Estimating the effects of global uncertainty in open economies

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Abstract

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 into account the time-varying dimension of country relative risk exposure. 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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1 Introduction

In recent years the role of uncertainty in driving business cycle fluctuations has become central 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.

This paper empirically investigates the effects of a global uncertainty shock 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. We first address question (i) through the estimation of a linear SVAR model and the computation of the impulse responses of output and the exchange rate to the global uncertainty shock. Then, we address question (ii) by employing an Interacted VAR (I-VAR) model, which allows to account for time variation in country relative riskiness, through the computation of state conditional impulse response functions, where the state of the economy is given by the level of risk exposure. Indeed, to assess whether different levels of countries' relative riskiness play a relevant role in the transmission mechanism of global uncertainty shocks, it is important to account for the time-varying dimension of this cross-country relationship in the empirical specification. 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. For this part of the analysis we only consider those countries for which a linearity test provides evidence in favour of the nonlinear specification.

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 shocks. 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. Following Gourio, Siemer, and Verdelhan (2013), 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.

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 the horizon of interest. Therefore, following Pellegrino (2014) and Caggiano, Castelnuovo, and Pellegrino (2015), the 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, 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 and the future shocks.

Our main results can be summarized as follows. First, concerning question (i) on the effects of the global uncertainty shock, the responses computed from the estimation of the linear model show that output negatively responds to the shock and the 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 a global uncertainty shock generates a significant reduction in real activity when the economy is in the high risk regime. Moreover, the dynamic responses of output are estimated to be statistically larger in the high risk state than in the low risk state, thus providing evidence for the presence of nonlinear effects in the transmission of global uncertainty shocks to economic activity. These findings support the theoretical model proposed in 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 the exchange rate, we find that it appreciates 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.

This paper contributes to the existing literature on uncertainty in several respects. First, we employ a measure of global uncertainty in order to identify global uncertainty shocks, rather than a country-specific measure of uncertainty. Second, we explore the effects of global uncertainty shocks in open economies, thus considering the dynamic responses of both economic activity and the exchange rate. Third, we employ a nonlinear model in order to explore the role of relative risk exposure in the transmission of the shocks and to account for the time varying dimension of this cross-country relationship. Fourth, we propose a multi-country rather than a single-country analysis.

The structure of the paper is the following. Section 2 discusses the relation to the literature. Section 3 presents the empirical model and the data employed in the analysis. Section 4 illustrates the results. Section 5 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, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2012); Fernandez-Villaverde, Guerron-Quintana, Rubio-Ramirez, and Uribe (2011); Benigno, Benigno, and Nisticò (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 uncertainty 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 consumers, 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 is modeled as a time-varying probability of an economic disaster, whereas disaster is modeled as a simultaneous large permanent decline in productivity and capital destruction. The two countries are identical in preferences and technology. Also disaster probability and disaster realization are the same for both of them. The only difference is in their exposure to aggregate risk: the country which is assumed to have a higher exposure to aggregate risk would be hit by larger productivity and capital shocks in case of disaster realization. As a result of model calibration, the high interest rate country is the one with the lower disaster risk exposure, whereas the low interest rate country is the more exposed to aggregate risk. This result is explained by referring to the different levels of precautionary savings in the two countries. Indeed, 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.

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. Indeed, in the model the exchange rate reflects the relative value of current and future consumption in the two countries, and since the more risky country expects the largest decline in consumption, then marginal utility of consumption rises more and its currency appreciates.

Relative to empirical contributions on the effects of uncertainty shocks on economic activity, most works in the literature 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., 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 will be organized as follows. First, we explore the effects of global uncertainty in open economies, through the estimation of a linear VAR model for a group of eleven countries: as will be explained later in the paper, we identify a global uncertainty shock and assess the responses of output and the exchange rate. Nevertheless, as we will see, the results provided by the estimation of a linear model are not useful to investigate the second issue, of whether countries' relative risk exposure does have a relevant role in the transmission of the shock. Therefore, we will employ a nonlinear specification and estimate an Interacted VAR model in order to address this second issue. Indeed, estimating a nonlinear model such as an I-VAR allows to compute state-dependent impulse responses, i.e. responses of output and the exchange rate conditional on the riskiness level of the economy. We will conduct this second part of the 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, the 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 the 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,[1] whereas for all of them the estimation period ends in June 2008. The period starting in July 2008 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 rates hit the zero lower bound (ZLB) in many countries and, as a consequence, the interest rate spread, which captures countries' relative risk exposure in the following analysis, stayed almost constant and very close to zero during the following period. This might significantly affect the results of our analysis.[2]

Seven 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) as a measure of prices and gross domestic product (GDP) and private consumption ($CONS$) as a measure of economic activity. IR is the difference between country i overnight interbank rate and the Federal Funds rate, and it is the variable that should capture countries' relative riskiness with respect to the U.S.. Macroeconomic data are taken from the Federal Reserve Bank of St. Louis database, whereas we refer to Bloomberg for financial data.[3]

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

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

[3] We use GDP Implicit Price Deflator, Index 2010=100, Quarterly, Seasonally Adjusted (all

The models are 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 the 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).[4]

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

countries but Sweden); Consumer Price Index All Items, Index 2010=100, Monthly, Not 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.

