Carry Trade, Uncovered Interest Parity and Monetary Policy*

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Abstract

It is well documented in the literature that identified vector autoregression (VAR) models often produce puzzling results when the effect of unexpected monetary policy movements is estimated. Many authors find that raising interest rate generates protracted appreciation of the exchange rate (the so-called delayed overshooting puzzle) which is in contradiction with traditional theory of exchange rate dynamics based on uncovered interest parity. We estimate a VAR for a panel of small open economies that are considered as targets for carry trade strategies. We identify structural shocks by allowing the interest rate and exchange rate to react simultaneously to monetary policy and changes in expected risk premium. Our results show that the delayed overshooting is not a robust finding. Exchange rate appreciation and carry trade movements take place almost on impact after an unexpected interest rate hike. Roughly half of the variation in carry trade positions can be explained by domestic interest rate changes and risk premium shocks.

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1 Introduction

There is an unpleasant disconnect between the best practice of monetary policy and empirical tests of exchange rate theories. While central banks' forecasts and decision-making rely on models assuming some sort of uncovered interest parity (UIP), there seems to be a wide consensus among econometricians that UIP can be rejected with high certainty. Nevertheless, the dynamic relationship between exchange rate and interest rate is of special interest for central banks in small open economies where the exchange rate channel of monetary transmission mechanism is important.

In our paper we focus only on one of the empirical puzzles, the so-called delayed overshooting (DOS). According to Dornbusch (1976)'s model in which UIP holds, after an (unexpected) monetary tightening the nominal exchange rate appreciates instantaneously and then gradually depreciates to its new level consistent with purchasing power parity. However, structural VAR estimates, like Eichenbaum and Evans (1995) or more recently Scholl and Uhlig (2008), often show a protracted appreciation lasting even for years.

There are, however, some authors who challenge the identification strategy of the studies reporting DOS. Already McCallum (1994) emphasized that the empirical failure of UIP may be caused by shocks to the exchange rate to which the monetary policy reacts within one period. Since in small open economies exchange rate movements can have a large impact on inflation and output, a quick response of central banks to those shocks can be justified. Cushman and Zha (1997), Kim and Roubini (2000), Faust and Rogers (2003), Bjørnland (2009), Jarocinski (2010) and Vonnák (2010) relax the assumption that monetary policy reacts to exchange rate shocks only with delay, which is often implicitly made by Cholesky decomposition of the variance-covariance matrix. Allowing simultaneity between monetary policy and the exchange rate yields impulse responses resembling to Dornbusch's overshooting model. It should be noted, however, that Scholl and Uhlig (2008) find DOS without assuming recursive structure among the shocks and the variables.

Another issue which recently has received much attention and is presumably related to delayed overshooting is carry trade activity. Carry traders borrow in low-interest-rate currency and lend in high-interest-rate currency. As long as UIP holds, the profit of this strategy is zero on average, since the interest rate premium is perfectly offset by the exchange rate depreciation. If we augment the UIP by a (time-varying) risk premium term, the return of a carry trade position correlates with this risk premium which can be regarded as the compensation for taking the exchange rate risk. Still, as long as exogenous changes in the policy rate do not affect the risk premium, UIP holds conditionally,[1] and after the infinitesimally short period during which the exchange rate jumps according to Dornbusch's model, there is no incentive for carry traders to change their exposure. Thus, after a monetary shock we would expect only a very temporary change in speculative positions.

On the contrary, the delayed reaction of exchange rate to monetary policy provides excess return for several periods. After an interest rate hike a carry trader could make profit from higher return on domestic assets as well as from the appreciation of the currency. Since the exchange rate appreciates gradually, DOS would imply protracted carry trade inflow. In the seminal paper of Brunnermeier, Nagel, and Pedersen (2009) slowly moving carry traders and DOS are shown to be the two sides of the same coin. The authors estimate a VAR and show that the reaction of both the exchange rate and carry traders to an interest rate shock is protracted.

In the model of Plantin and Shin (2011) carry traders endogenously amplify the effect of

[1] By "UIP holding conditionally" we mean that after a shock the realized return on a carry position does not change which implies that the effect of the shock on the interest rate differential is equal to its effect on the (expected) change in exchange rate.

monetary policy on the exchange rate. They assume that carry traders while going long in local currency, increase the credit supply and therefore generate an overheating in domestic demand. In response to this, the central bank increases further the interest rate which attracts more capital from abroad.[2] The result is a monetary policy generated bubble that ends up in a currency crash. In this model the role of carry traders is destabilizing, as opposed to the conventional UIP framework where it is the carry trader who helps the parity condition to be fulfilled quickly.

In our paper we deploy a robust econometric methodology to investigate the relationship between monetary policy, exchange rate and carry trade. Similarly to Brunnermeier, Nagel, and Pedersen (2009) we estimate the effect of the interest rate change on carry trade activity and the exchange rate within the same model. By doing this, we have the chance to uncover not only how monetary policy affects the exchange rate and carry trade, but also how carry trade transmits monetary policy shocks. We estimate our structural VAR on a panel of three small open economies (Australia, Canada, U.K.) having currencies considered to have been target for carry trade. However, unlike the above-mentioned paper, we distinguish between endogenous and exogenous interest rate movements by identifying monetary policy and other structural shocks. Following the previously mentioned studies that challenged the existence of DOS, we allow the monetary policy to react simultaneously to exchange rate or risk premium shocks by imposing sign instead of zero restrictions.

Our second contribution to the literature is that we try to find the main driving forces behind carry trade. To this end, we identify four domestic and four foreign shocks. The variance decomposition of carry trade data may inform us about whether the exchange rate is a shock absorber or a source of idiosyncratic shocks, and whether traders on the FX-market help the exchange rate react quickly to changes in fundamentals or generate undesired volatility.

Our approach is similar to that of Anzuini and Fornari (2012). Although they focus more on determinants of carry trade and less on DOS, their approach is common with ours in recognizing the importance of the identification of economically meaningful shocks. However, there are essential differences in the model specification. Probably the most important is that while they estimate a VAR on relative variables (domestic minus foreign), we use the original time series. This may have crucial consequences, since domestic variables are more likely to track the foreign ones than vice versa. Imposing identifying restrictions on the relative variables may cause substantial bias when there is high asymmetry in how foreign and domestic variables react to each other. The most obvious example is monetary policy, as we expect the central bank of a small open country to follow some extent the monetary stance in the big economy, but not the other way around. Therefore, we expect a better identification of the relevant structural shocks in our model.

Our results show that delayed overshooting is not a robust finding. Our exchange rate impulse response functions resemble rather Dornbusch (1976)'s overshooting model, consistently with UIP. Comparison with the Cholesky identification scheme confirms previous findings that improper identifying restrictions embedded implicitly in the recursive approach can be responsible to some extent for the puzzle found in some of the referred studies.

Another important finding is that carry traders react to monetary policy according to the UIP: the exogenous shift in monetary policy stance induces a contemporaneous change in speculative currency positions which start reverting already in the next period. These results suggest that the exchange rate channel of monetary transmission mechanism works as in the Dornbusch model and carry traders play an important role in it. Our findings are in line with those of Kisgergely (2012), who could reject the hypothesis that interest sensitive capital flows can reverse the effect

[2]This mechanism is also known as Tosovsky-dilemma, named after an earlier governor of the Czech central bank and appears often in central bank publications and financial market experts' analyses.

of monetary policy.

Variance decomposition shows that roughly half of the carry trade movements can be attributed to surprise movements in domestic monetary policy stance and changes in risk premium of the domestic currency. While the interpretation of the former is straightforward, the latter is not. On one hand, the dynamics of the exchange rate and carry trade after a monetary policy shock suggest that speculative position-taking help the UIP to restore quickly. On the other hand, the risk premium of a currency can change for two reasons: either because the fundamentals have changed and carry traders adjust their demand for compensation for taking risk, or because there is an idiosyncratic shock to carry trade activity. In the first case the role of currency speculation can be considered as greasing, as the new information about the current or future state of the economy is channelled into the exchange rate by carry traders. In the second case, however, currency speculation is a source of shocks that can lead to welfare losses. Unfortunately within our modelling framework it is not possible to decompose risk premium shocks to changes in the risk profile of the economy and changes in risk appetite, therefore we cannot draw firm conclusions to what extent carry trade activity is welfare-improving.

