responses and the differences in the point estimates for both exchange rate and output. The results of our baseline estimation are confirmed: the negative response of output is larger when the country is more risky, whereas the responses of the exchange rate are very similar in the two regimes.

Uncertainty shock dummy. To identify global uncertainty shocks, as an alternative to the volatility series included in baseline analysis, we build a global uncertainty shock indicator, following Bloom (2009) and applying a narrative approach. The indicator is a dummy variable that takes a value of 1 for each of the events that we define as global uncertainty shocks, and 0 otherwise. To select the events labeled as global uncertainty shocks, we follow Bloom and take the Hodrick-Prescott (HP) detrended ($\lambda = 129,600$) series of the 30-day realized

[19]To be precise, uncertainty is ordered second after the stock market index in our VAR, in order to identify a global uncertainty (volatility) shock which is orthogonal to shocks to stock market levels, following Bloom (2009).

volatility of the MSCI World Index log returns, computed as the standard deviations of daily returns over calendar months, and assign a value of one to the observations that correspond to a value of stock-market volatility more than 1.65 standard deviations above the HP detrended mean. Among the events selected by this procedure, we only keep those that we define as global shocks and exclude those that are more country-specific in our view. Moreover, since the analysis is carried out with quarterly data, we build a quarterly indicator in which a value of 1 is assigned to each quarter for which there is at least one month taking a value of 1 in our monthly series. The chosen global uncertainty shock events are shown in table 2 (they are also highlighted in figure 1, where the volatility series is plotted). Selected events are the major economic and political shocks in recent history at a global level. Results are reported in figures 35-38. The estimates are less precise than those obtained from our baseline specification. Nevertheless, the exchange rate appreciates on impact in boh regimes, and the negative response of output is larger in high risk than in low risk, in the cases of Germany and Sweden. These findings support our baseline results.

Table 2: Global uncertainty shocks

Quarter	**Event**
1973Q4	OPEC I, Arab-Israeli war
1982Q3	Monetary cycle turning point
1987Q4	Black Monday
1990Q3	Gulf war I
1997Q4	Asian crisis
1998Q3	Russian, LTCM default
2001Q1	Dotcom bubble
2001Q3	9/11
2002Q3	Worldcom, Enron
2003Q1	Gulf war II
2007Q3	Financial turmoils

Country-specific uncertainty. As a further robustness check, we ask whether including a measure of country-specific uncertainty would affect the responses of output and exchange rate to a global uncertainty shock. Indeed, it can be the case that the effects that we find are due to heightened country-specific uncertainty rather than to a global shock. Hence, to control for idiosyncratic movements in uncertainty, we re-estimate our model by including a measure of country-specific uncertainty in the vector of endogenous variables. For each country in the sample, this measure is obtained as the realized volatility of the log returns of a national stock market index at a quarterly frequency. Results are displayed in figures 39-42. The main findings of our analysis are confirmed.

Financial shocks vs. uncertainty shocks. There is a recent strand of literature that focuses on financial markets frictions as a possible channel through which uncertainty shocks can affect macroeconomic variables (Arellano et al., 2012; Gilchrist, Sim, & Zakrajsek, 2014; Alessandri & Mumtaz, 2014; Caldara, Fuentes-Albero, Gilchrist, & Zakrajsek, 2016). Since measures of uncertainty are highly correlated with measures of financial distress, as pointed out by Stock and Watson (2012), it is difficult to disentangle between these two potential channels of economic fluctuations (Caldara et al., 2016). Therefore, in order to isolate the effects of uncertainty shocks, it is important to control for financial shocks by including a measure of financial distress in the model. To this aim, we include as an endogenous variable in our specification the measure of credit spread recently proposed by Gilchrist and Zakrajsek (2012) as a proxy for financial distress, the "excess bond premium" (EBP). Figures 43-46 illustrate the dynamic responses of output and exchange rate and the differences in the point estimates and confirm our main results.

Size of the shock. In our baseline analysis, we compute GIRFs to a one standard deviation global uncertainty shock. In order to check whether our estimated responses are sensitive to the size of the global uncertainty shock, we re-compute GIRFs to shocks of a size up to five standard deviations. For the sake of illustration, figures 47-50 show the responses to a five standard deviations global uncertainty shock for both exchange rate and output. Our findings suggest that the size of the shock does not play a relevant role relative to the shape and magnitude of the impulse responses.

6 Conclusions

What are the effects of a global uncertainty shock in an open economy? Does the level of country exposure to aggregate risk have a role in the transmission of the shock? To answer these questions, we estimate an Interacted VAR model for a group of countries relative to the U.S., to account for the possible presence of nonlinearities in the transmission of the shock. Indeed, this empirical framework allows to identify a high risk and a low risk regime and to account for time variation in country relative riskiness, through the computation of state-conditional impulse response functions. Global uncertainty is measured as the realized volatility of the MSCI World Index log returns. We employ the spread between each country's interbank rate and the Federal Funds rate as our measure of relative risk exposure and as the conditioning variable which separates the two regimes in the empirical analysis.

We examine the responses of output and exchange rate. Concerning the response of output, our findings are in line with the main results in the literature on uncertainty, in that a global uncertainty shock significantly reduces real activity. We also find that the exchange rate responds to the shock by appreciating on impact. Relative to the role of risk exposure in the transmission of the shock, evidence of nonlinear effects is found. Indeed, the response of economic activity to the shock is significantly negative in high risk regime and the reduction in output is estimated to be larger when the country is in high risk than when it is in low risk. This result also supports the theoretical predictions of Gourio et al. (2013). For what concerns the exchange rate, it significantly appreciates on impact in response to the shock in both regimes, but we do not find evidence of a statistically significant difference between the responses in the two riskiness states. Some evidence pointing to the presence of nonlinear effects in the transmission of global uncertainty shocks to the exchange rate is provided by the analysis of "extreme" riskiness regimes. Indeed, when the distance in countries' relative riskiness widens, the responses of the exchange rate in the two regimes become more distant in both magnitude and shape. The same happens to the estimated responses of output, thus reinforcing our main findings.

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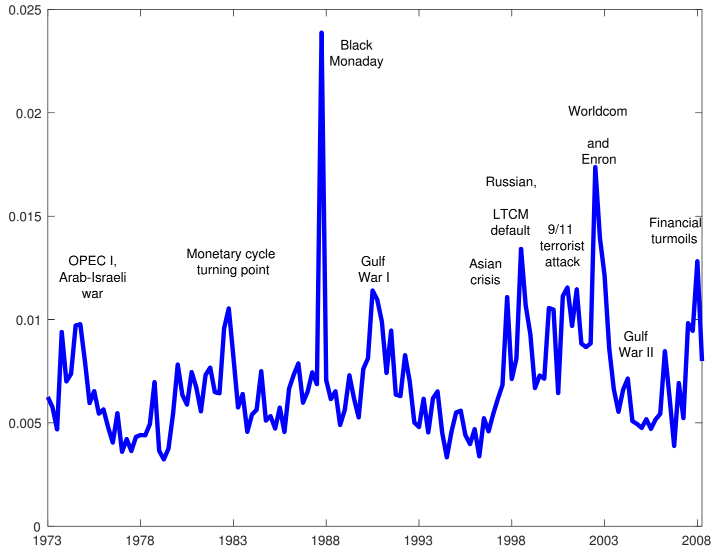

Figure 1: Plot of time series of MSCI World Index log returns realized volatility (1973:Q1-2008:Q2).

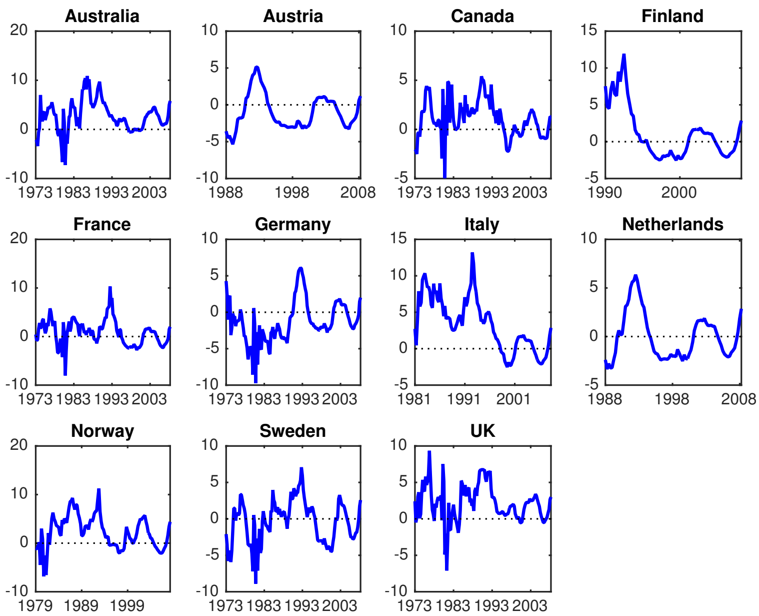

Figure 2: Time series of the spreads between each country's interbank rate and the Federal Funds rate.

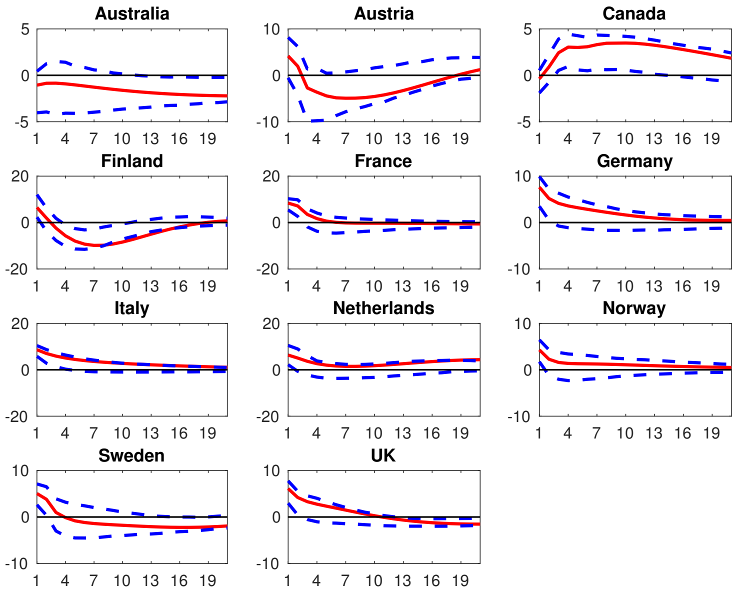

Figure 3: Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands).