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

implied volatility are not available (e.g., Bloom, 2009), in that they generally show 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 volatility as shocks to disaster probability, thus linking their work to the literature on uncertainty. Figure 1 plots the monthly 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.

3.2 The linear SVAR model

To assess the responses of output and the 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 $\mathbf{y}_t = [MSCI\ VOL\ S_{\$/i}\ CPI_i\ CONS_i\ GDP_i\ IR_i]'$ 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.

What can we infer about the role of relative risk exposure? The estimation of a linear VAR allows to compute impulse responses for our variables of interest and to evaluate how does a global uncertainty shock affect them. Nevertheless, the results that we get and that will be shown later in the paper, do not seem to be very useful to address the second issue we are interested in, about the relevance of countries' relative riskiness to the transmission mechanism of the shock. Indeed, impulse responses computed from the estimated linear model just allow to evaluate the average responses of the endogenous variables to the shock, without accounting for the possible presence of different states of the economy.

However, it is reasonable to consider countries' riskiness level as a feature that varies over time, and not as given once and for all. And the same should hold when considering the level of risk exposure of one country compared to that of other countries. Evidence in favour of this claim will be provided later. For this reason, it does not seem to be a good idea to rank countries' riskiness level according to an average measure, nor it is to evaluate the role of risk in the transmission of the shock based on the results of the estimation of a linear model, like the one presented above. Indeed, we believe that accounting for time variation in countries' relative riskiness in the empirical specification is essential to get meaningful results to answer our second question. The next section explains how we address this issue.

3.3 Relative riskiness and Interacted VARs

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 the model of 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. When the 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.. 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 on the one side, as well as shifts in the availability of funds provided by financial intermediaries on the other side. Therefore, 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). In our case, the interbank rate spreads should 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. Figure 2 shows the evolution over time of interest rate spreads for each of the considered countries. Time variation is an important dimension of this cross-country relationship, and it clearly emerges from the plots.

As already explained, accounting for time variation in countries' relative riskiness in the empirical specification is essential to get meaningful results for answering question (ii), about the role of risk exposure in the transmission of global uncertainty shocks. To address this issue, 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 for each country we can define two regimes, 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 (IR), 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:

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

where T is the sample size; $|\, \tilde{\mathbf{\Sigma}}_{\mathbf{u}}^{\mathbf{r}} \,|$ 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 Chi-squared 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.[5] The following table shows the results of the test. In red are the results which are not statistically significant.

Table 1: LR-test results

Country	LR	p-value
Australia	18.01	0.01
Austria	9.47	0.22
Canada	18.46	0.01
Finland	10.58	0.16
France	3.20	0.87
Germany	24.63	0
Italy	6.64	0.47
Netherlands	13.38	0.06
Norway	16.77	0.02
Sweden	17.18	0.02
UK	6.30	0.51

The null hypothesis of a linear VAR model is rejected for six out of eleven countries: Australia, Canada, Germany (at the 1% significance level), Netherlands (10% significance level), Norway and Sweden (5% 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.

[5] 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.

3.4 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 the horizon of interest, 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 into account the nonlinearity of the system, 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.[6]

[6] For the algorithm used to compute state-conditional GIRFs, refer to Caggiano, Castelnuovo, and Pellegrino (2015).

4 Results

4.1 Linear model: Impulse response functions

Figures 3 and 4 plot the impulse responses of the exchange rate and GDP to a one-standard deviation global uncertainty shock, identified through the realized volatility of the MSCI index log returns, computed from the estimation of the linear specification, 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 to the shock. 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 significantly negative in the cases of Canada, Finland, France, Germany, Norway, Sweden and UK (fig. 4). In most cases, the response of output is not statistically significant on impact, but then it turns significantly negative some quarters after the shock. In the cases of Australia and Austria, the response of output is not statistically different from zero, whereas GDP significantly increases in response to the shock in the Netherlands.

Hence, as a general conclusion for the linear part of the analysis, we have that in most countries the exchange rate appreciates and output reduces in response to a global uncertainty shock. These results provide an answer to the first of the two questions addressed in this paper. The results obtained from the estimation of the nonlinear model allow us to also answer the second question, the one about the role of relative riskiness in the transmission of the shock, and to account for the possible presence of nonlinear effects.

4.2 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 the high (red line) an low risk (blue line) regimes, for each of the countries in our sample. Figures 6 and 8 document the difference in the point estimates of the impulse responses computed in the two states, which are obtained by subtracting the response under the low risk state from the response under the high risk state. The 68% confidence bands resulting from the empirical distribution of such differences are plotted.