The remainder of the paper is structured as follows. Section 2 presents our econometric model and the restrictions used in the identification of the shocks. Section 3 describes our dataset. Section 4 presents the results. Section 5 shows results from alternative specifications as a robustness check. Finally, Section 6 concludes.

2 Modelling strategy

During the empirical analysis we build on the methodology presented in Uhlig (2005). By using a structural vector autoregression (SVAR) model we can identify structural, economically meaningful exogenous shocks and causal relationships between them and the endogenous variables.

In particular, a VAR is estimated in the form that is given by

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + C z_t + \boldsymbol{\varepsilon}_t \tag{1}$$

$$E(\boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}_t') \equiv \boldsymbol{\Sigma}_{\boldsymbol{\varepsilon}} \tag{2}$$

where $t = 1 \ldots T$, y_t is the vector of endogenous variables included in the VAR: the log of real gross domestic product, log of consumer prices, log of 3-month money market interest rate, log of the nominal exchange rate and a proxy for carry trade positions. A is the coefficient matrix and $\boldsymbol{\Sigma}$ is the variance-covariance matrix for the one-step ahead prediction error. z_t is the vector of exogenous variables.

Intrinsically, we are interested in the parameters of the structural VAR

$$B_0 y_t = B_1 y_{t-1} + B_2 y_{t-2} + \ldots + B_p y_{t-p} + D z_t + u_t \tag{3}$$

$$E(u_t u_t') \equiv \boldsymbol{\Sigma}_u = I_n \tag{4}$$

where u_t is the vector of mutually uncorrelated structural shocks, I_n is an n-dimensional identity matrix and

$$\boldsymbol{\varepsilon}_t = B_0^{-1} u_t \tag{5}$$

Equation (2) imposes $n(n+1)/2$ restrictions on B_0. To fully disentangle the structural shocks from the reduced-form innovations, we need $n(n-1)/2$ additional restrictions. One can find several approaches in the literature to carry that out. One is assuming a recursive structure among shocks and their contemporaneous effect on the endogenous variables, the so-called Cholesky ordering. Kim and Roubini (2000)'s identification scheme builds on non-recursive zero restrictions. Scholl and Uhlig (2008) use sign restrictions on impulse responses for a prolonged period (one year) after the shock. Bjørnland (2009) employs long-run neutrality restrictions. Bjørnland and Halvorsen (2010) combine sign and short-run restrictions.

Since in a small open economy both monetary policy shocks and sudden swings in carry trade (exchange rate or risk premium shocks) may affect the interest rate and the exchange rate simultaneously, recursive ordering is not appropriate for our purposes. Therefore, we identify the structural shocks using mainly sign restrictions. Zero restrictions are used only for separate financial shocks from those originating in real economy. Sign restrictions have the advantage of robustness at the price of wider confidence bands of impulse responses than in just-identified VARs.

The endogenous part of our VAR consists of GDP, CPI, short-term interest rate, exchange rate and carry trade. Following the slightly modified notation of Kilian (2011), B_0^{-1} can be written as

$$\begin{pmatrix} \varepsilon_t^{Prod} \\ \varepsilon_t^{Prices} \\ \varepsilon_t^{Interest} \\ \varepsilon_t^{Exchange} \\ \varepsilon_t^{Carry} \end{pmatrix} = \begin{bmatrix} 0 & 0 & + & + & \cdot \\ \cdot & \cdot & + & - & \cdot \\ + & + & + & \cdot & \cdot \\ - & + & \cdot & \cdot & \cdot \\ + & - & \cdot & \cdot & \cdot \end{bmatrix} \begin{pmatrix} u_t^{Monetary} \\ u_t^{Risk} \\ u_t^{Demand} \\ u_t^{Supply} \\ u_t^{5} \end{pmatrix} \tag{6}$$

where $+$ and $-$ denotes the sign of the restricted impact response, 0 indicates zero restriction and $\cdot$ denotes no restriction.

According to the restrictions, an unanticipated monetary tightening causes the domestic interest rate to increase and the exchange rate to appreciate on impact. Carry traders take long position in local currency due to higher interest rate.[3] An unexpected increase in the risk premium leads to higher interest rate and weakening of the currency, accompanied by a fall in carry trade. We do not impose any restrictions on prices, while, in both cases, the contemporaneous effect of the shock on production is zero, that is GDP responds to these shocks with delay. The latter assumption may receive some criticism as in small open economy production can be sensitive to exchange rate movements within the same quarter. In order to check to what extent our conclusions depend on these restrictions, we estimate a model on monthly data as well as with a pure sign restriction approach. The results reported in Section 5 confirm the main results of the benchmark model.

We use the standard sign restrictions to identify domestic demand and supply shocks. An unanticipated positive supply shock causes production to increase and prices to fall, while a demand shock causes both production and prices to increase on impact. Demand shocks are associated with an increase in the interest rate as monetary policy tries to counteract inflation. Finally, we leave the fifth domestic shock unidentified.

Besides domestic factors, foreign shocks may be important drivers of carry trade activity.

[3] At first glance it may seem contradicting to identify the effect of monetary policy shocks on exchange rate and carry trade by imposing restrictions on exchange rate and carry trade themselves. Indeed, imposing sign restriction on the impact response and being completely indifferent in the second period response may cause a bias against hump-shaped response functions. Still, we think that this bias is not that big as to influence significantly our results. Firstly, among our impulse responses there are several examples when a contemporaneous sign restriction is imposed, but the result is hump-shaped. Secondly, we estimated the same model by imposing the sign restrictions for 4 quarters and we got the same qualitative results. We also estimated it without imposing any restrictions on carry trade. Again, the results are very similar.

Thus, we identify foreign shocks as well. The corresponding restrictions are similar to the domestic ones, and are described in details in Section 4.3.

3 Data

Due to the relatively short time series we prefer the panel approach to the country-by-country estimations, similarly to Brunnermeier, Nagel, and Pedersen (2009). Our panel consists of three developed countries (Australia, Canada and the United Kingdom) that can be considered as targets of carry trade activity on our sample.[4] Our choice of this particular group of countries was determined primarily by the availability of carry trade statistics.

We have quarterly data for the macroeconomic variables from 1992Q2 to 2007Q4 taken from the International Financial Statistics (IFS) database.[5] In this way we leave out the recent financial crisis from the sample, as we are interested in monetary transmission and exchange rate dynamics in "normal times".[6] The starting period was chosen based on carry trade data availability.

Another option would be to include all the countries having long enough carry trade data, like Japan and the United States. The reason for investigating only these three countries is that pooling them together with big, closed economies would question our setup as we assume that the main dynamic properties of the vector of variables are approximately the same across countries.

All GDP and CPI data are seasonally adjusted in the IFS database. However, United Kingdom CPI data seemed to have some remained seasonality, therefore we corrected for that.[7] The end-of-period nominal exchange rates vis-à-vis the U.S. dollar are defined as the local currency price of one unit of foreign currency, thus an increase in the exchange rate means depreciation. The interest rate data is the quarterly average of short-term money market rate.

To control for foreign shocks, we use U.S. GDP, CPI, interest rate and exchange rate data as exogenous in the VAR. U.S. dollar exchange rate vis-à-vis the euro is taken from Eurostat. An increase in the exchange rate means depreciation of the dollar.

Following Brunnermeier, Nagel, and Pedersen (2009), we use the futures position data from the Commodity Futures Trading Commission (CFTC) as a proxy for carry trade activity. It is a widely used measure of speculative positions. We use the latest available data for each quarter to construct the net futures position of non-commercial traders in Australian Dollar (AUD), Canadian Dollar (CAD) and British Pound Sterling (GBP), expressed as a fraction of total open interest.[8] According to Brunnermeier, Nagel, and Pedersen (2009), despite its shortcomings, it is the best publicly available data for carry trade activity.[9]

[4]See the results of Brunnermeier, Nagel, and Pedersen (2009).

[5]See Table 1 in Appendix for details.

