Monetary Policy and Exchange Rate Dynamics: New Evidence from the Narrative Approach to Shock Identification

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Abstract: We argue that endogenous and anticipated movements in interest rates lead to underestimates of the speed and magnitude of the exchange rate response to monetary policy. Employing the Romer and Romer (2004) exogenous monetary policy shock measure, we find that the effect of a one percentage point increase in the U.S. interest rate is up to twice as large and 3 times as fast as that obtained using the actual federal funds rate to identify monetary shocks. Moreover, new evidence from open economy VARs emphasises the adjustment role of the exchange rate. U.S. prices and output respond almost twice as quickly as they do in a closed economy VAR using the Romer and Romer shock measure. There is also evidence of stronger international transmission of U.S. monetary shocks. Overall, the estimated response speeds and magnitudes are more easily reconciled with existing models than previous empirical work.

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1 Introduction

The determinants of exchange rate dynamics are a central focus of research in open economy macroeconomics. In the goods market, changes in export and import flows can induce exchange rate adjustment when tradeables prices are sticky. In the assets market, a positive domestic-foreign interest rate differential causes exchange rate appreciation to equilibrate real returns across countries. The Mundell-Fleming-Dornbusch model embeds this dual role of the exchange rate, generating the famous exchange rate overshooting result in response to monetary policy shocks.

Although theory predicts a systematic relationship between monetary policy and the exchange rate, the empirical evidence is weak. Eichenbaum and Evans [1995] find a typical delay of three years in the maximum response of bilateral US$ exchange rates to US interest rate shocks, a phenomenon since known as delayed overshooting.[1] Chen and Rogoff [2003] document a weak effect of interest rate differentials on exchange rates even after controlling for commodity prices, while Grilli and Roubini [1996] find that contractionary monetary policy in non-US G7 countries induces exchange rate depreciation rather than appreciation. These findings are not only at odds with standard models of the exchange rate, but also challenge theoretical results that assume a link between monetary policy and the exchange rate. For example, the Rogoff [1985] result that international monetary policy cooperation can reduce total welfare depends on differences in the impact of monetary policy on the exchange rate across cooperative and non-cooperative regimes. In related work, Guender and McCaw [2000] apply a standard monetary model of the exchange rate to show that the inflationary bias associated with discretionary monetary policy is negatively related to the elasticity of output supply with respect to the real exchange rate, lending support to Romer's [1993] empirical finding of a negative openness-inflation relationship.

We argue that endogenous and anticipated movements in interest rates lead to down-

[1] All interest rates throughout the paper are nominal, overnight inter-bank rates. For the US, the relevant interest rate is the federal funds rate.

ward bias in the estimated effect of monetary policy on the exchange rate.[2] Endogenous movements in interest rates result from changes in economic conditions. For example, during a business cycle expansion, output is high, shifting out money demand and boosting the federal funds rate. However, the economic expansion also typically raises expected inflation, which creates pressure for a nominal depreciation in order to stabilise the real exchange rate. This offsets the appreciation caused by a positive interest rate differential, leading to a dampened exchange rate response to the federal funds rate. Anticipated movements in the interest rate occur when the monetary authority responds to forecasts concerning future economic conditions. Foreign exchange market traders often predict such policy interventions and adjust their portfolios in advance, generating an exchange rate adjustment before a change in interest rates takes place. A regression of the exchange rate on current and past interest rates will then indicate a weak relationship between monetary policy and the exchange rate, despite the existence of an underlying causal relationship.

In an investigation of the effect of US monetary policy upon output and prices in the closed economy, Romer and Romer [2004] employ the narrative approach to identify monetary policy shocks in an attempt to overcome the endogeneity and anticipatory biases. By analysing the minutes and transcripts of Federal Open Market Committee (FOMC) meetings, they identify the Federal Reserve's intended changes in the federal funds rate, thereby eliminating interest rate changes that are endogenous to current economic conditions. The intended interest rate changes are then regressed upon the Federal Reserve's output, inflation and unemployment forecasts. The residuals from this regression are thus purged of anticipatory movements, forming an exogenous monetary policy shock measure. Romer and Romer show that the narrative-approach identified monetary policy shocks exert larger and faster effects on industrial production and the producer price index than the actual federal funds rate.

We examine the response of six bilateral US$ exchange rates to the Romer and Romer

[2] We specifically focus on monetary policy shocks as embodied by interest rate changes, but the general identification problem exists for other shock measures.

monetary policy shock measure, employing both single equation models and vector autoregressions (VARs).[3] The results show that the time until the maximum exchange rate response is often less than half that observed using the actual federal funds rate, and averages just 12.5 months in the case of the VAR estimates. Such time lags are easier to explain as a consequence of adjustment costs, investor uncertainty, bounded rationality and/or learning than are the previously estimated lags. For example, Lewis (1989a, 1989b) proposed agent learning as a possible source of delayed exchange rate adjustment. We also find that the maximum appreciation induced by a policy contraction is up to 2.5 times larger when using the Romer and Romer exogenous monetary policy measure rather than the federal funds rate. This suggests that a failure to properly address endogenous and anticipated interest rate movements accounts for some of the perplexing exchange rate dynamics found in previous empirical work.

Our results from open economy VARs also provide new evidence on price and output adjustment in the United States. Romer and Romer [2004] estimated larger and faster monetary policy effects on output and prices, but found that the maximum output response and price adjustment commencement occurred at 24 months. Cochrane [2004] argues that such lags are difficult to reconcile with economic theory. By placing the US in an open economy VAR, we find that the median delay in the maximum effect of an exogenous monetary policy shock on output is just 14 months. Price adjustment begins within one year, and within two years is significant at the 5% level and often more than half the adjustment observed at 48 months. We argue that the faster effects of monetary policy in the open economy VAR suggest a significant adjustment role for the exchange rate, which is neglected in the closed economy VARs.[4]

The VAR results also cast some light on the international transmission of US monetary policy. Replicating Kim's [2001] finding, an increase in the actual US interest rate measure

[3]We consider US exchange rates vis-à-vis the other member states of the G7: Canada, France, Germany, Italy, Japan and the United Kingdom (UK).

[4]New open economy macroeconomy models stress the exchange rate's adjustment role in the open economy [Obstfeld and Rogoff, 1995, 1996]. The 'exchange-rate disconnect puzzle' (defined as the weak estimated relationship between the exchange rate and any macroeconomic variables) represents an important challenge to these models [Obstfeld and Rogoff, 2001].

elicits only small increases in foreign interest rates, excepting Canada. In contrast, Romer and Romer's monetary policy shock measure generates statistically significant increases in foreign interest rates in all G7 countries, excepting the UK. The stronger international transmission of US monetary policy shocks is reflected in foreign output, which in 4/6 cases traces out a more pronounced U-shape than that observed following a shock to the actual federal funds rate.

We carry out a series of robustness tests. Mirroring Romer and Romer's closed economy findings, the results remain even after the inclusion of commodity prices in the open economy VAR. This suggests that endogeneity and anticipatory biases in the estimated effects of monetary policy arise from sources other than supply shocks. The results are also robust to the inclusion of a time trend, altering the lag structure and estimating the model over different sub-samples. Furthermore, our general conclusions are invariant to using the reduced form impulse responses for inference or to changing the placement of the monetary policy shock measure in the VAR ordering. This suggests that the Romer and Romer monetary policy measure is truly exogenous in the VAR.

The paper proceeds as follows. In section 2, we briefly review theoretical and empirical work on monetary policy and the exchange rate, focusing in particular on different approaches to monetary policy shock identification. We argue that the Romer and Romer [2004] monetary policy measure meets the requirements of an exogenous monetary policy shock set out in the theoretical literature, allowing for an accurate assessment of monetary policy's impact on the exchange rate. In section 3, we describe our empirical methodology and the data employed. Then, in section 4, we present the empirical results from the single equation and VAR models. We explore the robustness of our findings in section 5, and conclude with a brief summary and discussion in section 6.

2 Monetary policy and the exchange rate

In this section, we first present a brief review of how monetary policy is connected to the exchange rate in theory. Then, we discuss the various approaches that have previously been applied to identify monetary policy shocks and to evaluate their impact on the exchange rate. Finally, we consider Romer and Romer's [2004] narrative approach to monetary policy shock identification, explaining how this generates identification in the open economy context.

2.1 The Identification of Monetary Shocks: Theory and Practice

A simple Cagan-style model implies that the level of the exchange rate at a moment in time is the discounted infinite sum of expected future Home and Foreign money supplies (e.g., Obstfeld and Rogoff, 1996). The classic Mundell-Fleming-Dornbusch (MFD) model (see Dornbusch, 1976) generates a similar result.[5] In this model, an unexpected monetary expansion requires that the price level increase and the nominal exchange rate depreciate in equal proportion, to preserve the real equilibrium. In the short-run when prices are sticky, real interest rates fall below world levels. In order to satisfy the uncovered interest parity (UIP) condition (a no-arbitrage condition requiring that interest rate differentials today be offset by expected future currency movements), the nominal exchange rate must overshoot its long-run level such that there is an expected short-run appreciation. If the shift in monetary policy is permanent, the exchange rate will settle at its long-run level once prices adjust, while if the shift is temporary the exchange rate will return to its pre-shock level.[6]

These models highlight two points that are especially relevant to empirical work on monetary policy and the exchange rate. Firstly, since money supply shocks are related

[5] Dornbusch's original [1976] paper is a perfect foresight model. This is easily generalized to allow for a stochastic money supply as the model is log-linear.

[6] See Sarno and Taylor [2002] for an excellent summary of the literature on exchange rate determination, including micro-founded models.

to the interest rate via money demand, changes in interest rates represent an alternative measure of monetary policy shocks. Indeed, Bernanke and Blinder [1992] argue that the federal funds rate is a better measure of US monetary policy than quantity-based measures, such as non-borrowed reserves. This is because movements in quantity-based measures are more likely to reflect endogenous changes in money demand, rather than exogenous monetary policy actions.[7] Secondly, monetary shocks should be unanticipated. If shocks are anticipated, the largest exchange rate response likely occurs at the time at which the information arrives and not at the time of the shock. The full effect of monetary policy on the exchange rate will then be difficult to identify empirically.

Empirical studies of exchange rate dynamics typically involve fitting a vector autoregression (VAR) for a small system of open economy variables.[8] Identification is then achieved by imposing a set of restrictions that map the reduced form shocks to structural shocks. For example, the structural shock associated with the interest rate equation in the VAR is interpreted as the unanticipated shift in policy implemented by the monetary authority.

The most common restrictions employed are short-run restrictions on the contemporaneous linkages between variables, as determined by the chosen Wold causal chain in a recursive VAR.[9] The canonical open economy example of such an identification approach is Eichenbaum and Evans' [1995] paper. They fit a VAR for US output and prices, foreign output and foreign interest rates, a measure of non-borrowed reserves, the US federal funds rate and the nominal dollar exchange rate (foreign variables are drawn from one of the other six G7 countries). The monetary policy shock is equated with an orthogonal innovation to either the US federal funds rate or non-borrowed reserves. Eichenbaum and Evans find various 'anomalies' in the estimated impulse responses. The bilateral US$ exchange rate's peak response often occurs with a lag of three years. Such

[7]The Volcker experiment from 1979-1981 represents an exception to this principle. In section 5.3, we discuss the consequences of including or excluding this period in the empirical analysis.

[8]An exception is the study by Bonser-Neal et al. [1998], which we discuss in section 2.2.

[9]The Wold causal chain is reflected in the ordering of the variables in a recursive VAR, as this order affects the Choleski decomposition of the covariance matrix [Sims, 1980].

delayed overshooting is difficult to reconcile with the MFD model, which requires that the exchange rate act as a jump variable. The delayed overshoot also implies a forward premium anomaly, in that expected exchange rate movements magnify the excess returns available on US assets following an increase in interest rates. Eichenbaum and Evans also explore the robustness of their findings to the inclusion of the Romer and Romer 1989 monetary contraction dummy. Their general conclusions remain, although with a larger estimated response and larger associated standard error.[10]

Kim and Roubini [2000] argue that the short-run restrictions implied by a recursive identification scheme are likely invalid for the open economy.[11] Instead, Kim and Roubini employ restrictions on the monetary authority's reaction function to identify monetary policy shocks.[12] The resulting impulse response lines show fewer instances of delayed overshooting following federal funds rate shocks. However, bilateral US$ exchange rates continue to show perverse dynamics. Moreover, the maximum response is often small.[13]

Bernanke and Mihov [1998] identify monetary policy shocks by modelling the Federal Reserve's operating procedures in the context of a VAR. The resulting 'semi-structural' VAR allows for an endogenous Federal Reserve reaction to current reserve market conditions, thereby enabling the extraction of a more exogenous monetary shock. From this framework, they construct a measure of the overall monetary policy stance. Kalyvitis and Michaelides [2001] take the Bernanke-Mihov overall monetary policy stance measure and include it in a 5-variable open economy VAR, in addition to the short-term interest

[10]Blomberg [2001] extends this exercise by developing a refinement of Romer and Romer [1989]'s narrative approach, coding the shock dummy to include expansions. Using daily data, he investigates the out-of-sample performance of a single equation ARX model of the exchange rate which includes both the federal funds rate and the refined monetary shock dummy. The ARX model inclusive of the refined monetary shock dummy performs better (up to an 11% lower root-mean-square-error) than a random walk forecast of the exchange rate for the one to ten-day horizons.

[11]For example, a Wold causal chain implies that either interest rates may affect exchange rates contemporaneously or exchange rates may affect interest rates, but not both simultaneously. A richer two-way interdependency seems plausible.

[12]Cushman and Zha [1997] undertake a similar structural VAR identification strategy, arguing that the monetary authority's reaction function includes foreign variables. They implement the model for Canada, resolving its exchange rate puzzle (defined as an exchange rate depreciation response to a domestic interest rate increase).

[13]The maximum appreciation of the dollar across six bilateral rates following a 105 basis point increase in the federal funds rate is 1.9%, while the smallest is 0.6%. See Kim and Roubini [2000], Figure 4.

rate differential.[14] Kalyvitis and Michaelides contend that traditional VAR-based monetary policy shock measures fail to consider changes in the Federal Reserve's chosen target (e.g., interest rates or reserves). The Bernanke-Mihov measure implicitly allows for the target to switch, by combining information on the policy stance towards the interest rate and reserves. Kalyvitis and Michaelides find some evidence for immediate exchange rate overshooting, but a number of puzzles remain. For example, following a monetary contraction in the US, the dominant response of dollar exchange rates versus the French franc and the British pound is depreciation rather than appreciation.

Faust and Rogers [2003] investigate how the estimated impulse responses in open economy VARs change as the recursive identification assumptions are relaxed. They bound the likely impulse responses by assuming only partial identification.[15] Delayed overshooting of the exchange rate is less severe when a contemporaneous effect of US interest rates on foreign interest rates is allowed. However, the explanatory power of US monetary policy for bilateral US$ exchange rates against the UK pound and the German mark is typically small in such cases.[16]

We argue that endogenous and anticipated movements in the federal funds rate contribute to the generally weak relationship between monetary policy and the exchange rate that has been documented in the previous literature. As discussed in the introduction, interest rate movements need not originate with the monetary authority and may instead arise endogenously, in response to economic conditions. For example, during cyclical expansions output is high and this may shift out the money demand curve, boosting the federal funds rate. At the same time, the upswing in the business cycle likely increases expected inflation. While the higher federal funds rate may appreciate the exchange rate, the associated increase in expected inflation creates pressure for a nominal depreciation

[14] Their Wold ordering is $\left[\left(y^{us}-y^{f}\right)\ \left(p^{us}-p^{f}\right)\ BM\ \left(r-r^{f}\right)\ s\right]'$, which is relative output, relative prices, the Bernanke-Mihov measure, the interest rate differential, and the exchange rate.

[15] For example, the partial identification assumptions may take the form of sign restrictions, as opposed to contemporaneous exclusion restrictions. See Uhlig [2005] for a recent application of this strategy in the closed economy context. He finds little effect of monetary policy upon output.

[16] An alternative set of identifying assumptions is provided by long-run neutrality conditions. See Faust and Leeper [1997]. This approach has rarely been followed in open economy VARs.

in order to stabilise the real exchange rate. This dampens the exchange rate appreciation and may even cause a net depreciation. Alternatively, consider a case where exchange rate depreciation causes an increase in expected inflation, and thus nominal interest rates. Increases in nominal interest rates will then be correlated with exchange rate depreciation, contrary to what theories of monetary policy predict.[17] To measure the full impact of monetary policy on the exchange rate, it is important to identify shocks that arise solely from the intentions of the monetary authority.

