Exchange Rate Targeting and Economic Stabilization
An Empirical Exploration

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Abstract
In this paper, we investigate the effects of increasing exchange rate flexibility at the margin instead of comparing the polar regimes of fixed and flexible rates. A VAR model with a structural analysis of the financial sector, including exchange rate intervention, is set up for a set of five major industrial countries and estimated using monthly data from the post-Bretton Woods period. IRFs suggest that in most countries intervention appears to be effective, although responses seem very short-lived, lasting just a few months. Counterfactual experiments are undertaken in which the central bank limits exchange rate fluctuations within a prescribed band. Varying the bandwidths shows that the only variable that systematically changes is foreign reserves, which become more volatile with a narrower band. Greater exchange rate flexibility obtained through wider bands neither increases nor decreases volatilities in the interest rate, output, or inflation for the majority of cases. Our results suggest that exchange rate stability is not necessarily earned at the cost of sacrificing interest rate stability and thereby support the idea that stable exchange rates can be welfare improving from a purely domestic point of view and for countries with heavy external debt.

Keywords: Exchange rate targeting, macroeconomic stability, counterfactual experiment

JEL classification: F3, F4

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1. Introduction

Exchange rates among major industrial countries continue to fluctuate in large magnitudes. The euro declined more than 30 percent against the dollar in less than 20 months following its January 1999 inception before completely recovering by the end of 2002. The Japanese yen was no less volatile over the same period, fluctuating nearly 30 percent over the same three year period. Understanding the implications of these exchange rate changes is an important step in determining the relative merits of various exchange rate arrangements. Among other things, whether flexible exchange rates stabilize output and/or inflation more effectively than fixed rates in the presence of diverse shocks is a perennial issue in international finance.

The stabilizing property of exchange rate flexibility is model specific and dependent on the types of shocks. For instance, according to the Mundell-Fleming-Dornbusch model, fixed rate regimes have a superior stabilizing property against nominal shocks while flexible exchange rates can better handle real shocks. Nevertheless, the presumption is that greater exchange rate flexibility reduces volatility in the interest rate and that output and inflation are likely to be more stable with increases in exchange rate variability; see Friedman (1953). Frenkel and Mussa (1980) most succinctly represent this view, termed "conservation of volatility" by Flood and Rose (1995): stabilizing the exchange rate "may only transfer the effect of disturbances from the foreign exchange market to somewhere else in the economic system. … Since the foreign exchange market is a market in which risk can easily be bought and sold, it may be sensible to concentrate disturbances in this market, rather than transfer them to other markets, such as labor markets, where they cannot be dealt with in as efficient a manner." (p. 379)

Typical empirical studies on the issue compare the volatility of macroeconomic variables under different exchange rate regimes. Other than greater variability of real and nominal exchange rates in a flexible rate regime, Baxter and Stockman (1989) find little evidence of systematic differences in the behavior of macroeconomic aggregates under alternative exchange rate systems (pegged, floating, and cooperative systems). Similarly, Flood and Rose (1995) report that the volatility of macroeconomic variables such as money and output does not change much across exchange rate regimes and conclude that there is no clear tradeoff between reduced exchange rate volatility and macroeconomic stability. They argue that "the exchange rate volatility is not in fact transferred to some other part of the economy; it simply seems to vanish." (p. 4) On the other hand, Ghosh et al. (1997) find that pegged regimes are characterized by lower and more stable inflation but more pronounced output volatility. Levy-Yeyati and Sturzenegger (2003) report that greater exchange rate flexibility promotes economic growth and reduces output volatility in developing countries while it has no significant effects on either in industrial countries.

Other studies of the stabilizing property of the exchange rate regime have investigated narrower and more precisely defined types of shocks. For instance, Hutchison and Walsh (1992) employ structural VAR methods to show that flexible exchange rates allowed Japan some insulation from external influences, and thus were stabilizing compared to the Bretton Woods system. Broda (2001) finds that flexible rates were stabilizing for a panel of countries against terms-of-trade shocks. While an improvement over the earlier studies, these studies suffer from the same fundamental problem that all differences in the behavior of the variable under consideration are attributed to the change in the exchange rate regime.

A recently-recognized problem with empirical studies that condition their results on the extant exchange rate regime is that the nominal classification of the regime may be incorrect, as revealed by Calvo and Reinhart (2002) and Reinhart and Rogoff (2002). Even when countries say their currencies float, they often engage in heavy intervention in the foreign exchange market; conversely, when other countries claim to fix their exchange rates, they frequently undergo devaluation cycles. Therefore, a lack of guidance for proper classification of the exchange rate regime complicates interpretation of the empirical results.[1]

Truly fixed or flexible exchange rates for a significant length of time are a rarity. Very often, an important policy question for countries operating on the wide spectrum of intermediate regimes is whether the exchange rate should be allowed to fluctuate a bit more or less. Moving from a fixed rate to a free float or vice versa would be a virtual revolution, which is likely only with crisis situations. It is not expected to happen frequently. Nonetheless, studies on the issue of exchange rate regime still mainly deal with two polar regimes of fixed and flexible exchange rates. Their implications on exchange rate policy are limited and could be misleading.

In this paper, we investigate the effects of modifying exchange rate flexibility in small steps instead of comparing the polar regimes of fixed and flexible rates. We consider an exchange rate regime similar to a target zone system in which central bank interventions limit exchange rate changes within

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[1] Alesina and Wagner (2003) assess institutional reasons to explain why behavior of some countries reflects a "fear of floating" while other countries exhibit a "fear of pegging."

prescribed fluctuation bands. As a hybrid of fixed and flexible exchange rate systems, target zones have been a popular choice, de facto or de jure, among both developed and developing countries. This popularity is likely due to the fact that the system of target zones can potentially provide some exchange rate flexibility and monetary independence to shield exports and the current account from adverse shocks while at the same time providing the stability and anti-inflation commitment of fixed rates as long as the policy authority can credibly correct movements outside the band. See, *inter alia*, Williamson (1983, 2000), Frenkel and Goldstein (1986), and Svensson (1992, 1994) for more detailed discussion of the target zone system.[2]

The rest of the paper is organized as follows. In Section 2 we discuss estimation and specification of a simple macroeconomic model in which the central bank uses its foreign assets to intervene in the foreign exchange market. Section 3 introduces the simulation methodology based on the VAR model. The simulation results are reported in Section 4. The paper concludes with discussion in Section 5.

2. The Model

2.1 Overview

Using data from the post-Bretton Woods period, we estimate for a set of five major countries (Japan, Germany, the U.K., France and Canada) models in which we can evaluate the effects of exchange rate bandwidth on model variables. Specifically, we use the semi-structural VAR technique of Bernanke and Mihov (1998) to divide the model for each country into one block of variables representing the "fundamentals" for the exchange rate (world output and inflation, a supply shock, and domestic output and inflation) and another representing financial market conditions (the exchange rate, foreign reserve holdings,

[2] The target zone system had been employed in the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS) until its transition to the single currency system of the Economic and Monetary Union (EMU). While officially on an independent float, Canada is also known to have used a de facto moving band around the US dollar with bandwidth equal to ±2 percent since May 1970 (Reinhart and Rogoff, 2002). The G3 (the U.S., Japan, and Germany), however, have never actively pursued such an arrangement among themselves except for a brief period that started with the Louvre Accord in February 1987. In the latter, the G3 pledged to stabilize nominal exchange rates around the levels then prevailing. Target zones were set up with bands of ± 5 percent around the rates of DM1.8250/$ and ￥153.50/$. The range for the yen/dollar rate was adjusted in April 1987. The brief period of exchange rate stability ended with the stock market crash of October 1987.

the quantity of money, and domestic and world interest rates). A structural specification for the second block allows us to recover estimates of the structural shocks of the variables in this block.

Choosing the width of the exchange rate band and determining the method of intervention to enforce the band are important components of a monetary policy rule. In this paper, we use as the policy instrument the shock to the equation for central bank holdings of foreign reserves and then empirically determine the macroeconomic implications of various exchange rate bandwidths. We do so by identifying key structural elements of models of each country, including the policy shocks. Conditional on the assumption that the structural shocks are independent of each other, we can manipulate this shock without having implications for the other model shocks. Thus, we can use the shock in the policy equation to manage the exchange rate when it would otherwise violate the boundaries of the exchange rate band. These policy interventions, when combined with the other equation disturbances, can be used to construct the dynamic path the economy will follow given the policy interventions. Bootstrap trials then allow us to estimate the variances of key variables, such as output and inflation, implied by various bandwidths.

After specifying a particular bandwidth, we undertake a counterfactual analysis in which we take random draws from the estimated residuals. Using the moving average representation, this set of residuals implies values for all system variables, including the exchange rate. If the draw implies an exchange rate outside the band, then a policy response, in our case a shock to the equation for foreign reserves holdings, is computed that will return the exchange rate to the band. This policy shock, combined with the other shocks to the other equations, then implies values of the other variables under the chosen bandwidth. A large number of such draws then allows computation of statistics of interest, such as the standard deviations of output, inflation, and the domestic interest rate. Conducting these types of bootstrap experiments with different bandwidths then allows us to reach conclusions of how marginal changes in exchange rate policy affect economic outcomes. Since changes in exchange rate flexibility are small in each step, we have more assurance that the assumption of structural constancy can be a reasonable approximation, at least in the range of the actual (though perhaps implied) exchange rate variability allowed by the policy authority.