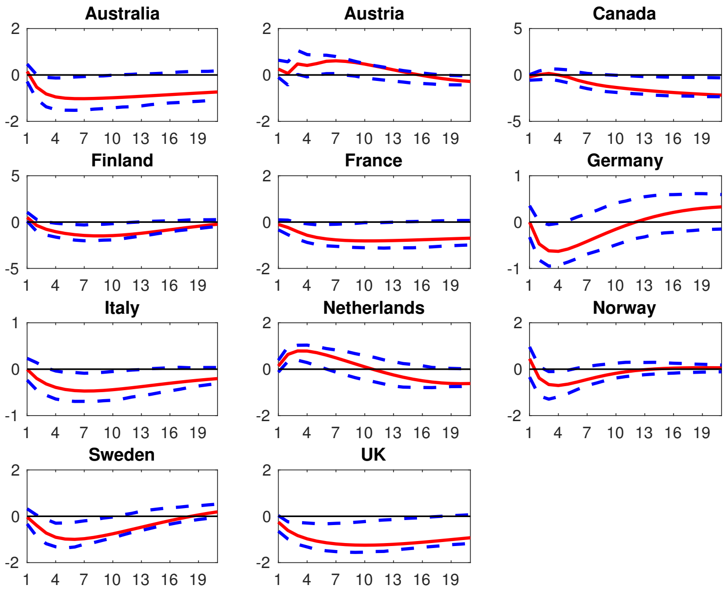

Figure 4: Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands).

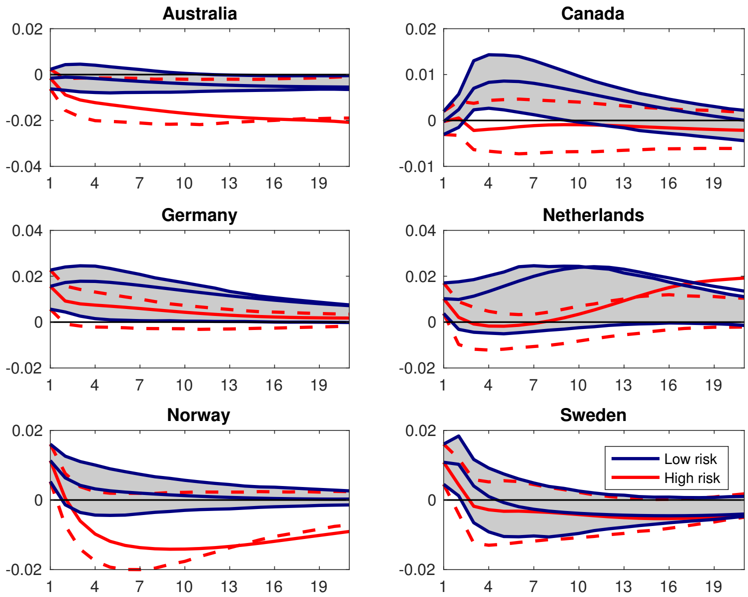

Figure 5: Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

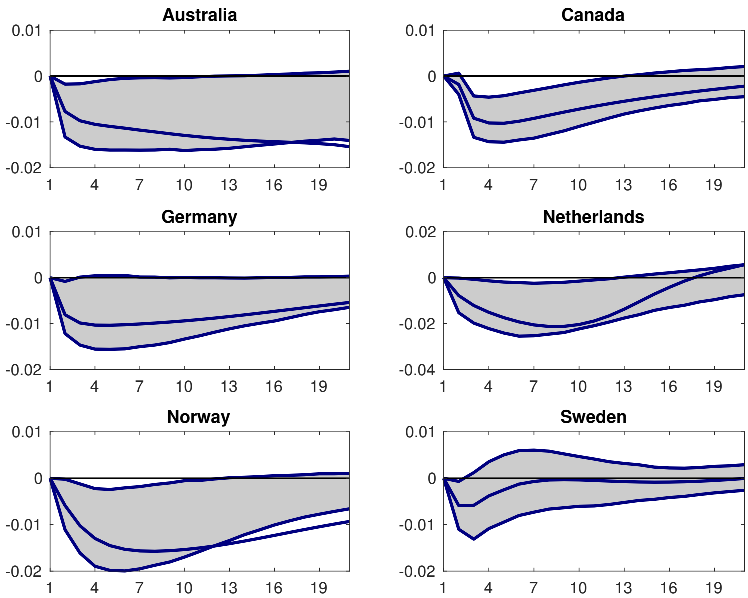

Figure 6: Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

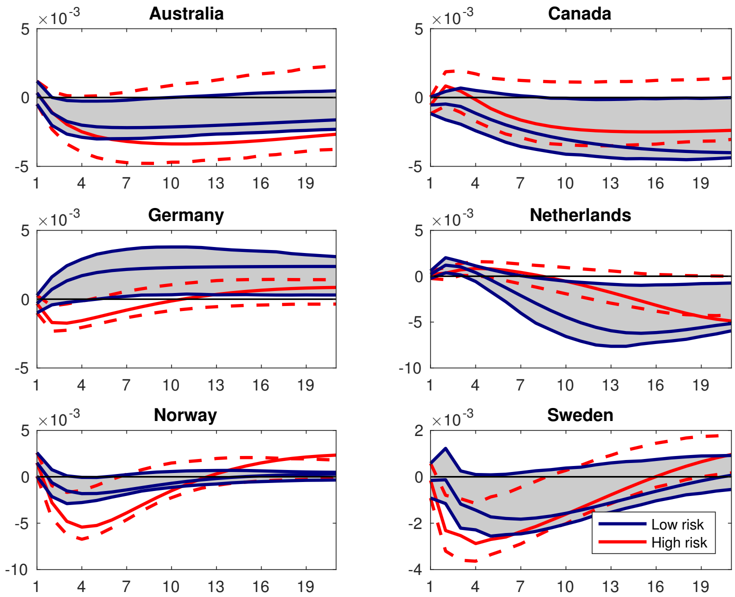

Figure 7: Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

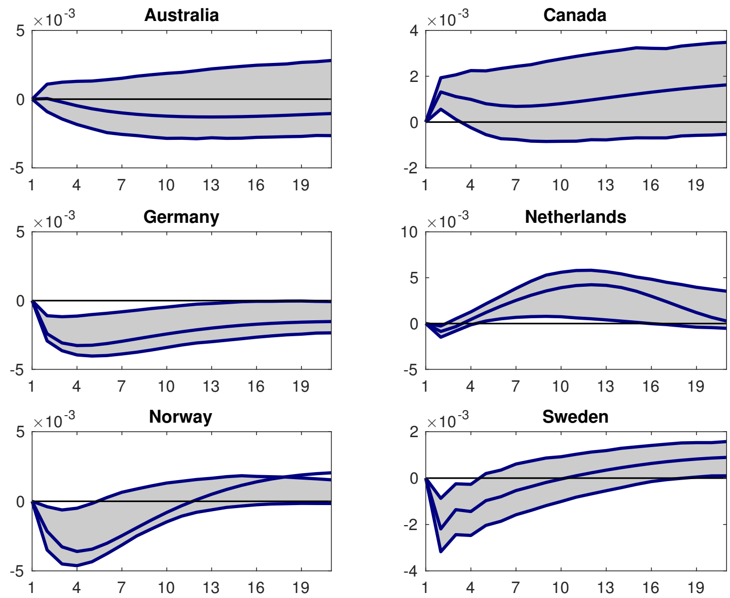

Figure 8: Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

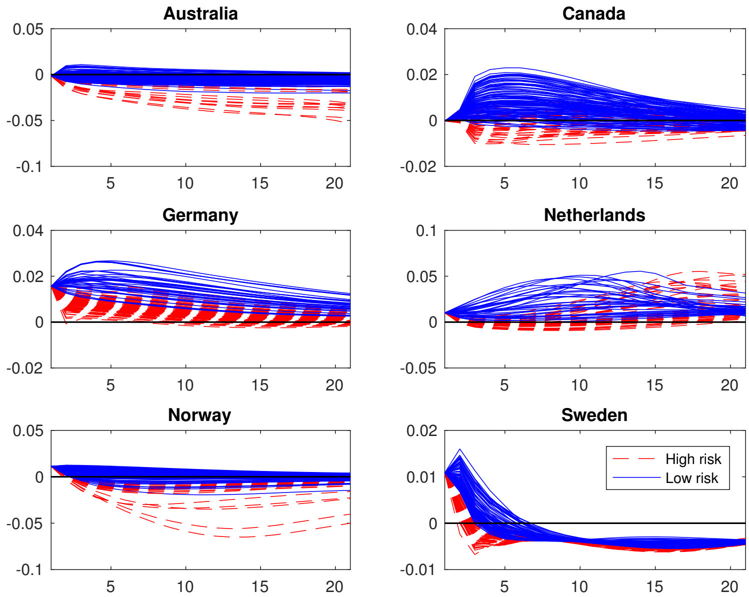

Figure 9: State-specific responses conditional on histories of the exchange rate. Blue: low risk; Red: high risk.

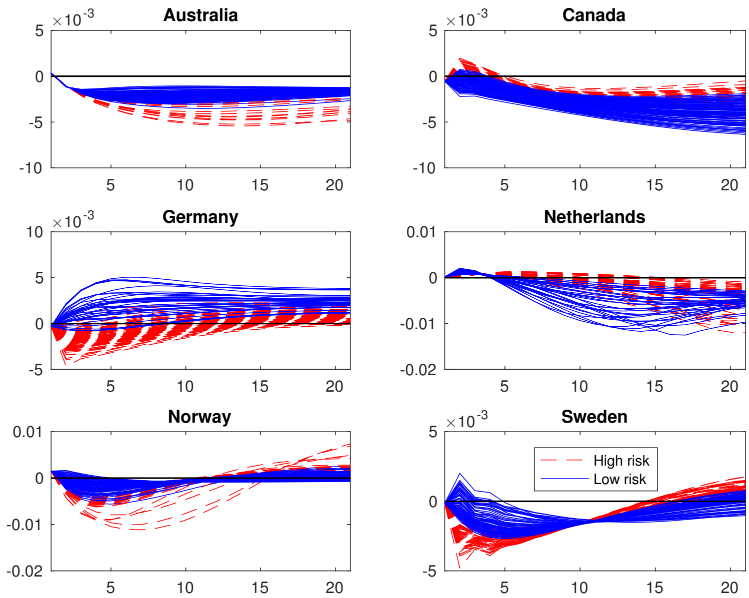

Figure 10: State-specific responses conditional on histories of output. Blue: low risk; Red: high risk.