Concerning the exchange rate (fig. 5), it significantly appreciates in response to the shock, in both states of the economy, for all countries except for Australia and Canada. For these two countries, the responses are not statistically significant in neither of riskiness regime. For all countries whose currencies display a significant response to the shock, the response in the low risk state seems to be larger than that in the high risk state, but the differences in the point estimates (fig. 6) show that the difference is only marginally statistically significant. 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 the high risk state, except for Canada and the Netherlands. The responses of GDP in the low risk state are not statistically different from zero, with the exception of Germany, where output displays a significant positive response about one year after the shock, and the Netherlands, where the response of output is significantly positive on impact. The differences in the point estimates of the responses in the two states confirm that the response in the high risk state is significantly larger than that in the low risk state, for all countries for which the response in the high risk state is significantly negative (Australia, Germany, Norway and Sweden, fig. 8). Hence, the state-conditional impulse responses of GDP obtained from the estimation of the non linear specification provide evidence of nonlinearities in the transmission of the uncertainty shock. 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 the global uncertainty shock 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's results, 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. Our estimated impulse response functions 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. In their 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 country, then marginal utility of consumption rises more and the currency appreciates. Our findings do not provide supporting evidence to these predictions, because currencies appreciate in response to the global uncertainty shock in the both riskiness states, and the two responses are estimated to be statistically the same.

Since in our reference theoretical framework the response of exchange rate is driven by consumption, it is worth showing the responses of consumption to the shock. Figures 9 and 10 plot the impulse responses of consumption to a global uncertainty shock and the differences in the point estimates respectively. 68% confidence bands are displayed. In most cases, consumption does not significantly responds to the shock. For Germany, Netherlands and Sweden, the response is significantly positive in low risk state, whereas it is not statistically different from zero in high risk (only marginally positive for Netherlands). In the case of Norway, consumption decreases in response to the shock in both states of the economy and the response in the high risk state is statistically larger than that in the low risk, in line with the predictions of Gourio et al..

4.3 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 the 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" risk/"very low" risk regime the initial conditions in which the value of the conditioning variable (the interest rate spread) is below/above two standard deviations from the mean. Then, for each of these four subsets of initial conditions we recompute the GIRFs.

Figures 11 and 12 show the GIRFs computed for the two extreme regimes and the differences in the point estimates of responses,[7] for both output and exchange rate, for each of the countries in our sample. 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 a global uncertainty shock.

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 significantly different from zero in the cases of Australia and Norway. For Canada they were already significant in the baseline estimation. For what concerns output (fig. 12), the response of economic activity becomes more negative as the level of riskiness increases for Germany, Norway and Sweden, consistently with our previous findings. This result is reinforced by the differences in the point estimates, which are statistically different from zero for these countries. We do not find any evidence in this sense for Australia and Canada.

To summarize the main results for this part of the analysis, it is worth noticing that the estimated responses to a global uncertainty shock of both exchange rate and output are sensitive to the level of relative riskiness. Indeed, the responses are generally stronger as the regime becomes more "extreme", i.e. as the distance in relative risk exposure increases. Moreover, as a general result, the difference between the responses in the two "extreme" regimes become more significant.

[7]The differences in the point estimates are computed as $(very\, high\, risk - very\, low\, risk)$. 68% confidence bands are displayed.

4.4 Robustness checks

The robustness of our results is tested through a series of perturbations of the baseline specification. We consider (i) a different identification scheme; (ii) the role of financial shocks; (iii) the role of financial flows; (iv) the role played by the size of the shock.

Uncertainty ordered last. Employing a recursive ordering VAR with the uncertainty measure ordered first, as we do,[8] it 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). Using this identification scheme implies that uncertainty shocks can immediately affect the exchange rate, prices, industrial production and the interest rate spread, whereas stock market volatility do not immediately react to the other shocks, except for the shock to stock market levels. Given that we are considering a measure of global uncertainty, whereas the other variables 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 the variables. For this reason, in the robustness checks we also consider the case in which uncertainty is ordered last. This allows us to remove the possible effects of other shocks from the estimated effects of the global uncertainty shock we are interested in. Our main results prove to be robust to the employment of an identification scheme with uncertainty ordered last.

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-

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

Albero, Gilchrist, & Zakrajsek, 2014). 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., 2014). 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 the second 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). The findings from the estimation of the model including the financial distress indicator confirm our baseline results.

Financial flows. International financial flows could have a relevant role in the transmission of a global uncertainty shock, particularly they might affect the dynamics of the exchange rate. For instance, a higher level of 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. For this reason, it is important to check whether including financial flows in our baseline specification does affect the results. The model is re-estimated by including our measure of financial flows ordered after uncertainty and before the exchange rate.[9] The estimation results confirm our findings from the baseline specification.

Size of the shock. In our baseline analysis we have computed GIRFs to a one standard deviation global uncertainty shock. In order to check whether the computed GIRFs are sensitive to the size of the global uncertainty shock, we re-compute the GIRFs to shocks of a size up to five standard deviations. 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.