Since one of main goals of this paper is to investigate the effects of exchange rate flexibility without drastic changes in regime itself, we pay close attention to the possibility that interventions are too frequent or too extreme.[3] In terms of our model, interventions that lead to negative rates of interest or negative foreign reserve holding are possible symptoms of such extremity. Interest rates, however, became negative especially when the band is very narrow, probably because rates were extremely low towards the end of our data set and there was not much room to maneuver. We exclude trials in which the nominal interest rate is negative in all results reported below. Even if trials with negative interest rates are included, however, virtually all the conclusions continue to hold and the empirical results are surprisingly close numerically to what we report.[4]

The main findings of the counterfactual experiments can be summarized as follows. The frequency and size of interventions declines as the bandwidth widens, as do the number of trials with any intervention. The only variable that systematically changes with the bandwidth is the variability of foreign reserves, with foreign reserves become more volatile as the bandwidth narrows. Reflecting the fact that the central banks of major industrial countries typically sterilize their interventions, however, the money supply is hardly related to the variability of the exchange rate. More importantly, greater exchange rate flexibility obtained through a wider band neither increases nor decreases volatilities in the interest rate, output, or inflation for the majority of cases. These results are broadly consistent with the findings of Baxter and Stockman (1989) and Flood and Rose (1995). They also confirm that the "exchange rate disconnect" puzzle (Obstfeld and Rogoff, 2000) may indeed be widespread.

2.2 Estimation: The General Strategy

We use the Bernanke-Mihov (1998) semi-structural VAR to build a model of the financial sector of each country's economy, controlling for broader macroeconomic fundamentals. This approach is useful in that it allows us to identify the structural policy shocks without having to identify (perhaps incorrectly) a complete structural system.

As in Bernanke and Mihov, we start with a structural model:

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[3] By design, the analysis does not preclude "instrument instability" where the policy shock needed to attain the exchange rate goal fluctuates wildly.

[4] In a different context, Cogley and Sargent (2001) restrict the roots in a Bayesian VAR to those which do not violate a stability condition, i.e., rejecting draws which produce autoregressive roots outside the unit circle. Intuitively, since explosive roots are not observed in the economy they study, the U.S., placing a zero probability on such draws seems appropriate. Without modeling it formally, we similarly reject draws which in our case produce negative nominal interest rates.

$$F_t = \sum_{i=0}^{k} B_i F_{t-i} + \sum_{i=1}^{k} C_i P_{t-i} + H^F \varepsilon_t^F$$

$$P_t = \sum_{i=0}^{k} D_i F_{t-i} + \sum_{i=0}^{k} G_i P_{t-i} + H^p \varepsilon_t^p$$

where F_t is an (Mx1) vector of fundamentals, P_t is an (Nx1) vector associated with the policy block, ε_t^F and ε_t^p are the structural shocks associated with these vectors, and the matrices B_i, C_i, D_i, G_i, H^F, and H^p are, respectively, (M×M), (M×N), (N×M), (N×N), (M×M), and (N×N) coefficient matrices. It is assumed that the structural shocks are orthogonal to one another. Under this assumption, non-zero off diagonal elements of the H^F and H^p matrices allow for shocks to one equation to affect other equations contemporaneously. While this assumption is of use in some settings, in our application we set these two matrices equal to identity matrices.

Notice two features of this system of equations. First, fundamentals are affected by the variables in the policy block only with a lag. In our particular case, this means that the variables in P_t do not affect the fundamentals within the month.[5] Second, P_t is expressed in terms of both fundamentals – i.e., variables in the F_t vector – as well as in terms of its own lags. As we will summarize below, the Bernanke-Mihov approach leads to estimation of the vector of structural shocks in the policy block - i.e., ε_t^p - so that we can analyze how this set of structural shocks affects the system, including the relevant influence of the fundamentals.

Straightforward manipulation of the structural model above yields the reduced-form:

$$\begin{bmatrix} F_t \\ P_t \end{bmatrix} = \sum_{i=1}^{k} \begin{bmatrix} \Pi_{11} & \Pi_{12} \\ \Pi_{21} & \Pi_{22} \end{bmatrix} \begin{bmatrix} F_{t-i} \\ P_{t-i} \end{bmatrix} + \begin{bmatrix} u_t^F \\ w_t^p \end{bmatrix} \quad (1)$$

with the Π_{ij} derived in the usual way by inverting the matrix of contemporaneous structural coefficients, with residuals in the F block given by

$$u_t^F = (I - B_0)^{-1} \varepsilon_t^F$$

[5]In the case where P_t is a scalar, setting $C_0 = 0$ allows identification of the structural shock of the policy variable without needing to identify the entire model, as in Bernanke and Blinder (1992).

and those in the P block given by

$$w_t^p = (I - G_0)^{-1} D_0 (I - B_0)^{-1} \varepsilon_t^F + (I - G_0)^{-1} \varepsilon_t^p .$$

Given the definition of u_t^F , we rewrite w_t^p as

$$w_t^p = \alpha u_t^F + u_t^p ,$$

where α = $(I - G_0)^{-1} D_0$.

We proceed as follows. First, we estimate the reduced-form equation (1), saving the residuals u_t^F and w_t^p . Second, we regress w_t^p on u_t^F , obtaining u_t^p . Since $u_t^p = (I - G_0)^{-1} \varepsilon_t^p$, $(I - G_0) u_t^p = \varepsilon_t^p$, or

$$u_t^p = G_0 u_t^p + \varepsilon_t^p , \quad (2)$$

where G_0 is the matrix of "own" contemporaneous structural parameters in the policy block of the original model. We estimate G_0 by specifying a model of the variables in the policy block.[6]

The residuals in equation (2), ε_t^p , represent the structural shocks to the variables in the policy block, which then allow construction of the IRFs and VDCs, the usual objects of interest in VAR analysis. In addition, and especially important for our purposes, by working under the maintained assumption that the structural shocks are independent of one another, we can replace the shocks to the policy equation with those needed to attain a given policy objective without, at least as a first approximation, having to consider the implications of these counterfactual shocks for the other shocks in the system.

For each country, we estimate a 10-variable model. The fundamentals block, F , contains five variables: deviations of the log of U.S. industrial production from its Hodrick-Prescott (HP) trend ($\tilde{y}^f$), the U.S. inflation rate as measured by the log change in the CPI (Δp^f), the change in the log of the world price of oil as a proxy for supply shocks, expressed as U.S. dollars per barrel (Δp^{oil}), deviations of the log of domestic production from its HP trend ($\tilde{y}$), and domestic inflation as measured by the log change in CPI (Δp). The "output gap" for both the U.S. and domestic economies not only gives the model a New

[6] This observation was first made by Bernanke (1986).

Keynesian flavor but, more importantly, allow us to focus on how policymakers use interest rate changes or respond to exchange rate fluctuations in order to maintain output at or near its long-term trend level.

The policy block, P , contains variables related to determination of contemporaneous exchange rate changes, including the variable used as the policy tool. P includes the log change in the central bank's foreign reserve holdings (Δfr), the log changes in the quantity of money (Δm), changes in the levels (rather than logs) of domestic and foreign (U.S.) interest rates (Δi , Δi^f), and the deviation of the log of the exchange rate around its HP trend ($\tilde{e}$). We model the policy authority as managing these percentage deviations of the exchange rate around its long run trend, using holdings of foreign reserves as the policy instrument. This approach allows policy makers to respond to short-run exchange rate movements without eliminating its low-frequency information, a problem in the alternative approach of first-differencing the data.[7]

Note several things about our approach. First, even though we focus on the deviation of the exchange rate from its HP trend, this deviation is nonetheless affected by the fundamentals, i.e., the variables in the F block. Thus, if during the simulation periods in the experiments conducted below, forces in the broader domestic or world economies persistently push this deviation in some particular direction, policymakers are modeled as taking these pressures into account. In fact, as we have set up the analysis, if such persistent movements occur, then ever-stronger policy actions will be needed to maintain the exchange rate in its band, and evidence of these actions will show up in the descriptive statistics of the policy actions. Implicitly, then, longer run pressures are accounted for. Second, by employing the deviation of the exchange rate around trend as our variable of focus, we mainly discuss the short-run operating procedures of policy authorities. That is, the objective of the policymaker on a monthly basis is maintaining the exchange rate within a given band.[8] The exchange rate policy considered here is of the leaning-against-

[7] The variables described as log changes (such as the price levels) are computed as the difference between the variable in a given month and the same month in the previous year. Thus, they represent annualized rates of change. Alternatively, we could have computed annual rates of change by taking the log difference of adjacent months and then annualizing these changes. Our view is that there is sufficient noise in the monthly changes that annualizing them tends to compound the noise in the monthly data and hence make it harder to extract the signals in the data. The interest rates are changes in the variables (not their logs).

[8] Whether the policymaker has the available resources to manage the exchange rate against its longer run trend is problematic. Preliminary analysis suggests that in no case does the policy authority in any country run out of foreign reserves in any trial in any experiment.

the-wind type to limit the short-run volatility of the exchange rate. Specifically, in the experiments we limit these deviations from trend by specifying bandwidths relative to short run fluctuations in the exchange rate around trend.

2.3 Specification of the Structural Component of the Model

For the level of data aggregation we employ, rather than identifying country-specific models, we instead choose to adopt a set of generic identifying restrictions. This approach is similar, for instance, to cross-country comparisons of the type reported by Eichenbaum and Evans (1995), Kim and Roubini (2000) and Kim (2002). This is not to claim that a "better" set of restrictions for a given country could never be found. But we would like to stress that the approach developed below to evaluate the empirical implications of various exchange rate bands can be applied to any structural model, so that a researcher with a different set of restrictions can still undertake a policy analysis of the type presented here.