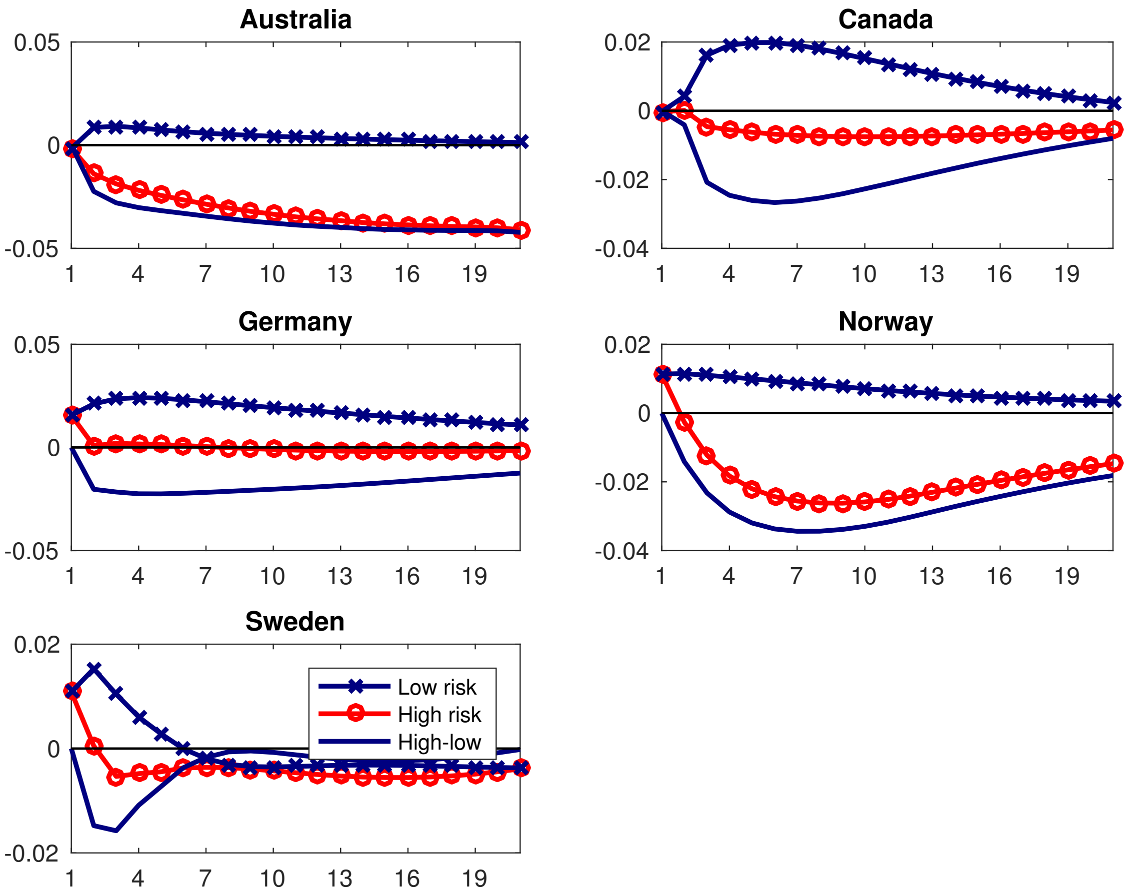

Figure 11: Impulse responses of exchange rate to a one standard deviation global uncertainty shock and differences in the point estimates. Very high risk: red line; very low risk: blue line.

Notes: For the Netherlands, there are no initial conditions in the "very high" risk regime subset, hence it is not possible to show the results for this part of the analysis.

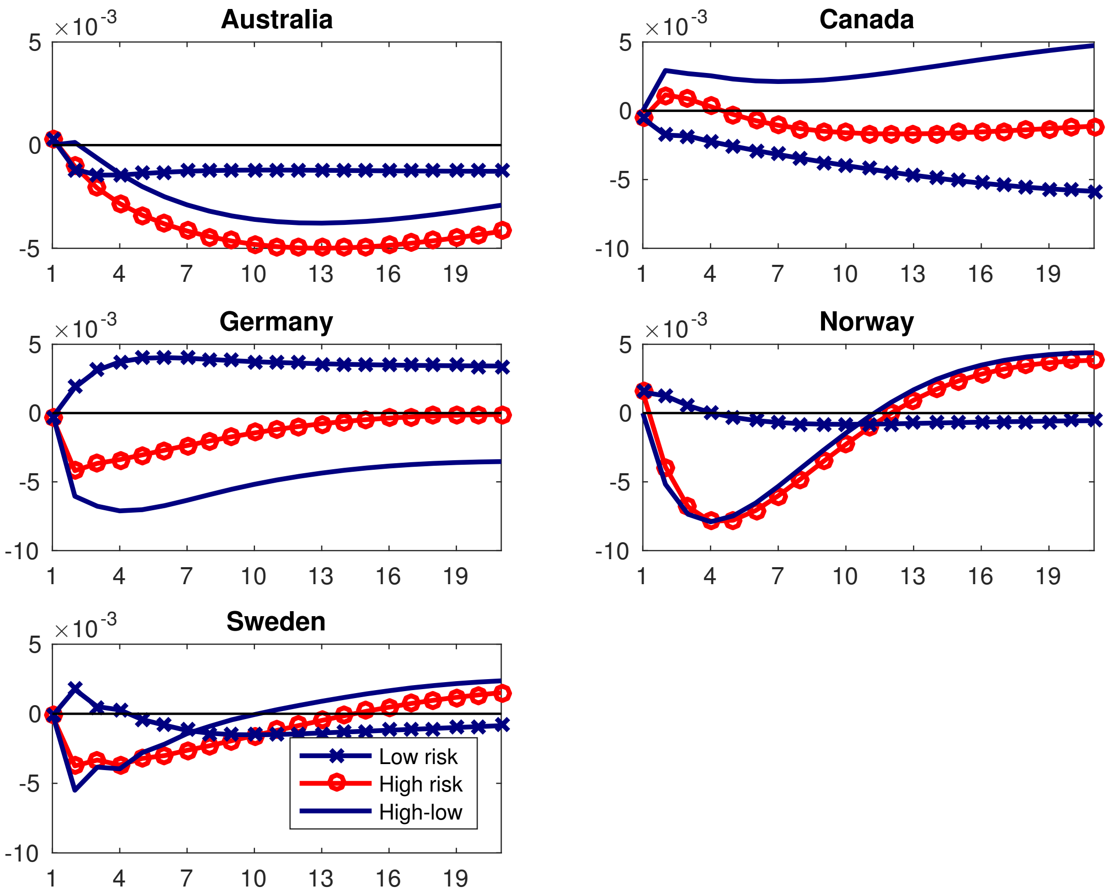

Figure 12: Impulse responses of output to a one standard deviation global uncertainty shock and differences in the point estimates. Very high risk: red line; very low risk: blue line.

Notes: For the Netherlands, there are no initial conditions in the “very high” risk regime subset, hence it is not possible to show the results for this part of the analysis.