When the monetary authority responds to expected future events, monetary policy may be anticipated. Consider a scenario in which the Federal Reserve's forecasts indicate higher output and inflation over the next year. In response, the Federal Reserve raises interest rates. If agents have at least some of the Federal Reserve's information and anticipate its interest rate response, agents may adjust their portfolios at the time at which information underpinning the forecast becomes known. Thus, the dollar moves in advance of the federal funds rate and the relationship between these variables estimated from a backward-looking VAR will be biased downwards.[18] A proper accounting of the impact of monetary policy on the exchange rate therefore also requires that unanticipated shocks be isolated.

As is clear from the earlier discussion, previous research has typically used either recursive or structural VAR restrictions in attempting to eliminate endogenous and anticipated federal funds rate movements. These identification schemes extract shocks through orthogonalising the residuals of the federal funds rate equation with respect to other residual series in the VAR. However, unless the VAR contains all variables which may shift money demand (e.g., measures of financial sector regulatory reform; asset prices such as those for housing and equity, etc.), then this identification scheme will fail to eliminate

[17]This arises from the failure to distinguish between changes in real interest rates and changes in expected inflation when nominal interest rate changes are used as monetary policy measures.

[18]Such behaviour appears commonplace. For example, a headline story on the Bloomberg news website on June 16th 2005 read: 'The dollar rose for the fourth day in five against the euro in London on expectations a Federal Reserve report today will show manufacturing growth accelerated in the Philadelphia region ... reinforcing speculation the Fed will raise interest rates for a ninth time in a year on June 30.'

the entire endogenous component.[19] Similarly, without the inclusion of forecasts of the economy's future direction, the anticipated component of interest rate movements will not be removed from the VAR-identified shocks.[20] We now turn to an alternative method of shock identification that tries to overcome these problems.

2.2 The narrative approach to shock identification

The narrative approach to shock identification uses historical documentation to identify exogenous changes in monetary policy. The origins of the narrative approach date from Friedman and Schwartz's [1963] review of the monetary history of the United States. Romer and Romer [1989] formalized the approach by analysing the minutes of Federal Open Market Committee (FOMC) meetings in order to determine the dates of exogenous monetary policy contractions.

Recently, Romer and Romer [2004] (henceforth R&R) have further refined the narrative approach by means of a two-step procedure applied to the United States' Federal Reserve Bank's monetary policy over the period 1969-1996.[21] In the first step, the narrative evidence is used to determine the size of the federal funds rate change targeted by the Federal Reserve. This eliminates endogenous interest rate movements linked to current economic conditions.[22] In the second step, the targeted interest rate change is purged of anticipated changes. R&R accomplish this by regressing the targeted interest rate change upon the Federal Reserve's Greenbook (in-house) forecasts of inflation, output and unemployment over horizons of up to six months.[23] The residuals from this

[19] Leeper et al. [1996] are able to include several such variables in their VAR study of US monetary policy by applying Bayesian methods to avoid the problem of parameter profligacy.

[20] Sims [1992] includes commodity prices in a VAR, as an 'information variable' that may predict future inflation, while Barth III and Ramey [2002] include output and inflation forecasts directly. However, both studies look at closed economy VARs.

[21] The procedure could readily be applied to other monetary authorities, contingent upon information availability. It addresses many of the objections raised to the narrative approach pioneered in Romer and Romer [1989].

[22] See Romer and Romer [2004] and the accompanying data appendix for full details.

[23] Inflation and output represent the central objective variables of the Federal Reserve. See Board of Governors of the Federal Reserve [2005], or the International Banking Act of 1978 (the Humphrey-Hawkins Act).

regression are the targeted interest rate changes which are orthogonal to the economy's expected time path.[24] R&R obtain one observation per FOMC meeting and then convert this time series to monthly data through summing the values for months in which more than one meeting occurred.[25] R&R show that this measure of monetary policy exerts an effect on output and prices that is both larger and faster than that associated with the raw federal funds rate, suggesting that endogenous and anticipated movements in interest rates distort the estimated effects of monetary policy.[26]

We propose to use the R&R monetary policy shocks to estimate the effects of monetary policy in the open economy, focusing upon its impact on bilateral US$ exchange rates. As this measure of monetary policy has been purged of endogenous and anticipated movements, it should exert a larger and faster effect on exchange rates. One might argue that in an open economy context, an exogenous measure of monetary policy should be orthogonal to forecasts for future exchange rates, similar to the closed economy context, where R&R orthogonalise intended changes in interest rates with respect to output, inflation and unemployment forecasts. However, there are two arguments against such an approach. Firstly, the Federal Reserve generally does not target exchange rates directly; effective exchange rate forecasts are notoriously difficult to formulate.[27] Secondly, exchange rates likely affect Federal Reserve decisions via output, inflation and unemployment forecasts. For example, an over-valued dollar may reduce these forecasts and the Federal Reserve will respond by cutting interest rates. However, this implies that the appropriate second step in the construction of the R&R shock measure is exactly the one undertaken by R&R: purge the targeted interest rate of output and inflation forecasts.[28]

[24]The Federal Reserve's economic forecasts likely represent the best (most informative) expectations of the economy's future path. See Romer and Romer [2000].

[25]At present there are approximately 8 meetings per year but historically the figure has been higher. In months in which there are no meetings, the shock measure is set to zero.

[26]R&R examine the response of the log of an industrial production index and the log producer price index.

[27]This is famously articulated by Meese and Rogoff [1983].

[28]This argument also provides some insurance against the source of bias identified by Grilli and Roubini [1996]. They contend that the weak effect of monetary policy on the exchange rate arises because increases in the federal funds rate are a policy response to contemporaneous dollar depreciation. If the weaker dollar feeds into output and inflation forecasts, its effect on the target federal funds rate are removed by the R&R procedure's second step.

It remains likely that some component of the R&R shock series is endogenous to current and expected exchange rate behaviour. For example, if the Federal Reserve responds to forecasts at horizons beyond 6 months, or if there are instances in which the Federal Reserve sets policy in response to concerns over the future value of the dollar (R&R discuss a possible example of this during 1984/85), then some endogeneity and/or anticipatory biases are introduced. The presence of such biases would weaken the estimated effect of monetary policy on the exchange rate. This suggests that the estimated effect of the R&R monetary policy measure on the exchange rate likely represents a lower bound on the true effect.[29] Regardless, the R&R monetary policy measure is still likely free of most endogenous and anticipated movements, and is thus an improvement over previous measures in understanding the effect of monetary policy on the exchange rate.

There have been previous attempts to address the endogeneity and anticipatory biases which may arise when using the actual federal funds rate to measure monetary policy in exchange rate studies. Bonser-Neal et al. [1998] argue that the actual federal funds rate is a noisy measure of the Federal Reserve's true monetary policy position, due to temporary fluctuations in the reserve market causing large movements in the actual federal funds rate. Instead, they advocate the use of Rudebusch's [1995] daily federal funds rate target series as a monetary policy measure. Bonser-Neal et al. regress daily spot and forward exchange rate changes upon contemporaneous changes in the target rate series. They find effects of monetary policy which are consistent with overshooting. Furthermore, they argue that the inclusion of foreign exchange interventions as an explanatory variable bolsters their findings. However, their econometric framework does not reveal the dynamics of the exchange rate response, nor does it correct for anticipatory biases.

Faust, Rogers, Swanson, and Wright [2003] address possible anticipatory bias in VAR-identified monetary policy shock measures by defining an unanticipated monetary policy shock as the change in the federal funds rate from before the FOMC interest rate an-

[29]Including six impulse dummies, for months in the last quarter of 1984 and the first quarter of 1985, in the empirical models does not change our finding that the new monetary policy measure exerts more powerful effects on exchange rates. In some cases the results actually get stronger, indicating a small amount of endogeneity of the R&R series with respect to the exchange rate.

nouncement to just after the FOMC announcement. Using high frequency data, they regress observed changes in the exchange rate and the prices of spot and three and six month-forward federal funds rates' futures on the change in the federal funds rate at the time of the FOMC announcement. If exchange rates and asset prices embody market expectations and if risk premia are constant, the fitted values from such a regression give the effects of an unanticipated change in the federal funds rate at horizons of zero, three and six months. Eichenbaum and Evans' [1995] open economy VAR is then identified by assuming that monetary policy replicates these effects from the high frequency data regressions. Focusing on Germany and the United Kingdom as the foreign economy, Faust et al. find fewer instances of delayed overshooting and a larger maximum exchange rate response. However, they note that the results are imprecise and a possibly large and persistent price puzzle (defined as a positive response of prices to interest rates) remains. The maintained assumptions of the Faust, Rogers, Swanson, and Wright [2003] procedure are that asset markets appropriately embody expectations, as is implied by the efficient markets hypothesis, and that risk premia do not change over time so that futures' rate changes reflect expected future spot rate changes.

The R&R [2004] monetary policy shocks represent an alternative which does not require these assumptions. Their validity instead hinges upon the appropriate interpretation of the narrative evidence and the Greenbook forecasts accounting for all anticipated movements in interest rates. Furthermore, because they employ high frequency data in the first step, Faust et al. [2003] must use a shorter time series, beginning in 1994 and only including 62 FOMC meetings. By contrast, the R&R data include 272 FOMC meetings and therefore bring more information to bear in identifying exogenous monetary policy. In the next section, we describe the methods that we use to estimate the response of bilateral exchange rates to the R&R monetary policy shocks and to assess how exchange rate adjustment bears on price and output dynamics and the evolution of foreign macroeconomic variables.

3 Econometric methodology and data

In order to gauge the impact of monetary policy on bilateral dollar exchange rates, we estimate two sets of econometric models – single equation regressions and VARs. We describe each in turn.

3.1 Single equation models

The single equation models estimated have the following general form:

$$\Delta s_t = \alpha + \sum_{i=1}^{24} \beta_i \Delta s_{t-i} + \sum_{j=1}^{36} \gamma_j \Delta r_{t-j}^{us} + \sum_{k=1}^{36} \lambda_k \Delta r_{t-k}^{f} + \sum_{l=1}^{11} \phi_l D_l + \varepsilon_t \tag{1}$$

where s_t is the (log) exchange rate measured as US dollars per foreign currency unit, r^{us} is either the actual federal funds rate (FF) or the cumulated R&R shocks measure (RR), r^f is the foreign interest rate and D is a seasonal (monthly) dummy.[30] All interest rates are measured in percentage points. The foreign country is one of the non-US G7 countries: Canada, France, Germany, Italy, Japan and the UK. The data are monthly and the sample period runs from the early 1970s to the end of 1996, though varying slightly by country. See the appendix for tables containing the sample periods and variable definitions and sources.

We include 24 lags of the dependent variable and 36 lags of each exogenous variable, replicating the baseline structure in R&R [2004]. Contemporaneous interest rate effects are excluded; this is justified by R&R on the grounds that monetary policy may exert a delayed effect. Such an argument is less tenable in the case of the exchange rate, but will be relaxed in the later VAR analysis, which allows for contemporaneous effects from the structural monetary policy shocks. Equation (1) is estimated by OLS. The exchange rate's dynamic response to a permanent 100 basis point shift in either FF or RR can then be graphed and standard error bands computed via the delta method.[31]

[30] Seasonal dummies are included to control for possible seasonality. However, our results hold independent of their inclusion.

[31] A permanent 100 basis point shift is simulated by assuming the sequence (..0, 0, 1, 0, 0, ..) for Δr_t^{us}.

3.2 VAR models

VAR models offer some advantages in evaluating the effects of monetary policy shocks. Rather than causing a permanent change in the interest rate, interest rate shocks may decay over time. Furthermore, the VAR endogenises the foreign interest rate, thus controlling for exchange rate movements triggered by the foreign monetary authority. Hence, the VAR permits experiments that more closely resemble those undertaken in theoretical analysis.

We estimate the VAR analysed in Eichenbaum and Evans [1995] and revisited by Faust and Rogers [2003] and Faust, Rogers, Swanson, and Wright [2003]. These studies focus on the vector of variables $[y^{us}\ \ p^{us}\ \ y^f\ \ r^f\ \ NBRX\ \ r\ \ s]'$, where y^{us} is industrial production in the US, p^{us} is the US CPI, y^f is foreign industrial production (price and production series are logs of index numbers) and $NBRX$ is the log ratio of non-borrowed reserves to total reserves (other variables are defined above). The VAR includes a full set of monthly dummies and each variable enters with 12 lags. Previous estimates of this 7-variable VAR have typically used 6 lags, but we find that this shorter lag structure leads to residual autocorrelation and heteroscedasticity. This problem is rectified by using the more general lag structure.[32] The inclusion of 12 or even 18 lags in VARs fitted using monthly data is not uncommon (e.g., Bernanke and Mihov, 1998).[33]

We follow Eichenbaum and Evans [1995] in assuming a recursive causal ordering: a variable responds contemporaneously only to those variables placed higher in the VAR. A Choleski decomposition is then used to retrieve the monetary policy shock for cases in which the domestic interest rate is either (a) the actual federal funds rate; or (b) the cumulated R&R shock measure. Note that the problems associated with recursive identification schemes discussed by Kim and Roubini [2000] and Faust and Rogers [2003] are likely less severe in VARs in which the R&R variable is used. For example, the assumption that monetary policy cannot respond to exchange rate shocks within a month

[32]The appendix provides a full set of residual diagnostic tests for the single equation and VAR models.
[33]In our robustness section, we discuss results based on VARs containing 6 lags.

is thought unrealistic, but as the R&R variable has been purged of endogenous and anticipated movements, it is more defensible.[34]

Before proceeding to the empirical results, there are two caveats. Firstly, the foreign interest rate measures that we employ have not been purged of endogenous and anticipated movements. This principally affects the response of exchange rates to overseas monetary policy shocks, which is not the focus of our analysis. However, to the extent that these components of foreign interest rates correlate with the R&R shock measure, the impulse responses associated with the latter may be affected and this point should be kept in mind throughout. Secondly, the R&R shock measure is a generated regressor, while the standard errors that we report do not account for this fact. However, as Pagan [1984] shows, hypothesis testing versus a null of no effect is still valid.[35]

4 Empirical results

In Figures 1 and 2, we present the response of bilateral US dollar exchange rates to 100 basis point increases in the actual federal funds rate (FF) and the cumulated R&R shock measure (RR). Figure 1 presents simulations based on the single equation models in which the interest rate increase is permanent, while Figure 2 graphs results for a temporary interest rate shock that dissipates according to the VAR dynamics. In Tables 1 and 2 we report the percentage deviation in the exchange rate (from its initial level) that has maximum absolute value over 12 and 48 month horizons.[36]

In Figure 1, the dollar appreciation is generally larger and faster following a change in RR. The response lines obtained for the dollar versus the Italian lira, the Japanese yen and the British pound following an RR innovation are everywhere below the corresponding

[34]In our robustness section, we discuss the consequences of changing the causal ordering assumed by Eichenbaum and Evans [1995].

[35]For comparison, we also calculated bootstrapped standard errors for the US-UK VAR, which do correct for the presence of a generated regressor. Specifically, we employed a residual bootstrap with 500 replications. The bootstrapped and delta-method based standard errors are virtually identical, indicating that hypothesis tests versus non-zero nulls are also likely valid.

[36]Positive numbers indicate appreciation and negative numbers depreciation.

lines for FF. The same is almost true of dollar rates against the French franc and the German mark. Only when measured against the Canadian dollar does the US$ exchange rate show a smaller response to RR than to FF. In Table 1, we see that in the first year the largest appreciation of the dollar following a change in RR always exceeds that obtained using FF, often by a factor of more than two. At the 48 month horizon, the maximum appreciation induced by RR is larger than that induced by FF in 5/6 cases (the Canadian dollar rate is the exception).

Turning to the VAR evidence, it can be seen that each monetary policy measure exerts a smaller impact on the exchange rate than in the single equation case, reflecting the fact that the shocks are temporary rather than permanent in this case. Differences in the effects of FF and RR are still clear. Excepting the case in which Canada is the foreign country, the US dollar exchange rate traces out a more pronounced U-shape following shocks to RR.[37] Table 2 shows that short-run exchange rate responses to FF are often perverse. For example, after a policy contraction, the dominant movement in the first year is depreciation in 3/6 cases. In contrast, the dominant effect following a shock to RR is appreciation in all cases. At the 48 month horizon, the maximum appreciation induced by RR exceeds that induced by FF in all 6 cases, by a factor of approximately 2 (US$/UK£, US$/FRF), 1.5 (US$/CN$, US$/GRM) and slightly more than one (US$/JP¥, US$/IT£).[38]

Table 2 shows that monetary policy exerts its maximum effect on the exchange rate with a significantly shorter lag when measured using RR rather than FF. The average time until the maximum appreciation is some 16.8 months less when RR is used in place of FF. This means that the forward premium anomaly, which refers to the propensity for exchange rate fluctuations to reinforce the excess returns implied by interest rate differentials, is much less persistent when RR is the monetary policy measure. However,

[37]The weak response of the US$/CN$ exchange rate appears to be due to Canadian interest rates adjusting rapidly to US interest rates, so that interest rate differentials and the scope for exchange rate adjustment are short-lived. The endogeneity of Canadian monetary policy with respect to US monetary policy is confirmed by other results reported later in this section.