Our specification of equation (2) above, which allows estimation of the structural parameters in the policy block in the original model, is:

$$u_e = g_{0,12}u_{fr} + g_{0,13}u_m + g_{0,14}(u_i - u_{i^f}) + \varepsilon_e \qquad (2.1)$$

$$u_{fr} = g_{0,21}u_e + \varepsilon_{fr} \qquad (2.2)$$

$$u_m = g_{0,31}u_e + g_{0,34}(u_i - u_{i^f}) + \varepsilon_m \qquad (2.3)$$

$$u_i = g_{0,41}u_e + g_{0,42}u_{fr} + g_{0,43}u_m + g_{0,45}u_{i^f} + \varepsilon_i \qquad (2.4)$$

$$u_{i^f} = \varepsilon_{i^f} \qquad (2.5)$$

In equations (2.1) – (2.5), u_e, u_{fr}, u_m, u_i, and u_{i^f} are the individual elements of the u_t^p vector, with the subscripts referring to the exchange rate, holdings of foreign reserves, money, and the domestic and foreign interest rates.

Before beginning explicit discussion of the structural part of the model, note that in equations (2.1)-(2.5) we suppress notation relating to the role of the "fundamentals." That is, each equation also has some response to the U.S. output gap, U.S. inflation, the price of oil, as well as the domestic output gap and inflation. We have chosen the Bernanke-Mihov approach in large part to avoid having to build a larger structural model with the potential for a relatively large number of "incredible" identifying restrictions. Thus, while this approach captures the relevant reduced-form relationship between the fundamentals and those variables in the policy block, for our purposes we do not need to model all the underlying structural relations in order to attain estimates of the structural policy shocks

Equation (2.1) allows the exchange rate to respond to central bank holdings of foreign reserves, shocks to money demand, and the interest rate differential between the domestic and world interest rate. Equation (2.2) represents the equation for foreign reserve holdings, which respond to the exchange rate. Note that the policy variable, ε_{fr}, is used for intervention as appropriate, altering the level of foreign reserve holdings over and above the endogenous response of these reserves to both the fundamentals as well as exchange rate shocks. Through equation (2.2), ε_{fr} affects the exchange rate at the margin, which as detailed below allows us to maintain the exchange rate inside a pre-specified band. Equation (2.3) is the money demand schedule, which responds to the exchange rate as well as the interest rate differential. The inclusion of the exchange rate in the money demand schedule reflects the assumption that exchange rate variability reflects changes in relative prices of goods across countries, and so alters the quantity of domestic currency held for local purchases. The interest rate differential reflects the relative opportunity cost of holding the domestic currency. Equation (2.4) assumes that the monetary authority sets the interest rate as its monetary policy instrument, and allows the local interest rate to respond to all the other variables. In our setup, when the exchange rate is within the pre-specified band, there is modest room for interest rate adjustments for domestic control purposes. Equation (2.5) allows the world interest rate to respond to fundamentals, but not to contemporaneous movement in variables in the policy block.

Equation (2) is estimated according to Bernanke's (1986) method of moments approach. He notes that this estimator provides consistent estimates of the parameters regardless of distributional assumptions and that the estimates are numerically equivalent to full information maximum likelihood when the structural residuals are normal and the model is just-identified.

2.4 Descriptive Data Analysis

We employ monthly data for Canada, France, Germany, Japan, and the United Kingdom. The U.S. is used as a proxy for the rest of the world for all cases except France, for which Germany is substituted as the proxy. The basic period of analysis begins in 1975:1, after the breakdown of the Bretton Woods system. For Canada, Japan and the UK, our estimation ends at 1998:12, with the period 1999:1 – 2001:12 being used for counterfactual simulations, to be described below, to evaluate alternative exchange rate bands and their implications for the fluctuations of output, inflation, and selected financial market variables. For France and Germany, the estimation period ends in 1995:12, with 1996:1-1998:12 being held out for the simulations. The shorter period for France and Germany is due to the fact that data on their exchange rates ends with the introduction of the euro.

Table 1 here

Standard deviations of the main variables employed in this study are reported in Table 1, where period I refers to the estimation period and period II to the simulation period. All variables except the interest rate are in logs. Δ denotes the difference operator.[9] Industrial production and the nominal exchange rate are expressed as deviations from their Hodrick-Prescott trends. Typical flexible-rate countries such as Japan and Germany have large exchange rate changes. The variability of the U.K. pound during the estimation period approaches a similar level. In contrast, Canada has maintained much more stable exchange rate while officially on a managed float. In period I, the standard error of Canada's exchange rate is even lower than that of France, which has been under a target zone for the majority of the period, with the franc-mark rate kept within a narrow band except for several devaluations.

It appears that most macroeconomic aggregates were more stable during the simulation period (period II) than during the estimation period (period I), perhaps reflecting the higher rate of growth in the industrialized economies along with lower variability that are said to characterize the 'new economy'.[10] Exchange rates became less volatile in all countries, and notably, the standard error declines to less than half in the U.K. and virtually disappears in France. Volatility in the interest rate, foreign reserves, money supply and inflation declined in all countries without exception. Output was also more stable in period II with the exception of Japan.

[9] Due to seasonality, we use 12-month differencing.

[10] We refer to an emerging evaluation of whether the high growth/low volatility of key macro indicators are indeed reflective of the so-called new economy, the result of an acceleration of productivty growth. It remains an open question as to whether the productivity improvements during the 1990s were temporary or permanent, and whether these affected the growth rate, volatility, or both. The issue of whether the economy has become more stable is addressed, e.g., in Kim and Nelson (1999) and McConnell and Perez Quiros (2000); the issue of more rapid growth is discussed in Gordon (2000), Jorgenson and Stiroh (1999) and Oliner and Sichel (2000).

2.5 Estimation Results

The results of estimation of the contemporaneous structural parameters, by country, are reported in Table 2. While some of the coefficients are imprecisely estimated, a number of key coefficients are significant and of the expected sign. Among them are (i) in the exchange rate equation, we find that increases in holdings of foreign assets lead to depreciations (rises in the exchange rates) and that increases in the interest rate differential tend to lead to appreciations; (ii) in the equation for foreign reserve holdings, a depreciation leads to declines in foreign reserves, presumably as each central bank sells foreign assets to limit the fall in the values of its currency; (iii) in the money demand equation, rises in the local interest rate relative to world rates leads to declines in the quantity of money demanded; (iv) in the interest-rate setting equation, depreciations lead to increases in the domestic interest rate and using domestic assets to acquire foreign assets leads to a decline in domestic rates.

Table 2 here

The contemporaneous coefficients represent only a small portion of the overall model, and accepting or rejecting the model based solely on their signs and/or statistical significance is a highly restrictive approach. Accordingly, we also present and briefly discuss selected impulse response functions since the entire dynamic response of the model to innovations are also of interest. Our focus is on how the exchange rate (relative to the HP trend) responds to domestic financial shocks (changes in foreign asset holdings, the money stock, and the domestic interest rate) and how exchange rate deviations from trend affect these same domestic financial market variables.

Figure 1 here

For each country, we present in Figure 1 six selected impulse response functions, along with 95% confidence bands. [11] The impulse responses appear reasonable and consistent across countries. For each country, the first three panels show the responses of the exchange rate to a unit shock in foreign reserves, the interest rate, and money demand, respectively. In all cases except France, the exchange rate rises with an increase in foreign reserves indicating that a buying intervention by the monetary authority depreciates the domestic currency. Also in all cases except France, the effects on the exchange rate appear to be

[11] We have employed the Sims-Zha (1995) approach to computation of the confidence bands.

significant although they invariably last just a few months. A higher interest rate appreciates the domestic currency in all countries but Canada and Japan. However, the effects are significant only in France and Germany. A money demand shock, representing a rise in liquidity preference, depreciates the domestic currency only in Japan, which is also insignificant. It leads to an appreciation in all other countries with some significance in Canada, France, and the UK. The last three panels for each country show the responses of foreign reserves, the interest rate, and money, respectively, to a unit shock in the exchange rate. In all cases except France, an exchange rate shock is followed by a significant reduction in foreign reserves, indicating that these countries have been quite ready to intervene to stabilize the exchange rate. The extent of intervention appears to vary across countries, strongest in Canada and weakest in the two ERM countries - Germany and France. The fifth panel suggests that, in response to an exchange rate shock, the domestic interest rate is raised in all countries except Japan. The last panel suggests that money demand increases in the aftermath of a surprise depreciation. Increases in money demand may be due to increases in the import prices and the overall price level. Money demand may also increase if domestic assets including money become more attractive as the unanticipated depreciation breeds anticipation of currency appreciation. Finally, these policy responses seem very short-lived, lasting just a few months.

The impulse responses suggest that our models behave reasonably well compared to previous structural VAR studies such as Eichenbaum and Evans (1995), Cushman and Zha (1997), and Kim and Roubini (2000). What is more interesting is that central bank intervention in the foreign exchange market through buying and selling foreign reserves is effective and moves the exchange rate and the interest rate in the expected direction. The effects on the exchange rate seem to last only a few months, however. These results are consistent with recent studies of the effectiveness of central-bank intervention surveyed in Edison (1993) and Sarno and Taylor (2001) showing that sterilized intervention is effective through portfolio-balance and signaling channels and the effects are mainly short term. It is interesting that we are able to confirm the effectiveness of intervention using structural VAR analysis and monthly data unlike typical studies that rely on high frequency data and single equation regression of the intervention function.

3. Simulation Methodology

In this section, we present the basic methodology used to evaluate measures of volatility of key variables, such as output, inflation, and key financial market variables, for alternative bandwidths. Prior to the technical presentation, we provide a brief overview of our approach.