[6]The sample ends before the recent global financial crisis, due to the possibility of nonlinear effects caused by the severe shocks that may pose a bias to the estimation of the (linear) VAR model. For a robustness check, we extended the estimation of the baseline model to the 1992Q2 - 2012Q2 period and found that the main results qualitatively still hold.

[7]In 2000Q3 the Australian Government introduced a Goods and Services Tax, which results in a level shift in Australian CPI data. Controlling for this with a dummy variable does not alter our results, therefore we use the original data.

[8]Classified by the CFTC, non-commercial traders use futures for speculative purposes and not for hedging against currency risk.

[9]One of the main deficiencies is that it does not cover all speculative exchange rate positions as, for instance, hedge funds reportedly trade more in forward markets than in futures markets. Other proxies for carry trade activity also exist, but none of them seem to be more suitable enough to justify a deviation from the approach of Brunnermeier, Nagel, and Pedersen (2009). Returns of Exchange Traded Funds (ETFs) and Exchange Traded Notes (ETNs) are linked to carry-trade strategies making them appealing candidates. But they have the same

Of course, the sum of speculative positions reported to CFTC is only a fraction of total open interest. Hence, behaviour of CFTC carry trade does not necessarily apply to all interest sensitive position-taking. Still, if we find that CFTC carry traders eliminate excess return quickly, we can safely assume that there are no incentives to take positions by other market participants.

A Bayesian VAR with 4 lags is estimated on quarterly frequency using the previously introduced panel data set.[10] Contemporaneous and one period lagged U.S. data appear as exogenous variables. We use country-specific intercepts in the VAR. Following Uhlig (2005), we use flat prior for the VAR. The coefficients are drawn from the posterior distribution, which is a normal-inverse-Wishart distribution parameterized by the OLS estimates of coefficient and variance-covariance matrices. Calculation of posterior distributions is made following Reppa (2009). 2000 draws satisfying the sign restrictions have been generated.

In order to measure the failure of UIP, we calculate excess return impulse responses. We define (expected) excess return as the sum of the interest rate and the (expected) appreciation expressed in annual terms[11]:

$$z_t = i_t - 4(e_{t+1} - e_t) \tag{7}$$

where (i_t) is the (log) nominal interest rate and (e_t) is the (log) nominal exchange rate in period t. If UIP holds conditionally after a shock, a positive interest rate differential is offset by the depreciation of the domestic currency resulting in no excess return. In other words, the conditional expectation $E_t z_{t+p}$ must be zero for all $p \geq 0$ as long as UIP holds. The effect of the structural shocks on excess return can be calculated from the impulse responses of the domestic and U.S. interest rates, and the exchange rate.

4 Results

In this section we discuss the empirical results obtained from our preferred identification scheme, and then briefly compare our results with the Cholesky decomposition. It is followed by an analysis of the effect of foreign shocks. Finally, we present variance decomposition with focus on the determinants of carry trade activity.

4.1 The effect of monetary policy and risk premium shocks

We are interested first of all in the effect of monetary policy shocks. As mentioned earlier, separation of them from risk premium shocks can be crucial. Therefore we focus here on these shocks. Responses to all the identified domestic shocks can be found in the Appendix (Figure 13).

Figure 1 shows the estimated impulse responses to a domestic contractionary monetary policy shock and an unfavourable risk premium shock, respectively, up to 5 years after the shock. We report the median, the 2.5th, 16th, 84th and 97.5th percentiles of the posterior distribution.

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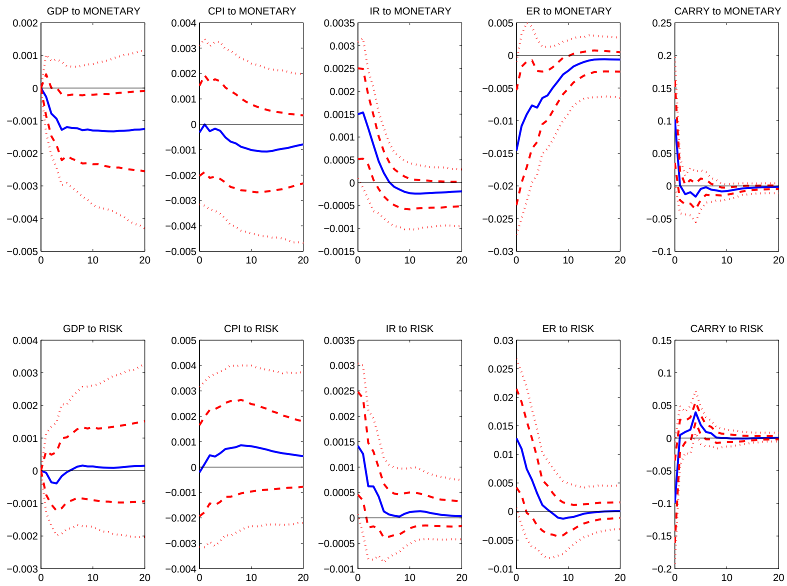
weakness as CFTC data as ETFs and ETNs are mostly used by retail investors and are unlikely to represent a large part of overall carry trade activity; and their time series start only in mid-2000s resulting in relatively short sample periods. Another potential proxy is the BIS international banking statistics that measure the amount of cross-border lending, including a currency breakdown of banks' international assets and liabilities. Unfortunately, banks report only their on-balance sheet positions, without explicitly distinguishing between carry trade positions and other activities, same problem as in case of CFTC futures positions data. For more details, see Curcuru, Vega, and Hoek (2011).

[10] Standard selection criteria suggest 1-2 lags for the VAR; however, we include 4 lags to be able to reject serial correlation in the residuals.

[11] Since U.S. interest rate is assumed to be exogenous and not affected by domestic shocks, when calculating excess return we can ignore it.

Figure 1: Responses to a monetary policy and a risk premium shock



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

The impulse responses are intuitive, albeit not always significantly different from zero. A typical monetary policy shock can be characterized by a 15 basis points interest rate increase, which then starts decreasing, finally dropping slightly below its initial level. The gradual withdrawal of the initial tightening stance reflects some smoothing in the conduct of monetary policy, which is a well-known finding in the literature. The exchange rate appreciates by 1.5 per cent on impact, which is followed by a gradual depreciation towards its initial level. Hence, the adjustment of the exchange rate is instantaneous without any delayed overshooting pattern, in line with the prediction of the Dornbusch (1976) model. We do not observe any significant price puzzle either; the price index starts declining in the second year after the shock, but the effect of the monetary contraction is not significant. Output declines quickly and to a statistically significant[12] extent, which is in line with what we expect after a contractionary monetary policy shock. The fast GDP and slow CPI responses resembles the monetary transmission in New Keynesian sticky price models.

Shocks to risk premium increase short-term interest rate and depreciates the currency on impact, according to our identifying assumptions. The effect of higher interest rate and weaker currency on GDP is not significantly different from zero. They affect domestic production in different ways: while the increase in interest rate reduces domestic demand, the depreciation makes

[12]Since we adopt a Bayesian approach, "significant" means that large part of the posterior distribution is below or above a certain value. In this particular case the lower 84 (i.e. the entire middle 68) percent of the impulse response posterior is below zero.

export more competitive. In the CPI response the exchange rate channel seems to dominate: domestic prices increase, presumably due to the weaker currency. The initial drop in carry trade position is followed by a gradual recovery of risk appetite. In the second year after the shock long speculative positions are significantly higher than originally. This can be explained by the higher interest rate and the still appreciating exchange rate.

The most important result is that exchange rate and carry trade seem to react quickly to monetary policy, and there is no sign of delayed overshooting or prolonged carry trade inflow. Our impulse responses are in favour of Dornbusch (1976) and contradict to Brunnermeier, Nagel, and Pedersen (2009) and Plantin and Shin (2011).

Since drawing conclusions about the shape of impulse responses based on pointwise median can be misleading (Sims and Zha, 1999), we report the posterior distribution of the horizon when exchange rate and carry trade have their maximum response. We calculate two measures to describe the peak response. We call "turning point" the earliest quarter when appreciation turns to depreciation. We call "minimum" the quarter where the exchange rate response has its minimum value over the 20 quarters horizon. These definitions apply to carry trade with similar logic.