[38]There is no marked improvement in the statistical significance of the impulse responses, likely reflecting RR's lower sample variation.

the absolute size of the forward premium anomaly increases in the short-run due to the larger exchange rate changes observed in response to RR. On average, the maximum effect of RR occurs after just 12.5 months, and after less than one year in 3/6 cases. Such lags in exchange rate adjustment are easier to explain in terms of adjustment costs, investor uncertainty, bounded rationality or learning than are the long lags obtained using the actual federal funds rate, which are at least 47 months in 3/6 cases. Such changes in the timing of the exchange rate's response demonstrate that the impulse responses to RR are not merely vertically stretched versions of the impulse responses to FF. This would occur if RR's variance is smaller than that of FF but impulse responses were generated by considering shocks of identical size (as opposed to variable-specific standard deviations). Instead, the estimated exchange rate responses reflect a genuinely stronger reaction to RR, especially during the first two years after a shock.

We also calculated forecast error variance decompositions (FEVDs) following shocks to both FF and RR. Although at the 12 month horizon RR explains a larger proportion of exchange rate fluctuations than does FF in 4/6 cases, the explanatory power of either monetary policy measure is small. For example, RR explains at most 7% of exchange rate fluctuations at the 12 month horizon (the statistics for FF are even smaller). Hence, while removing endogenous and anticipated movements in the federal funds rate leads to larger and faster effects of monetary policy on the exchange rate, exogenous movements in monetary policy are not large enough to explain a substantial proportion of exchange rate fluctuations. This is consistent with findings from previous studies (e.g., Faust and Rogers [2003]).[39]

4.1 Intermediate measures of monetary policy

In analysing the effect of monetary policy on output and prices, R&R consider two intermediate measures of monetary policy. DTARG is the change in the intended federal funds rate identified from the narrative records, while DRESIDF is the residual series

[39] Full FEVD results are available upon request.

obtained by regressing the change in the actual federal funds rate on the Greenbook forecasts. These variables can be used directly in the single equation models, while their cumulated values can be used in the VARs. The first variable (TARG) measures the intended stance of monetary policy, but is not orthogonal to forecasts of future economic conditions. The second (RESIDF) removes anticipated policy changes, but may include endogenous elements. In Figure 3, we present exchange rate responses to 100 basis point increases in TARG and RESIDF from the single equation models, while in Figure 4 we present the evidence from VARs. Tables 3 and 4 present summary information on maximum exchange rate responses at 12 and 48 month horizons.

The results indicate that neither the endogeneity or anticipatory biases alone explain differences in the effects of FF and RR. This is similar to the conclusions reached by R&R regarding output and prices. However, a closer inspection of the results reveals some intriguing regularities. The single equation models (Table 3) show that the appreciation induced by TARG over the 48 month horizon exceeds that induced by RESIDF in 5/6 cases. Similarly, the VAR models (Table 4) show that the appreciation of the dollar associated with TARG over the 48 month horizon is larger than that associated with RESIDF (in 5/6 cases, it is larger than that associated with RR). Hence, a tentative conclusion is that the correction for endogeneity embodied in TARG accounts for the greater long-term magnitude of the RR effects relative to the FF effects.

Correcting for anticipated policy movements seems to drive the speed of exchange rate adjustment. In the single equation models, the maximum exchange rate appreciation associated with RESIDF during the first 12 months generally occurs sooner than that associated with TARG. During the first 48 months, a maximum is always reached sooner using RESIDF. The results from VAR models indicate no clear pattern in response speeds at the 12 month horizon. Over 48 months, the maximum appreciation occurs with a shorter lag when using RESIDF in all cases except that in which Canada is the foreign country.

4.2 Price and output responses

The responses of the price level and output to FF and RR shocks are evaluated by R&R, but there are at least two reasons for revisiting the subject here. Firstly, most of the evidence presented by R&R is based on single equation models. When VARs are used, they include only three variables (output, prices and interest rates), and incorporate 36 lags, many more than the number usually considered in the literature. The open economy VARs considered here are richer and more typical of the literature. Secondly, and more importantly, the open economy VARs may cast some light on the channels through which exogenous monetary policy shocks influence prices and output.[40]

In Figure 5, we present impulse response functions for the US CPI.[41] The maximum price effects obtained using both FF and RR are smaller than those reported by R&R, reflecting the fact that richer VAR specifications condition out many of the factors underpinning a high unconditional correlation between RR and the CPI (a similar result is obtained for the output responses below). The important feature of the results is the impact of RR relative to that of FF. A positive FF shock first leads to a persistent increase in consumer prices. This is the price puzzle documented by Sims [1992]. In contrast, any price puzzle associated with RR is small and is always eliminated within a few months. The expected decline in the CPI then begins within a year. After 24 months (the time at which downward price adjustment begins in the R&R analysis), the reduction in prices is significant at the 5% level and is between one half and two thirds the total change observed after four years. Hence, in the open economy VAR, using an exogenous measure of monetary policy not only ensures that a prolonged price puzzle is avoided, but also greatly reduces the delay in the deflationary effects of contractionary monetary policy. This finding is important because it suggests that theoretical models intended to explain delays in the deflationary effects of monetary contractions (e.g., Barth III and Ramey,

[40]See Frankel and Chinn [1995] and Guender and McCaw [2000] for theoretical models in which the exchange rate influences price and output adjustment.

[41]R&R employ the US producer price index, but show that their results are robust to the use of a consumer expenditure deflator, which is very similar to the CPI.

2002) need only generate delays of 6-12 months rather than 24 months.

A possible interpretation is that pass-through from exchange rates to consumer prices is a channel through which monetary policy contractions reduce prices.[42] The exchange rate channel is not explicitly modelled in Romer and Romer's empirical application. When monetary policy-induced exchange rate movements are correlated with other sources of exchange rate fluctuations, such as those due to foreign interest rates and foreign output, the importance of the exchange rate channel may be understated. There is omitted variable bias, leading to delayed US price adjustment in the VAR. By including the exchange rate in the VAR system, the exchange rate's dynamic response is disentangled from the other variables in the VAR, potentially accounting for the quicker price response observed in the open economy VAR.

Figure 6 presents impulse response functions for US industrial production. Except for the VAR versus Canada, the maximum effect of RR exceeds that of FF by a factor ranging from more than 2 (France) to just 1.1 (Italy/Germany). These findings confirm the conclusions drawn by R&R from a 3-variable VAR with 36 lags. The most striking feature of the results in Figure 6 is the increased speed with which monetary policy takes effect when measured using RR. Cochrane [2004] argues that the 24 month delay in the maximum effect of interest rates on output estimated by R&R is problematic because theoretical models are generally unable to explain such lags. In the open economy VARs that we estimate, the mean delay in the maximum effect of RR on output is just 12.3 months, less than half the equivalent statistic for FF, and less than the lags estimated by R&R. Furthermore, following an increase in RR, output always returns to equilibrium within 3 years, and sometimes within 2 years, again pointing to much faster adjustment. As in the case of prices, these results may reflect the role of the exchange rate in the monetary policy transmission mechanism.

In Figure 7, we present impulse responses for the CPI following shocks to TARG

[42]The degree of such pass-through likely varies across countries, reflecting differences in pricing strategies by foreign exporters in their respective markets, as well as differences in the extent to which each of the foreign countries trades with the US.

and RESIDF. The effects of TARG resemble those of FF whilst the effects of RESIDF resemble those of RR. Following a shock to RESIDF, a sustained fall in the CPI starts after less than 12 months in most cases, matching the effects of RR. In contrast, TARG yields a persistent price puzzle similar to that associated with FF. However, the maximum effect of RESIDF on the CPI is two to three times smaller than the maximum effect of RR, suggesting that the correction for endogenous policy movements associated with TARG is important in explaining the size of the final effect induced by RR. Figure 8 provides impulse response functions for output following shocks to TARG and RESIDF. There are three points to note. Firstly, the unexpected increase in output following an increase in interest rates is statistically significant when TARG is used but is small and insignificant when RESIDF is used. Secondly, the maximum effect of RESIDF on industrial production always occurs with a shorter lag than the maximum effect of TARG. Thirdly, in 5/6 cases the impact of TARG on industrial production eventually exceeds that of RESIDF. Hence, as was true of exchange rate adjustment, price and output adjustment are consistent with the view that corrections embodied in RESIDF account for the increased speed with which RR takes effect, while the corrections embodied in TARG account for the greater magnitude of the effects of RR.

4.3 Foreign adjustment to US monetary policy shocks

In Figures 9 and 10, we present the response of foreign interest rates and foreign industrial production to FF and RR. Foreign interest rates show a stronger response to movements in RR in 4/6 cases and the differences involved are large, for example in the first year the response of French interest rates to RR is more than three times the response to FF. Exceptions are found for Italian interest rates, which respond in equal measure to FF and RR, and for UK interest rates, which appear more closely linked to FF.[43] However,

[43] The UK evidence appears to depend on interest rate movements through the early 1980s. Fitting a model with a sample that begins in 1982:6 yields an impulse response for UK interest rates that is positive for the first 7 months following a shock to RR. This is marginally bigger than those associated with FF.

the broad picture is that foreign interest rates respond more strongly to RR than to FF. Purging the data of endogenous and anticipated interest rate changes suggests a stronger international propagation of US monetary policy.

It is interesting to note that the maximum response of foreign interest rates to RR always occurs within 12 months (and often within 6 months), which is a shorter lag than that observed for the maximum exchange rate response. This suggests that initial movements in foreign interest rates are a direct response to US monetary policy, as opposed to a response to the depreciation of the exchange rate (from a foreign country perspective).

The behaviour of foreign interest rates is relevant to understanding exchange rate dynamics. Recall that the US$/CN$ exchange rate is the least responsive to monetary policy. One reason for this appears to be the endogeneity of Canadian interest rates, which move more than one-for-one with innovations to RR. Interest rate differentials between the US and Canada are relatively small and short-lived. Therefore, the exchange rate between these two countries adjusts very little in response to monetary policy.[44] A further striking feature of the foreign interest rate response to RR is that the lines always turn negative at horizons of more than one year. Such periods of relatively low foreign interest rates may contribute to the larger appreciations of the US dollar observed following shocks to RR. However, it is not clear that this is a central channel in exchange rate adjustment. The largest reduction in foreign interest rates occurs in Canada, but it is against the Canadian dollar that the US dollar appreciates the least.[45]

The impulse responses for foreign output indicate that in 5/6 cases, RR induces larger foreign recessions than FF. This suggests that the negative effect on foreign output from interest rate pass-through dominates the positive effect from increased competitiveness of foreign exports following appreciation of the US dollar. The recession is largest in Canada, the country that initially raises interest rates most and sees its currency depreciate least.

[44]Interest rate pass-through is also large in the case of France, but takes much longer than in the Canadian case.

[45]A richer foreign interest rate reaction function specification (e.g., including foreign prices) might clarify the channel.

The tendency for Canadian and UK output to end up significantly above zero after four years is due to the negative effect of RR on Canadian and UK interest rates at long horizons.

Finally, in Figures 11 and 12, we present impulse response functions for foreign interest rates and foreign output following shocks to TARG and RESIDF. Both variables appear to respond more strongly to changes in TARG, the intended level of interest rates, than to RESIDF, thus matching the findings for US macroeconomic variables. However, there is no clear evidence that responses to RESIDF are faster than those to TARG, suggesting that anticipatory bias is not crucial in explaining the weak international transmission of FF shocks. One explanation is that foreign monetary authorities respond to anticipated movements in US monetary policy after they have been implemented rather than before. The US may act as a leader in setting world interest rates, with foreign monetary authorities following.[46]

5 Robustness

We now investigate the robustness of our results. The first issue that we address is whether or not the main findings hold in VARs that include further controls. Sims [1992] notes that increases in commodity prices often eventually cause inflation episodes. Thus, a commodity price index can act as an 'information variable' which controls for any associated preemptive moves in policy rates. The extended VAR that we estimate includes the log level of the commodity price index from the IMF's International Financial Statistics and used by R&R in their single equation robustness analysis. The commodity price term is included as the fourth variable in the VAR – commodity prices may respond to US industrial production and US consumer prices contemporaneously, but only respond to lagged financial market variables. This ordering reflects the approach taken by Kim [2001]. In Figure 13, we present impulse responses for bilateral dollar exchange rates

[46]Chinn and Frankel [2003] show that US interest rates drive European interest rates, but report only weak evidence of causation in the opposite direction.

following orthogonal innovations to FF and RR. The maximum effect of RR on bilateral dollar exchange rates always arises more quickly than that of FF. The difference in the magnitude of the FF and RR effects is generally smaller than those obtained from the baseline models, particularly when Germany is the foreign country. However the differences remain large in the other cases. For example, when the UK is the overseas country the dollar appreciation in response to RR is 2.5 times the appreciation in response to FF.

In Figure 14, we present CPI responses for the extended VAR models. Controlling for commodity prices provides only a very partial resolution of the price puzzle associated with FF. Furthermore, the contrast with the reductions in the CPI in response to innovations in RR remains striking – the latter are large, fast and highly significant. Figure 15 presents the new impulse responses for US output. The maximum effect of RR occurs with a much shorter delay than the maximum effect of FF, and the magnitude of the RR effect relative to the FF effect is actually larger than in the baseline VARs.

In Figures 16 and 17, we present impulse responses for foreign interest rates and foreign industrial production respectively. The results are largely similar to those obtained from the baseline VARs (Figures 9 and 10). The response of Italian interest rates to RR innovations is slightly smaller than in Figure 9 and the UK results remain puzzling. However, interest rate pass-through exceeds unity for Canada and France and is greater than 0.5 for Germany and Japan. These results contrast with Kim's [2001] finding that only Canadian interest rates respond to the US federal funds rate when commodity prices are held constant.

A second extension of the information set in the baseline VAR that we considered was the addition of a time trend to each equation. Giordani [2004] shows that the removal of the underlying trend from variables such as output alters the results from VARs, such that the price puzzle disappears. The inclusion of a time trend also absorbs much of the non-stationarity in the data and as such represents an interesting robustness check. Full results from this experiment are available upon request. The larger and faster effects of RR relative to FF generally remain for all variables. In the VAR in which Germany is the foreign country, the difference in the speed of exchange rate responses narrows somewhat, although the relative size of the maximum responses increases. The price puzzle associated with FF typically disappears, except in those cases in which Canada and the UK are the foreign country. This reflects the Giordani [2004] result. In all cases however, the greater speed and magnitude of the RR effect on prices remain intact.

5.1 An alternative VAR ordering

Faust and Rogers [2003] criticise the recursive ordering used by Eichenbaum and Evans because it assumes that overseas monetary authorities do not respond contemporaneously to Federal Reserve decisions. To judge the sensitivity of our results to Eichenbaum and Evans' ordering, we also estimated VARs based on the vector $[y^{us}\ p^{us}\ y^f\ r\ r^f\ NBRX\ s]'$, allowing for a contemporaneous effect of US interest rates on foreign interest rates. To save space, we simply note the key findings from the impulse responses.[47] The size of the responses of exchange rates and other macro variables to RR shocks remain intact under the alternative ordering, and if anything are slightly larger than those documented in section 4. The lags in the maximum effects of monetary policy increase slightly, but remain shorter than those obtained using the actual federal funds rate.

We also experimented with the ordering $[r\ y^{us}\ p^{us}\ y^f\ r^f\ NBRX\ s]'$. This assumes that US interest rates are the least endogenous variable in the system, which is true if one accepts that the R&R procedure yields truly exogenous monetary policy shocks, and allows for a non-zero contemporaneous effect of monetary policy on each of the other variables. The results are similar to those just described – magnitudes increase but there is some small reduction in speed. Finally, we obtained impulse responses through not imposing any recursive ordering and simply shocking the estimated reduced form. The key features of the responses to RR are virtually unchanged, reflecting the fact that this variable represents exogenous monetary policy shocks identified outside the model. The responses to FF show some changes in shape and magnitude, but the contrast with the

[47] Full results for all experiments reported in this sub-section are available upon request.

RR responses in terms of both and speed and magnitude are even more striking than in the baseline case.