We set up the historical decomposition of the VAR, using a planning horizon of 36 months. We take a random draw from the set of historical residuals and use these to compute the values of the model variables, starting with the residuals drawn for the first month. Combined with the base projection as of the end of the estimation period, if the exchange rate is within the pre-specified band, we compute the values of the system variables implied by the first month's shocks and proceed to the next month. However, if the value of the exchange rate violates the pre-specified band, a policy intervention is undertaken designed to bring the exchange rate back to some pre-determined point within the band. This intervention is represented as a shock to the foreign reserves equation, and replaces the shock from the random draw for the foreign reserves equation for this particular month. We re-compute the values of the system variables and then incorporate the next month's residuals. Again we test to see if the exchange rate lies inside the band. If it does, no intervention is computed; if it does not, we again find the size of the intervention needed to return to the band and again re-compute the values of the system variables. As we pass through the planning horizon, in some months the policymaker would intervene, and in other months no policy action is needed. At the end of a trial, we have the path the system would follow for this particular set of draws combined with any needed policy interventions. If policy makers read and react (when needed) to incoming information on a monthly basis, then our procedure mimics policy implementation.[12] Repeating these trials, sampling from the estimated residuals with replacement, we can simulate the means and standard deviations of the variables in the system under the given policy regime, keep track of the frequency of the policy interventions, monitor the size of the interventions to compare with the historical shocks to the policy equation, etc.

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[12] Thus, we formalize the description of policy formulation and revision described by Blinder (1997). In particular, he argues: "First, you plan an entire hypothetical path for your policy instrument, from now until the end of the planning horizon, even though you know you will activate only the first step of the plan. It is simply illogical to make your current decision in splendid isolation from what you expect to do in subsequent periods. Second, when next period actually comes, you must appraise the new information that has arrived and make an entirely new multiperiod plan. If the surprises were trivial, that is, if the stochastic errors were approximately zero, step one of your new plan will mimic the hypothetical step two of your old plan. But if significant new information has arrived, the new plan will differ notably from the old one. Third, you must repeat this reappraisal process each and every period."

Our goal is to simulate policy in the presence of a tolerance band around a given exchange rate objective, using foreign reserves as the policy tool. Three kinds of bandwidths merit attention. At one extreme, the policymaker may choose to manage foreign reserves, net of the endogenous response of these reserves to other variables in the system, so as to set the bandwidth to zero. This policy amounts to a "hard peg" and implies a specific foreign reserves path designed to attain a specific time path for the exchange rate. In terms of a moving average representation, when combined with the other shocks in the system, such a path implies specific paths for variables such as output and inflation. Second, the policymaker may want to evaluate as the policy objective a given exchange rate path, plus or minus some non-zero tolerance range. In this case, a policy intervention is not undertaken unless the exchange rate moves outside the pre-specified band. The bandwidth, along with the chosen path (the midpoint of the chosen band, for example) and a rule as to where to return the exchange rate if it wanders outside the band, presumably determines the frequency of policy interventions, the magnitude of the interventions, and the variability of the goal variables of output growth and inflation.[13] We presume that the policymaker would like to know the behavior of the economy under different, nonzero but finite, bandwidths. Finally, the policymaker may like to evaluate the impact of a freely floating exchange rate, which can be thought of as the limiting case of an arbitrarily large bandwidth. While we do not explicitly set up a loss function to be minimized subject to our empirical model, it is nonetheless easy to compute the values of "loss functions" from these various bandwidths by picking a weight for output relative to inflation and using the simulation results to select the "optimal" bandwidth.

A more detailed investigation of our analysis of policy alternatives begins with the properties of the historical decomposition of the moving average representation (MAR) of the structural model. Recalling the notation from equation (1), define $\Pi(L) = (I-\Pi_1 L^1-...-\Pi_k L^k)$. Next define $C(L) = [\Pi(L)]^{-1}$, with $C_0 = I$. Then the MAR of equation (1) is:

$$\begin{bmatrix} F_t \\ P_t \end{bmatrix} = \sum_{s=0}^{\infty} \begin{bmatrix} C_{11,s} & C_{12,s} \\ C_{21,s} & C_{22,s} \end{bmatrix} \begin{bmatrix} u_t^F \\ \alpha u_t^F + u_t^p \end{bmatrix} = \sum_{s=0}^{\infty} \begin{bmatrix} C_{11,s} & C_{12,s} \\ C_{21,s} & C_{22,s} \end{bmatrix} \left[\begin{pmatrix} u_t^F \\ \alpha u_t^F \end{pmatrix} + \begin{pmatrix} 0 \\ u_t^p \end{pmatrix} \right],$$

[13] Specifically, policy designed to return to the edge of a band is smaller in magnitude than one aimed at returning to an interior value but may need to be undertaken more frequently. Conversely, policy aimed at returning to the inside of the band is larger in magnitude but may be undertaken less frequently. This tradeoff between magnitude and frequency is important for policy makers who wish to avoid actions that cause agents to alter their behavior.

$$= \sum_{s=0}^{\infty} \begin{bmatrix} C_{11,s} & C_{12,s} \\ C_{21,s} & C_{22,s} \end{bmatrix} \left[\begin{pmatrix} u_t^F \\ \alpha u_t^F \end{pmatrix} + \begin{pmatrix} 0 \\ (I - G_0)^{-1} \varepsilon_t^p \end{pmatrix} \right]. \quad (3)$$

To help fix some basic ideas, suppose that one equation, say equation i (in the policy block of system (3)), is the equation of the target variable, the exchange rate in this discussion. Let equation j (also in the policy block) be the equation for the policy tool, central bank holdings of foreign reserves in our example. The element in ε_t^p corresponding to equation j is the structural shock to the foreign reserves equation. The policymaker is seen as using this tool to achieve a particular time path for the dependent variable in equation i. The policymaker controls the level of foreign reserves by manipulating the shock in the foreign reserves equation. Since transactions in foreign reserves alter the exchange rate, in each trial we obtain the appropriate time series of shocks that brings about the desired time path of the exchange rate. We refer to the time path of the policy interventions as the ε-path for equation j, or, for brevity, the "ε_j -path". By choosing a particular ε_j -path, the policy authority reinforces (or offsets) the endogenous response of foreign reserves to the economy, in the process producing the desired path for the exchange rate.[14] The impact of the chosen ε_j -path on the ultimate variables of interest is also evident from equation (3), where system variables are expressed, *inter alia*, in terms of shocks to the foreign reserves equation. That is, a shock to the foreign reserves equation that brings about the desired exchange rate also affects the other variables in the economy, whose responses are captured by the appropriate elements of the C_s, α , and G_0 matrices.

Focusing on the policy block in equation (3), and advancing to period t+h, the policy block may be written in terms of its historical decomposition (HD):

$$P_{t+h} = \sum_{s=0}^{h-1} \{C_{21,s} u_{t+h-s}^F + C_{22,s} \alpha u_{t+h-s}^F\} + \sum_{s=0}^{h-1} C_{22,s} u_{t+h-s}^P$$

[14] In equation (3), foreign reserves respond to the various shocks in the economy. For shocks other than the own shock, the elements of the jth row of the coefficient matrices represent how these reserves respond to other variables. Thus, if the ε_j-path is constrained to zero, then the implied values of reserves represent the endogenous response to nonpolicy impulses. With a minor exception to be noted below, we view the impact on foreign reserves of the own shock as the exogenous, policy component. Thus the foreign reserves equation in system (2) contains both endogenous and exogenous components. This distinction between the endogenous and exogenous components of the policy equation is discussed further in Bernanke, Gertler and Watson (1997).

$$+\sum_{s=h}^{\infty}\{C_{21,s}u_{t+h-s}^{F}+C_{22,s}\alpha u_{t+h-s}^{F}\}+\sum_{s=h}^{\infty}C_{22,s}u_{t+h-s}^{P} \tag{4}$$

An important aspect of equation (4) is the in-sample accounting identity associated with the HD. In particular, from the perspective of time t, the data at time t+h is the sum of four terms. The last two terms in (4) represent the dynamic forecast or base projection (BP) of P_{t+h} based on information at time t; the first of these terms corresponds to the contribution to the BP of the shocks to the fundamentals while the second corresponds to the contribution of the shocks to the variables in the policy block. The initial two terms in (4) are weighted averages of the actual shocks over the period t+1 to t+h, again with contributions from both fundamental and policy block variables.[15] Conditional on the identification of the model, the historical decomposition quantifies, period by period, the relative importance of the various shocks to the system. Taking into account the terms relating to the BP and the relationship between the u_t^P and ε_t^P,

$$P_{t+h}=\sum_{s=0}^{h-1}C_{2\bullet,s}u_{t+h-s}^{F}+\sum_{s=0}^{h-1}D_{22,s}\varepsilon_{t+h-s}^{P}+BP_{t+h}\ , \tag{5}$$

where $C_{2\bullet,s}=C_{21,s}+C_{22,s}\alpha$ and $D_{22,s}=C_{22,s}(I-G_0)^{-1}$.

We exploit this accounting identity in the following way. Model estimation produced not only estimates of the structural parameters in the policy block but also estimates of the structural residuals in this block. From the perspective of equation (5), at time t we can make a base projection. Using the residuals from the random draw we add to the BP the first two terms on the right hand side of equation (5), yielding the vector P_{t+h}.[16] Finally, if the value computed for the exchange rate equation lies outside the desired exchange rate band, replace the shocks to the policy variable in equation j with those needed to meet the policy objective, retaining the shocks to the other equations. Using these, we can compute the values of the elements of P_{t+h}, the path the economy *will follow* under this policy, conditional on this particular draw.[17]

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[15] Note that this identity uses the structural shocks and MAR coefficients estimated using data through t+h. Our evaluation of exchange rate targets below will be out-of-sample and so will not be subject to this particular problem.

[16] Of course, the residuals also allow computation of the variables in the fundamentals block as well.

[17] Also note that when the elements of the ε_j-path are small relative to the endogenous component, as should be the case with normal policymaking, agents are unlikely to benefit from reassessing the

We call this the "fundamental property of counterfactual analysis." Repeated trials allow us to compute the moments of the entire system of variables given the particular policy objective under consideration.