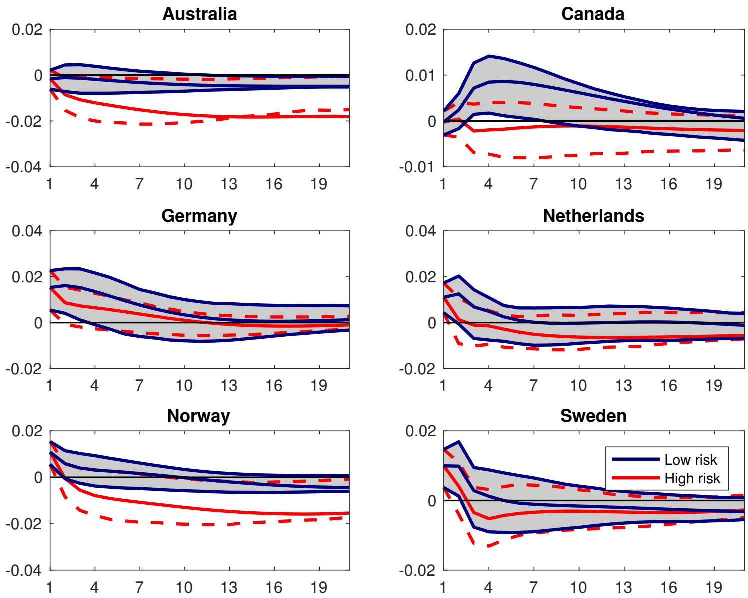

Figure 13: Consumption. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

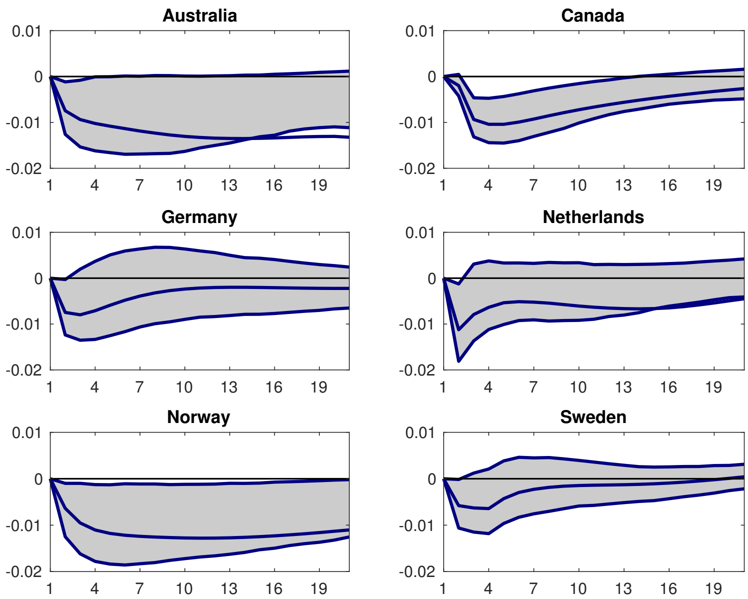

Figure 14: Consumption. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

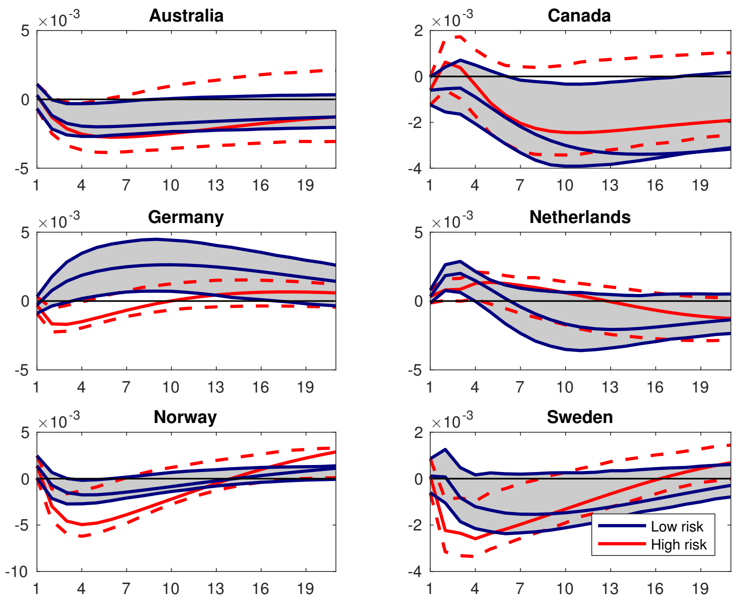

Figure 15: Consumption. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

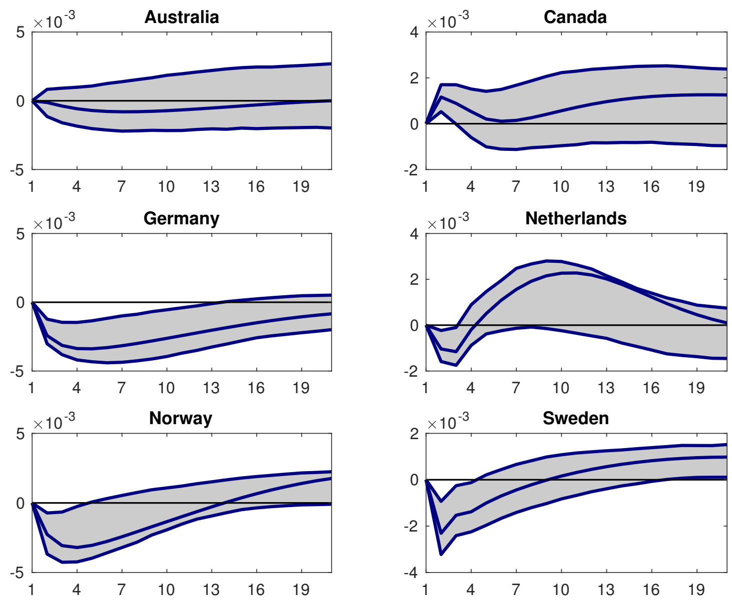

Figure 16: Consumption. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

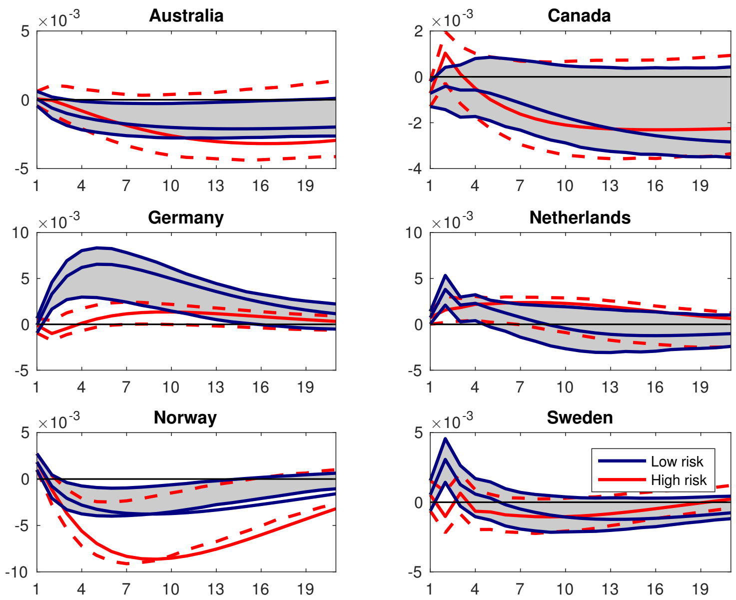

Figure 17: Consumption. Impulse responses of consumption to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

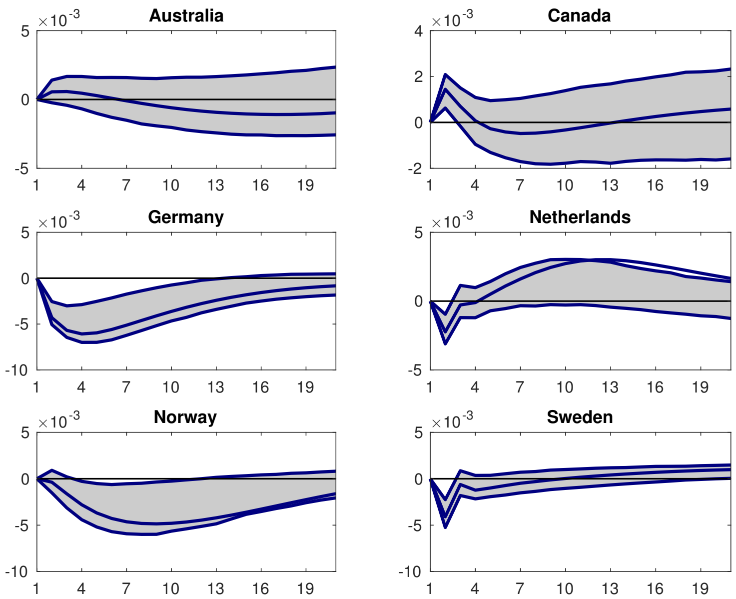

Figure 18: Consumption. Differences in the point estimates of the impulse responses of consumption in the two states (high risk - low risk). 68% confidence bands.

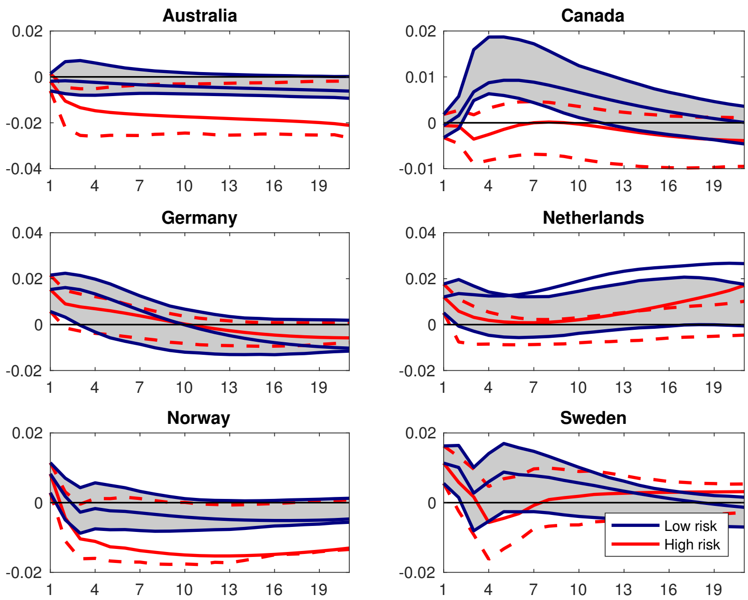

Figure 19: Net exports. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

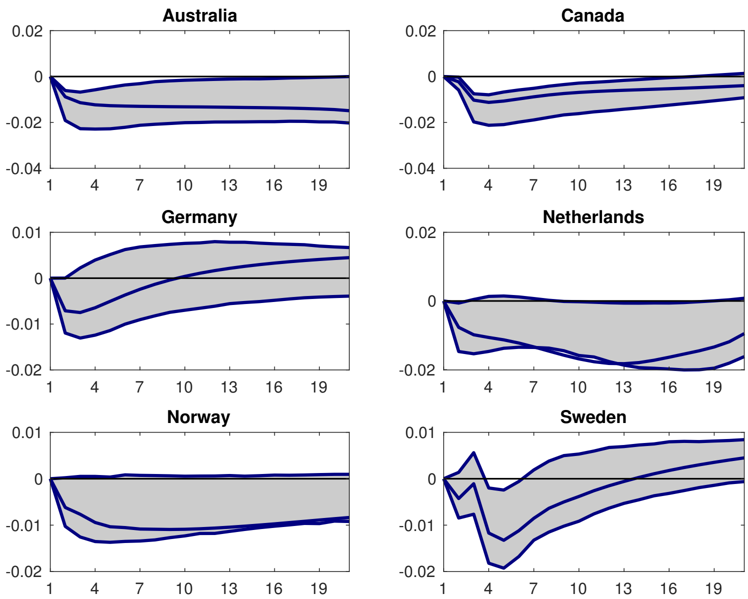

Figure 20: Net exports. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

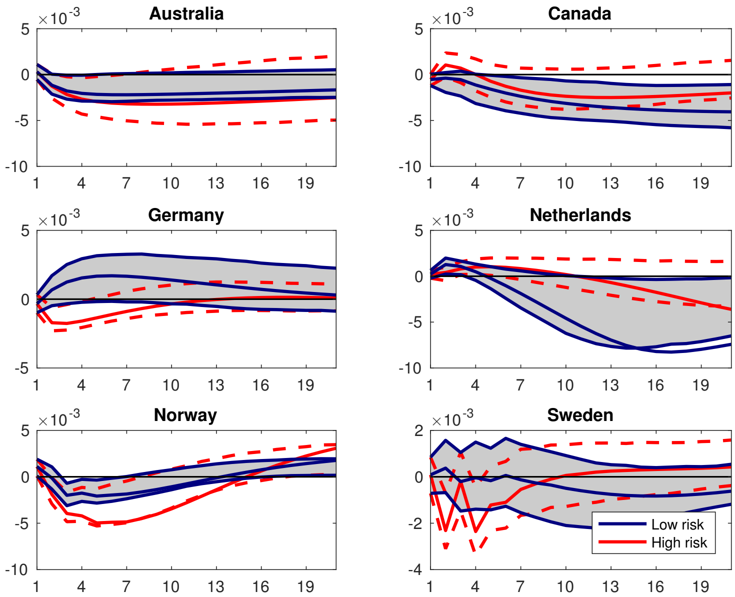

Figure 21: Net exports. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

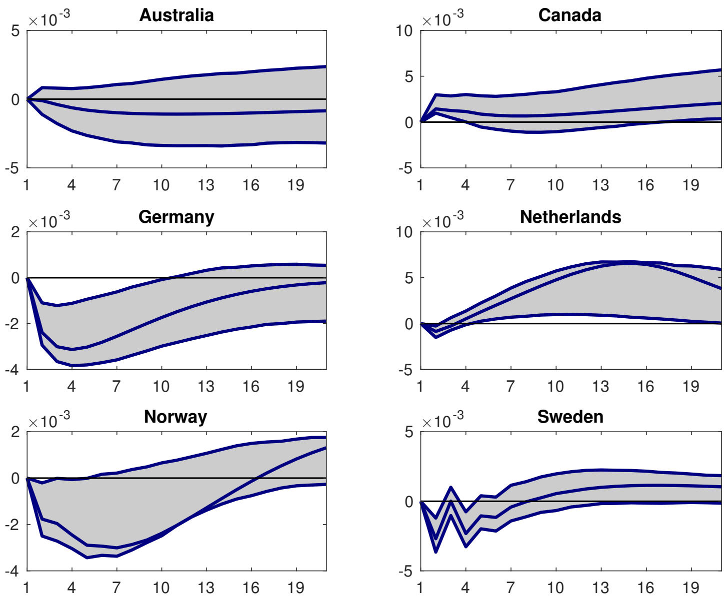

Figure 22: Net exports. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

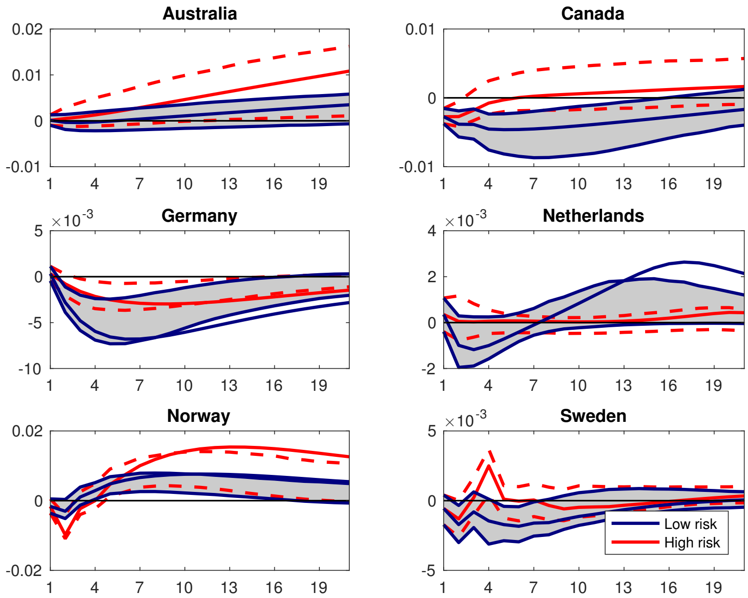

Figure 23: Net exports. Impulse responses of net exports to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

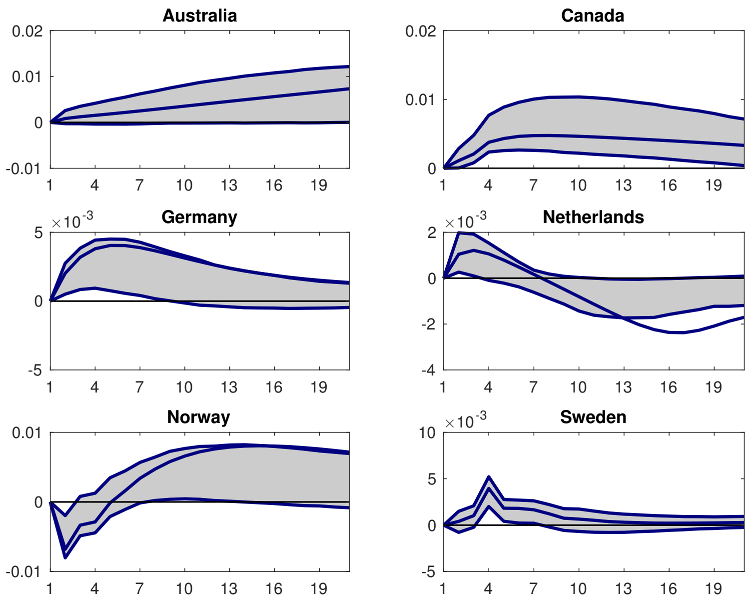

Figure 24: Net exports. Differences in the point estimates of the impulse responses of net exports in the two states (high risk - low risk). 68% confidence bands.