5.2 An alternative lag structure

The 7-variable Eichenbaum and Evans VAR is often estimated using 6 lags of monthly data rather than 12. In section 3, we noted that 12 lags are required to remove evidence of residual serial correlation and heteroscedasticity. However, we checked the robustness of our results to using 6 lags.[48] The exchange rate responses to RR remain faster than those to FF in all six cases. In terms of magnitude, we find that at the 12 month horizon the appreciation of the US$ following a policy contraction is always larger when RR is the monetary policy measure. At the 48 month horizon, the maximum appreciation associated with RR exceeds that associated with FF in just three cases: Canada, Japan and the UK. For France, Germany and Italy, the appreciation associated with FF is larger. Hence, our findings concerning the magnitude of exchange rate movements are less robust than those relating to their speed. However, we stress that our core results are associated with the more general lag structure and that the restricted lag structure induces serial correlation and heteroscedasticity in the residuals.[49]

5.3 Sub-sample stability

The final robustness test is based on sub-sample regressions. R&R note that during the early stages of Volcker's chairmanship of the Federal Reserve, policy was often implemented by targeting quantities (the level of non-borrowed reserves) rather than the federal funds rate. This experiment lasted until June 1981. Thus, we fit the baseline VARs for the period 1982:6-1996:12, so that no observations prior to 1981:7 are used in the estimation. This sub-sample also excludes the turbulent years of the 1970s and a major outlier in RR in April 1980. The second sub-sample for which we estimate the

[48] Full results are available upon request.

[49] Our findings concerning the speed and magnitude of price and output adjustment in the US, and foreign interest rate and output adjustment, are robust to varying the lag structure.

VARs begins at the same time as the core sample and ends in 1992:8. This leads to the exclusion of the exchange rate crises that saw the pound and lira drop out of the European Exchange Rate Mechanism (ERM) and the bands for the French franc against the German mark widen.

The key points follow.[50] Firstly, both monetary policy measures generate exchange rate responses which are larger, though not necessarily faster, in the post-1982:6 period than the pre-1992:8 period.[51] Nevertheless, exchange rate responses pre-1992:8 are generally at least as big as the full sample responses and the main point is that the evidence for larger responses to RR than to FF is observed in both sub-samples. The same is generally true of the greater speed of RR effects, though the differences are less pronounced than in the full sample for some countries.

Secondly, turning to the results for other macroeconomic variables, US output responses to RR are sometimes perverse using the post-1982:6 sample – the dominant response to a policy contraction is higher, rather than lower, output. In contrast, the pre-1992:8 sample always suggests large recessions in the US following policy contractions, and this sub-period seems to drive the full sample results suggesting faster and larger US output effects of RR relative to FF. The use of RR in place of FF resolves the price puzzle in each of the sub-samples, though the results are stronger for the pre-1992:8 period. Overall, while the results exhibit some temporal instability, there are no systematic changes and our main findings remain intact.

6 Conclusion

We have argued that endogenous and anticipated movements in the federal funds rate lead to downward bias in the estimated effect of monetary policy on the exchange rate, potentially explaining the extremely long delays and small magnitudes in the response

[50]Full results available upon request.

[51]E.g., in the former period the maximum exchange rate response to RR exceeds 10% when Japan is the foreign country in the VAR. This is three times the full sample response.

of bilateral dollar exchange rates to movements in US interest rates that have often been documented in previous work. To investigate this issue, we used both single equation and VAR models to estimate the response of six bilateral dollar exchange rates to a new measure of monetary policy shocks derived by Romer and Romer [2004]. Their monetary policy measure uses evidence from narrative sources to isolate interest rate movements that are due to Federal Reserve intentions. These are then orthogonalised with respect to the Federal Reserve's forecasts, generating exogenous monetary policy shocks that more closely match the theoretical definition of a shock. The results demonstrate that exchange rate adjustment is generally larger and faster than that associated with the actual federal funds rate, suggesting that monetary policy exerts a more powerful effect on exchange rates than has previously been documented. Furthermore, our results from open economy VARs cast new light on the effects of exogenous monetary policy on other macroeconomic variables. The reductions in output and prices achieved through a monetary contraction occur more rapidly than in the closed economy models considered by Romer and Romer [2004]. This suggests that explicit modelling of open economy aspects of the monetary transmission mechanism, such as the deflationary effects of exchange rate appreciation, is crucial in accurately identifying the timing and magnitude of the impact of monetary policy on the US economy.

The results are robust along multiple dimensions. We believe that they are important for the future direction of theoretical and empirical research in macroeconomics. Models incorporating sluggishness via methods such as adjustment costs, investor uncertainty, bounded rationality and/or learning, only need to explain delays in the exchange rate response on the order of 12 months, rather than the 24-36 months suggested in past work. Similarly, our findings concerning price and output adjustment in the United States suggest that recent theoretical work intended to explain the price puzzle (e.g., Barth III and Ramey, 2002), and the inertia in output and inflation (e.g., Christiano et al., 2005), do not have to generate the extremely long lags previously believed. Our impulse responses also implicitly bound plausible parameter values that may be used in calibration exercises. For future empirical work, the striking results obtained by Romer and Romer [2004] and the parallel open economy results presented here indicate that the use of narrative evidence and central bank forecasts in deriving monetary policy measures is likely a fruitful exercise for other countries where researchers wish to estimate the true effect of monetary policy upon the economy.

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Figure 1:

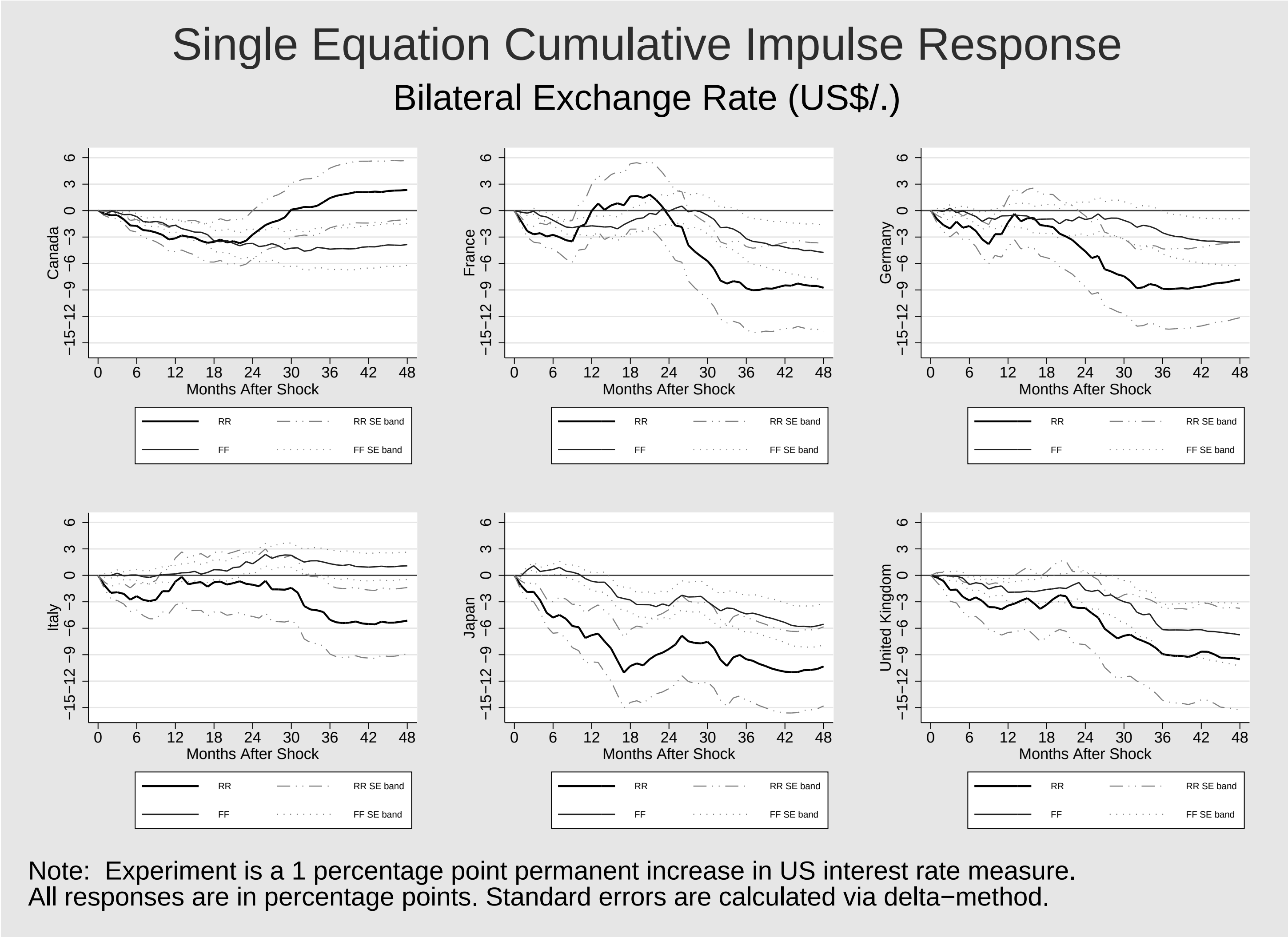

Single Equation Cumulative Impulse Response
Bilateral Exchange Rate (US$/.)
Canada
France
Germany
Italy
Japan
United Kingdom
−15 −12 −9 −6 −3 0 3 6
0 6 12 18 24 30 36 42 48
Months After Shock
RR
RR SE band
FF
FF SE band
Note: Experiment is a 1 percentage point permanent increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 2:

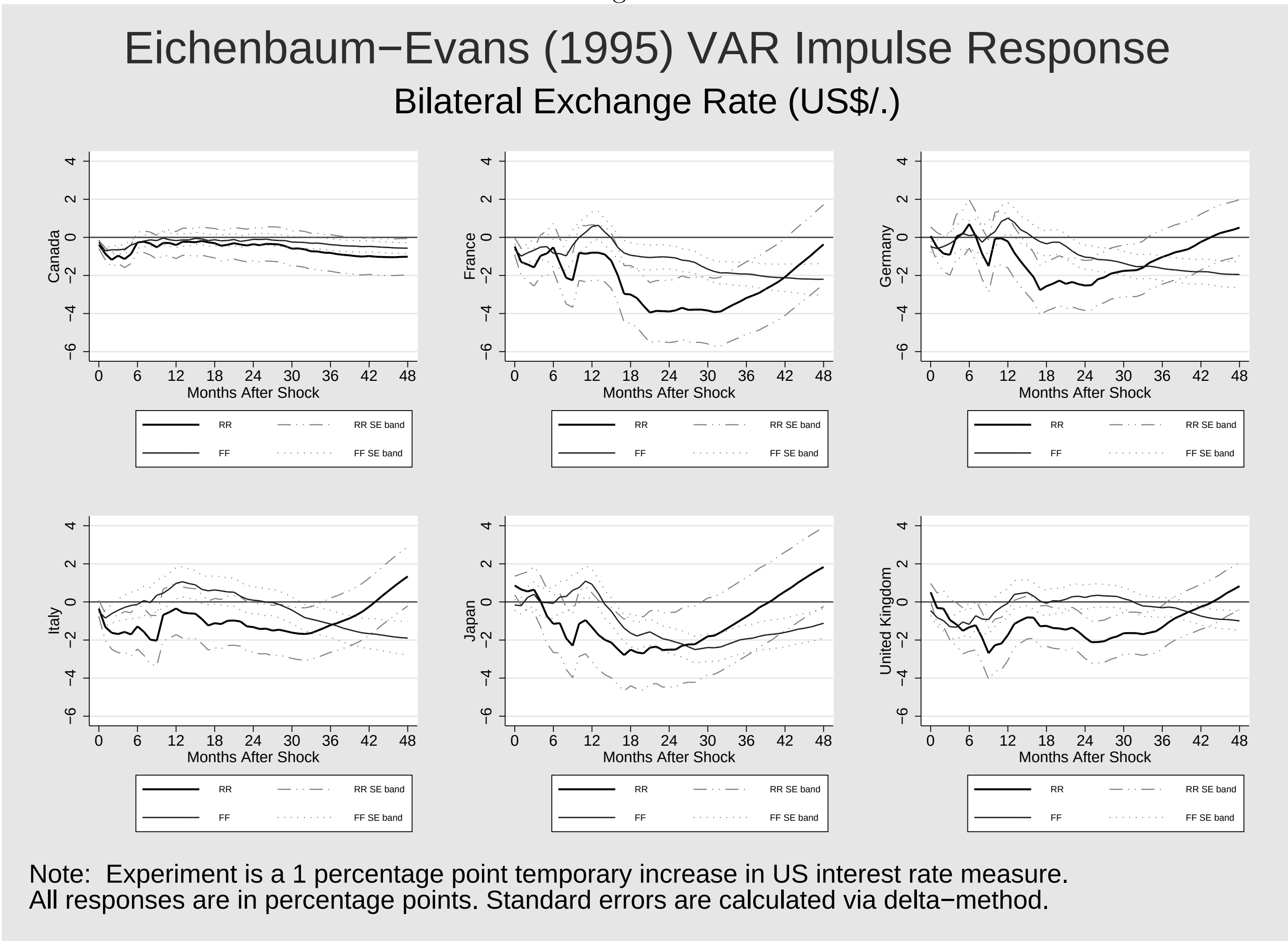
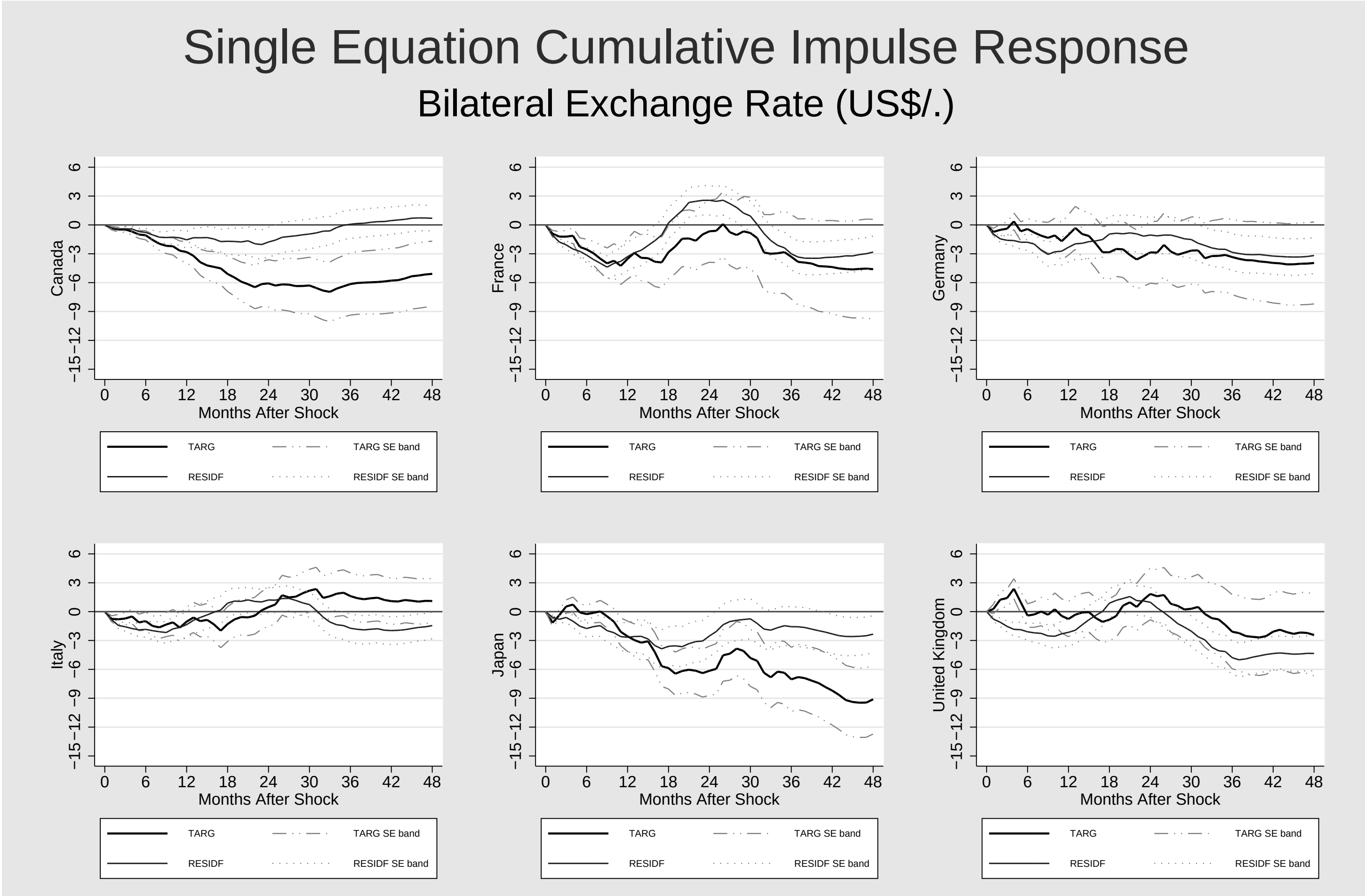
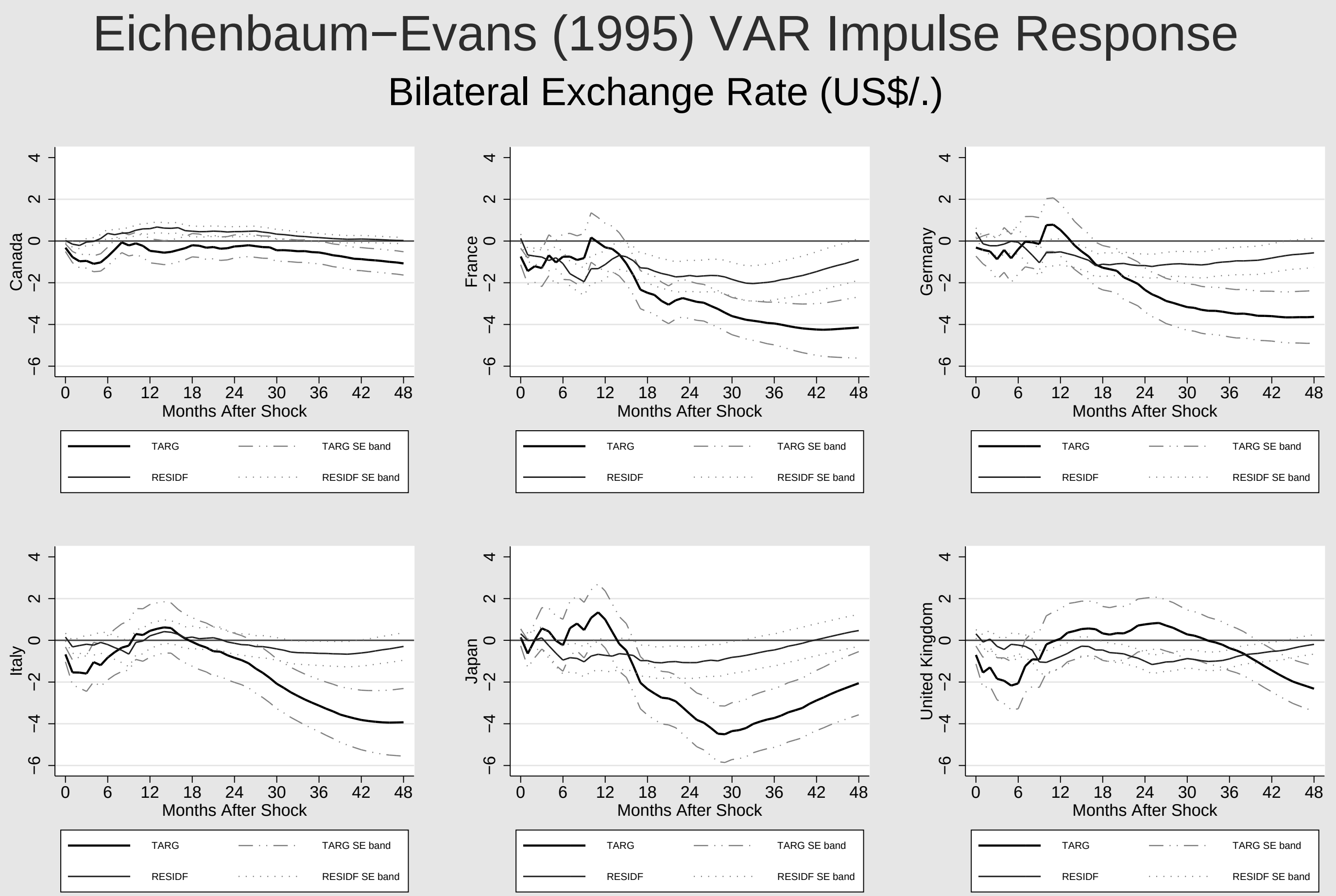