The technical steps needed to evaluate a given policy alternative are now discussed. The initial step is to show how to compute the policy shocks needed to attain a given path of the exchange rate specified by the policymaker. (For the moment, we ignore the possibility of conducting policy with tolerance bands; equivalently, we assume the width of the band is zero.) Using the coefficients estimated through period t, equation (5) shows the decomposition for a particular period, t+h, in terms of the base projections conditional on information at time t and the contributions of non-policy shocks subsequent to t, which for now we assume known. Consider the ith equation in system (5) for h=1:

$$P_{i,t+1} = \sum_{k=1}^{M} c_{2\bullet,0,ik} u^F_{k,t+1} + d_{22,0,ij} \varepsilon^p_{j,t+1} + \sum_{\substack{k=1 \\ k \neq j}}^{N} d_{22,0,ik} \varepsilon^p_{k,t+1} + BP_{1,i,t}$$

where $c_{2\bullet,0,ik}$ is the i,k element of the $C_{2\bullet,0}$ matrix, $d_{22,0,ik}$ is the i,k element of the $D_{22,0}$ matrix, $BP_{1,i,t}$ is the one-period-ahead base projection for the ith equation at time t, and where $\varepsilon^p_{j,t+1}$ is the shock to the foreign reserves equation.[18]

Suppose we want to find the policy shock that will produce a pre-determined value for the exchange rate, denoted by $P^*_{i,t+1}$. Given the other shocks to the economy, there is an $\hat{\varepsilon}^p_{j,t+1}$ such that:

$$P^*_{i,t+1} = \sum_{k=1}^{M} c_{2\bullet,0,ik} u^F_{k,t+1} + d_{22,0,ij} \hat{\varepsilon}^p_{j,t+1} + \sum_{\substack{k=1 \\ k \neq j}}^{N} d_{22,0,ik} \varepsilon^p_{k,t+1} + BP_{1,i,t}$$

the solution for which is

$$\hat{\varepsilon}^p_{j,t+1} = (d_{22,0,ij})^{-1} [P^*_{i,t+1} - BP_{1,i,t} - \sum_{k=1}^{M} c_{2\bullet,0,ik} u^F_{k,t+1} - \sum_{\substack{k=1 \\ k \neq j}}^{N} d_{22,0,ik} \varepsilon^p_{k,t+1}], \qquad (6)$$

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systematic policy rule. This is the empirical analog to the arguments by Sims (1982; 1987) and Cooley-LeRoy-Ramon (1984) that with "normal" policymaking the Lucas critique is unlikely to be violated.

[18] We view this shock as, in principle, having two components. One component is the policy innovation needed to attain a given objective. A second component represents randomness that will occur in the manner in which agents in the economy call on the central bank to exchange domestic currency for foreign currency, which policy makers may offset if they choose. While we could model these components separately, we have not; instead, we have chosen to represent policy maker behavior as offsetting the second component only if, in the absence of policy, this and other forces in the economy would suggest an exchange rate outside the pre-specified band.

which is the value for the policy shock the policy authority must achieve to attain the target value for the exchange rate. This policy response takes into account the values of the fundamentals, expressed in terms of the u_t^F terms, as well as the values of the other variables in the policy block, expressed in terms of the ε_k^p terms for k ≠ j.

Proceeding in a similar manner, it can be shown that the structural residual needed to achieve a particular value for $P_{i,t+2}$, denoted by $P_{i,t+2}^*$, is:

$$\hat{\varepsilon}_{j,t+2}^p = (d_{22,0,ij})^{-1}[P_{i,t+2}^* - BP_{2,i,t} - \sum_{k=1}^{M} c_{2\bullet,0,ik} u_{k,t+2}^F - \sum_{k=1}^{M} c_{2\bullet,1,ik} u_{t+1}^F - \sum_{\substack{k=1 \\ k\neq j}}^{N} d_{22,0,ik}\varepsilon_{k,t+2}^p$$

$$- \sum_{\substack{k=1 \\ k\neq j}}^{N} d_{22,1,ik}\varepsilon_{k,t+1}^p - d_{22,1,ij}\hat{\varepsilon}_{j,t+1}^p] \qquad (7)$$

Similar iterations produce a path of structural shocks that generate a path for $P_{i,t+h}$ that matches the desired path $P_{i,t+h}^*$, for h = 1,...,T, where T is the planning horizon. This path of structural shocks for the policy variable, combined with the values of the shocks to the other variables, then produces an expected path for the system as a whole.[19]

Note that in computing the policy shock needed to attain the policy objective, as in equations (6) and (7), we assume that the policy maker can observe the set of shocks and respond within the period represented by the data frequency, monthly in our case. In markets as deep as the worldwide financial markets, including the currency markets, this seems a reasonable approximation. An alternative that could be explored, but which we have not, is to allow the exchange rate to move outside the band in a particular month, pursuing policy actions that would return the exchange rate to its objective the following month (assuming no further shocks in the second month in this sequence).[20]

The second step in constructing the algorithm we use in the experiments below is to compute the ε_j -path when the objective is keeping the exchange rate within a target band. For some period t+r, r=1,…,T,

[19] Note that if the values for P^* follow the actual data, then the system as a whole follows the actual path of the data.

[20] It is also possible to compute the policy shocks needed to return the exchange rate to the band more gradually if desired.

we want the exchange rate within the pre-specified band $P^*_{i,t+r} \pm \tau$ where τ is half the bandwidth.[21] It may be that no policy intervention is needed, which will occur when

$$P^*_{i,t+r} - \tau < \sum_{q=0}^{r-1} \sum_{k=1}^{M} c_{2\bullet,q,ij} u^F_{k,t+r-q} + \sum_{q=0}^{r-1} \sum_{\substack{k=1 \\ k \neq j}}^{N} d_{22,q,ik} \varepsilon^p_{k,t+r-q} + \sum_{q=0}^{r-1} d_{22,q,ij} \hat{\varepsilon}^p_{j,t+r-q} + BP_{r,i,t} < P^*_{i,t+r} + \tau ,$$

where $\hat{\varepsilon}^p_{j,t+r-q}$, q=0,…,r-1, are the shocks to the policy equation, some of which may represent policy interventions undertaken prior to period t+r to attain that period's objective, and some of which may simply represent the random draw for those periods in which no policy intervention is needed. That is, when the above inequalities hold, the shocks in the economy, combined with the base projection, imply an exchange rate within the target band, so that no policy intervention is required in period r. If, on the other hand,

$$\sum_{q=0}^{r-1} \sum_{k=1}^{M} c_{2\bullet,q,ij} u^F_{k,t+r-q} + \sum_{q=0}^{r-1} \sum_{\substack{k=1 \\ k \neq j}}^{N} d_{22,q,ik} \varepsilon^p_{k,t+r-q} + \sum_{q=0}^{r-1} d_{22,q,ij} \hat{\varepsilon}^p_{j,t+r-q} + BP_{r,i,t} < P^*_{i,t+r} - \tau$$

or if

$$\sum_{q=0}^{r-1} \sum_{k=1}^{M} c_{2\bullet,q,ij} u^F_{k,t+r-q} + \sum_{q=0}^{r-1} \sum_{\substack{k=1 \\ k \neq j}}^{N} d_{22,q,ik} \varepsilon^p_{k,t+r-q} + \sum_{q=0}^{r-1} d_{22,q,ij} \hat{\varepsilon}^p_{j,t+r-q} + BP_{r,i,t} > P^*_{i,t+r} + \tau ,$$

the endogenous forces in the economy, along with any previous policy interventions, produce values for the exchange rate outside the band. Then a policy intervention is needed to return the exchange rate either to the edge of the band or to some pre-specified value interior to it. For instance, if the policy choice is to return to the edge of the band, as we assume in the following exercise, then the policy innovations analogous to those in equations (6) and (7) are computed so as to attain $P^*_{i,t+r} \pm \tau$, depending on whether the exchange rate is expected to be above or below the tolerance range.[22]

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[21] As specified, the band is symmetric. It is straightforward to allow for asymmetric bands. Also note that the path for the target, $P^*_{i,t+h}$, need not be constant. For instance, we could allow for a crawling peg with a band around it.

[22] It is widely accepted that intra-marginal interventions were frequent under the ERM. Our assumption about the intervention mode, although somewhat simplistic, has an advantage that it allows us to avoid the arbitrary decision regarding how much deviation from the central rate prompts intervention and which level the central bank intends to push the exchange rate to after intervention. See Krugman (1991) and Svensson (1992), for details.

In the experiments below, we specify a target path, construct a band around this path, and then take 1000 draws from the estimated residuals by employing a bootstrap. Note that in this approach, we do not impose an arbitrary assumption about the probability density generating the residuals. Rather, by sampling from the estimated residuals, we hope to capture the type of randomness that is in the economy. For each trial, computed values for the system variables, consistent with our fundamental property, are those the economy will follow under the assumed ε_j -path that attains the desired exchange rate path, given the shocks to the other equations.[23]

To reinforce the earlier discussion of how the policy process is mimicked by our approach, note that the iterative process by which we compute $\hat{\varepsilon}^p_{j,t+1}$, $\hat{\varepsilon}^p_{j,t+2}$, …, incorporates the 'new information' that has arrived in the form of the shocks to the entire ε vector in the previous periods. If the realized values of these shocks are negligible, the shocks are such that the exchange rate stays within the target zone. But the policy shocks are modified in response to realizations of shocks to any system variables when they move the exchange rate outside the target zone.