The histograms confirm our previous finding that carry traders respond to monetary policy within the same quarter which results in a prompt adjustment of the exchange rate (Figure 2). According to the left panel, the peaks of the impulse responses are in the first period in most of the cases. The first peak mostly also coincides with the extreme value of the impulse response, as shown in the right panel.

A more direct way to assess the role and incentives of carry trade is to quantify the realized return after a shock. If the exchange rate appreciates fast enough to an unexpected rate hike by the central bank, the subsequent depreciation can eliminate the excess return, which is the

Figure 2: Posterior distribution of the location of peak response to a monetary policy shock

(as a percent of total draws)

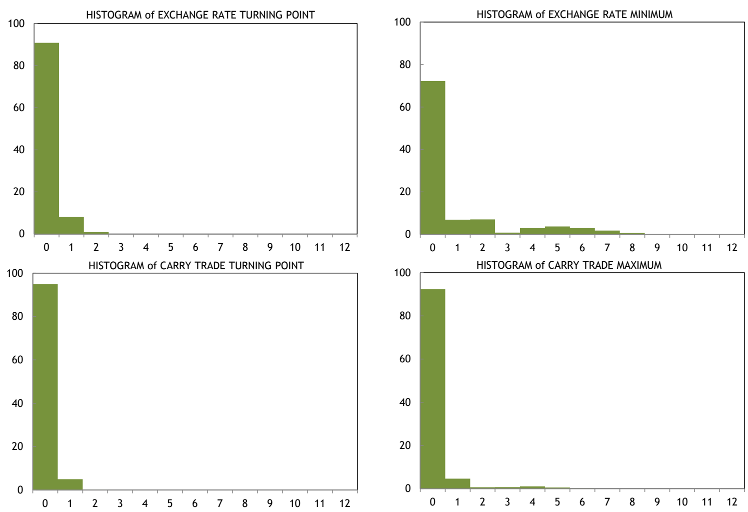
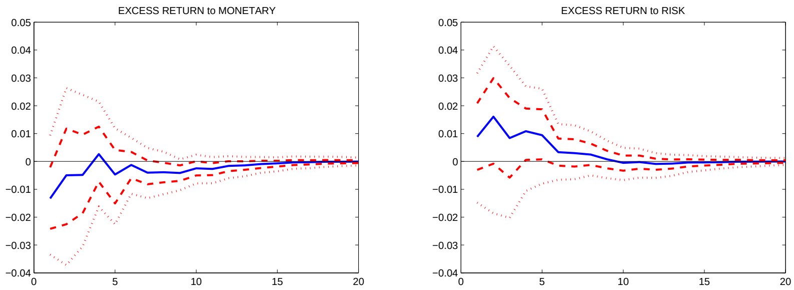


Figure 3: Excess return to monetary policy and risk premium shocks



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

logic of the uncovered interest parity theorem. The impulse response of (predictable) excess return suggests that the reaction of the exchange rate is even stronger a bit than what the UIP would imply (Figure 3). Right after the shock the excess return becomes slightly negative, suggesting that the rate at which the exchange rate depreciates after the quick appreciation is a bit faster than the corresponding interest rate differential. In the case of risk premium shock the response of excess return is positive for several quarters. This means that the exchange rate depreciates immediately, and during the subsequent periods, together with the higher interest rate, its gradual recovery offers an excess return to compensate for the lower risk appetite or the higher perceived risk.

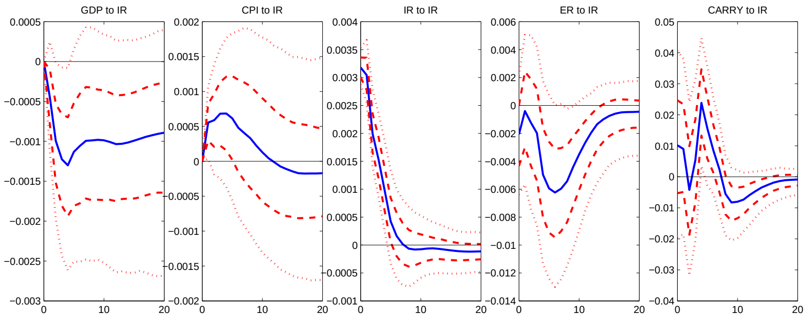
4.2 Comparison with the Cholesky decomposition

We briefly discuss the results with the Cholesky decomposition of the covariance matrix with a recursive ordering. This is a standard starting point in the literature studying the effect of monetary policy shocks (see Bjørnland, 2009; Uhlig, 2005, among others). Besides, it allows us to highlight the main theoretical difference between the recursive and the sign restrictions approach. In the former case — as long as the interest rate is ordered before the exchange rate, which is usually the case — it is (implicitly) assumed that an "exchange rate" or "risk premium" shock has no immediate effect on the interest rate. However, central banks tend to incorporate information about the exchange rate into their decisions as well as any other data that may influence the evolution of the key variables like consumer prices or output gap. Therefore, we need to take this channel into account to properly identify monetary policy shocks.

Using the same VAR model, we calculate the impulse responses assuming a recursive structure of shocks, too. Our ordering is the following: GDP, CPI, interest rate, exchange rate and carry trade. Here we identify monetary policy shocks as an unexpected increase in the interest rate that affects GDP and CPI only with delay. Note again that the recursive scheme implies that monetary policy does not react to the last two shocks (exchange rate and carry trade) on impact.

The results are displayed in Figure 4. Contrary to the findings in the benchmark model, the dynamic response of the exchange rate exhibits delayed overshooting, reaching its peak response nearly 2 years after the shock. The sluggishness of the exchange rate response is comparable to what Scholl and Uhlig (2008) have found using sign restrictions and somewhat longer than in Bouakez and Normandin (2010). It is also similar to the Cholesky decomposition results of

Figure 4: Responses to a monetary policy (interest rate) shock, Cholesky decomposition



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

Bjørnland (2009). Consistently with the delayed appreciation, significant carry trade activity can be detected even one year after the shock. Our median impulse responses are quite similar to what Brunnermeier, Nagel, and Pedersen (2009) have found, which is line with expectations since they also applied Cholesky decomposition.

The posterior distribution of the peak exchange rate response as well as the excess return confirm that the recursive identification scheme does favour for prolonged UIP failure more than the sign restriction approach (Figure 5 and 6). Our conclusion is that identification based on Cholesky decomposition may indeed generate delayed overshooting.[13]

4.3 Identification of foreign shocks

Since foreign shocks may be important drivers of carry activity, identification of them is essential for a thorough variance decomposition analysis. In the literature cited above, some attempts have been already made to distinguish domestic and foreign structural shocks. Kim and Roubini (2000), for instance, include the Federal Funds rate to control for foreign monetary policy, but since they do not identify U.S. monetary policy shocks, its movements may reflect other structural shocks as well.

Anzuini and Fornari (2012) use their variables in terms of differences to the corresponding U.S. variables, so they cannot separately identify the effect of foreign shocks. We take it for important to distinguish between domestic and foreign shocks because even if they may have similar short-run effect on the differences, due to the asymmetric behaviour between a small and a big country, the medium and long-run effects may differ a lot. A trivial example is a monetary policy shock. While in the small country we expect the monetary policy to react to the change in the foreign interest rate, the same is not expected from the central bank of the big country. Thus, the implication on exchange rate and carry trade response may differ substantially.

