Why do Central Bankers Intervene in the Foreign Exchange Market? Some New Evidence

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Abstract

This paper provides new empirical evidence about the effectiveness of sterilized interventions on exchange rates. A VAR formulation and information from the Exchange Stabilization Fund in U.S. are used to identify a shock that is orthogonal to the U.S. money supply and therefore mimics the role of sterilized interventions. According to my identification strategy, a sterilized intervention shock in favor of the U.S. dollar appreciates it against a trade-weighted currency index by roughly 1 percent. This appreciation is statistically significant, lasts for about 1 year, and is robust to alternative identification strategies.

Key Words: Exchange Rate, Sterilized Intervention, VAR, Open Economy

JEL Classification: C32, F3, E58

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1 Introduction

Sterilized interventions have been a controversial topic of international economics. Throughout the world, central bankers often use sterilized interventions to keep the exchange rate under control hoping not to affect domestic variables such as inflation and the interest rate. Recent examples of such interventions include China,[1] and Australia and Japan (Kearns and Rigobon, 2005). Similarly, Neeley (2001) presents the results from a survey distributed by the Bank for International Settlements to central banks worldwide. 18 out of 22 responding central banks reported to have intervened in the FX market at least once during the last decade. Moreover, those central bankers strongly believe in the effectiveness of interventions in the sense of altering the exchange rate without changes in the money supply.[2]

Yet scholars have shown great skepticism about the usefulness of exchange rate interventions. Their disbelief is based on the mixed evidence drawn from empirical studies. For example, the 1980s were characterized by studies, which agreed that sterilized interventions had at most a very short and hard to measure effect on exchange rates.[3] Dominguez and Frankel (1993a, b, and c), however, provide empirical evidence sympathetic with the idea that interventions, sterilized or not, do have effects on the exchange rate. Although they successfully provide empirical evidence of the effects of interventions, they agree that those affects tend to be short lived, at most a couple of weeks. Following Dominguez and Frankel's contribution, common wisdom has become more favorable towards intervening in the foreign exchange market, but there is no complete agreement among scholars.

In this paper, I revisit this old debate about the usefulness of sterilized intervention. I use a VAR framework as the econometric tool, U.S. data, and information from the

[1]The January 28th, 2006 issue of The Economist provides a comprehensive discussion of how China continuously used sterilized interventions to contain speculative capital inflows between 2002 and 2005.

[2]Among the countries answering the survey were Australia, Mexico, Poland, Japan, and Chile. More recently, Humpage and Ragnartz (2005) document the interventions by the Sveringes Riksbank over the period 1993 - 2002.

[3]See Edison (1993) for a comprehensive review of the literature during the 1980s

Exchange Stabilization Fund (ESF) to analyze the effects of U.S. sterilized interventions on the U.S. economy over the past 40 years.[4] Compared to previous studies, a VAR framework facilitates the study of the dynamic reaction of exchange rates following an intervention shock. The agnostic identification approach outlined in Uhlig (2005) is applied to uncover a shock to the ESF account with a minimal effect on the U.S. money supply. Therefore, this shock mimics the textbook definition of sterilized interventions.

The main results are: Following a 15 percentage increase in the U.S. currency holdings in the ESF account, the U.S. Dollar appreciates roughly 1 percent with respect to the Deutschmark, the Canadian Dollar, and a trade-weighted exchange rate. The appreciation is statistically significant and persistent, usually lasting at least for one year. The result is robust to alternative identification procedures and additional variables. Interestingly, the initial appreciation of 1 percent is close to the results reported in Dominguez and Frankel (1993c), Kim (2003), and Kearns and Rigobon (2005). I also find that sterilized intervention shocks explain between 10 and 20 percent of the total variability in the Deutschmark-Dollar exchange rate.

It is important to note that my study does not address other relevant questions related to interventions and exchange rates. First, the paper focuses on the post Bretton-Woods era so it is completely silent about interventions during periods with fixed exchange rate regimes. Second, past experience, e.g. the Plaza Agreement, shows that interventions are likely to be a coordinated effort by at least two countries.[5] Due to data availability, I concentrate on the effects of one-sided interventions, i.e. those in which only U.S. intervenes.