4. Simulation Results

The panels in Table 3 contain selected results for the countries in the sample. Prior to discussing specific results, several comments about Table 3 are needed. First, the target zone in each experiment is expressed in terms of percentage deviations around the HP trend. That is, we adopt the position that at least in the short-run, the policy authority does not (or cannot) alter the fundamental forces in the domestic economy relative to the world economy, so that management of the exchange rate is relative to the existing value of the trend.[24] Second, as indicated above, in the reported results we have excluded trials for which

[23] In addition to the additive uncertainty obtained when we draw from the actual residuals, it is also possible to incorporate multiplicative uncertainty in the spirit of Brainard (1967) by using the computed standard errors of the coefficients. For simplicity, we do not undertake this exercise here.

[24] We are modeling the deviation of the log of the exchange rate from its HP trend, $\log e_t - \log \overline{e}_t = \log(e_t / \overline{e}_t)$, where $\log \overline{e}_t$ is the HP trend. The target zone is constructed as $\log \overline{e}_t$ ± (half bandwidth), and the policy authority responds if $\log e_t$ is outside this range. For instance, for a ±2% band, the target zone would be $\log \overline{e}_t \pm 0.02 = \log \overline{e}_t \pm \log(\exp^{0.02}) = [\log(\overline{e}_t \exp^{-0.02}), \log(\overline{e}_t \exp^{+0.02})]$. In terms of the level of the exchange rate, it would be ±2% around the target rate, $\overline{e}_t$.

the domestic interest rate turns out to be negative.[25] Third, we increase the bandwidth in each country until it becomes wide enough that no policy interventions are called for. For Canada, this threshold is ±10% and for France it is ±5%, so no additional results are reported for in those panels.

Table 3 here

The first two rows of each panel show the number of policy interventions needed under the various bandwidths for the alternative cases where the exchange rate is above and below the pre-specified bands. Note that each experiment has 1000 trials, and each trial has a 36 month horizon. Thus, for example, using Canada and a ±1% bandwidth, we intervene 3,466 times of the 36,000 months in the trials when the exchange rate violates the top of the band, and 4,113 times when the exchange rate is below the band. (Note that lower in the table we also report these statistics combined in the form of the average number of interventions per trial, which adds together these numbers and divides by the number of trials. For instance, for Canada for the ± 1% bandwidth, we report average interventions per trial of 7.6.)

The remaining rows of each table give impressionistic evidence as to whether the Lucas critique is applicable. Before starting a review of this evidence in rows 3 and 4 of each panel, recall that when the exchange rate is within the target band, the shock to the foreign reserves equation is simply the result of the random draw for that particular trial. When the exchange rate is outside the band, the foreign reserves shock is computed so as to return the exchange rate to the edge of the band. Thus, for each of the 1000 trials, we have a vector of length 1000 where element i of this vector represents the maximum shock to the foreign reserves equation in trial i. Similarly, there is another vector in which element i is the minimum shock in trial i. The intent is to discover if the required policy interventions are far outside the bounds of the historical record; that is, whether these interventions are frequent and unusually large in absolute value.[26] When the band is narrow, we relatively frequently need to replace the random draws with computations of the shocks needed to return to the band. If these interventions are large and/or frequent enough, then policy

[25] We have also performed experiments where we include trials with negative interest rates. Results and conclusions from experiments that include cases where the counterfactual nominal rate is negative not only remain unchanged, but are surprisingly close numerically to what we report.

[26] One formal possibility is to investigate the policy innovations as draws from a mixture of distributions. For example, suppose the actual residuals are normally distributed. If the interventions that occur when the exchange rate lies outside the band are also drawn from a normal distribution but perhaps with a different mean and/or variance, it should be possible to draw inferences about whether the policy actions when the exchange rate lies outside the band are from the same distribution. For now, though, we focus on the more casual analysis outlined in the text.

makers would need to be concerned about whether policy interventions were signaling to agents that the model had changed in some fundamental way; if not, then policy makers have a much better chance at implementing the indicated policy without having to worry about Lucas critique issues. Note that as the band widens and fewer policy interventions are needed, the distribution of the elements of these vectors will converge to the distribution of the actual residuals in the foreign reserves equation.

We report in rows 3 and 4, respectively, the 95th percentile of the maximum shocks and the 5th percentile of the minimum shocks across the 1000 trials. (We cut off the tails to avoid outliers; however, this has virtually no effect on the reported results as there is little difference between these percentiles and the absolute maximum or minimum.) We also report the interquartile ranges for the vectors of maximum and minimum shocks to obtain an impression of both the central tendency and variability of these shocks. In the cells labeling these rows, we also note the maximum and minimum structural residuals from the estimation. For example, for France with the ±2% band, the 95th percentile for positive policy shocks was .370, and the interquartile range was (.153, .077) compared with a maximum in-sample residual for the foreign reserves equation of .132. For the 5th percentile for negative policy shocks, the extreme value in the interventions was -.227 with an interquartile range of (-.062, -.110) compared with a value of -.104 in the estimated residuals.

Our general observation from the results in rows 3 and 4 is that for all the countries in our sample, when exchange rate targets are controlled with a bandwidth of ±5%, the extreme values of the policy interventions are seldom larger than a factor of about 1.2 of the largest residual from the estimation. At least casually, policy authorities should be able to pursue an exchange rate within about five percent of its long run trend without needing unduly large policy shocks. Note that this includes the cases of Germany, Japan and the UK for whom frequent interventions are made in this range.

The remaining rows of each panel give additional information on whether the Lucas critique may be appropriate. Row 5 reports on the average number of interventions per trial, along with the computed standard deviation. This row allows the reader to judge whether the interventions are “frequent enough” to alert agents that a policy different than what may have been observed in the estimation period is in place, regardless of the size of the interventions reported above. Row 6 reports on the average maximum number of consecutive months of intervention, also with a standard deviation.[27] Rows 5 and 6 are included, in addition to rows 3 and 4, since it may be not only the size of the policy shocks relative to estimated residuals that signal to agents that a new policy is in place, but also the frequency and/or duration of intervention. The final row reports on the number of the 1000 trials which require any intervention.

The frequency and size of interventions declines as the bandwidth widens, as do the number of trials with any intervention. In all countries, with a 15% band, little or no intervention is necessary. The results indicate that maintaining a narrow band is possible only with relatively frequent, relatively large-sized interventions. For instance, maintaining a ±1% band around the German mark requires on average interventions in 27 out of 36 months. However, for ±1% bands, the sizes of policy shocks are large and often well outside the boundary set by actual maximum or minimum values. On the other hand, midsize bands of ±5% to ±10 % would not cause excessive strain in any of the economies we examine in that the number of interventions in most cases is in the range of three or four months using a 36 month horizon. These results on frequency are in addition to those noted above, where the size of the shocks for bandwidths in the range of ±5% is also not unduly large. It is also interesting to note that the "comfortable" degree of exchange rate flexibility closely matches actual flexibility that each country has experienced. For instance, countries that have maintained fairly narrow exchange rate bands such as Canada and France may handle a 5% band with little difficulty. For the other countries, typical floaters such as Germany, Japan, and the UK, the same bandwidth may likely cause some strain and perhaps a wider band such as 10% or so appears more plausible. With a 10% band, the need for intervention is reduced to less than one in 36 months in all three floaters. Incidentally, most proposals of target zones for G-3 currencies recommend ±10 to 15 % (Clarida, 2000)[28] ; our results suggest that bands on the order of ±5 to 10 % may also be viable.

[27] We have only kept track of whether interventions are needed. Thus, when we report on average maximum consecutive interventions, some of the interventions in a given trial may be negative and some may be positive.

[28] According to Reinhart and Rogoff (2002), Canada has been on unofficial target zone with a 2% band against the US dollar since May 31, 1970. France, under ERM, had maintained a 2.25% band against the mark. Although the band was widened to ±15% in the aftermath of the 1992-3 financial crises of the EMS, France kept the exchange rate close to the parity. This is shown in Table 1. Standard deviation of the exchange rate (deviation from the HP trend) is lower in the recent simulation period than in the earlier estimation period.

Germany and Japan are considered quintessential floaters against the dollar. Although both exchange rates became slightly more stable in the simulation period than in the estimation period, the difference appears insignificant. In the case of the UK, the exchange rate was as volatile as the mark or yen

Figure 2 here

Six plots for each country shown in Figure 2 summarize the main results of this paper. Each plot shows changes in the standard deviation over the final 24 months (of the 36 month simulation period) of a particular variable as the bandwidth varies. We drop the initial 12 months to guard against initial conditions affecting the results. We consider various bandwidths: ±1, ±2, ±5, ±10, and ±15. The maximum bandwidth we consider is ±99 %, which approximates a float, and is shown on the far right side of each plot.

The first row of plots shows that across countries exchange rates become more variable as the band widens. It should be noted that, even with an extremely wide band, the exchange rate changes may be at least partially constrained by actual data. For instance, the standard deviation of simulated exchange rate changes never goes beyond 1.5% for Canada. In all cases, it is held within a 5 % range.

The second row in Figure 2 shows that with a wider band, the standard deviation of changes in foreign reserves in most countries declines since the central bank does not have to intervene as often or as aggressively. In marked contrast, money supply variability, shown in row 3, appears hardly affected by variations in the bandwidth, excluding the case for France. Although we do not constrain the results by imposing sterilized intervention, they are consistent with the conventional wisdom that most interventions are sterilized.

Interest rate volatility, shown in the fourth row, seems hardly affected by exchange rate bands with the sole exception of the narrowest band for France. This suggests that (presumably sterilized) intervention does not entail significant changes in the interest rate.[29] In Japan and Germany, whose interest rates would affect more countries in the world, varying the width of the exchange rate bands has little or no effect on interest rate volatility.