[9] 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), from Federal Reserve Bank of St. Louis (FRED) database.

5 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 two questions we first estimate a linear SVAR model for a group of countries relative to the U.S.. Then, we consider an Interacted VAR model to account for the possible presence of nonlinearities in the transmission of the shock. Indeed, this empirical framework allows to distinguish between a high risk regime and a low risk regime and to account for time variation in country relative riskiness, through the computation of state-conditional impulse response functions. Following the theoretical model of Gourio et al. (2013), 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.

Our findings from the linear part of the analysis 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. Concerning the nonlinear part of the analysis, we find evidence of nonlinear effects in the transmission of the shock. Indeed, the response of economic activity to the shock is significantly negative in the high risk regime and the reduction in output is estimated to be statistically larger when the country is in the high risk state, than when it is in the low risk regime. This result supports the theoretical predictions of Gourio et al.. For what concerns the exchange rate, it significantly appreciates in response to the shock in both regimes, but we do not find evidence of a statistically significant difference between the two responses. Some evidence in favor of the presence of nonlinearities in the transmission of global uncertainty shocks to the exchange rate is provided by the "extreme" regimes part of the analysis. Indeed, when the distance in countries' relative riskiness widens, the difference between the responses of exchange rate in the two regimes becomes more significant.

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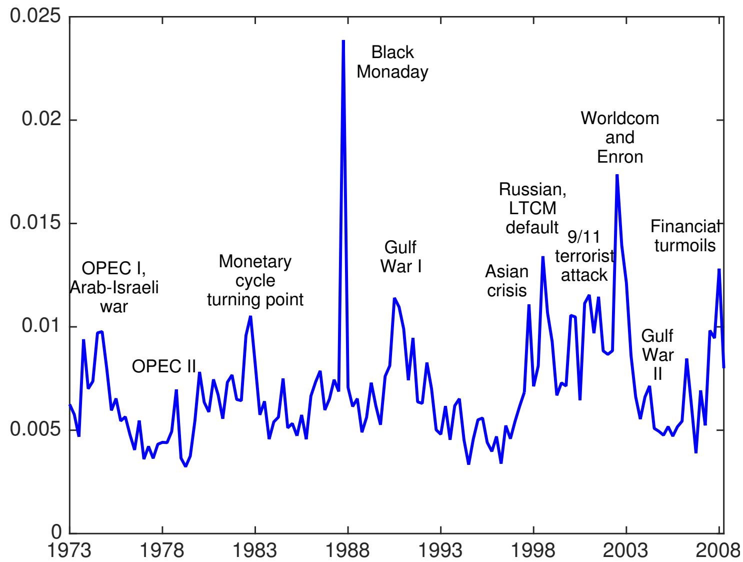

Figure 1: Plot of time series of MSCI World Index log returns realized volatility (1973:Q1-2008:Q2).

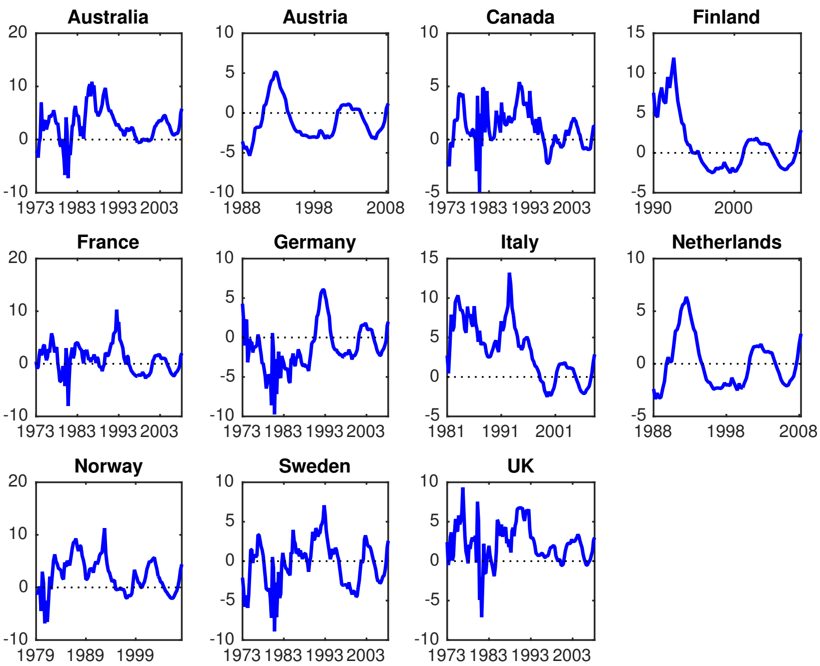

Figure 2: Time series of the spreads between each country's interbank rate and the Federal Funds rate.