The rest of the paper is organized as follows. Section 2 provides a description of the database and the econometric tool applied in this study. Section 3 discusses the results and several robustness checks. Finally, Section 4 provides concluding remarks.

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[4] To my knowledge Kim (2003) is the only paper studying interventions within a VAR framework. My study, however, departs from his in two dimensions: The identification strategy and the variable measuring interventions.

[5] See Edison (1993) for a comprehensive discussion of the coordinated intervention following the Plaza Agreement.

2 Econometric Methodology

From the methodological perspective the contribution of this paper is twofold. First, I exploit the information in the Exchange Stabilization Fund, which has traditionally been used to conduct international monetary policy in U.S. Surprisingly, this account has been largely ignored in empirical studies, especially in intervention studies. Second, this paper uses VARs to undercover the effects of sterilized interventions on exchange rates.

My choice of VARs is motivated by two observations. First, the VAR literature has evolved significantly over the past decade thanks to efforts to understand the effects of monetary and technology shocks (Christiano et al., 1999 and Fisher, 2003). Paradoxically, studies on interventions have concentrated on single regressions with the only exception being Kim (2003). Second, by construction VARs can easily undercover the dynamics of not only exchange rates but also other variables like prices and interest rates. Of course, VARs suffer from the curse of dimensionality, which may deliver imprecise estimates but I consider that the benefits outweigh the dimensionality problem.

2.1 The Exchange Stabilization Fund (ESF)

In a sterilized intervention the monetary authority carries out equal foreign and domestic asset transactions in opposite directions such that the net effect on the domestic money supply is zero. For the U.S., however, the Treasury is the institution in charge of interventions and the international monetary policy. Every intervention in the foreign exchange market by the Treasury is recorded in the Exchange Stabilization Fund. In general, movements in this account are the result of three types of operations: purchase or sale of foreign currency, changes in U.S. holdings of special drawing rights (SDR), and financial aid to foreign governments.[6]

Broadly speaking the ESF holds three types of assets: U.S. assets that include U.S.

[6] As discussed later on, there is no way to distinguish between pure sterilized interventions and loans to foreigners whose net effect on the money supply is zero.

dollars and treasury bonds, foreign currencies and foreign bonds, and SDR.[7] A simple balance sheet for the ESF is presented in Table 1.

Table 1.

Liabilities	Assets
SDR Allocations	U.S. Securities
SDR Certificates	SDR
	Foreign Securities

Table 2 provides statistics for some variables in the ESF and the nominal exchange rate during the 1980s (Foreign currency per dollar, s_t^{For} where For = [Yen, Deutschmark(Dm), Canadian Dollar(Cd)]).[8] It is clear the significant variation the dollar experienced during the 1980s. By October 1984, just prior to the Plaza Meeting, the dollar traded at 3 Deutschmarks. Starting in 1985, however, the dollar quickly depreciated reaching a low of 1.52 Deutschmarks per dollar by the end of 1987. With regard to the ESF's portfolio we see that 4/5 of it is allocated to foreign securities.[9]

The last row in Table 2 presents the correlation between foreign securities and the bilateral exchange rates between the U.S. and Germany, Canada, Japan, and the U.K., respectively. According to this table, the Yen-U.S. Dollar rate was negatively correlated (-0.78) with foreign securities in ESF's portfolio. Intuitively, this number tells us that increases in foreign securities were associated with dollar depreciations suggesting that interventions may have been effective. It is a well-known fact that there is an endogeneity problem between the decision to intervene and the exchange rate (see Kearns and Rigobon 2002, for a recent discussion), so we cannot conclude that changes in the ESF induced changes in the exchange rate. However, the numbers in Table 2

[7] The ESF's balance sheet is reported in the Treasury Bulletin on a quarterly basis.

[8] The 1980s was the period with most activity in the ESF coming from interventions in the foreign exchange market.

[9] ESF's foreign securities were mainly denominated in Yen, Deutschmarks, and Pounds.

suggest that a more comprehensive study based on the ESF's portfolio composition may shed light on the effects of interventions on exchange rates.

Table 2.