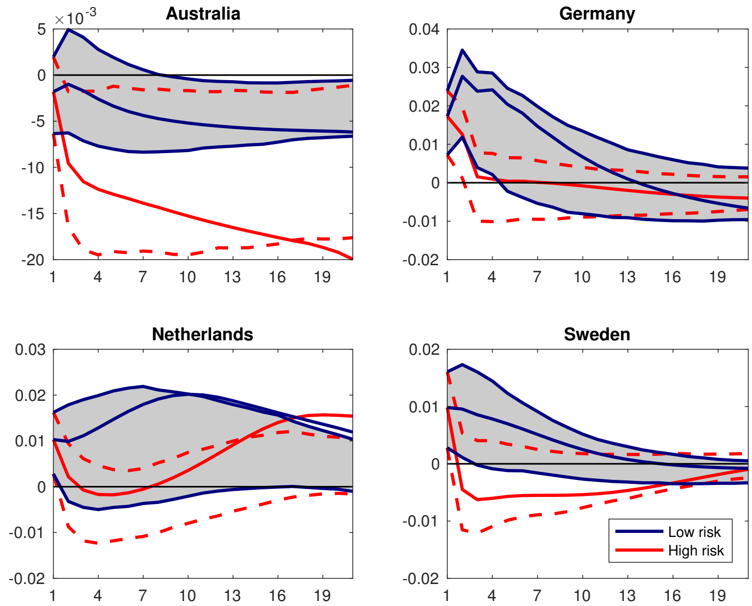

Figure 25: Financial flows. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

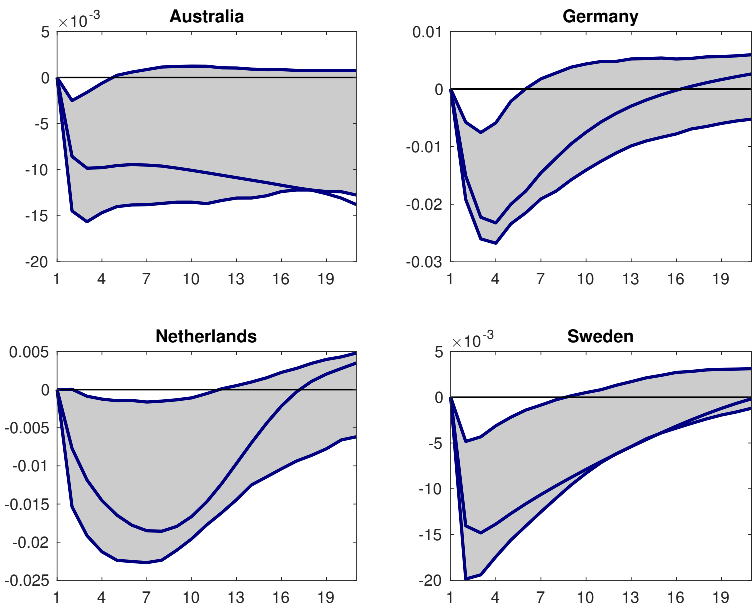

Figure 26: Financial flows. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

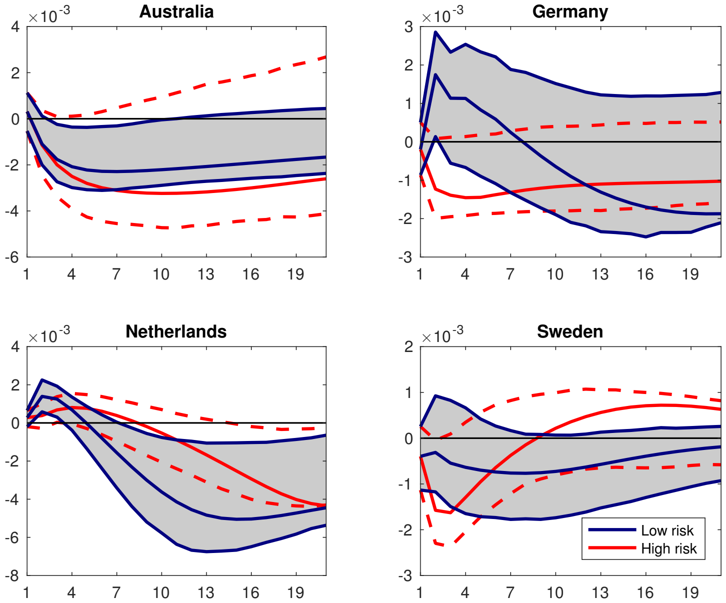

Figure 27: Financial flows. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

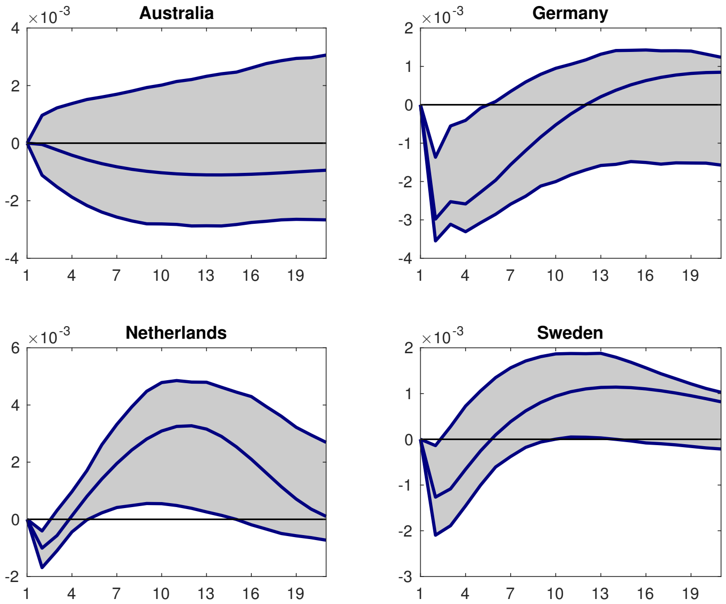

Figure 28: Financial flows. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

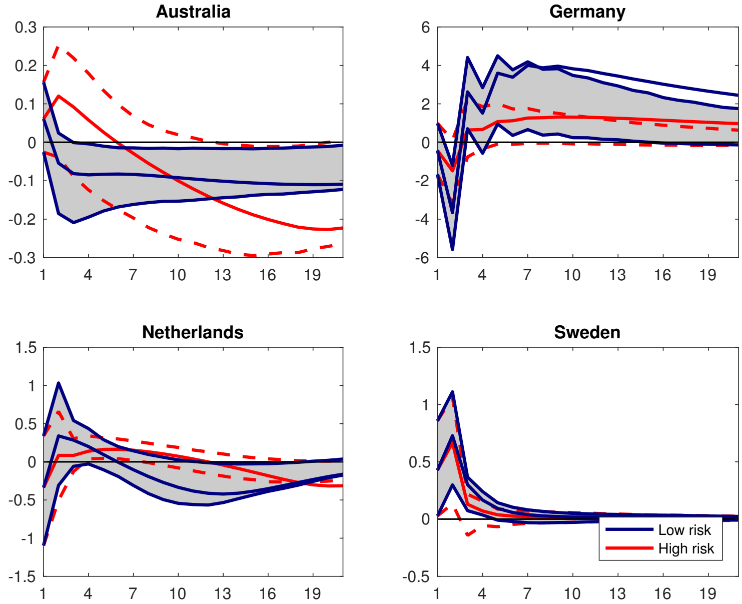

Figure 29: Financial flows. Impulse responses of financial flows to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

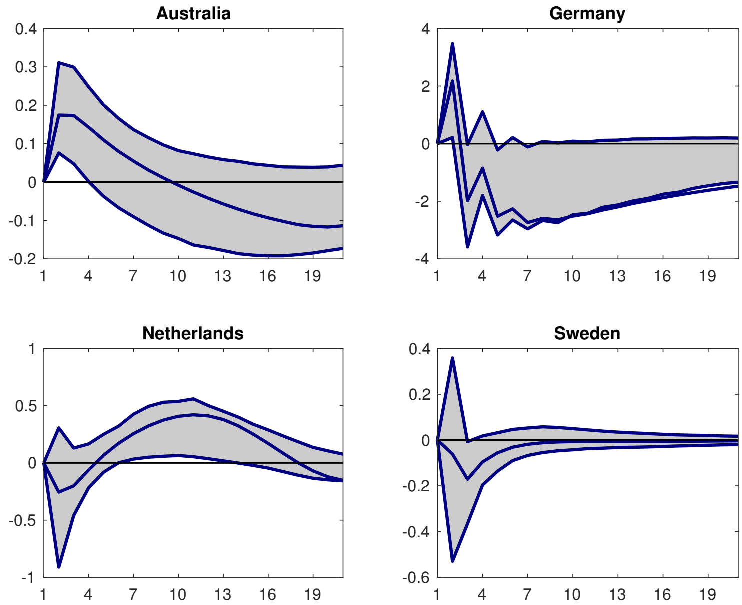

Figure 30: Financial flows. Differences in the point estimates of the impulse responses of financial flows in the two states (high risk - low risk). 68% confidence bands.