Eichenbaum−Evans (1995) VAR Impulse Response
Bilateral Exchange Rate (US$/.)
Canada
France
Germany
Italy
Japan
United Kingdom
Months After Shock
RR
RR SE band
FF
FF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 3:



Note: Experiment is a 1 percentage point permanent increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 4:



Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 5:

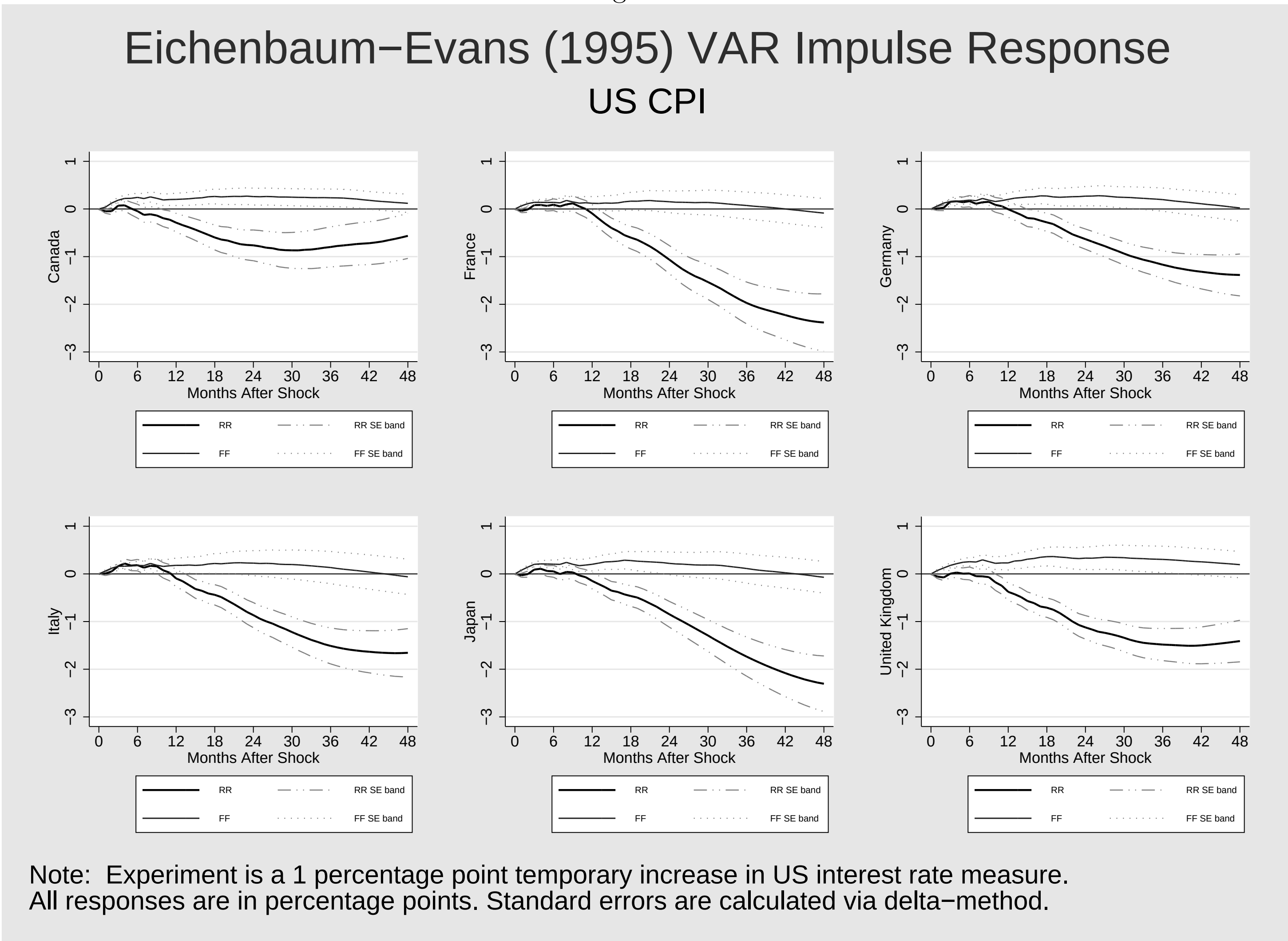

Eichenbaum−Evans (1995) VAR Impulse Response
US CPI
Canada
France
Germany
Italy
Japan
United Kingdom
Months After Shock
RR
FF
RR SE band
FF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 6:

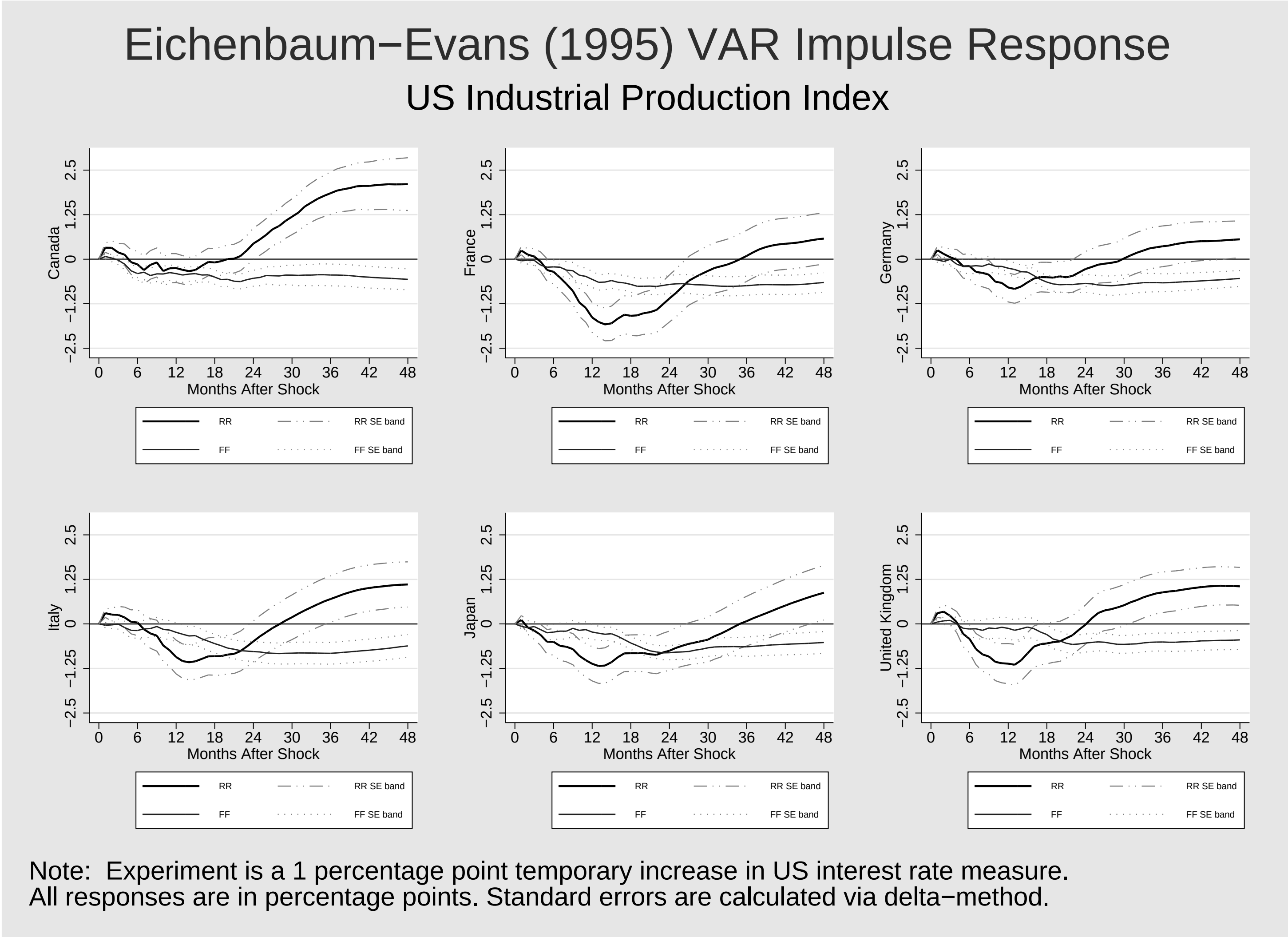
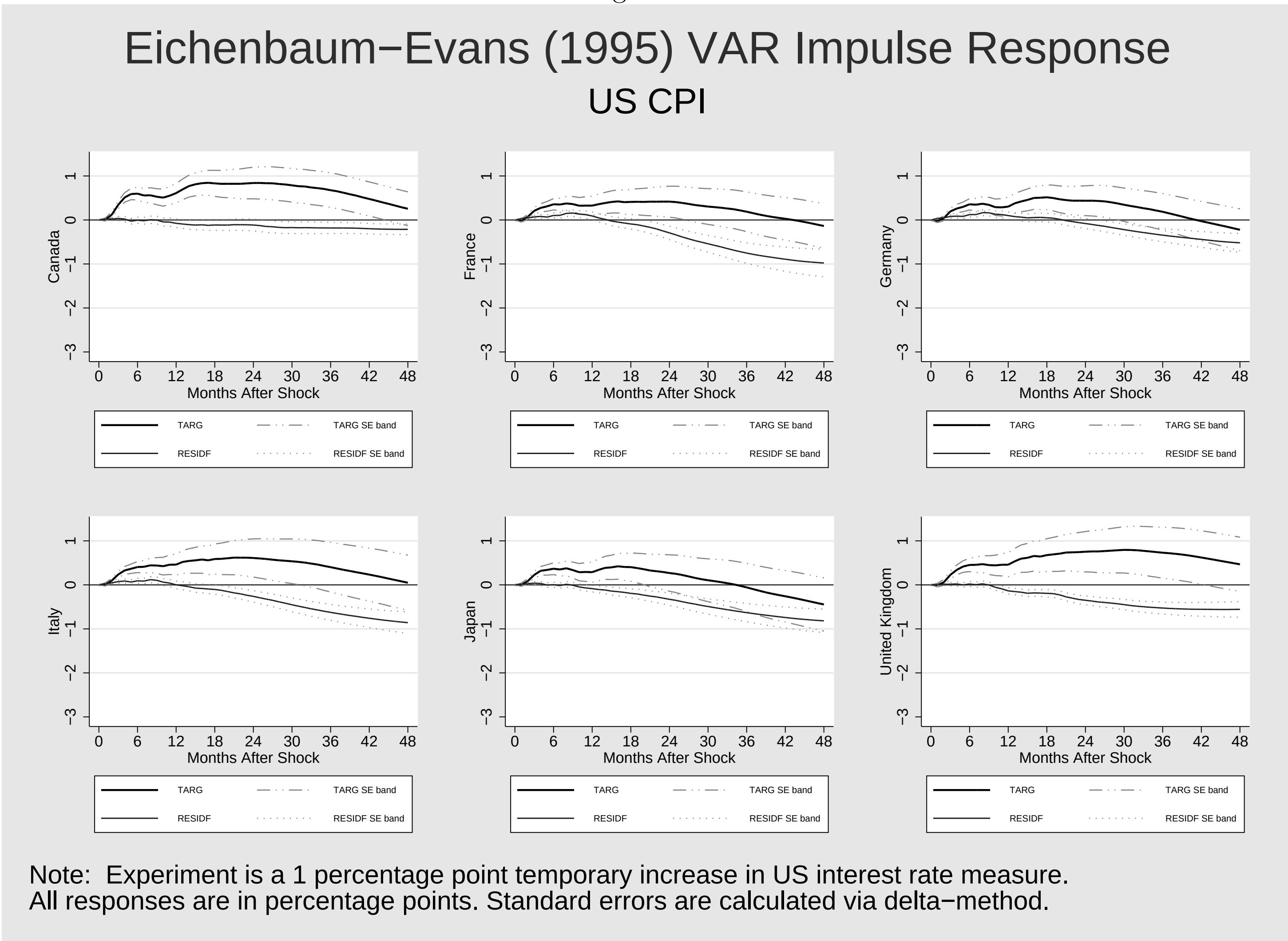

Eichenbaum−Evans (1995) VAR Impulse Response
US Industrial Production Index
Canada
France
Germany
Italy
Japan
United Kingdom
−2.5 −1.25 0 1.25 2.5
0 6 12 18 24 30 36 42 48
Months After Shock
RR
RR SE band
FF
FF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 7:



Eichenbaum−Evans (1995) VAR Impulse Response
US CPI
Canada
France
Germany
Italy
Japan
United Kingdom
Months After Shock
0 6 12 18 24 30 36 42 48
−3 −2 −1 0 1
TARG
TARG SE band
RESIDF
RESIDF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 8:

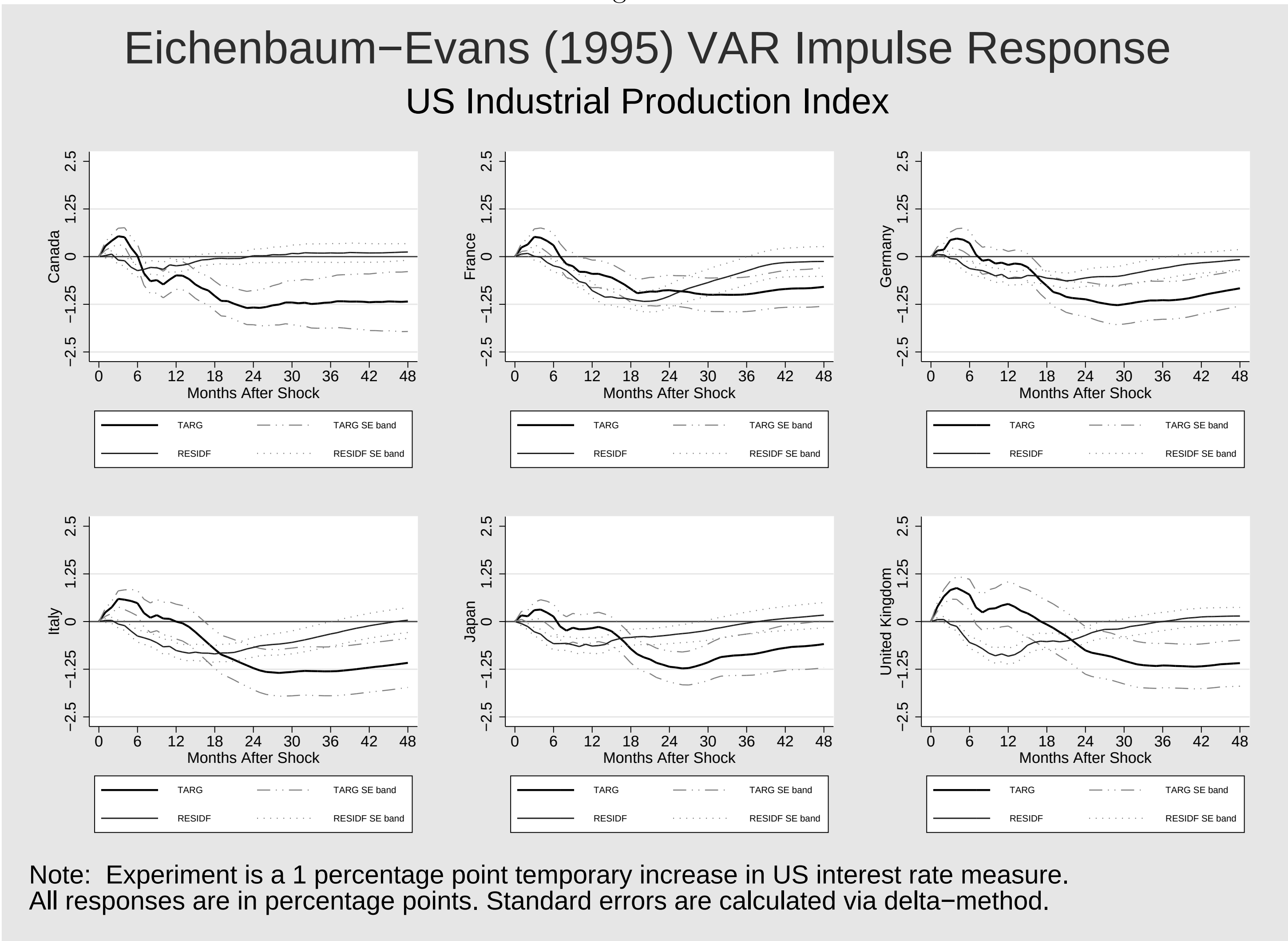
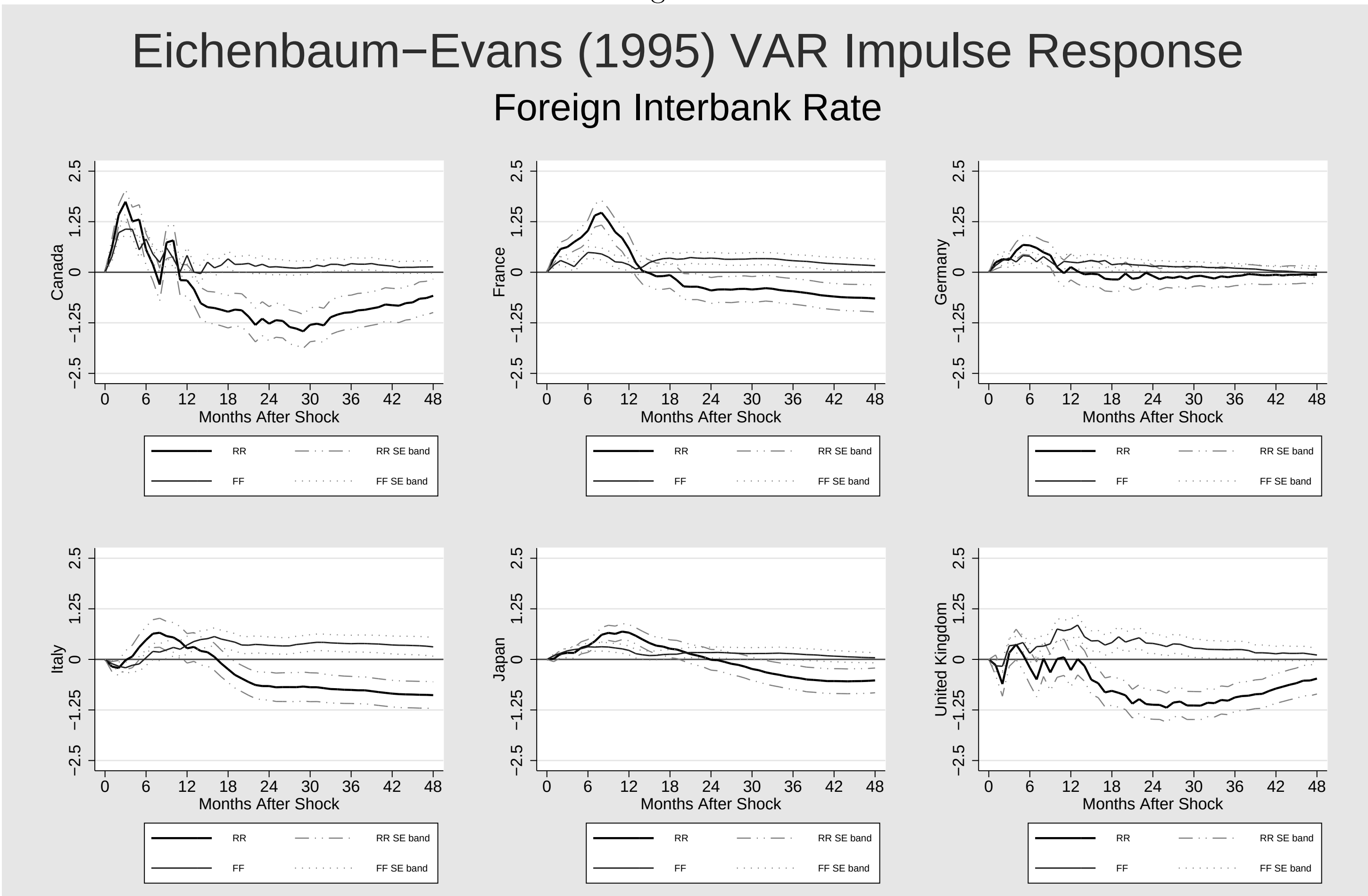

Eichenbaum−Evans (1995) VAR Impulse Response
US Industrial Production Index
Canada
France
Germany
Italy
Japan
United Kingdom
−2.5
−1.25
0
1.25
2.5
0 6 12 18 24 30 36 42 48
Months After Shock
TARG
TARG SE band
RESIDF
RESIDF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 9:



Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 10:

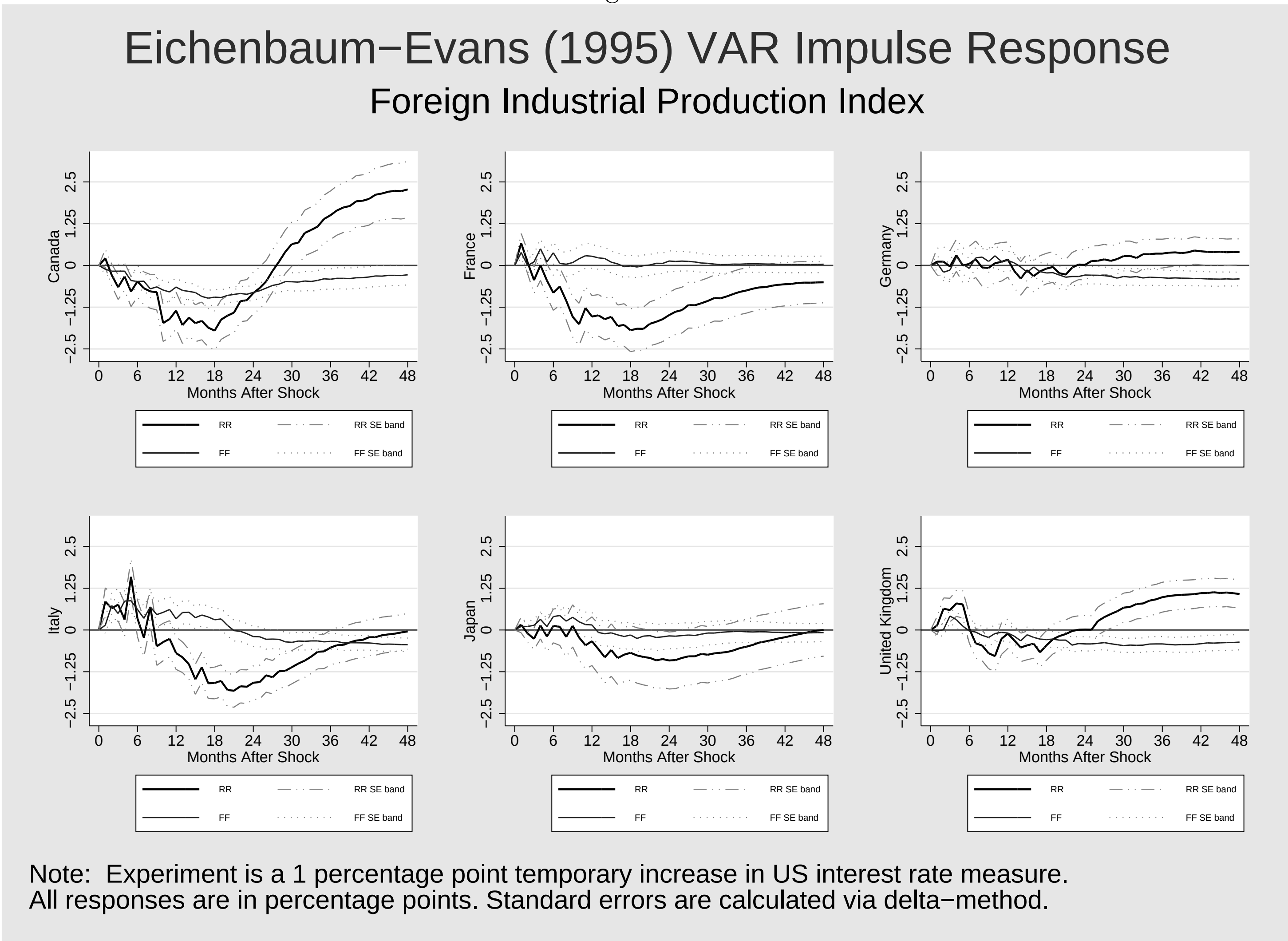
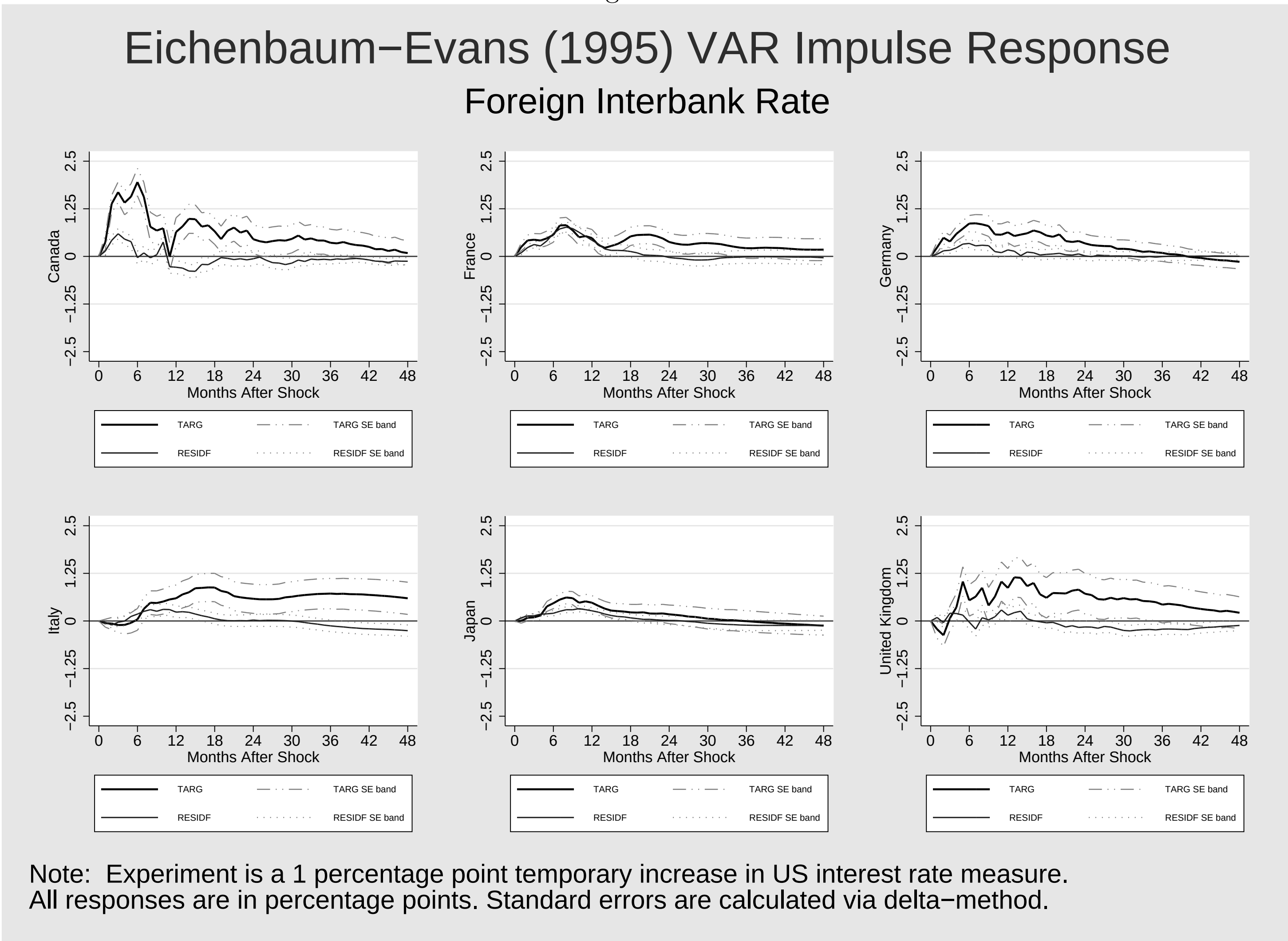
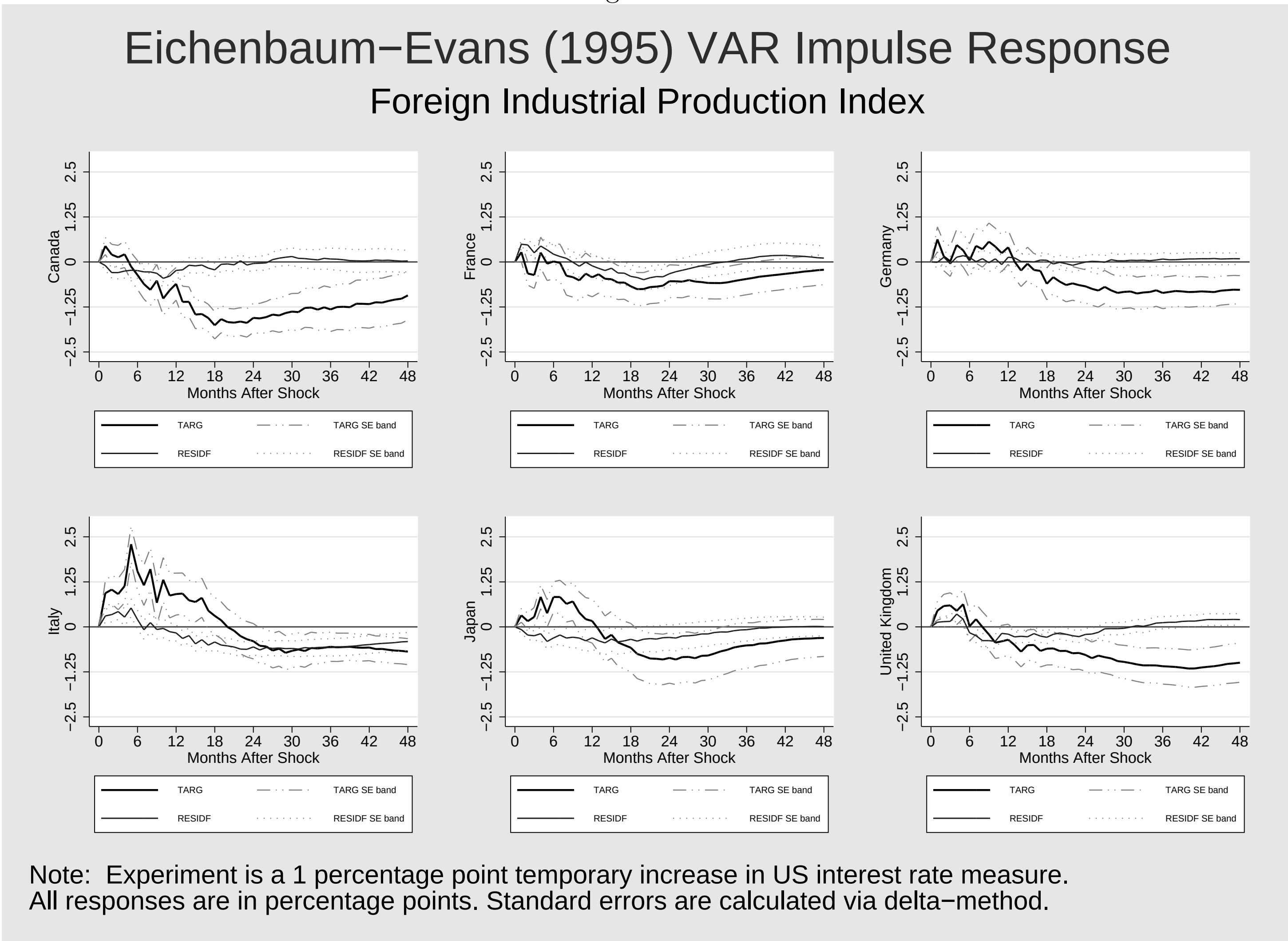