	Statistic			
Variable	max	min	mean	σ
Domestic Securities*	6,386	1,330	3,225	1,204
Foreign Securities & SDR*	28,784	8,522	15,115	8,198
s^{DM}	3.17	1.52	2.22	0.45
s^{Cd}	1.41	1.15	1.26	0.07
s^{Yen}	271.62	124.9	191.27	48.28
	Correlations			
	s^{DM}	s^{Ca}	s^{Yen}	s^{Pd}
Foreign Securities	-0.78	-0.45	-0.78	0.19

*Quantities in millions of US Dollars

Sample: 1980:I - 1989:IV

2.2 A VAR framework

Unlike previous papers, this study proposes a VAR as the tool to analyze the effects of interventions. To do so, I begin by defining a sterilized intervention in terms of the information enclosed in the ESF account. Then, I describe the identification strategy that is an application of Uhlig (2005).

2.2.1 Some discussion about Sterilized Interventions

Ideally, a sterilized shock is an innovation to the ESF's assets that leaves the U.S. money supply unchanged at every single period following the intervention. Imposing this restriction, however, requires an infinite number of restrictions, one for each period, over a finite number of coefficients defined by the elements of the VAR. Therefore, we need to truncate the definition to convert the problem into a finite and tractable one. With this in mind we can say that a sterilized shock is an innovation to ESF's assets, which does not change the money supply for K periods following the shock, where K is a number suitably chosen. Based on those observations I provide the following identifying assumption.[10]

Assumption A sterilized intervention is a shock to the ESF's assets such that the domestic money supply does not change for K periods.

This assumption, however, is not enough to identify a sterilized shock as there may be several shocks that leaves the domestic money supply either unchanged or its impulse response statistically insignificant. Let us consider the following cases: monetary shocks, fiscal shocks, and loan and credit shocks.

Monetary Shocks:

- Christiano, Eichenbaum, and Evans (2005) propose a model where the money supply does not change during the first two quarters following a decline in the interest rate. To rule out this type of shock, I require that the change in the money supply be as close to zero as possible for the first K periods, see program (P.1) for the exact implementation of my identification scheme.

- Empirically, Christiano, Eichenbaum, and Evans (1999) show a case (Figure 8 in their paper) in which the response of money supply to a monetary policy shock is statistically insignificant. They argue that for the particular sample period under consideration (1989:10 - 1995:03) not only the impulse responses of the money supply and other variables such as prices, non-borrowed reserves, total reserves, funds rate, are very close to zero. This pattern seems related to the sample period under consideration (see Sections 4.4.4. and 4.4.5 in their paper).

[10] Some guidance can be obtained from the variance decomposition analysis in the VAR literature. There the contribution of some orthogonal innovation to the total variance of a given variable is computed based on a period sample ranging between 2 to 5 years.

As will become clear, my sample is quite different from their period. To be safe, however, I consider an identification scheme that delivers a significant change to the ESF account (there is no reason to suspect that ESF account should behave differently than the rest of the nominal variables Christiano et. al.'s sample).

Fiscal Shocks:

- A non-monetized fiscal shock does not change the money supply. In principle, this shock could be taken as a sterilized intervention shock. However, the ESF is unlikely to react to fiscal shocks. This is due to the fact that the ESF is exclusively used to stabilize the exchange rate or to provide international financial aid.

Loan and Credit Shocks:

- Loan and credits do change the ESF. They are short-term transactions (typically less than 6 months) which temporary change the money supply. However, one can think of situations where the loans are repaid within one period (a quarter in this study) such that the recorded transactions suggest that a sterilization took place. This situation is impossible to distinguish from those in which the Treasury conducts a true sterilized intervention. The loan and credit transaction, however, has the advantage of adding additional variation to the ESF. These fluctuations are particularly important for the post-1995 period when the Treasury decreased its interventions in the foreign exchange market.