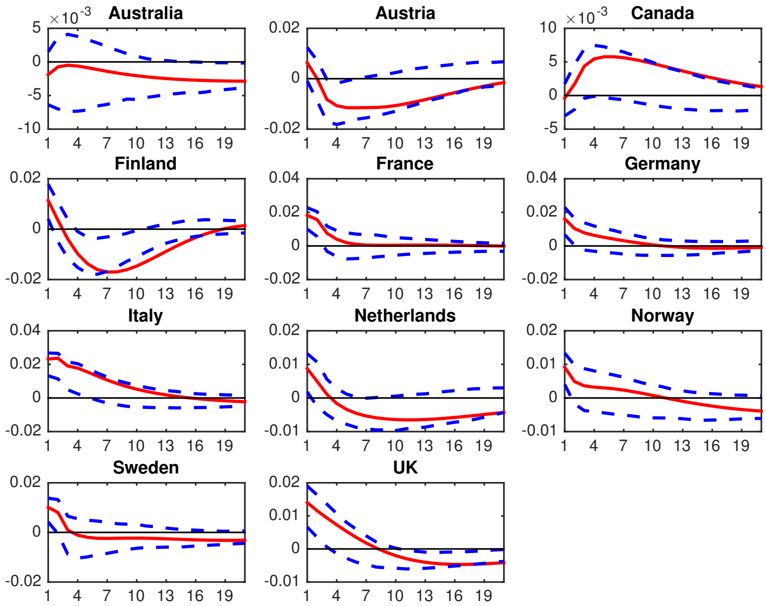

Figure 3: Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands).

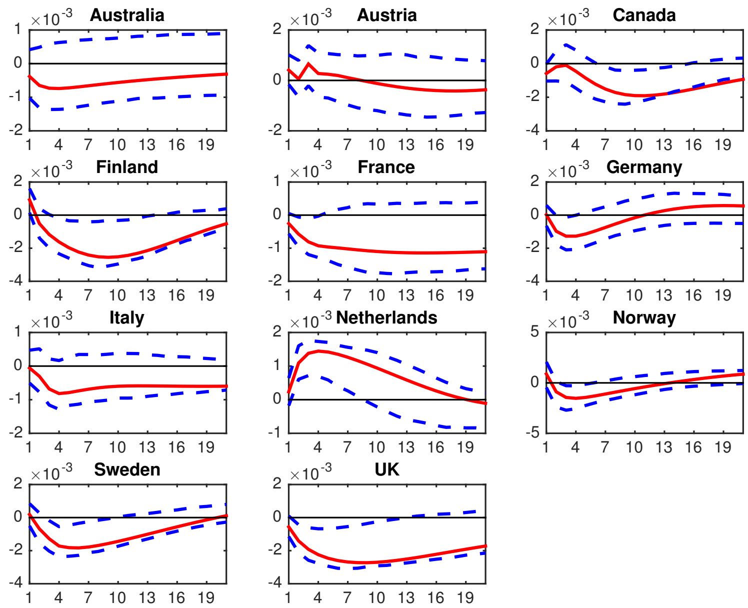

Figure 4: Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands).

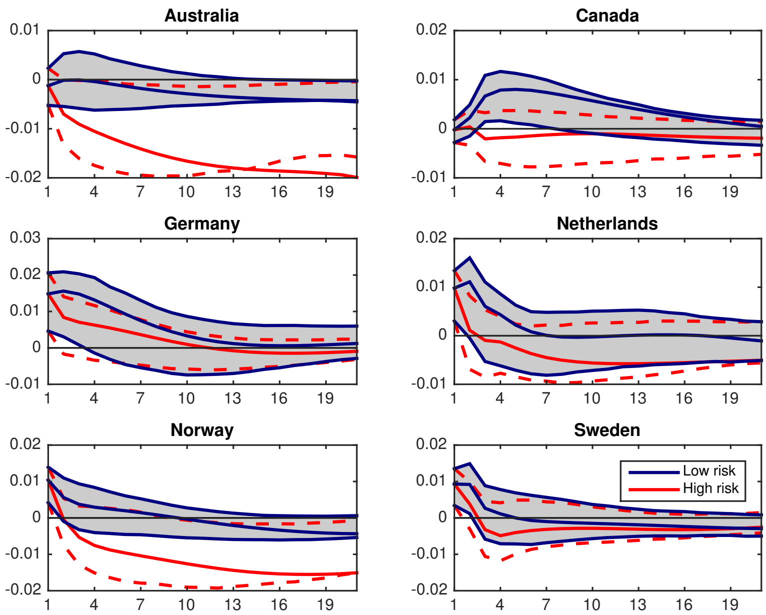

Figure 5: Impulse responses of the exchange rate to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