Eichenbaum−Evans (1995) VAR Impulse Response
Foreign Industrial Production Index
Canada
France
Germany
Italy
Japan
United Kingdom
−2.5
−1.25
0
1.25
2.5
0 6 12 18 24 30 36 42 48
Months After Shock
RR
RR SE band
FF
FF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 11:



Eichenbaum−Evans (1995) VAR Impulse Response
Foreign Interbank Rate
Canada
France
Germany
Italy
Japan
United Kingdom
−2.5
−1.25
0
1.25
2.5
0 6 12 18 24 30 36 42 48
Months After Shock
TARG
TARG SE band
RESIDF
RESIDF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 12:



Eichenbaum−Evans (1995) VAR Impulse Response
Foreign Industrial Production Index
Canada
France
Germany
Italy
Japan
United Kingdom
−2.5
−1.25
0
1.25
2.5
0 6 12 18 24 30 36 42 48
Months After Shock
TARG
TARG SE band
RESIDF
RESIDF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.

Figure 13:

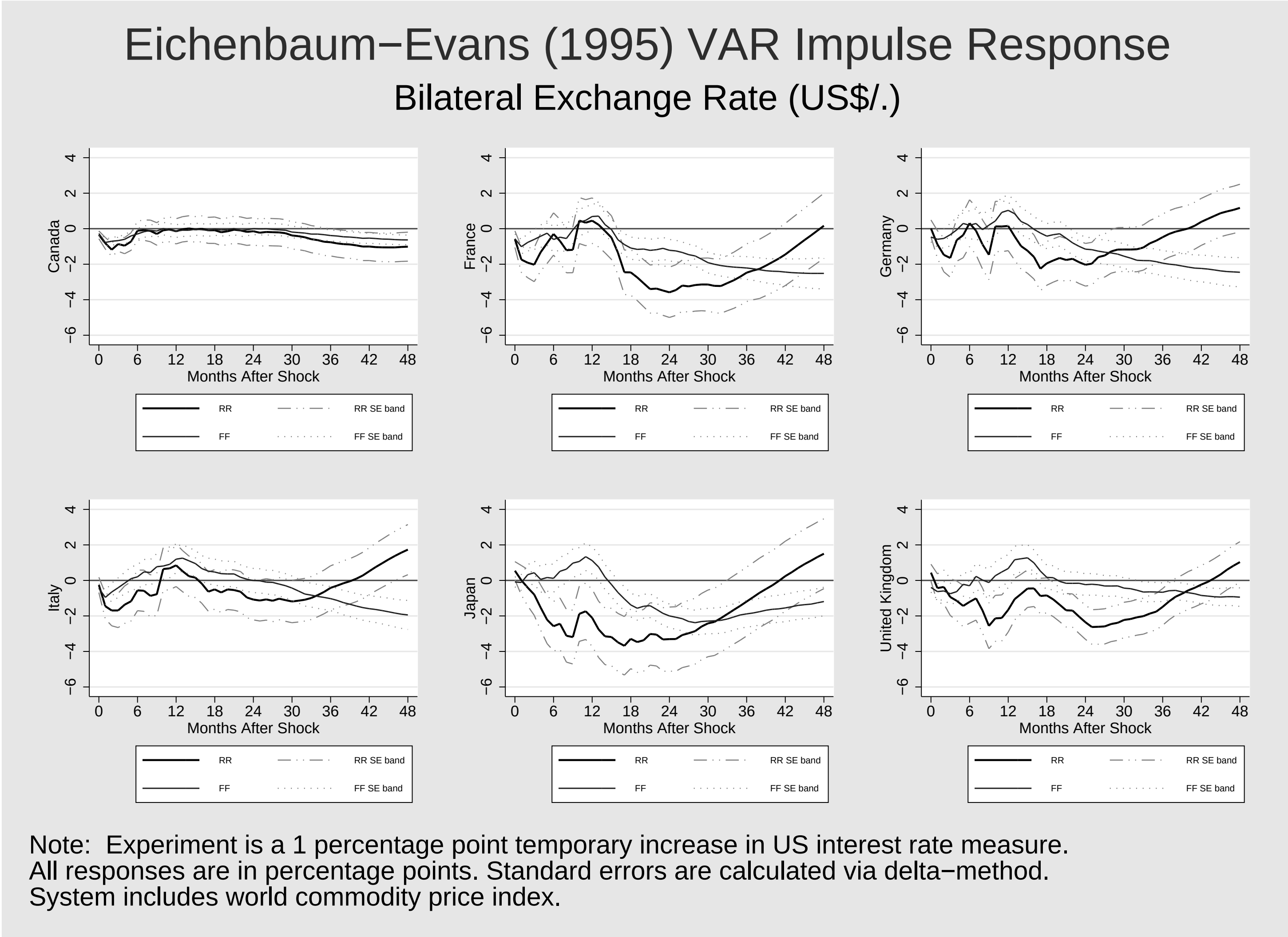
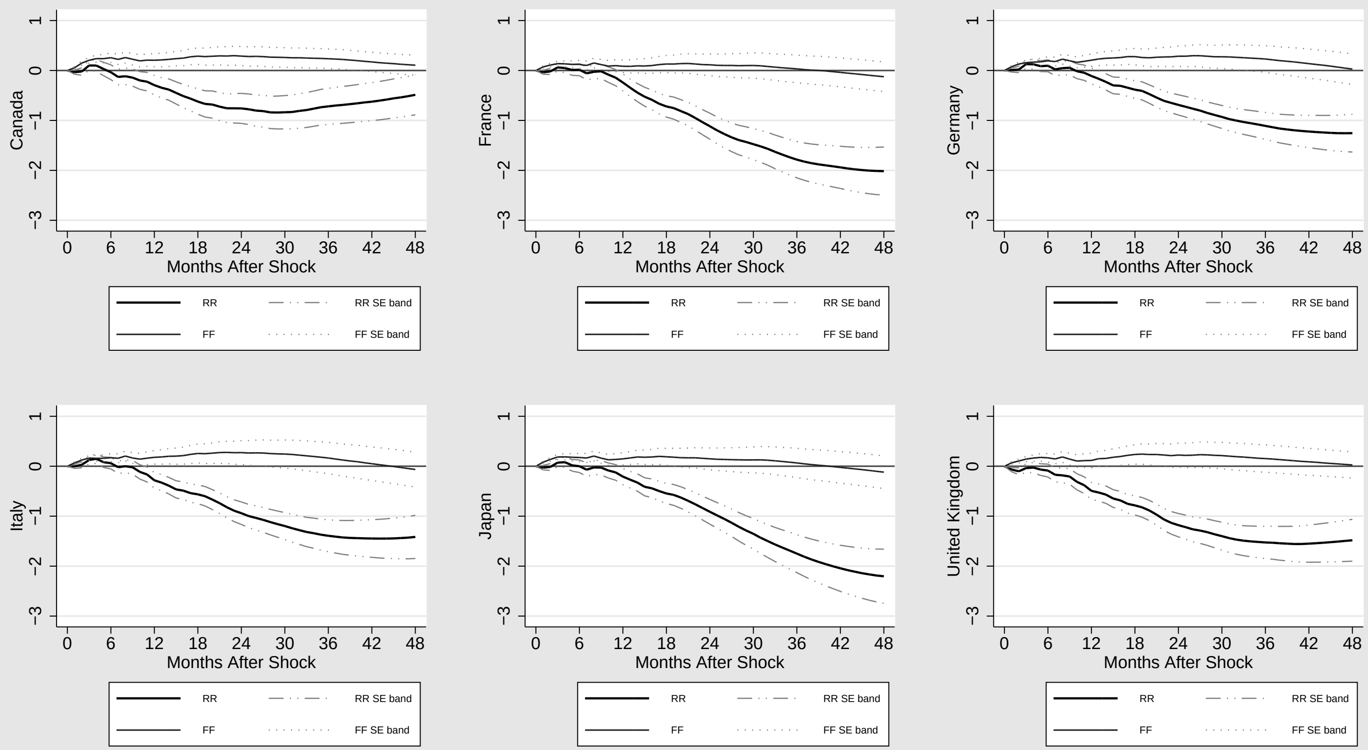

Eichenbaum−Evans (1995) VAR Impulse Response
Bilateral Exchange Rate (US$/.)
Canada
France
Germany
Italy
Japan
United Kingdom
−6 −4 −2 0 2 4
0 6 12 18 24 30 36 42 48
Months After Shock
RR
RR SE band
FF
FF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.
System includes world commodity price index.

Figure 14:

Eichenbaum−Evans (1995) VAR Impulse Response

US CPI

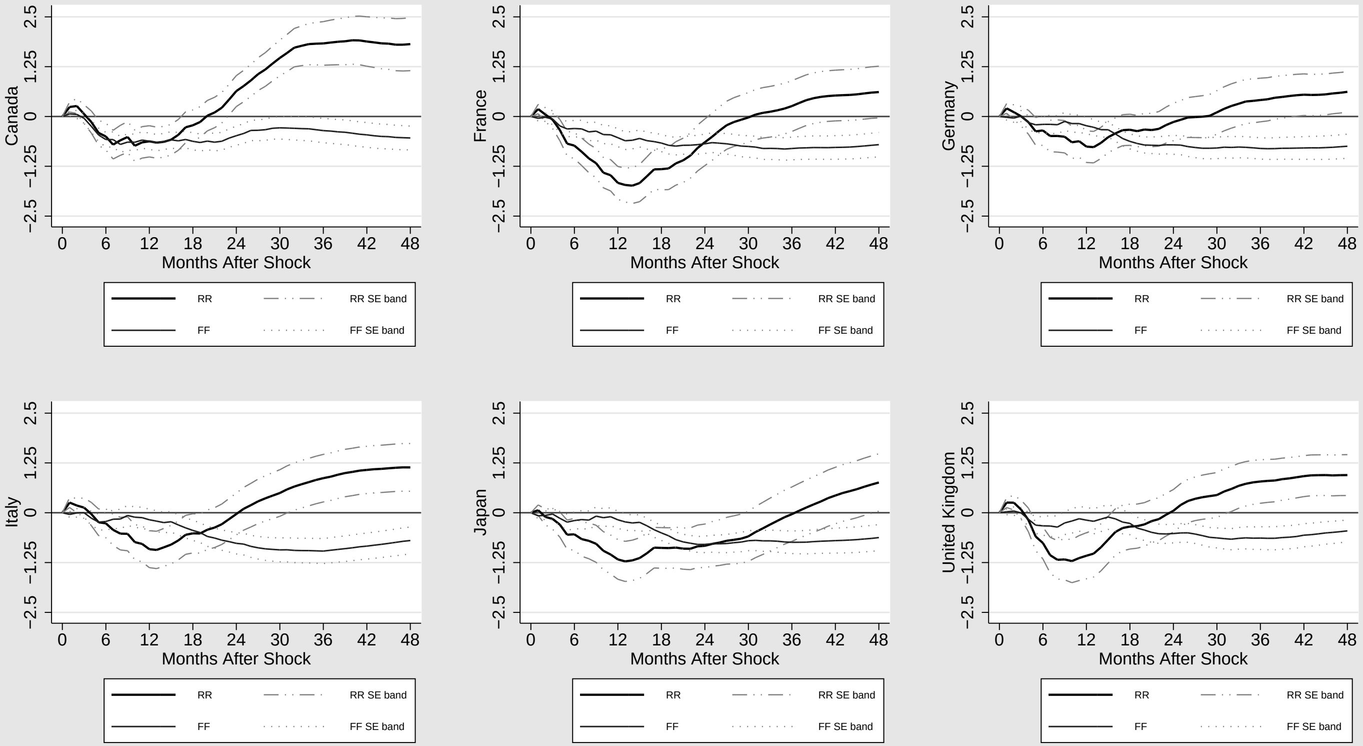


Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.
System includes world commodity price index.

Figure 15:

Eichenbaum−Evans (1995) VAR Impulse Response

US Industrial Production Index



Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.
System includes world commodity price index.