2.2.2 Method

Broadly speaking the econometric approach consists of applying Uhlig (2005) to identify a sterilized shock.[11] Consider the following VAR representation:

$$Y_t = B_{(1)}Y_{t-1} + B_{(2)}Y_{t-2} + \cdots + B_{(l)}Y_{t-l} + u_t, \tag{1}$$

[11] Uhlig's approach has become increasingly popular thanks to its flexibility and straightforward implementation. Some recent examples include: Scholl and Uhlig (2005) who uses this methodology to undercover the effects of monetary shocks on the exchange rate. Similarly, Braun, DeBock, and DeCeccio (2005) apply Uhlig's procedure to analyze the interaction between money and labor.

where u_t is the one-period ahead forecast error, Y_t is an m dimensional vector that includes, among other things, the money supply stock, the exchange rate and the information from the ESF account. Let $\widetilde{A}$ denote the Cholesky decomposition of $\sum = Euu'$, i.e. $\widetilde{A}\widetilde{A}' = \sum$, and let A be the matrix relating the forecast errors, u, to the structural errors, v, through the equation $u = Av$. As in the related literature, I normalize the structural errors to have an identity variance matrix and therefore A satisfies AA' $= \sum$. If a is the i-th column of A, then it represents the initial response of Y to a one-standard deviation shock to the i-th fundamental innovation. We ultimately want to identify the column corresponding to a sterilized shock.

Proposition 1 in Uhlig (2005) shows that any vector a can be characterized by the matrix $\widetilde{A}$ and some m dimensional vector α of unit length so that $a = \widetilde{A}\alpha$. Therefore, identification of a reduces to the identification of the unit-length vector α. Operationally, it is a lot easier to work with α than with a.

Once we have identified the column a, computing impulse responses is straightforward. Let $r_i(k) \in R^m$ be the vector response at horizon k to the i-th shock in a Cholesky decomposition of $\sum$. Then, the impulse response vector $r_a(k) \in R^m$ for a at period k is given by:

$$r_a(k) = \sum_{i=1}^{m} \alpha_i' r_i(k). \tag{2}$$

The vector α has $m - 1$ coefficients to be identified, as the remaining coefficient is pinned down by the condition $||\alpha|| = 1$.

Let $r_{m,esf}(k) \in r_{esf}(k)$ denote the response of the money supply to a sterilized intervention shock. Then, identifying this shock imposes the following set of conditions on $r_{m,esf}(k)$:

$$r_{m,esf}(1) = r_{m,esf}(2) = \cdots = r_{m,esf}(K) = 0,$$

where K is the maximum number of periods in which the money supply does not react to an intervention shock. Simple accounting shows that the zero-restriction condition can be imposed in at most $m - 2$ periods, i.e. the system is exactly identified if

$K = m - 2$.[12] For K greater than $m - 2$, we need an alternative procedure to identify α. The approach I propose here is to identify α such that $r_{m,esf}(k)$ is as close as possible to zero for K periods. In particular, I choose the following program to identify a sterilized intervention shock:

$$\alpha = \arg\min_{\widetilde{\alpha}} \sum_{t=1}^{K} \delta_t \left[r_{m,esf}(t) \right]^2, \tag{P.1.}$$

$$\begin{aligned} \text{subject to } \|\widetilde{\alpha}\| &= 1, \\ r_{esf,esf}(1) &\geq 0, \end{aligned}$$

where $r_{m,esf}(t)$ is the dynamic response of money resulting from the application of (2). I impose the last inequality to concentrate in those cases in which there is a significant and positive movement of the ESF account following a shock to it. In Section 3, I explain that the inequality condition is related to interventions aiming to appreciate the U.S. dollar, an intervention in favor of the U.S. dollar. Alternatively, we can switch the inequality sign and interpret the intervention as one whose goal is to depreciate the dollar. Finally, δ_t is a positive coefficient that declines with t; I introduce this coefficient to penalize more severely initial deviations from zero of the domestic money supply.

There are two remaining issues to be discussed. First, we need to consider the variables to be included in Y. A known disadvantage of VARs is that their precision, as measured by standard errors, decreases with the number of parameters to be estimated. Therefore, I choose the parsimonious representation followed by Eichenbaum and Evans' (1995) study of exchange rates they include the following variables: domestic output, interest rate differentials, exchange rate, domestic price deflator, and a money aggregate. Initially, my study uses a vector Y composed of domestic output, a price deflator, domestic interest rate, the ESF account, the exchange rate and a money aggregate.