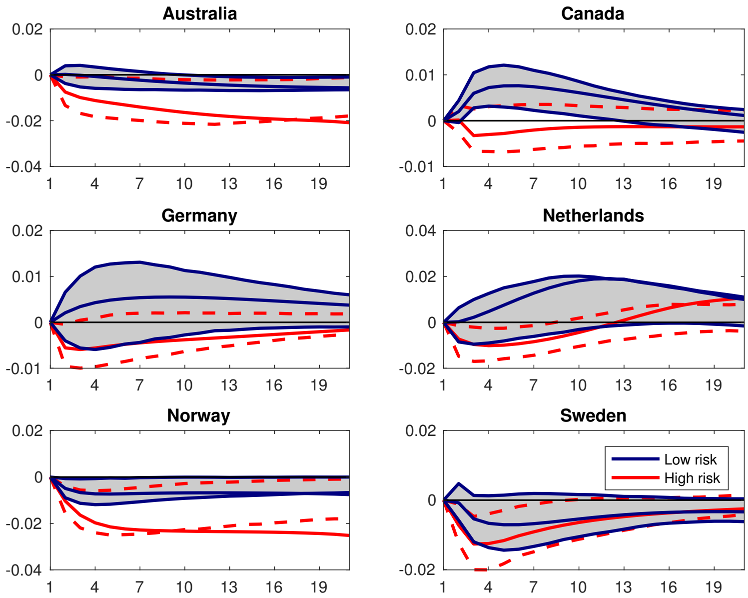

Figure 31: Uncertainty last. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

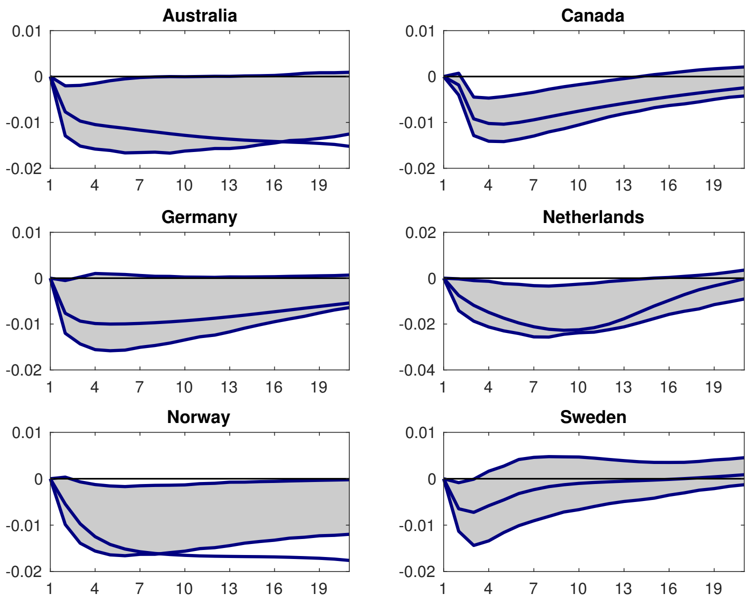

Figure 32: Uncertainty last. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

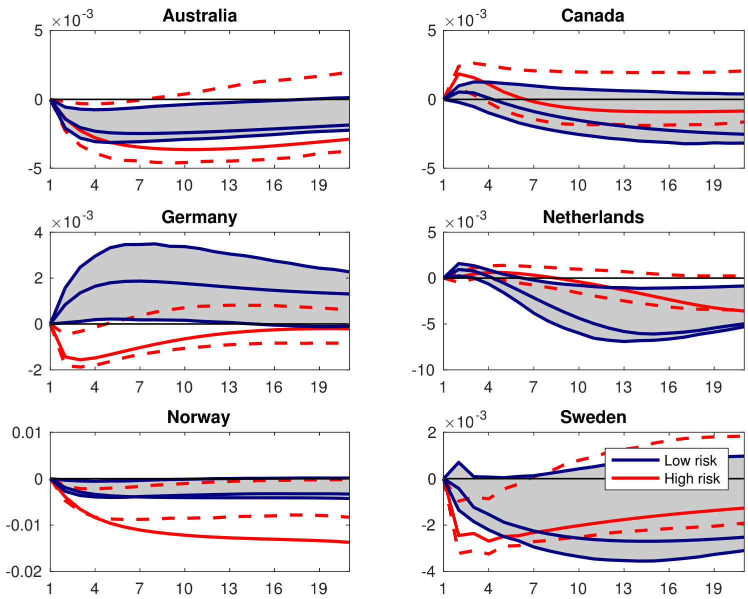

Figure 33: Uncertainty last. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

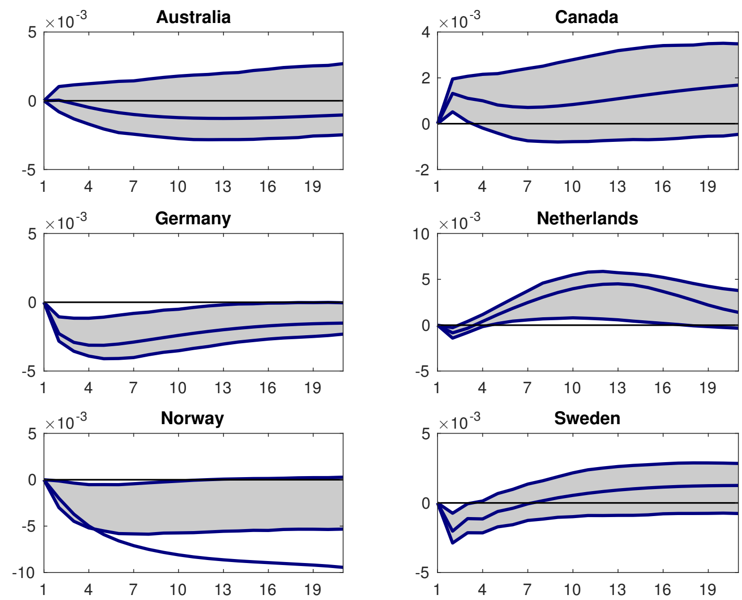

Figure 34: Uncertainty last. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

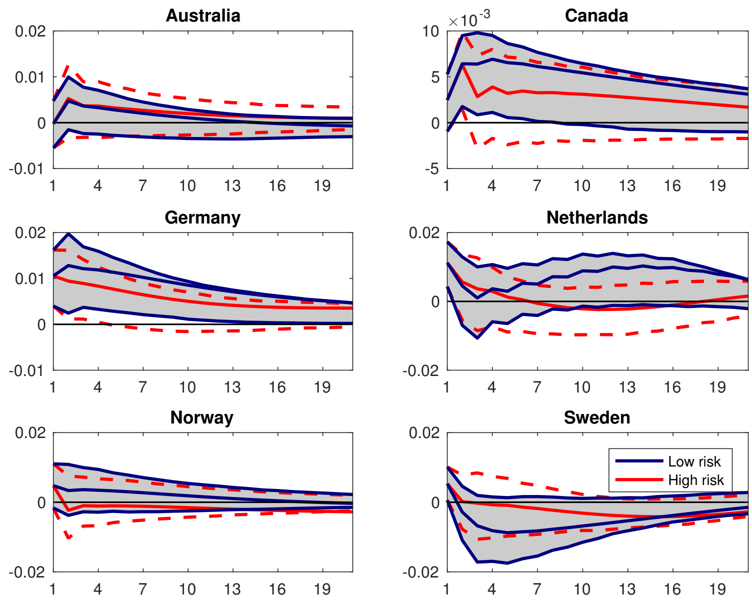

Figure 35: Uncertainty dummy. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

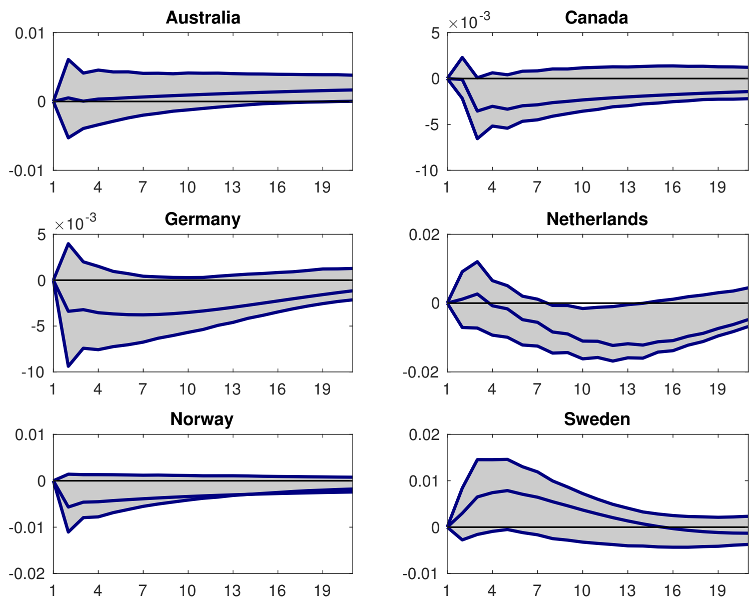

Figure 36: Uncertainty dummy. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

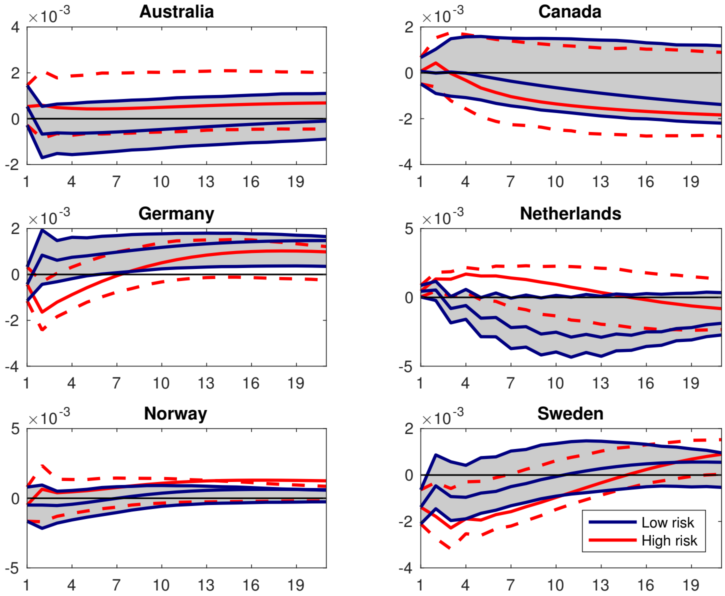

Figure 37: Uncertainty dummy. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

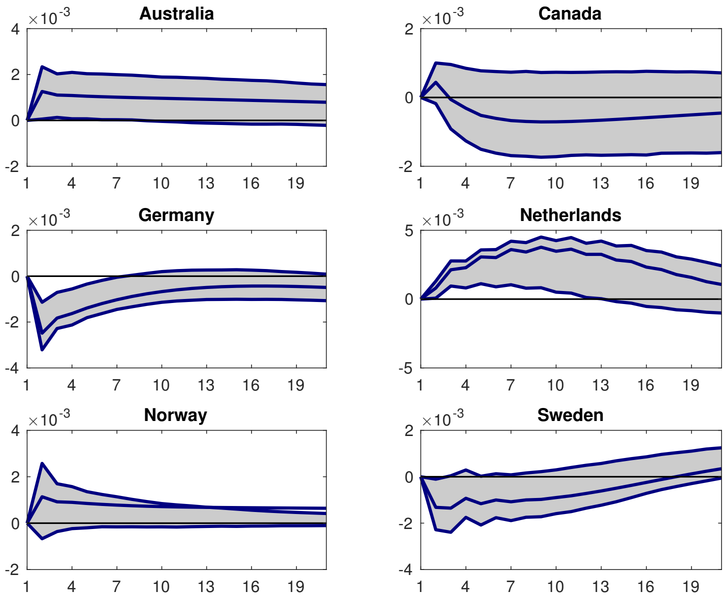

Figure 38: Uncertainty dummy. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