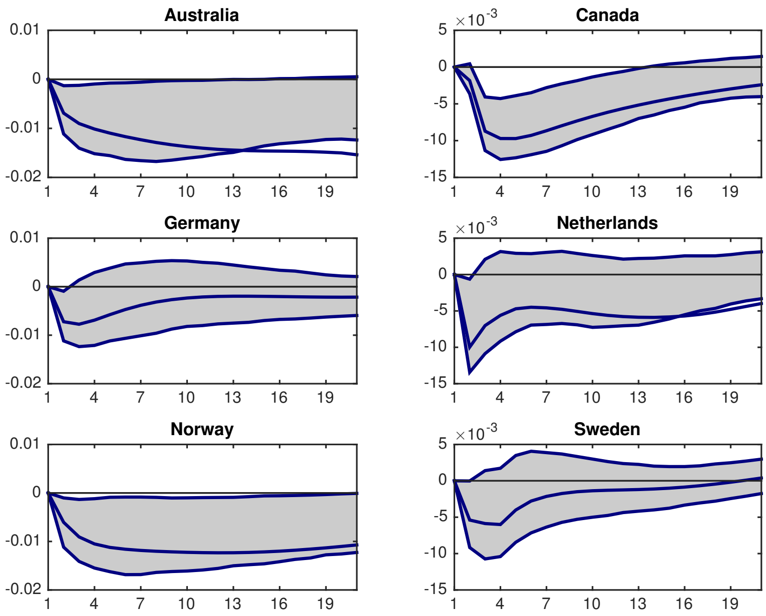

Figure 6: Differences in the point estimates of the impulse responses of the exchange rate in the two states (high risk - low risk). 68% confidence bands.

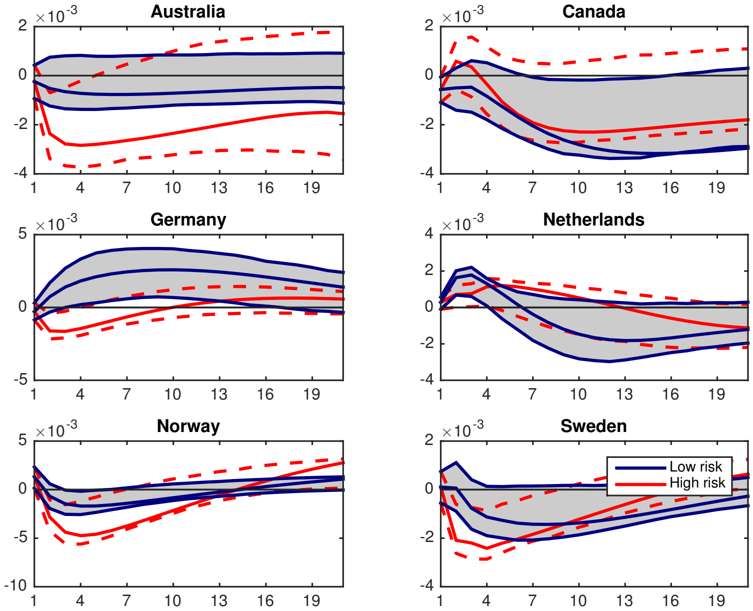

Figure 7: Impulse responses of output to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

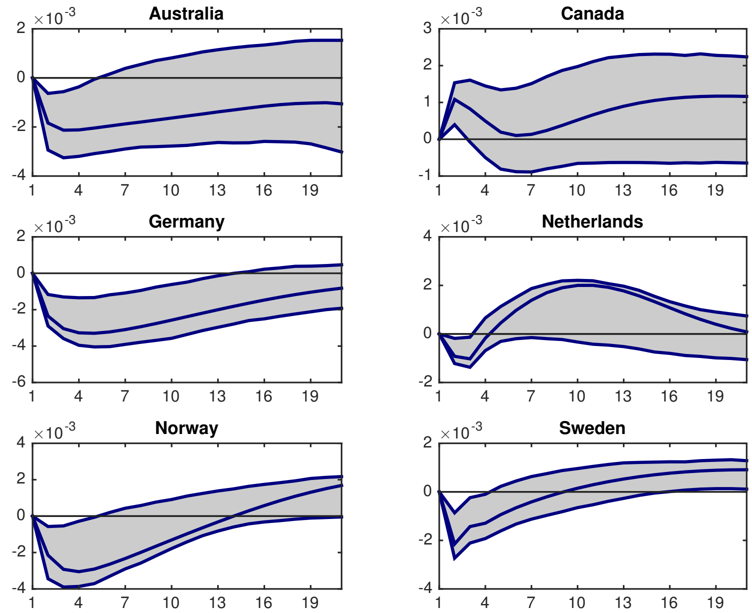

Figure 8: Differences in the point estimates of the impulse responses of output in the two states (high risk - low risk). 68% confidence bands.