[12] There are m - 1 conditions that can be imposed. However, if this were the case, then we end up with the trivial solution in which m - 1 coefficients of α are zero and the last coefficient is one. To solve this triviality one needs to impose m - 2 conditions, which identify α up to a scaling. See the next section for an example of how to choose the scale.

Later I extend the analysis to include the foreign interest rate. I choose not to include an interest rate differential because this imposes a restriction between the interest rates. I leave the data to decide whether this is the case.

Second, we must decide what asset from the ESF to use in the study. In principle, we could choose either domestic or foreign assets for the study. I choose the first option: U.S. bond holdings in the ESF. This choice avoids the endogeneity problem common to empirical studies involving exchange rates and foreign assets (see Kearns and Rigobon, 2005). Endogeneity might arise in my study since foreign assets reported in the ESF were originally issued in foreign currencies, not dollars. The ESF, however, reports those securities in dollars using an average exchange rate for the period under consideration. This means that foreign assets in the ESF contain fluctuations that are not only because of interventions but also because of movements in fundamentals that affect the exchange rate.

2.2.3 Data

Data are quarterly and cover the post Bretton-Woods era: 1974:I-2000:IV. The information for the ESF comes from several issues of the Treasury Bulletin. For the domestic variables including the bilateral exchange rates I use the information available from the Federal Reserve Bank of St. Louis.[13] Prices correspond to the GDP deflator, the interest rate corresponds to the interest rate for U.S. T-Bills, and the money aggregate is MZM.[14] Finally, the foreign interest rate comes from International Financial Statistics available from the IMF.

[13] The series for the Deutschmark ends on December, 2001. According to the St. Louis Fed, the rates for the years 1999 - 2001 were derived using the official fixed euro conversion rates.

[14] My choice of MZM as the monetary aggregate is motivated by two observations. First of all, Altig, Christiano, Eichenbaum, and Linde (2004) find that a MZM-based VAR delivers well behaved impulse responses to monetary and technology shocks; this is not the case with an M1-based VAR. Secondly, program P.1 identifies an intervention shock by minimizing its effect on money supply. If we used M0 or M1, a broader monetary aggregate might have a significant change following the intervention through the money multiplier channel. As a consequence, exchange rates might significantly react to the intervention because of the change in M2 or MZM even though the monetary base is not economically different from zero.

2.2.4 Estimation

A direct assault on program $P.1$ might create computational problems due to the nonlinear condition $||\alpha|| = 1$. Following Uhlig (2005), I overcome this problem by parameterizing α in terms of new parameters λ_i. In particular, I use the following parameterization:

$$\alpha = \begin{bmatrix} cos(\lambda_1)cos(\lambda_2)cos(\lambda_3) \\ cos(\lambda_1)cos(\lambda_2)sin(\lambda_3) \\ cos(\lambda_1)sin(\lambda_2) \\ sin(\lambda_1)cos(\lambda_4)cos(\lambda_5) \\ sin(\lambda_1)cos(\lambda_4)sin(\lambda_5) \\ sin(\lambda_1)sin(\lambda_4) \end{bmatrix}. \quad (3)$$

It is straightforward to show that the nonlinear relation $||\alpha|| = 1$ is satisfied with this parameterization.

For inference and estimation I use the Bayesian approach outlined in Uhlig (1994). This approach has two appealing advantages. First, its implementation is relatively easy. Second, it provides a conceptually clean framework to draw error bands and impulse responses. Using traditional procedures I determine that the optimal number of lags in our VAR representation is four.

Let B and $\sum$ be the coefficient and variance matrices in (2) and $\widehat{B}$ and $\widehat{\sum}$ their maximum likelihood estimates. Moreover, I assume that $(B, \sum)$ belongs to the Normal-Wishart family. Then, we can show that the posterior of $\left(\widehat{B}, \widehat{\sum}\right)$ belongs to the Normal-Wishart family too, see for example Uhlig (1994). Once the posterior has been derived, we can draw error bands and other statistics using Gibbs sampling.[15] Alternatively, we could use bootstrapping as in Christiano, Eichenbaum, and Evans (1999) to compute error bands. I choose the former since its implementation is more transparent for the case under consideration.