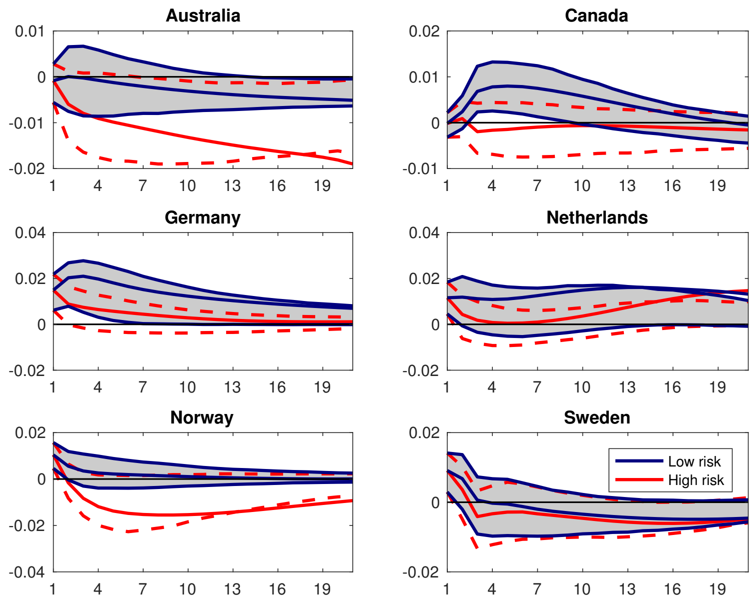

Figure 39: Country-specific uncertainty. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

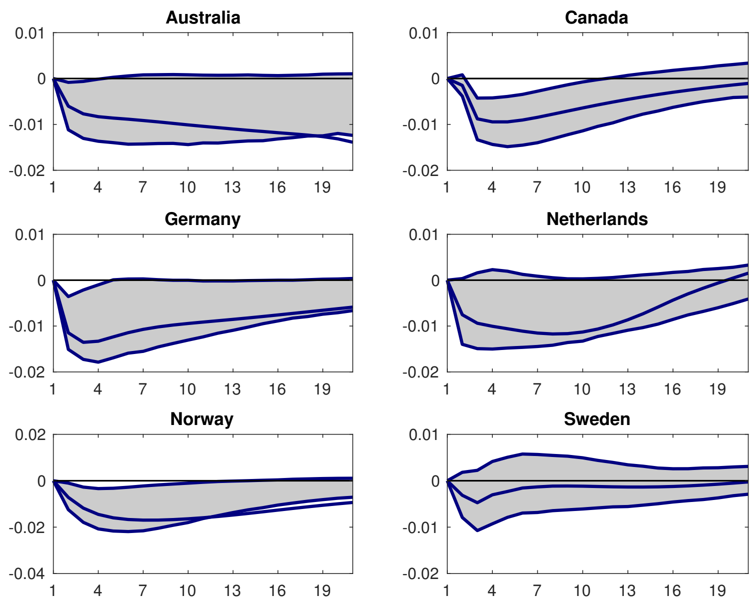

Figure 40: Country-specific uncertainty. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

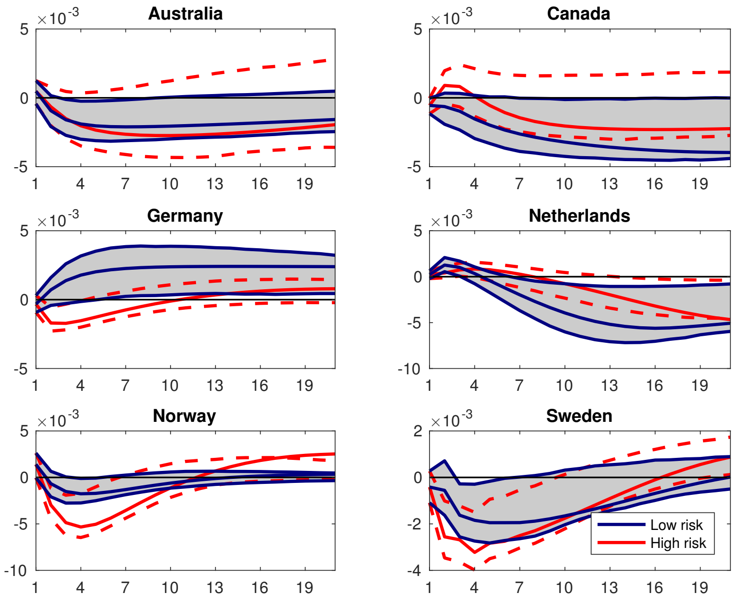

Figure 41: Country-specific uncertainty. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

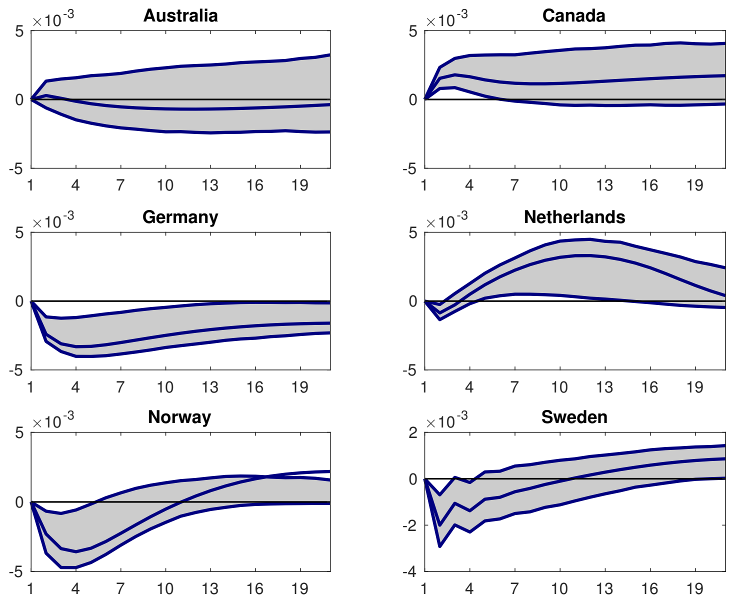

Figure 42: Country-specific uncertainty. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