Figure 16:

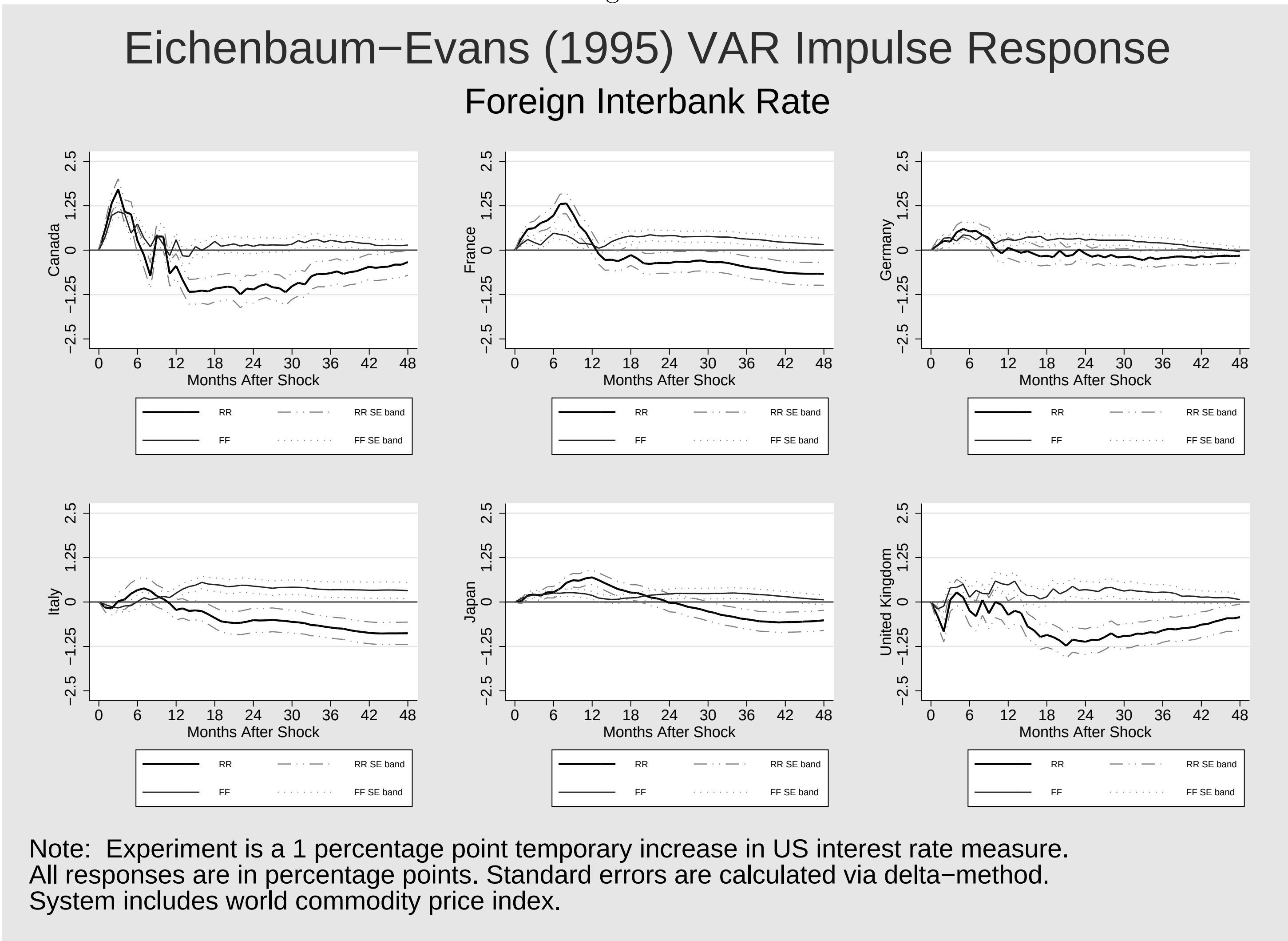

Eichenbaum−Evans (1995) VAR Impulse Response
Foreign Interbank Rate
Canada
France
Germany
Italy
Japan
United Kingdom
−2.5
−1.25
0
1.25
2.5
0 6 12 18 24 30 36 42 48
Months After Shock
RR
FF
RR SE band
FF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.
System includes world commodity price index.

Figure 17:

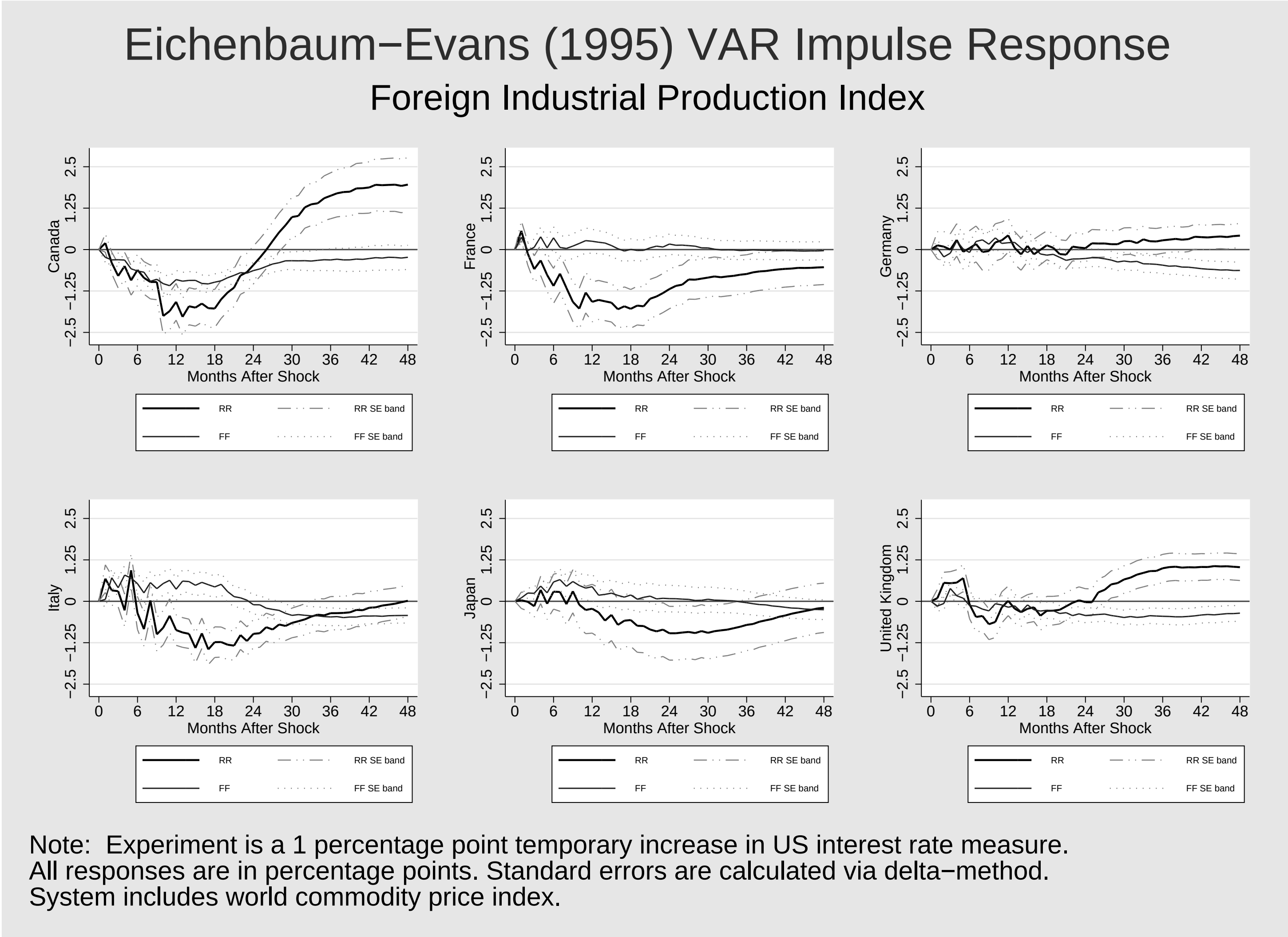

Eichenbaum−Evans (1995) VAR Impulse Response
Foreign Industrial Production Index
Canada
France
Germany
Italy
Japan
United Kingdom
−2.5 −1.25 0 1.25 2.5
0 6 12 18 24 30 36 42 48
Months After Shock
RR
RR SE band
FF
FF SE band
Note: Experiment is a 1 percentage point temporary increase in US interest rate measure.
All responses are in percentage points. Standard errors are calculated via delta−method.
System includes world commodity price index.

Table 1:

Maximum exchange rate responses based on the single equation models					
		12 Month Horizon		48 Month Horizon	
Country	FF/RR	Maximum response (t-ratio)	Timing	Maximum response (t-ratio)	Timing
Canada	FF	1.789 (2.63)	11	4.600 (2.14)	32
Canada	RR	3.269 (2.43)	11	3.697 (1.43)	22
France	FF	1.942 (2.25)	9	4.742 (1.51)	48
France	RR	3.498 (1.48)	9	9.037 (1.89)	37
Germany	FF	1.218 (1.35)	8	3.574 (1.36)	47
Germany	RR	3.806 (1.71)	9	8.901 (1.96)	37
Italy	FF	-0.244 (0.64)	3	-2.376 (1.86)	26
Italy	RR	2.920 (1.46)	8	5.558 (1.45)	43
Japan	FF	-1.095 (2.77)	3	5.843 (2.50)	46
Japan	RR	7.104 (2.51)	11	11.030 (2.75)	17
UK	FF	1.908 (1.74)	12	6.747 (1.91)	48
UK	RR	3.851 (1.32)	11	9.509 (1.65)	48

Notes: Maximum responses refer to the largest absolute change in the US$ within a 12 or 48 month interval, following a 100 basis point increase in interest rates. The units are percentage points and positive numbers denote appreciation. The t-ratios are calculated using the delta method. Timing indicates the number of months after which a maximum occurs.

Table 2:

Maximum exchange rate responses based on the VAR models

		12 Month Horizon		48 Month Horizon	
Country	FF/RR	Maximum response (t-ratio)	Timing	Maximum response (t-ratio)	Timing
Canada	FF	0.712 (4.02)	1	0.712 (4.02)	1
Canada	RR	1.178 (3.21)	2	1.178 (3.21)	2
France	FF	0.984 (2.43)	1	2.202 (2.69)	47
France	RR	2.252 (1.59)	9	3.946 (2.51)	21
Germany	FF	-1.011 (1.26)	12	1.947 (2.85)	48
Germany	RR	1.508 (1.10)	9	2.772 (2.13)	17
Italy	FF	-0.979 (1.19)	12	1.895 (2.16)	48
Italy	RR	2.031 (1.54)	9	2.031 (1.54)	9
Japan	FF	-1.093 (1.35)	11	2.500 (3.55)	28
Japan	RR	2.298 (1.37)	9	2.793 (1.49)	17
UK	FF	1.326 (2.04)	4	1.326 (2.04)	4
UK	RR	2.692 (1.98)	9	2.692 (1.98)	9

Notes: Maximum responses refer to the largest absolute change in the US$ within a 12 or 48 month interval, following a 100 basis point increase in interest rates. The units are percentage points and positive numbers denote appreciation. The t-ratios are calculated using the delta method. Timing indicates the number of months after which a maximum occurs.

Table 3:

Maximum exchange rate responses based on the single equation models					
		12 Month Horizon		48 Month Horizon	
Country	TARG/RESIDF	Maximum response	Timing	Maximum response	Timing
Canada	TARG	2.818 (2.53)	12	6.956 (2.25)	33
Canada	RESIDF	1.548 (1.77)	12	2.039 (1.33)	23
France	TARG	4.254 (2.19)	11	4.625 (0.92)	45
France	RESIDF	4.385 (3.76)	9	4.385 (3.76)	9
Germany	TARG	1.697 (0.87)	11	4.098 (0.97)	44
Germany	RESIDF	3.065 (2.50)	9	3.338 (1.76)	45
Italy	TARG	1.663 (1.17)	11	1.977 (1.18)	17
Italy	RESIDF	2.170 (1.91)	9	2.170 (1.91)	9
Japan	TARG	2.560 (1.63)	12	9.463 (2.62)	46
Japan	RESIDF	2.664 (1.56)	12	3.862 (1.95)	17
UK	TARG	-2.384 (0.95)	4	2.685 (0.68)	40
UK	RESIDF	2.556 (2.06)	10	5.004 (2.84)	37

Notes: Maximum responses refer to the largest absolute change in the US$ within a 12 or 48 month interval, following a 100 basis point increase in interest rates. The units are percentage points and positive numbers denote appreciation. The t-ratios are calculated using the delta method. Timing indicates the number of months after which a maximum occurs.

Table 4:

Maximum exchange rate responses based on the VAR models

		12 Month Horizon		48 Month Horizon	
Country	TARG/RESIDF	Maximum response	Timing	Maximum response	Timing
Canada	TARG	1.091 (2.86)	4	1.091 (2.86)	4
Canada	RESIDF	-0.592 (2.30)	12	-0.672 (2.64)	13
France	TARG	1.442 (2.30)	1	4.251 (3.33)	43
France	RESIDF	1.950 (2.96)	9	2.038 (2.40)	33
Germany	TARG	0.876 (0.91)	3	3.659 (3.01)	44
Germany	RESIDF	1.041 (1.65)	9	1.220 (2.14)	25
Italy	TARG	1.592 (1.86)	3	3.943 (2.53)	46
Italy	RESIDF	0.661 (1.27)	9	0.665 (1.09)	40
Japan	TARG	-1.344 (0.98)	11	4.501 (3.32)	29
Japan	RESIDF	1.030 (1.43)	9	1.076 (1.43)	20
UK	TARG	2.169 (1.87)	5	2.319 (2.12)	48
UK	RESIDF	1.055 (1.87)	10	1.159 (2.64)	25

Notes: Maximum responses refer to the largest absolute change in the US$ within a 12 or 48 month interval, following a 100 basis point increase in interest rates. The units are percentage points and positive numbers denote appreciation. The t-ratios are calculated using the delta method. Timing indicates the number of months after which a maximum occurs.

A Appendix

Table A.1:

Sample Periods for Single Equation and VAR Models		
Foreign country	Single Equation	VAR
Canada	1978:2 to 1996:12	1976:1 to 1996:12
France	1974:2 to 1996:12	1972:1 to 1996:12
Germany	1974:2 to 1996:12	1972:1 to 1996:12
Italy	1974:2 to 1996:12	1972:1 to 1996:12
Japan	1974:2 to 1996:12	1972:1 to 1996:12
UK	1975:2 to 1996:12	1973:1 to 1996:12

Table A.2:

Data sources	
Variable	Source
Bilateral dollar exchange rates	Board of Governors of the Federal Reserve System Foreign exchange releases URL: federalreserve.gov/releases/h10/Hist/
US consumer prices	International Financial Statistics, line 64 ... ZF
Industrial production	International Financial Statistics, line 66 ... CZF
Foreign interest rates	International Financial Statistics, line 60B ... ZF
Non-borrowed reserves	Board of Governors of the Federal Reserve System Identifier: TRARR URL: www.federalreserve.gov/releases/h3/
Total reserves	Board of Governors of the Federal Reserve System Identifier: BOGNONBR URL: www.federalreserve.gov/releases/h3/
Federal funds rate	AER data archive URL: www.e-aer.org/data
RR monetary policy shocks	AER data archive URL: www.e-aer.org/data
World commodity prices	AER data archive URL: www.e-aer.org/data

Table A.3:

Residual diagnostics for single equation models			
Foreign country	AR(1-7)	Heteroscedasticity	Normality
Canada	0.089	0.356	0.426
France	0.685	1	0.261
Germany	0.284	1	0
Italy	0.188	1	0
Japan	0.987	1	0.075
UK	1	1	0.002

Notes: The figures reported are p-values from the following tests: AR(1-7) is an F-test of the hypothesis that the errors are serially uncorrelated at lags 1-7. Heteroscedasticity is an F-test of unconditional homoscedasticity of the errors and Normality a Jarque-Bera test of normality of the errors.

Table A.4:

Residual diagnostics for VAR models

Equation	AR(1-7)	Heteroscedasticity	Normality
Foreign country: Canada			
y^{us}	0.025	0.317	0.084
p^{us}	0.795	0.452	0.271
y^{f}	0.617	0.429	0
r^{f}	0.192	0.241	0
NBRX	0.204	0.248	0
r	0.188	0.064	0
s	0.593	0.875	0.142
Foreign country: France			
Equation	AR(1-7)	Heteroscedasticity	Normality
y^{us}	0.274	1	0.529
p^{us}	0.198	1	0
y^{f}	0.299	1	0
r^{f}	0.082	1	0
NBRX	0.284	1	0
r	0.332	0.999	0
s	0.075	1	0
Foreign country: Germany			
Equation	AR(1-7)	Heteroscedasticity	Normality
y^{us}	0.453	1	0.085
p^{us}	0.05	0.999	0.039
y^{f}	0.566	1	0
r^{f}	0.137	0.893	0
NBRX	0.848	0.999	0
r	0.201	1	0
s	0.087	1	0

Notes: The figures reported are p-values from the following tests: AR(1-7) is an F-test of the hypothesis that the errors are serially uncorrelated at lags 1-7. Heteroscedasticity is an F-test of unconditional homoscedasticity in the errors and Normality a Jarque-Bera test of normality of the errors.

Table A.4: continued

Residual diagnostics for VAR models			
Foreign country: Italy			
Equation	AR(1-7)	Heteroscedasticity	Normality
y^{us}	0.459	1	0.026
p^{us}	0.23	1	0
y^{f}	0.288	0.999	0
r^{f}	0.603	1	0
NBRX	0.188	1	0
r	0.715	1	0
s	0.175	1	0.002
Foreign country: Japan			
Equation	AR(1-7)	Heteroscedasticity	Normality
y^{us}	0.938	1	0.04
p^{us}	0.522	1	0
y^{f}	0.176	1	0.475
r^{f}	0.999	1	0
NBRX	0.048	1	0
r	0.737	1	0
s	0.401	0.999	0
Foreign country: UK			
Equation	AR(1-7)	Heteroscedasticity	Normality
y^{us}	0.103	1	0.966
p^{us}	0.421	1	0
y^{f}	0.714	1	0
r^{f}	0.266	1	0
NBRX	0.516	1	0
r	0.384	0.862	0
s	0.648	1	0

Notes: The figures reported are p-values from the following tests: AR(1-7) is an F-test of the hypothesis that the errors are serially uncorrelated at lags 1-7. Heteroscedasticity is an F-test of unconditional homoscedasticity in the errors and Normality a Jarque-Bera test of normality in the errors.