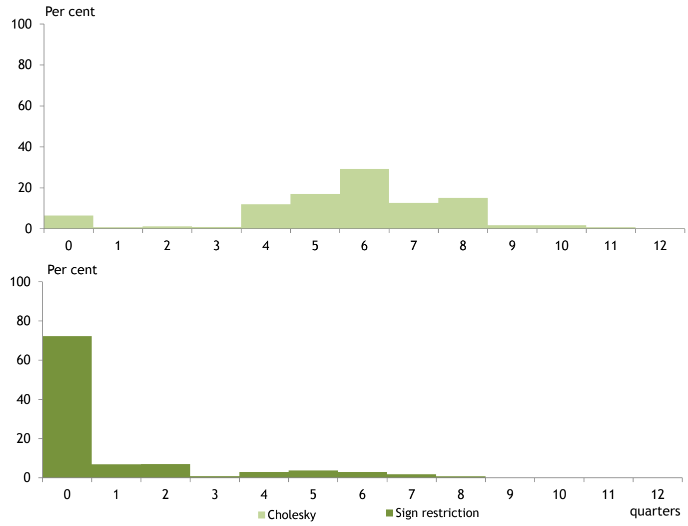
In order to identify foreign shocks, we estimate a structural VAR separately for the U.S. variables with the same methodology as in the domestic case. The VAR includes the same four U.S. variables used in the panel VAR as exogenous, with 4 lags[14] on the same sample. The

[13]It is noteworthy that delayed overshooting is not a robust finding even with Cholesky identification. Using 2 lags in the VAR, the mode of peak responses with recursive ordering takes place much earlier. This is in line with Istrefi and Vonnak (2012) who find that Cholesky decomposition does not always yield delayed overshooting.

[14]The number of lags was selected by looking at the usual information criteria and making sure that the residuals are free of autocorrelation.

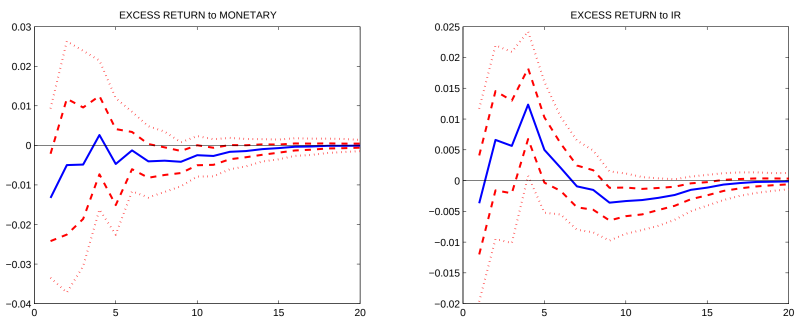
Figure 5: Location of exchange rate peak response under various identification schemes to a monetary policy (or interest rate) shock

(as a percent of total draws)



Note: The location where exchange rate impulse response has its minimum value are shown, see Figure 2.

Figure 6: Response of excess return to a monetary policy shock using sign restrictions (left) and Cholesky decomposition (right)



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

only difference is that we did not include carry trade data and exogenous variables. We identify demand, supply, monetary policy and risk premium shocks using the same restrictions as in the panel model presented before, obviously without the restrictions on carry trade.

In order to calculate the effect of foreign shocks to domestic variables, we randomly draw from the posterior of U.S. impulse responses for each draw from the panel VAR, and feed the former into the latter through the exogenous U.S. variables. This way the shocks from the U.S. economy are channelled into the small open economy VAR. Figure 14 in the Appendix depicts the estimated impulse responses of the U.S. VAR.

Regarding the response of domestic variables to U.S. shocks, domestic interest rate reacts positively and the exchange rate depreciates after a contractionary U.S. monetary policy shock (Figure 15 in the Appendix). GDP and CPI do not show statistically significant responses, neither the main variable of interest, the carry position, although its immediate response is intuitive. Carry trade jumps to an U.S. risk premium shock significantly, but the magnitude is again much smaller than in the case of domestic shock. This suggests that U.S. shocks have a minor role in carry trade activity.

4.4 Variance decomposition

Figure 7 shows the decomposition of the variance of k-step ahead forecast error of the carry trade. According to the median estimates, domestic monetary policy and risk premium shocks explain more than 20-20 per cent of carry trade variability over almost the whole 5-year horizon. Median estimates are surrounded by large posterior uncertainty. The other shocks seem to play only a minor role in carry trade. This is consistent with the variance decomposition of forecast error of the exchange rate (Figure 16 in the Appendix), where the explanatory power of domestic monetary policy and risk premium shocks is similarly high.[15] The median of unexplained variance remained less than 10 per cent at each horizon.

It is worth mentioning that the role of U.S. shocks, including monetary policy shocks is of second order in explaining carry trade variation. The main reason for it can be that domestic monetary policy reacts to foreign shocks so that interest rate differential does not change too much, which discourages carry trade and thereby mitigates the exchange rate response. This interpretation is confirmed by the results as the posterior distribution of the interest rate differential after a U.S. monetary policy shock[16] is quite symmetric around zero at each horizon. On the other hand, domestic monetary policy shocks are important for carry trade, because they lead to persistent changes in interest rate differential. Note again, that in order to get these results both domestic and foreign shocks have to be identified.

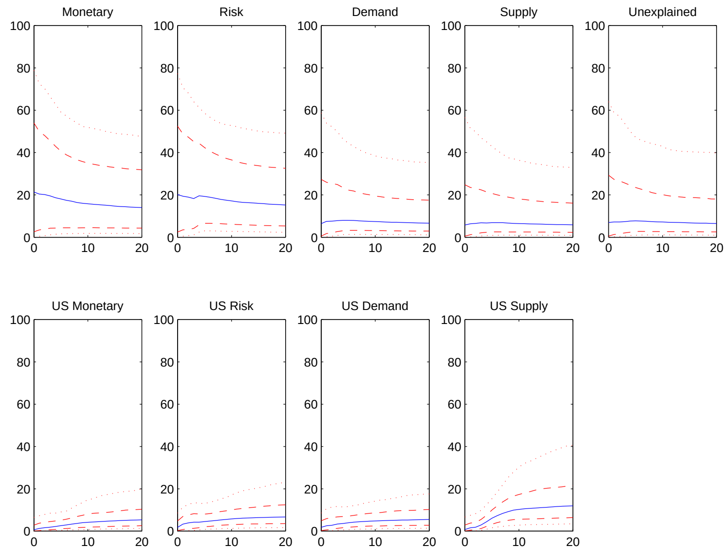
5 Robustness analysis

In this section we test the robustness of the results to the identification assumptions and the data frequency. Both tests are motivated by the zero restrictions we imposed in our benchmark model. As mentioned earlier, the assumption that GDP and prices respond to monetary policy and risk premium shocks with several months delay can be criticised in case of small open economies where the exchange rate channel is strong.

[15] Another issue in recent literature is the connection between monetary policy shocks and exchange rate variation. Our results show that monetary policy shocks explain 20 per cent of exchange rate fluctuations at shorter horizon, while the contribution is 5 per cent at longer horizon. This is broadly in line with Scholl and Uhlig (2008) but smaller than what Bouakez and Normandin (2010) have reported. Kim and Roubini (2000) have found much higher contribution, around 60 per cent at short horizon.

[16] Not shown in the paper, but available upon request.

Figure 7: Variance decomposition of carry trade



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

In the first experiment we relax the zero restrictions. In the second case we use higher frequency data to make zero restrictions more credible.

5.1 Pure sign restriction approach

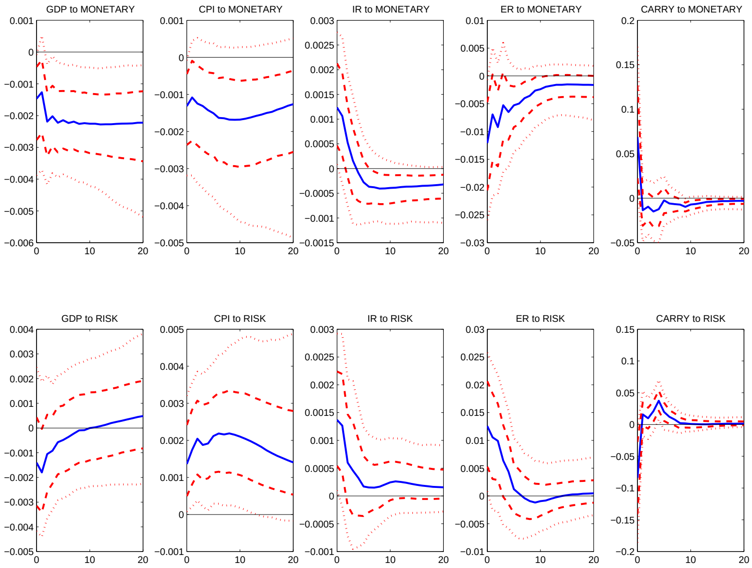
First, we consider a pure sign restriction approach as an alternative identification strategy. More specifically, our restrictions are the following in this case:

$$\begin{pmatrix} \varepsilon_t^{Prod} \\ \varepsilon_t^{Prices} \\ \varepsilon_t^{Interest} \\ \varepsilon_t^{Exchange} \\ \varepsilon_t^{Carry} \end{pmatrix} = \begin{bmatrix} - & \cdot & + & + & \cdot \\ - & + & + & - & \cdot \\ + & + & + & \cdot & \cdot \\ - & + & - & + & \cdot \\ + & - & \cdot & \cdot & \cdot \end{bmatrix} \begin{pmatrix} u_t^{Monetary} \\ u_t^{Risk} \\ u_t^{Demand} \\ u_t^{Supply} \\ u_t^{5} \end{pmatrix} \tag{8}$$

where the notation is the same as in the benchmark model. Compared to the baseline specification, some additional restrictions are necessary to disentangle the shocks of interest. Particularly, we use sign restrictions for the responses of GDP and prices, with the exception of the unrestricted response of GDP to a risk premium shock (see the upper left 2×2 matrix). Furthermore, we assume that the exchange rate appreciates after an unexpected demand shock, and depreciates following a supply shock, which is broadly in line with standard macroeconomic models.

Impulse responses that are in the centre of our interest do not alter significantly compared to the benchmark model (Figure 8). The price puzzle is now avoided by construction, as in Uhlig

Figure 8: Responses to a monetary policy and a risk premium shock with pure sign restrictions



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

(2005). No delayed overshooting of the exchange rate can be observed either in this case, and the responses of carry activity (which were unrestricted) move in the direction presented previously (Figure 9).

Turning to the variance decomposition, Figure 10 shows that monetary policy and risk premium shocks explain less variance in carry activity, and larger explanatory power is attributed to other domestic shocks compared to the benchmark result. This can be a consequence of restricting the sign of the exchange rate response to other shocks as well.

5.2 Monthly frequency

To make the zero restrictions more credible, we estimate the same model on monthly frequency. The assumption that the response of GDP and CPI to monetary and risk premium shocks is lagged by one month is more defendable than the one quarter delay. We use monthly data from 1992M4 to 2007M12 and the VAR includes 3 lags of the endogenous variables. In the U.S. VAR we use 7 lags.[17] As GDP data is not available on monthly frequency, we opt for industrial production instead. The authorities of Australia do not publish monthly data on consumer prices and economic activity, therefore we have to restrict our panel sample to Canada and the United Kingdom.

[17]The choice of lag numbers was motivated by the rejection of serial correlation in the residuals. We estimated an alternative version with 9 lags for both panel and U.S. models as in this case no serial correlation was detected either. Results do not change significantly compared to the case described above.

Figure 9: Posterior distribution of the location of peak response with pure sign restrictions to a monetary policy shock

(as a percent of total draws)

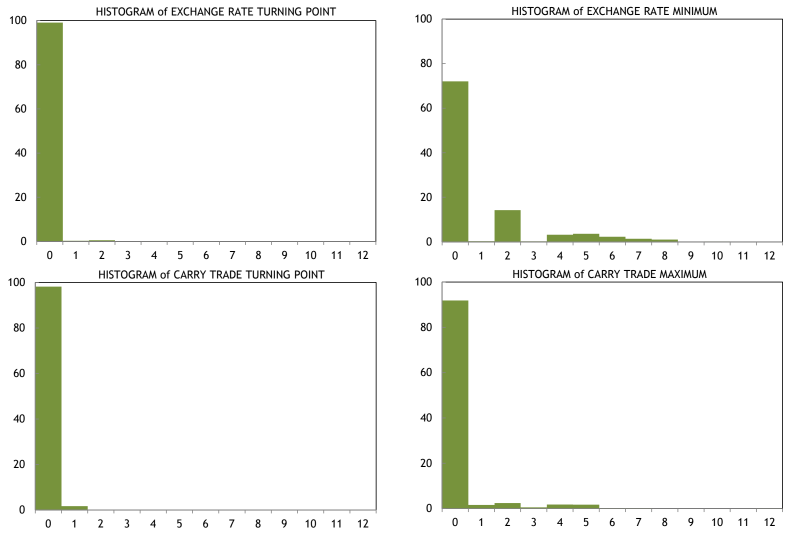
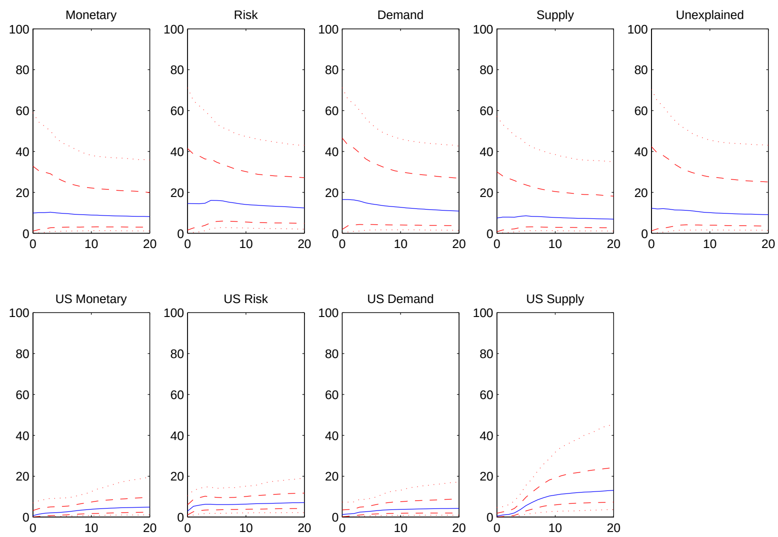
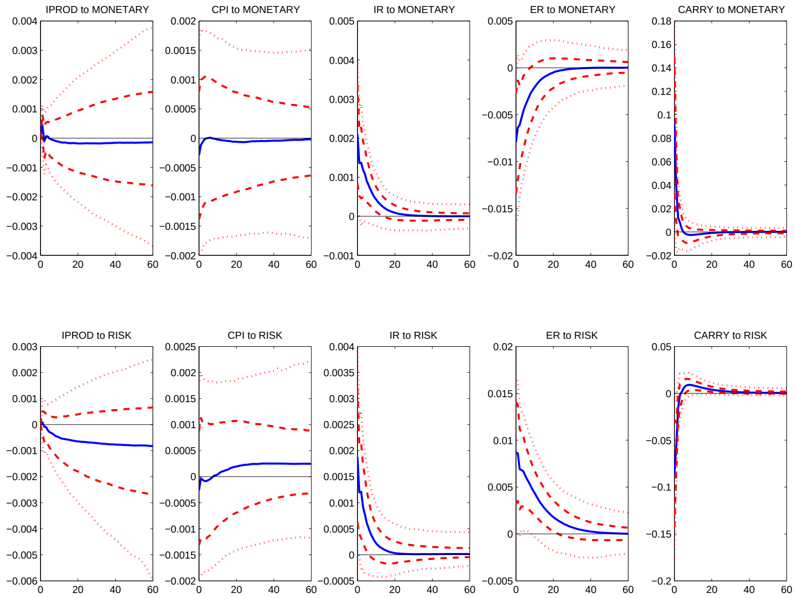


Figure 10: Variance decomposition of carry trade with pure sign restrictions



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

Figure 11: Responses to a monetary policy and a risk premium shock with monthly data



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

The results depicted in Figure 11 confirm that the exchange rate and carry activity react within a quarter (at most 1-2 months) to a monetary policy shock, generally. Unfortunately, the responses of industrial production and consumer prices are not significantly different from zero. Variance decompositions lead to the same conclusion, with monetary policy and risk premium remaining dominant in explaining the total variance of carry activity.

Our robustness checks confirm the main results of the benchmark model. However, their impulse responses are less convincing in general than the original specification. Moreover, relaxing zero restrictions requires additional restrictions, and changing the frequency decreases the sample. Taking all these trade-offs together, we find it reasonable to stick to the benchmark model.