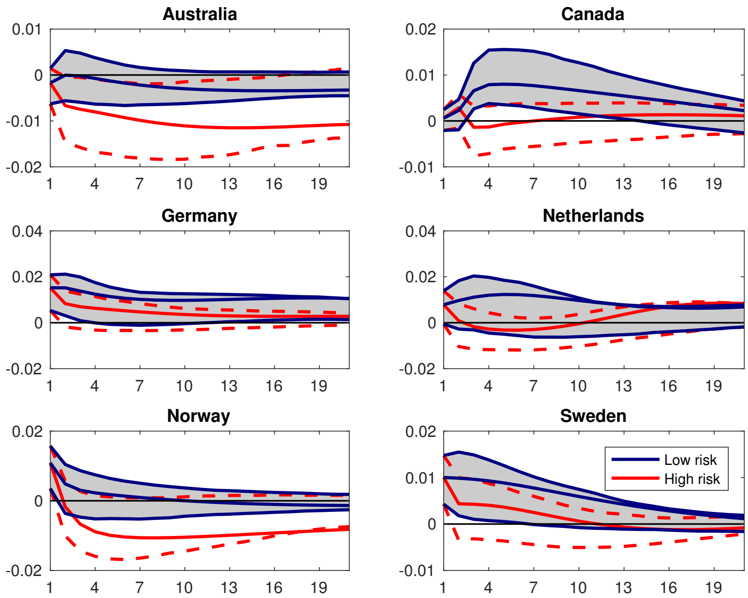

Figure 43: EBP. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

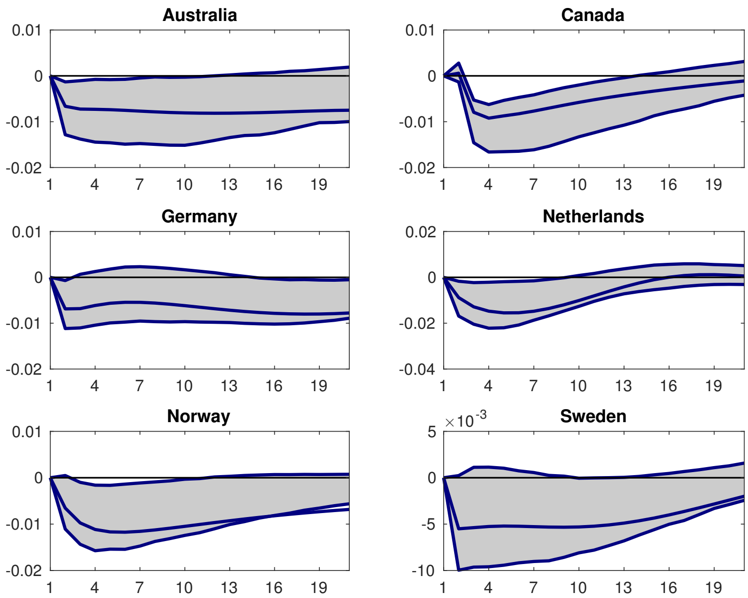

Figure 44: EBP. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

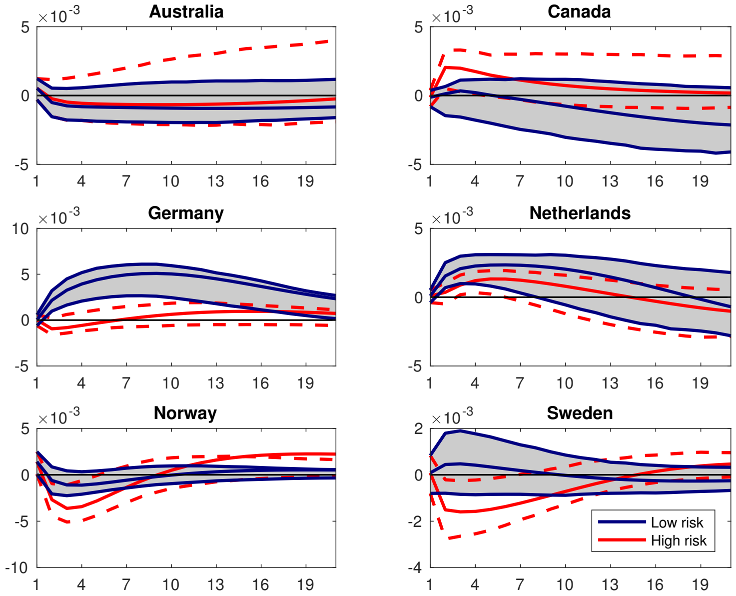

Figure 45: EBP. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

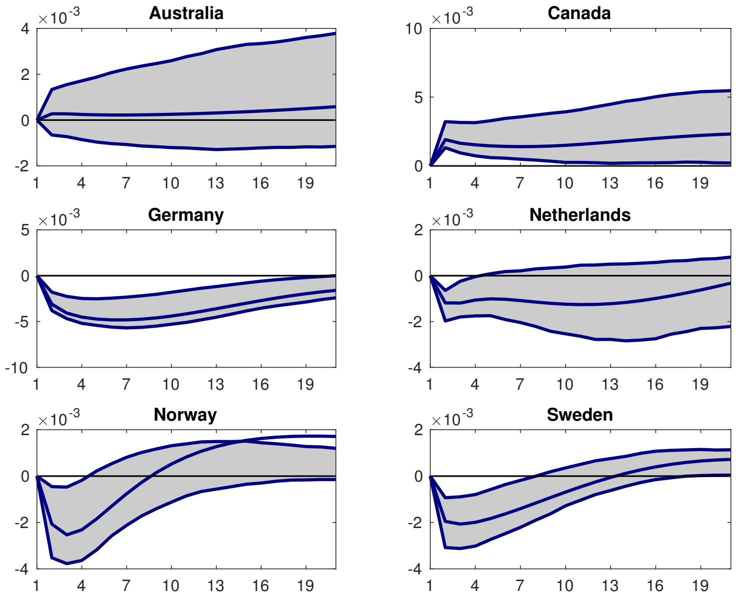

Figure 46: EBP. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

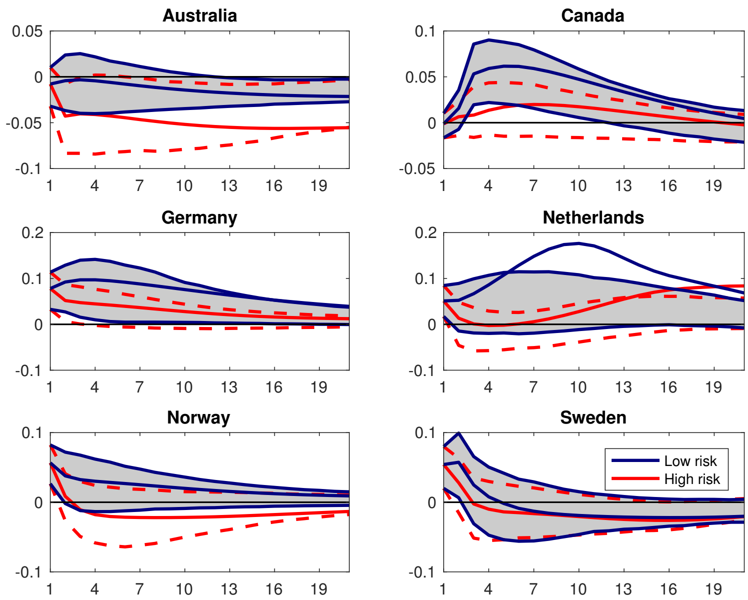

Figure 47: Size of the shock. Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

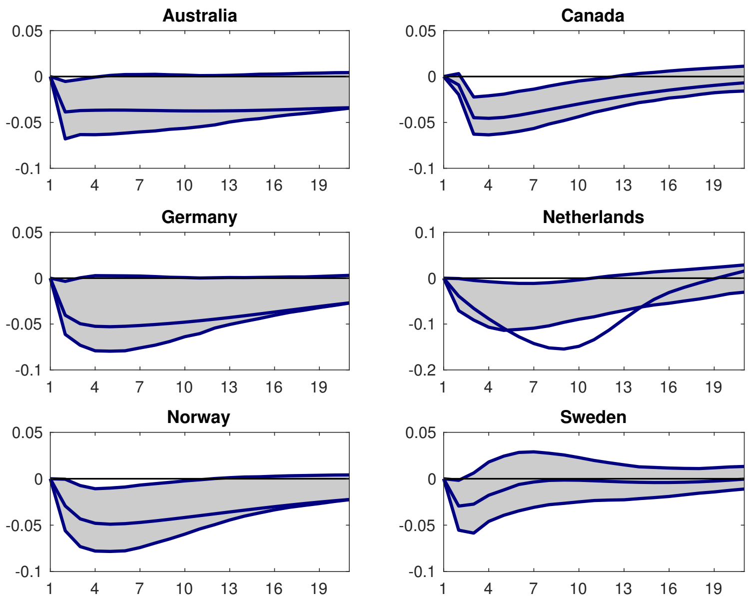

Figure 48: Size of the shock. Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

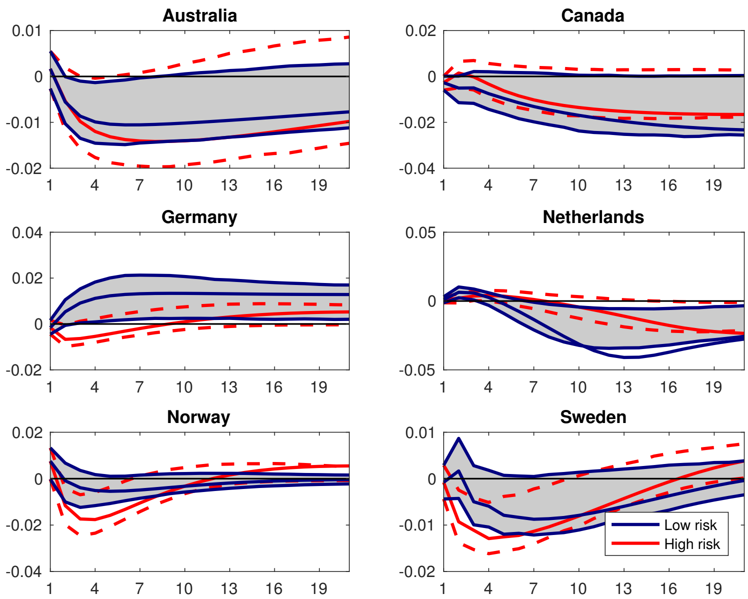

Figure 49: Size of the shock. Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

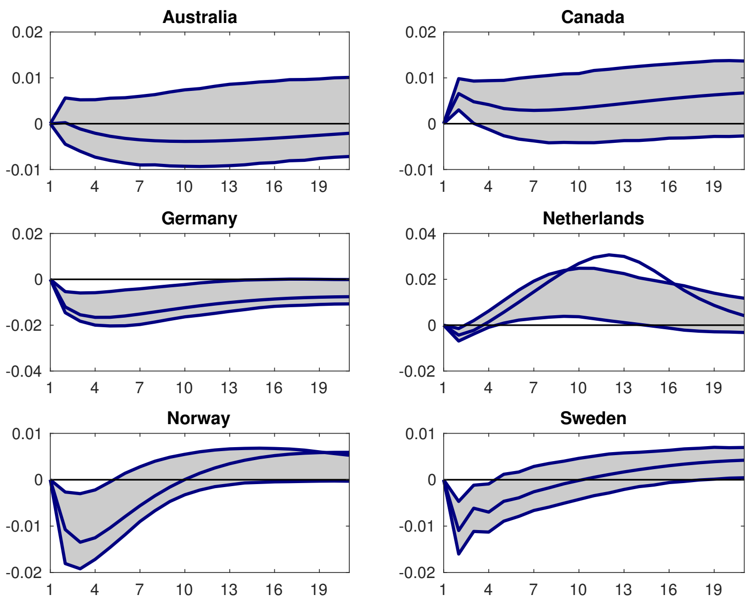

Figure 50: Size of the shock. Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

Appendix

Computation of GIRFs

To compute state-conditional Generalized Impulse Response Functions (GIRFs) we follow the algorithm proposed in Caggiano, Castelnuovo, and Pellegrino (2015), which in turn follows the steps in Koop et al. (1996) and simulates the effects of an orthogonal structural shock as in Kilian and Vigfusson (2011).

The idea is to compute the empirical counterpart of the theoretical $GIRF_{\mathbf{y}}(h, \delta, \omega_{t-1})$ of the vector of endogenous variables $\mathbf{y}_t$, h periods ahead, for a given initial condition $\omega_{t-1} = \{\mathbf{y}_{t-1}, \ldots, \mathbf{y}_{t-k}\}$, k being the number of lags in the I-VAR, and a structural shock hitting at time t δ. Following Koop et al. (1996), we express such GIRF as follows:

$$GIRF_{\mathbf{y}}(h, \delta, \omega_{t-1}) = E[\mathbf{y}_{t+h} \,|\, \delta, \omega_{t-1}] - E[\mathbf{y}_{t+h} \,|\, \omega_{t-1}]$$

where $E[\cdot]$ is the expectation operator and $h = 0, 1, \ldots, H$ indicates the horizons for which the GIRF is computed.

The procedure to compute it is the following:

1. Pick an initial condition ω_{t-1}.

2. Conditional on ω_{t-1} and the I-VAR structure of the model, simulate the path $[y_{t+h}|\omega_{t-1}]^r$, by loading the VAR with a sequence of randomly extracted (with repetition) residuals $\tilde{u}^r_{t+h} \sim d(0, \hat{\Sigma})$, where d is the empirical distribution of the residuals, $\hat{\Sigma}$ is the estimated variance-covariance matrix and r indicates the particular sequence of residual extracted.

3. Conditional on ω_{t-1} and the structure of the model, simulate the path $[y_{t+h}|\delta, \omega_{t-1}]^r$, by loading the VAR with a perturbation of the randomly extracted residuals $\tilde{u}^r_{t+h} \sim d(0, \hat{\Sigma})$ obtained in Step 2.
   To obtain perturbed residuals, first recover the vector of orthogonalized shocks $\tilde{\epsilon}^r_t$. Take the Cholesky decomposition of $\hat{\Sigma} = \hat{C}\hat{C}'$, where $\hat{C}$ is a lower triangular matrix. The orthogonalized shocks are given by $\tilde{\epsilon}^r_t = \hat{C}^{-1}\tilde{u}^r_{t+h}$. Then, to obtain a series of perturbed orthogonalized shocks, add a quantity

$\delta > 0$ to the element $\tilde{\epsilon}^r_{unc,t}$, which is the scalar stochastic element loading the uncertainty equation in the VAR. Finally, to move from perturbed orthogonalized shocks to perturbed residuals that we use to simulate $[y_{t+h}|\delta, \omega_{t-1}]^r$, compute them as $\tilde{u}^r_t = \hat{C}\tilde{\epsilon}^r_{t+h}$.

4. At each horizon, compute the difference between the simulated paths $[y_{t+h}|\delta, \omega_{t-1}]^r - [y_{t+h}|\omega_{t-1}]^r$.

5. For each initial condition ω_{t-1}, repeat Steps 2-4 for $R = 500$ times. Then, store the average realization across repetitions for each horizon h. In this way, a consistent estimate of the GIRF for any given initial condition is obtained: $\widehat{GIRF}_{\mathbf{y}}(h, \delta, \omega_{t-1}) = \hat{E}[\mathbf{y}_{t+h} \,|\, \delta, \omega_{t-1}] - \hat{E}[\mathbf{y}_{t+h} \,|\, \omega_{t-1}]$.

6. To produce the point estimates of state-conditional GIRFs, average history-dependent GIRFs over a particular subset of initial conditions of interest. In our case, an initial history ω_{t-1} belongs to "high risk" regime if $SPREAD_{i,t-1} < 0$ and to "low risk" regime if $SPREAD_{i,t-1} \geq 0$.

7. Confidence bands are computed via a bootstrap procedure. To implement it, simulate $S = 1000$ samples of the same size as actual data. Then, for each simulated dataset estimate the I-VAR model and repeat Steps 1-6 to compute state-dependent GIRFs. Confidence bands are given by the 16th and the 84th percentiles of the resulting distribution of state-conditional GIRFs.