The issue of whether a wider band reduces output or inflation volatility is addressed in rows 5 and 6 of Figure 2. Both output and inflation volatilities decline sharply in France as the bandwidth increases

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in the estimation period. In the recent period, however, there is some noticeable reduction in exchange rate volatility.

[29] In developing countries, in sharp contrast, sterilized intervention (in support of the domestic currency) tends to increase the domestic interest rate, which constitutes a nonnegligible cost of intervention. See Calvo (1991).

from 1 to 2%, but little thereafter. In Germany, the standard deviation of output declines almost 20 percent by moving from a 1% to a 5 % band. Some considerations suggest that it is difficult to consider these cases as representative. First of all, these volatility reductions occur when the band widens from a very narrow range of 1 or 2%. As mentioned above, the results obtained from such narrow bands are less reliable and should be viewed with more care especially when the band under consideration is very different from the actual band. In all other cases, neither output nor inflation volatility is affected by changes in bandwidths, especially around the realistic ranges of 5 to 10%.[30]

Our findings are generally consistent with Baxter and Stockman (1989), Flood and Rose (1995), and Obstfeld and Rogoff (2000a).[31] These authors suggest that the increases in real and nominal exchange rate volatilities since the move to the generalized float in 1973 have not been associated with any significant changes in volatilities of macroeconomic variables. Our results, in addition, suggest that the tradeoff between exchange rate and interest rate volatility investigated in Svensson (1991) is not inevitable. As a corollary, the suggestion by Reinhart and Reinhart (2001) that the G-3 should be concerned with increases in interest rate volatility when they attempt to reduce exchange rate volatility might be misguided. This paper also casts doubt on the applicability of the finding by Ghosh et al. (1997) that pegged regimes are characterized by lower and more stable inflation but more pronounced output volatility. A more recent study by Levy-Yeyati and Sturzenegger (2003) shows, consistent with our findings, that exchange rate regimes have no significant impact on output growth or volatility in industrial countries although they find that greater exchange rate flexibility promotes output stability and growth in developing countries.

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[30] Various proposals have been made regarding the size of bandwidths for target zones for major industrial countries. McKinnon (1988) has proposed a quasi-fixed exchange rate regime among the G3 to be achieved by monetary policy rules aimed at the exchange rate. Krugman (1989) and Williamson (2000) propose wider bands such as ±10 % or wider. Our study seems to suggest that an optimal band could be narrower than 10% but probably not narrower than 5% or smaller.

[31] Flood and Rose (1995) find some evidence of a volatility tradeoff between exchange rate and output in monthly data for eight industrial countries. However, they find little evidence that greater exchange rate flexibility reduces volatility in interest rate, money, or even foreign reserves. The difference between their results and ours may be due to the difference in the data period. The 1960-1991 period used by Flood and Rose (1995) encompasses the Bretton Woods period, which had low foreign reserves volatility as well as low exchange rate volatility since at least during early part of the period the pegs were credible and speculative attacks on currencies were much rarer due to controls on international capital mobility. This suggests that the relationship between the two variables is probably nonlinear and there may be other factors that link the two. For instance, when the exchange rate is credibly fixed, it will be stable with little or no intervention. When credibility is in doubt, active intervention may not be sufficient to stabilize it, causing both the exchange rate and foreign reserves to be more volatile.

5. Discussion

In this paper, we develop a methodology with which we can evaluate the stabilizing properties of exchange rate flexibility. Instead of dealing with polar regimes, we consider changes in exchange rate flexibility at the margin by adjusting the size of exchange rate fluctuation band in a target zone. The main findings of paper can be summarized as follows.

Coefficient estimates and impulse response functions indicate that a generic, small structural VAR model employed in this study captures the behavior of key relationships in the foreign exchange and money markets of major industrial countries. The IRFs are consistent with the notion that the effects of intervention dissipate in a matter of a few months; intervention can be effective but the effectiveness is largely short term.

Our most notable result is that greater exchange rate flexibility obtained through a wider band neither increases nor decreases volatilities in the interest rate, output, or inflation for the majority of cases. These results are broadly consistent with the findings of Baxter and Stockman (1989) and Flood and Rose (1995). They confirm that the "exchange rate disconnect" puzzle (Obstfeld and Rogoff, 2000a) may indeed be widespread.

We also find a variety of additional results of interest. First, our results show little effect on the variability of the money supply. Specifically, in Table 2 we reported that the during the simulation period, the actual standard deviation for log changes in the money supply in Canada was .046. In our experiments with Canada pictured in Figure 2, we find that the standard deviation across bandwidths is, with slight variability, .036. Similar results hold for France (.017 in the data in the simulation period vs. .018 for bandwidths greater than ±1%), Japan (.026 vs. .030) and the United Kingdom (.015 vs. .014). The only country where this observation does not hold is Germany (.017 vs. .032). Thus, to the extent that actions by countries to sterilize their interventions are in the data, in practice, adoption of target zones and the accompanying change in monetary policy would not dramatically alter the stability of key macroeconomic variables. Second, we find evidence that intervention significantly affects exchange rate volatility in all countries but France. Further, as documented in Table 3, the frequency and size of interventions declines as the bandwidth widens, as do the number of trials with any intervention. Third, we find that foreign reserves become more volatile as the exchange rate band is narrowed, reflecting the need for the policy makers to be more active in attaining the exchange rate goals.

An important implication follows from the finding that varying the width of the exchange rate band has virtually no impact on the volatility of key macroeconomic variables such as the interest rate, output and inflation. Specifically, promoting exchange rate stability, at least at the margin, does not in any obvious way result in higher costs typically associated with greater volatility in output or inflation. While in some cases very narrow bands do tend to raise output and inflation volatility, our results suggest that promoting exchange rate stability in small steps does not obviously sacrifice interest rate stability. The results thus support the idea that promoting stable exchange rates is welfare improving from a purely domestic point of view. One could make even a stronger case for greater exchange rate stability by invoking the fact that both exchange rate and interest rate stability of major industrial countries are public goods for countries with heavy external debt. If greater exchange rate stability of the G-3 currencies can be obtained with little or no increase in interest rate volatility, pursuing greater exchange rate stability appears to be more worthwhile than previously thought; for additional discussion, see Frankel (1999), Mussa, et al ., (2000), and Reinhart and Reinhart (2002).[32]

A variety of topics remain for future research. First, what is the source of the repeated occurrence of negative interest rates, especially with narrow bands? It may be a technical issue: in a world with historically low interest rates, bootstrapping exercises in which we draw from historical residuals may simply imply a relatively high incidence of these negative rates. Since, in our analysis, variability of virtually all the variables under discussion is unaffected whether trials with negative rates are included or not, it is not obvious that there are any empirical implications. Or, it may be a substantive issue: we have assumed that all responses are unilateral. Further analysis that models (at least occasional) policy coordination between countries may help address this issue. For example, if a country suspects that unilateral action will cause nominal interest rates to approach zero, it may trigger a request to other countries for joint action in the currency markets. Second, we have expressed exchange rates for all countries terms of the U.S. dollar (except France, where we employ the German mark), but have not

[32] On the other hand, Obstfeld and Rogoff (2000b) argue that, as domestic rules improve and international financial markets become more complete, gains from international cooperation in the setting of international monetary rules (such as exchange rate targets) may quite possibly of the second order.

modeled any U.S. policy behavior. Of course, U.S. policy action, either in terms of domestic policy initiatives or international ones, may have an impact on the manner in which other countries manage their exchange rates.

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Table 1: Standard Deviations

	Canada		France		Germany		Japan		UK		US	
	I	II	I	II	I	II	I	II	I	II	I	II
$\widetilde{e}$	.014	.013	.016	.003	.042	.035	.047	.037	.042	.020		
Δi , Δi^f	.031	.013	.026	.014	.022	.007	.021	.002	.031	.012	.026	.018
Δfr	.238	.041	.271	.145	.107	.053	.301	.255	.381	.201		
Δm	.062	.046	.048	.017	.055	.017	.042	.026	.035	.015		
$\widetilde{y}$, $\widetilde{y}^f$	.017	.010	.015	.010	.017	.013	.017	.025	.014	.008	.013	.009
Δp	.033	.008	.039	.006	.018	.005	.031	.004	.054	.008	.030	.007
Δp^{oil}											.298	.383

Note: I and II denote the estimation and simulation period, respectively.

Table 2: Estimation Results of Structural Policy-Block Parameters

Coefficient (t-stat)	Canada	France	Germany	Japan	U.K.
$g_{0,12}$	0.30 (1.11)	-0.13 (0.73)	0.14 (1.53)	0.14 (0.68)	0.17 (0.91)
$g_{0,13}$	-0.12 (0.53)	0.97 (0.56)	-1.44 (0.85)	0.22 (1.05)	-0.25 (0.54)
$g_{0,14}$	-1.89 (1.17)	-0.40 (1.69)	-0.45 (2.37)	-0.20 (0.79)	-0.56 (1.53)
$g_{0,21}$	-30.69 (2.14)	0.36 (0.45)	-1.24 (0.82)	-2.43 (0.63)	-4.17 (1.23)
$g_{0,31}$	-0.21 (1.51)	-0.13 (0.54)	0.33 (0.67)	-0.07 (0.28)	0.09 (1.83)
$g_{0,34}$	-0.15 (0.83)	-0.12 (1.02)	0.03 (0.20)	-0.39 (2.24)	-0.03 (0.45)
$g_{0,41}$	0.39 (1.88)	0.08 (2.37)	0.05 (2.90)	0.02 (2.04)	0.23 (2.74)
$g_{0,42}$	-0.06 (3.36)	-0.04 (2.37)	-0.01 (1.77)	-0.01 (2.25)	-0.04 (2.46)
$g_{0,43}$	-0.03 (0.40)	0.01 (0.16)	-0.04 (1.26)	0.01 (0.68)	0.14 (0.71)
$g_{0,45}$	-0.11 (0.78)	0.02 (0.36)	-0.04 (1.25)	0.01 (0.42)	-0.07 (0.63)