6 Conclusions

In our paper we investigated the effect of monetary policy on exchange rate and the role carry trade plays in the exchange rate channel of monetary transmission within the same model. We estimated a VAR for a panel of three small open economies regarded as target of carry trade strategies. We identified domestic and foreign structural shocks by using sign restrictions.

We found that allowing for simultaneous interest rate and exchange rate reactions to both monetary policy and risk premium shocks, the delayed overshooting found by other authors can be rejected by high probability. The exchange rate behaves as predicted by uncovered interest parity. Our result suggests that speculative position-taking plays an important role in it. After an unexpected monetary policy shock carry traders react promptly helping the exchange rate jump and eliminate excess return, which may be an important contribution to the literature.

Variance decomposition shows that the main drivers of carry trade are domestic monetary policy and risk premium shocks. While in the first case we attribute a beneficial role to currency speculation in transmitting monetary policy, in the second case the idiosyncratic exchange rate shocks generated by carry trade activity may incur welfare losses.

We tested the robustness of our results to the choice of restrictions used to identify the VAR, and to the data frequency. Our main findings proved to be fairly robust, with the exception of variance decomposition, which proved to be sensitive to identifying restrictions.

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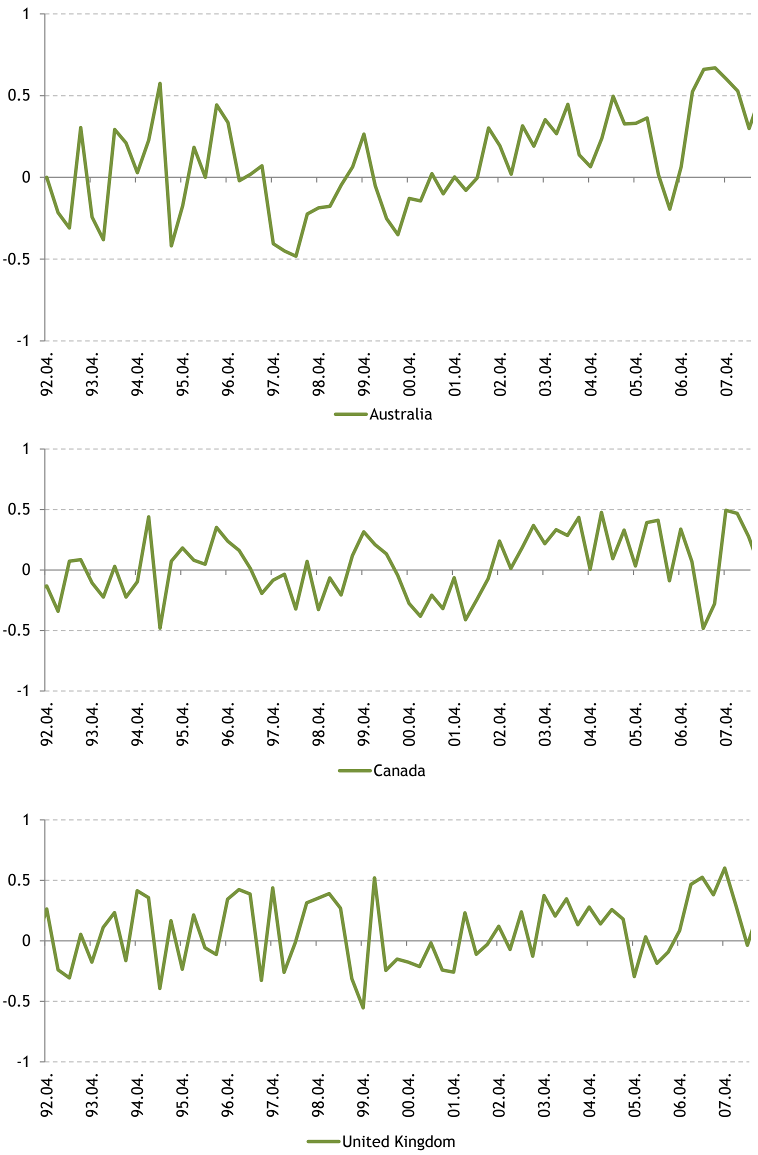
Appendix

Table 1: IFS data

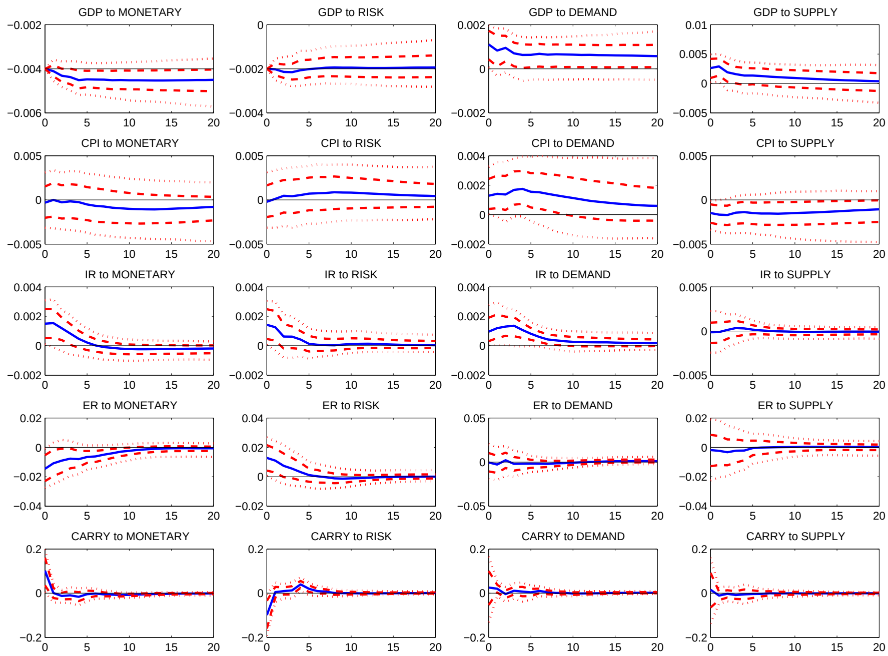
Country	Variable	IFS Code
Australia	NEER from INS	193..NECZF...
Australia	GDP vol. (2005=100)	19399BVRZF...
Australia	CPI: all groups, six capitals	19364...ZF...
Australia	Average rate on money market	19360B..ZF...
Canada	NEER from INS	156..NECZF...
Canada	GDP vol. (2005=100)	15699BVRZF...
Canada	CPI: all cities pop. over 30,000	15664...ZF...
Canada	Overnight money market rate	15660B..ZF...
United Kingdom	NEER from INS	112..NECZF...
United Kingdom	GDP vol. (2005=100)	11299BVRZF...
United Kingdom	CPI: all items	11264...ZF...
United Kingdom	Overnight interbank min.	11260B..ZF...