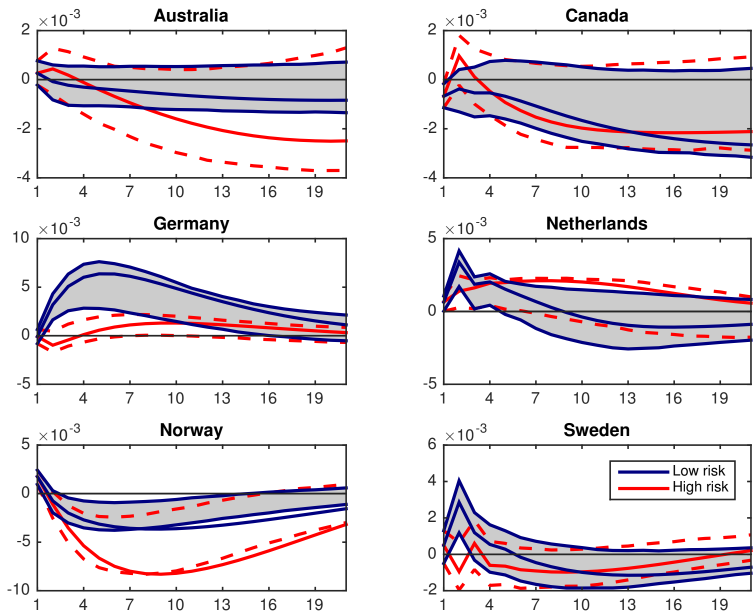

Figure 9: Impulse responses of consumption to a one standard deviation shock to global uncertainty (68% confidence bands). Blue: low risk; red: high risk.

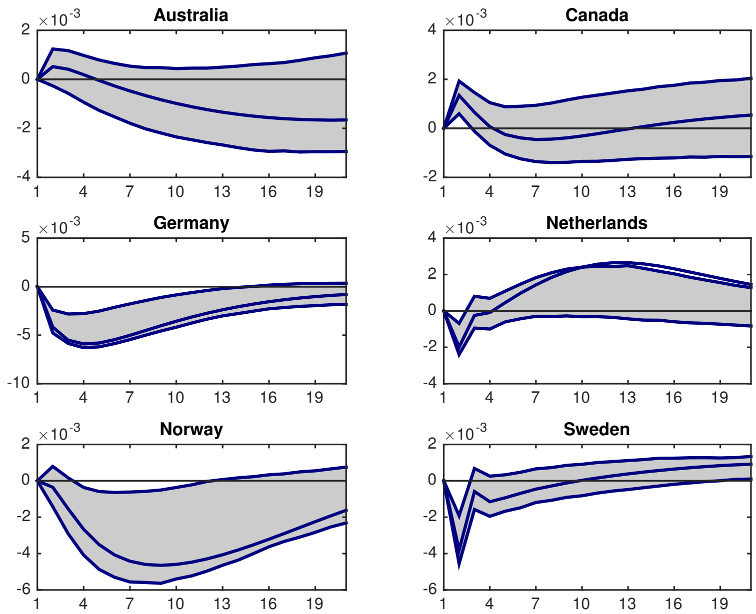

Figure 10: Differences in the point estimates of the impulse responses of consumption in the two states (high risk - low risk). 68% confidence bands.