Table 3: Selected Simulation Results

A. Canada	±1.0%	±2.0%	±5.0%	±10.0%	±15.0%	Float
1. Interventions at upper bound	3466	743	7	0		
2. Interventions at lower bound	4113	873	0	0		
3. Max policy shock, 95 %	.492	.638	.693	.693	.	.
(actual maximum: .736; s.d.: 0.25)						
IQ Range: 75%	.333	.485	.653	.653		
25%	.162	.183	.486	.486		
4. Min policy shock, 5 %	-.516	-.697	-.710	-.710		
(actual minimum: -.720; s.d.: 0.25)						
IQ Range: 25%	-.372	-.481	-.656	-.656		
75%	-.209	-.211	-.436	-.436		
5. Mean # of interventions / trial	7.6	1.6	0.01	0		
(s.d.)	(2.9)	(1.0)	(0.8)			
6. Mean max consecutive interventions	2.6	1.2	0.01	0		
(s.d.)	(1.1)	(0.6)	(0.8)			
7. No of trials with any intervention	935	856	810	779		

B. France (/Germany)	±1.0%	±2.0%	±5.0%	±10.0%	±15.0%	Float
1. Interventions at upper bound	3556	587	0			
2. Interventions at lower bound	4825	348	0			
3. Max policy shock, 95 %	0.618	.370	.135			
(actual maximum: .132; s.d.: 0.038)						
IQ Range: 75%	.406	.135	.112			
25%	.161	.077	.077			
4. Min policy shock, 5 %	-2.05	-.227	-.128			
(actual minimum: -.104; s.d.: 0.038)						
IQ Range: 25%	-.660	-.110	-.110			
75%	-.159	-.062	-.069			
5. Mean # of interventions / trial	13.7	1.1	0			
(s.d.)	(7.5)	(1.6)				
6. Mean max consecutive interventions	5.7	0.8	0			
(s.d.)	(4.4)	(1.0)				
7. No of trials with any intervention	997	490	0			

C. Germany	±1.0%	±2.0%	±5.0%	±10.0%	±15.0%	Float
1. Interventions at upper bound	14225	10053	3022	218	3	0
2. Interventions at lower bound	12401	9464	2867	137	5	0
3. Max policy shock, 95 %	.892	.741	.500	.358	.358	.358
(actual maximum: .385; s.d.: 0.066)						
IQ Range: 75%	.601	.665	.423	.127	.217	.217
25%	.261	.223	.088	.088	.088	.094
4. Min policy shock, 5 %	-.979	-.800	-.516	-.516	-.516	-.516
(actual minimum: -.520; s.d.: 0.066)						
IQ Range: 25%	-.660	-.529	-.322	-.264	-.264	-.264
75%	-.309	-.233	-.101	-.087	-.010	-.010
5. Mean # of interventions / trial	27.1	19.8	5.9	0.4	0.01	0
(s.d.)	(4.2)	(5.2)	(3.6)	(0.8)	(0.1)	
6. Mean max consecutive interventions	13.7	8.3	2.7	0.3	0.01	0
(s.d.)	(8.0)	(5.6)	(1.9)	(0.6)	(0.1)	
7. No of trials with any intervention	1000	1000	984	240	6	0

D. Japan	±1.0%	±2.0%	±5.0%	±10.0%	±15.0%	Float
1. Interventions at upper bound	13046	9229	3160	295	6	0
2. Interventions at lower bound	11265	8234	3016	326	12	0
3. Max policy shock, 95 %	.612	.545	.408	.376	.376	.376
(actual maximum: .381; s.d.: 0.101)						
IQ Range: 75%	.491	.434	.284	.255	.268	.268
25%	.332	.268	.140	.150	.173	.173
4. Min policy shock, 5 %	-.636	-.582	-.444	-.333	-.333	-.333
(actual minimum: -.323; s.d.: 0.101)						
IQ Range: 25%	-.496	-.434	-.312	-.317	-.317	-.317
75%	-.328	-.268	-.141	-.175	-.163	-.186
5. Mean # of interventions / trial	24.8	18.0	6.5	0.6	0.02	0
(s.d.)	(2.9)	(3.5)	(2.9)	(0.8)	(0.1)	
6. Mean max consecutive interventions	8.3	5.0	2.5	0.6	0.02	0
(s.d.)	(3.5)	(2.2)	(1.1)	(0.8)	(0.1)	
7. No of trials with any intervention	1000	1000	998	407	17	0

E. United Kingdom	±1.0%	±2.0%	±5.0%	±10.0%	±15.0%	Float
1. Interventions at upper bound	14957	10393	2999	229	5	0
2. Interventions at lower bound	7844	4932	1332	153	6	0
3. Max policy shock, 95 %	.492	.462	.340	.340	.340	.340
(actual maximum: .417; s.d.: 0.114)						
IQ Range: 75%	.374	.324	.324	.307	.307	.307
25%	.208	.147	.120	.182	.195	.214
4. Min policy shock, 5 %	-.544	-.501	-.401	-.501	-.501	-.501
(actual minimum: -.543; s.d.: 0.114)						
IQ Range: 25%	-.425	-.377	-.271	-.307	-.309	-.307
75%	-.281	-.241	-.140	-.163	-.171	-.171
5. Mean # of interventions / trial	23.7	16.1	4.5	0.4	0.1	0
(s.d.)	(3.5)	(4.0)	(2.5)	(0.7)	(0.1)	
6. Mean max consecutive interventions	8.2	5.1	2.2	0.4	0.1	0
(s.d.)	(4.1)	(2.6)	(1.1)	(0.6)	(0.1)	
7. No of trials with any intervention	1000	1000	989	280	8	0

Figure 1: Impulse Responses

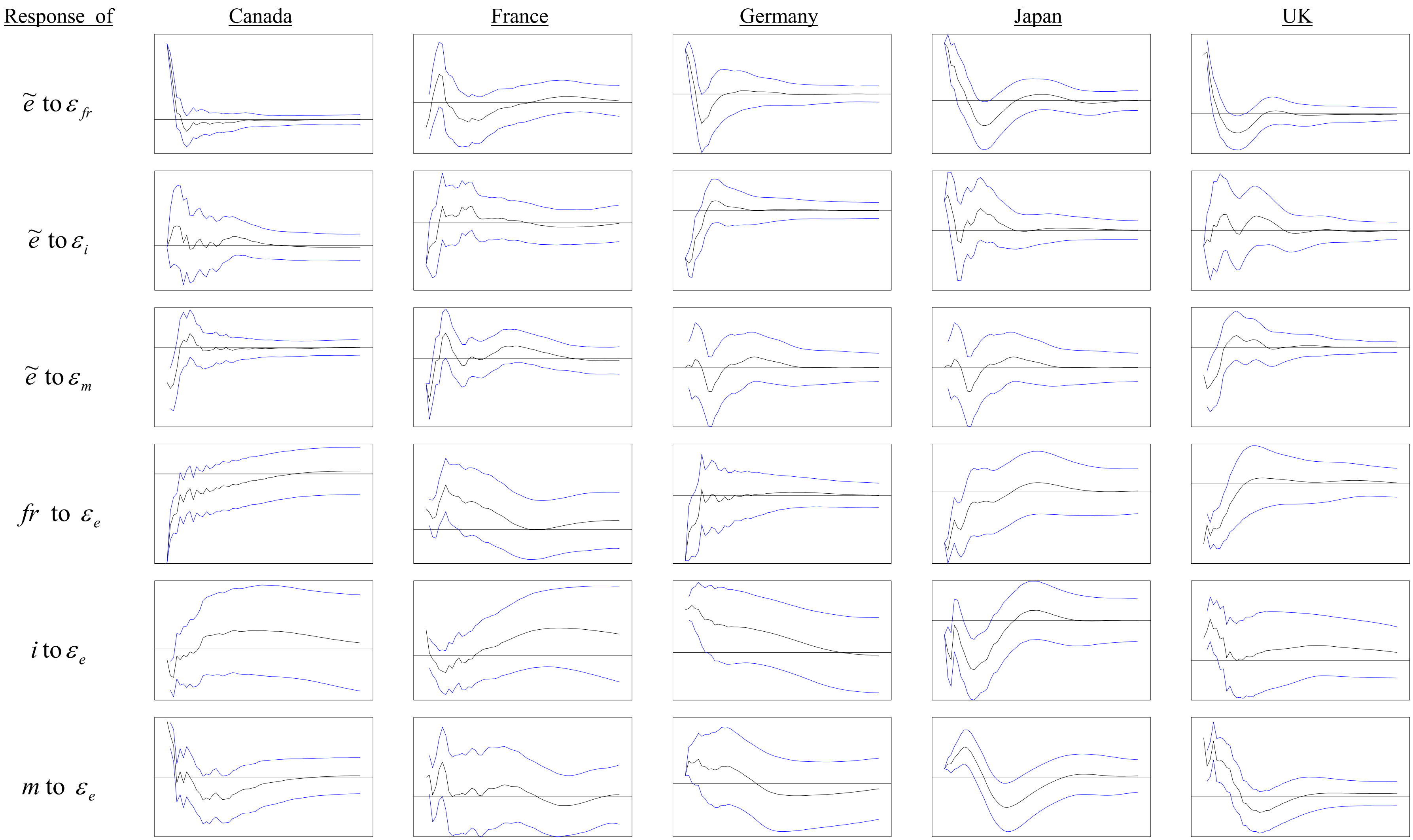

Figure 2: Bandwidth and Macroeconomic Volatility