Figure 12: Net futures positions of non-commercial traders



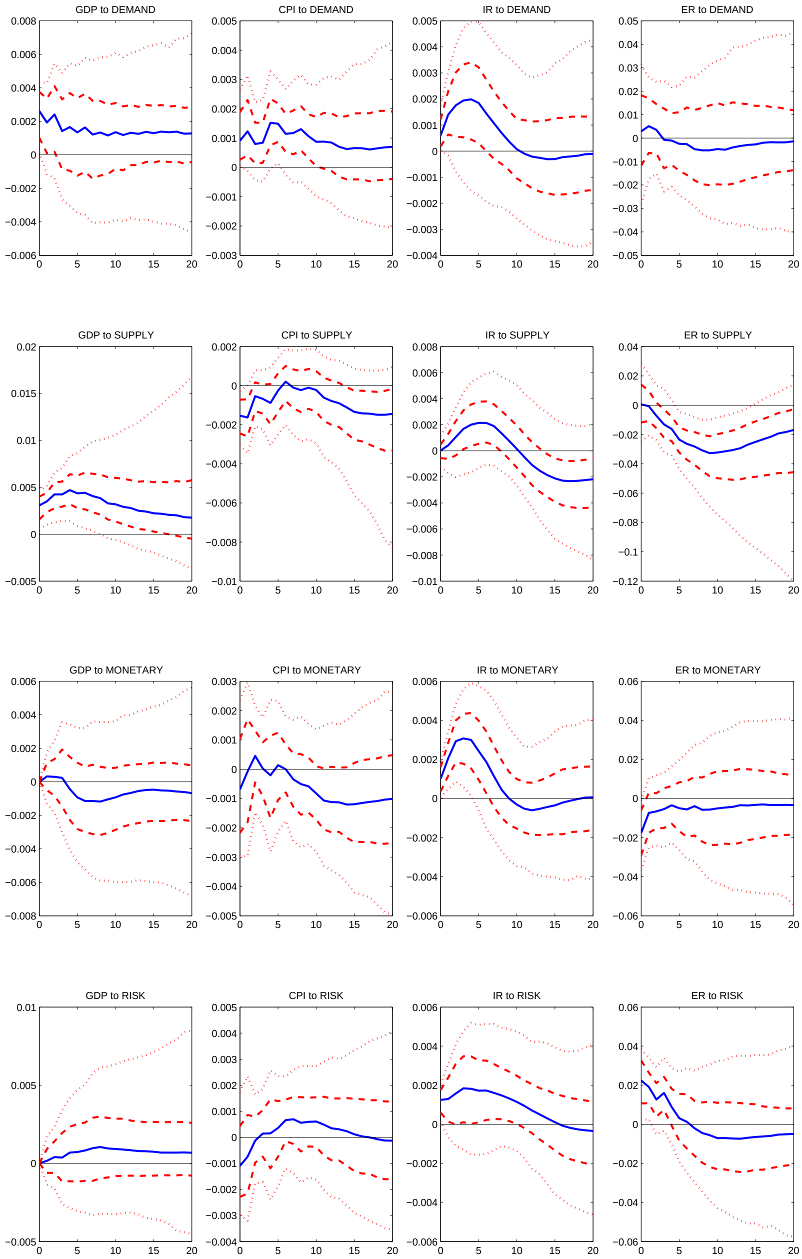
Source: CFTC, authors' calculation.
Note: We use the last available CFTC positions report in each quarter to construct the net futures position of non-commercial traders for selected currencies, expressed as a fraction of total open interest.

Figure 13: Responses to domestic structural shocks (benchmark model)



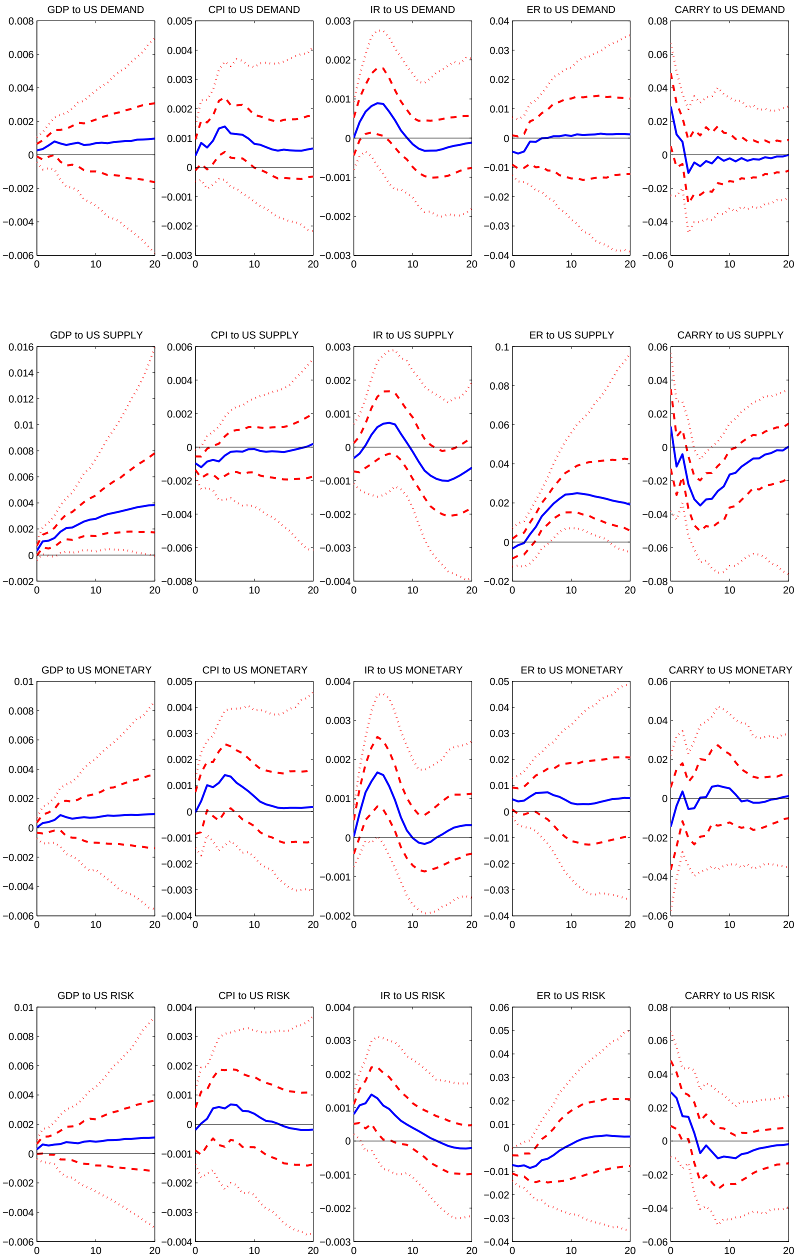
Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

Figure 14: Responses of U.S. variables to U.S. shocks (benchmark model)



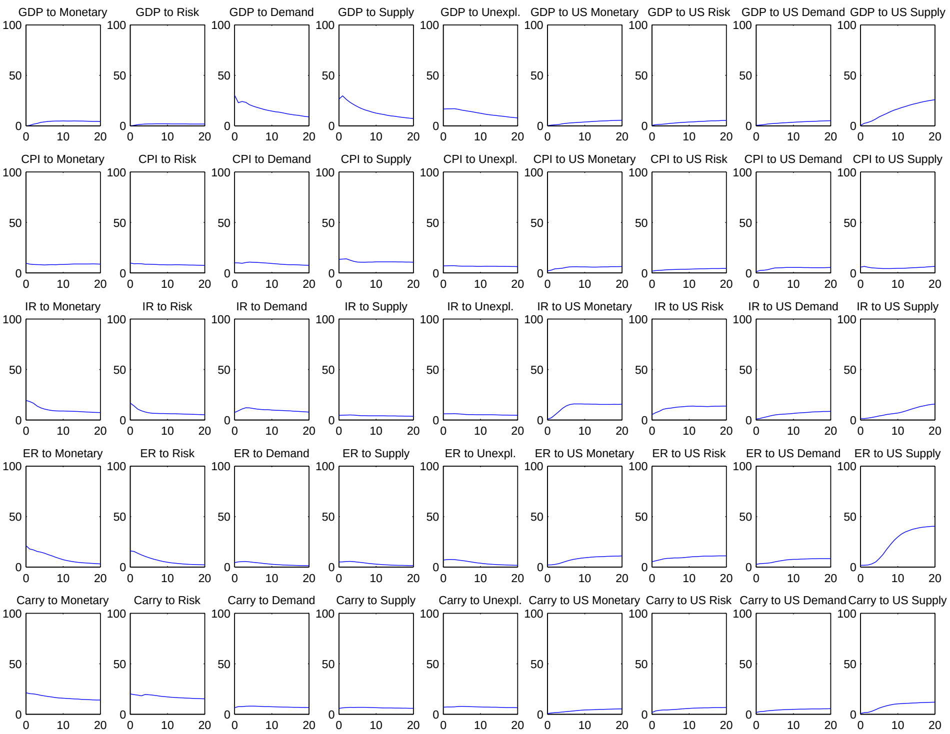
Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

Figure 15: Responses of domestic variables to U.S. shocks (benchmark model)



Note: The solid line is the pointwise median of all successful draws. Dashed and dotted lines encompass the middle 68 and 95 per cent of the posterior distribution, respectively.

Figure 16: Variance decomposition (benchmark model)



Note: The solid line is the pointwise median of all successful draws.