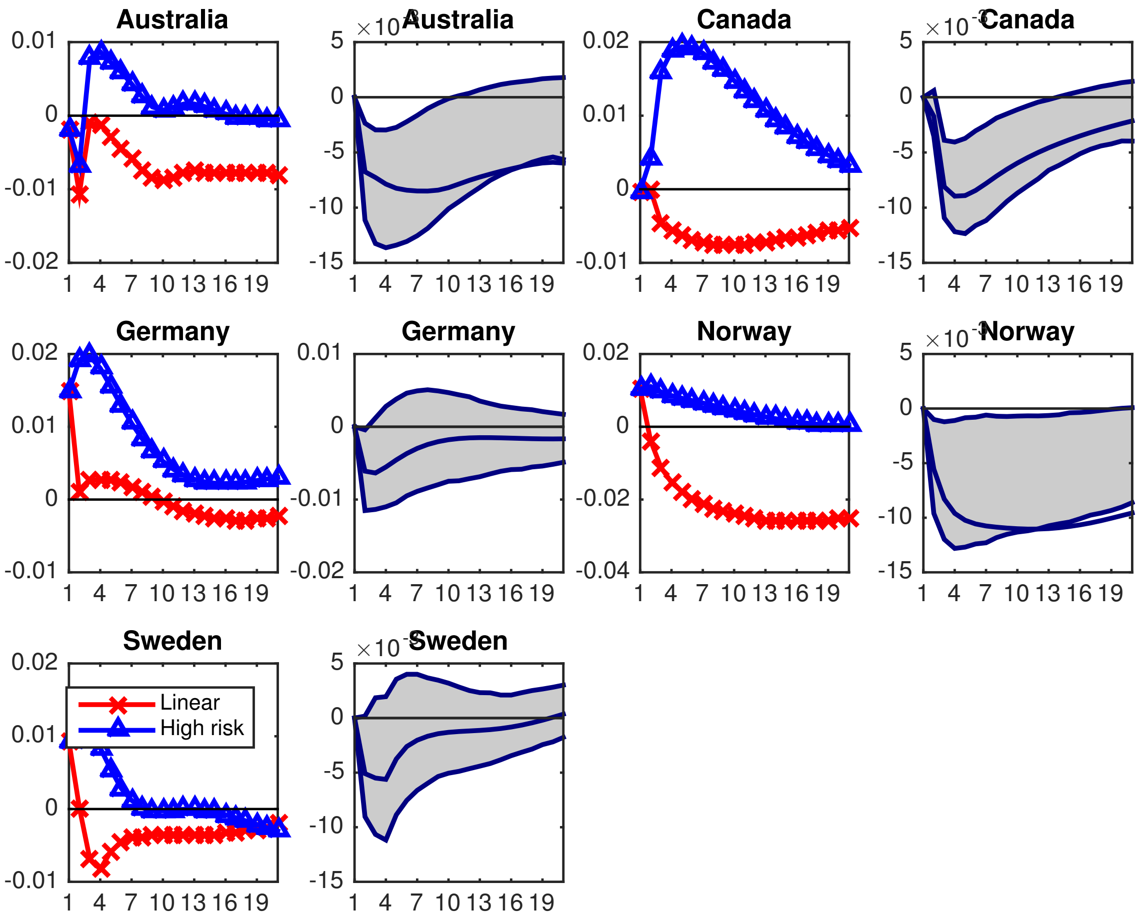

Figure 11: Impulse responses of exchange rate to a one standard deviation global uncertainty shock and differences in the point estimates. Very high risk: red line; very low risk: blue line.

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.

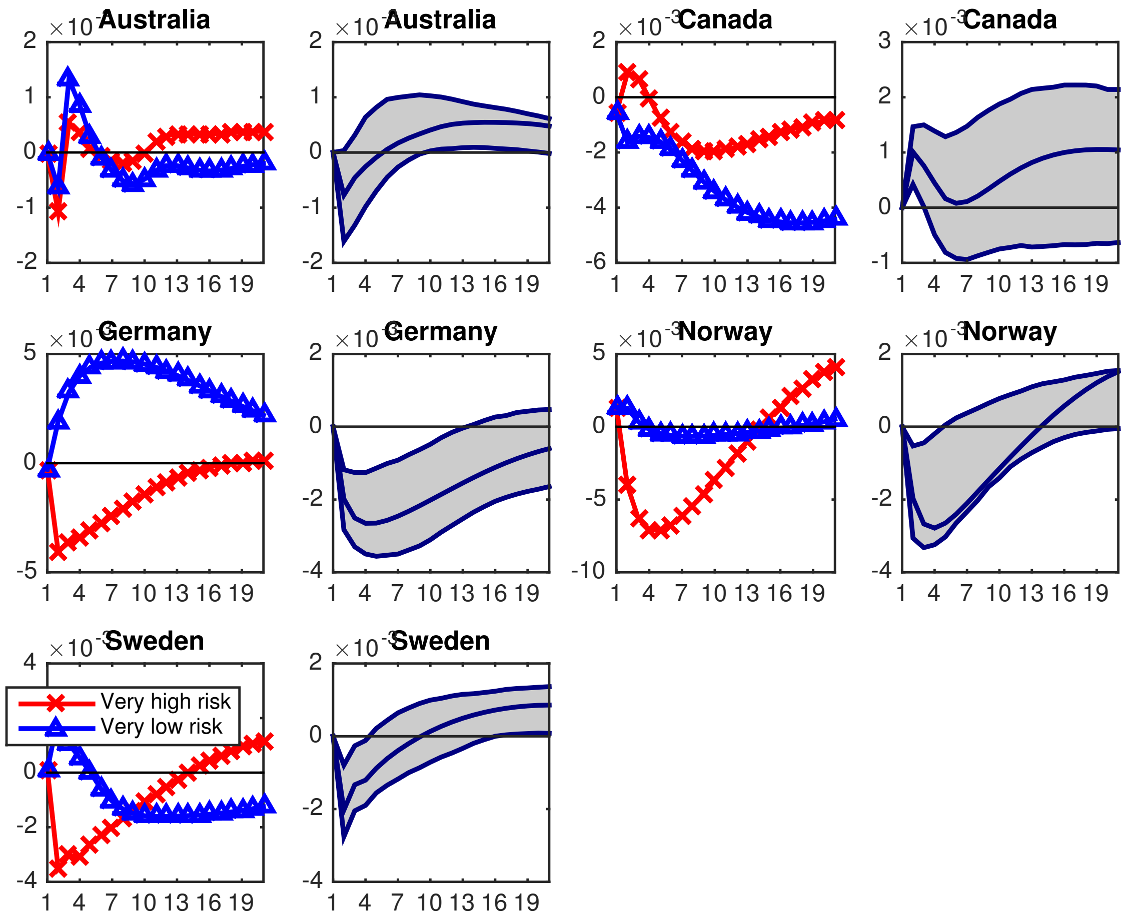

Figure 12: Impulse responses of output to a one standard deviation global uncertainty shock and differences in the point estimates. Very high risk: red line; very low risk: blue line.

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.