[15] In the following sections, I discard the first 100 draws, and then use the next 200 draws that solve problem (P.1) to compute the mean and error bands for the impulse responses. Adding additional draws did not change significantly the results.

3 Results

3.1 The Benchmark Case

Initially, I consider a VAR that includes output, the interest rate, the exchange rate, the money supply, the price deflator, and the ESF (ESF holdings of U.S. T-bills and dollars for the reasons explained above.)[16] I impose the zero restriction on the money supply to be 20 periods (5 years); $K = 20$ in program P.1. I include four different exchange rates: a trade-weighted exchange rate, the Deutschmark-Dollar exchange rate, the British Pound-Dollar exchange rate, and the Canadian dollar-U.S. dollar exchange rate. Figure 1 presents the impulse response functions of the exchange rate to a one standard deviation shock to the ESF account, i.e., a one-standard deviation sterilized intervention shock. Since the ESF account is defined in terms of domestic bonds, a positive shock to this account implies an increase in the demand for domestic bonds. Each figure shows the response of a given exchange rate to the sterilized intervention shock. The grey are represents one-standard deviation error bands. We see that on average the U.S. dollar appreciates after a positive sterilized intervention shock.

Upon impact the Deutschmark depreciates about 1.5% against the U.S. dollar. Moreover, it keeps depreciating until around 6 quarters after the intervention. Based on the median response, the maximal depreciation is 2.5%. The initial depreciation is statistically significant at 68% but not at 95% confidence levels. Perhaps this initial weak response rationalizes why previous studies, based on different econometric approaches and concentrated in weekly or monthly data, have rejected the effectiveness of sterilized interventions.

Figure 1 also shows that the exchange rates respond slowly to the intervention. Intuitively, we may explain this delayed response based on secrecy of interventions performed by the U.S. Treasury. It may take time for investors to obtain, process and fully understand all information regarding the intervention. In addition, the ESF

[16] Including output as part of the VAR indirectly incorporates the assumptions of theoretical models like Mundell (1961), and Fleming (1962).

account's persistent response suggests that the Treasury keeps intervening even one year after the initial shock.[17] This action may in turn contribute to the delayed response of exchange rates.

The error bands for the DM/Dollar exchange rate are tighter than in the other cases. The smaller errors are because foreign bonds in the ESF were mainly denominated in Deutschmarks. Therefore, we expect that most of interventions were exchanges of U.S. T-bills for German bonds or the other way around. It is not surprising that the DM/Dollar exchange rate is more sensitive to the sterilized shock.

The second row in Figure 1 displays the responses of the ESF account to the sterilized intervention shock. Clockwise we have the ESF responses when the \$U.S./DM, \$U.S./TWI, \$U.S./£, and \$U.S./\$Ca exchange rates are used in the VAR specification. Let us analyze the response under the trade-weighted exchange rate. First, following a sterilized purchase of domestic assets, the ESF account increases by 15 percent, which means that the ESF holdings of domestic assets increased after the intervention.[18] Second, the response is highly persistent; even after one year the point estimate is above its pre-shock level. The combined evidence suggests that the intervention shock has the desired effect. A similar argument can be applied for the other exchange rates.

Figure 3 displays the dynamic responses of domestic interest rate and money supply to the sterilized shock. A general conclusion from that figure is that the response of the interest rate is not significantly different from zero. Let us consider the DM/Dollar case one more time. Upon impact, the domestic interest rate declines about 5 basis points. However, the errors are considerably large so we cannot rule out the null hypothesis that the effect is zero. Similar conclusions are drawn from the other cases. The response of money supply is not different from zero. We expect this result since by construction the shock we are identifying has the smallest effect on the money supply. For example,

[17] The inertial response of ESF is a consequence of the identification scheme. The initial swap of securities is engineered to keep the money supply unchanged upon impact. However, the dynamic response of exchange rates may require persistent adjustment of the securities in the ESF. Such changes are needed to maintain the money supply constant in future dates. This is exactly what Figure 1 shows.

[18] Using the average holdings of U.S. assets in the ESF account over the period 1974 - 2000, a 15 percent increase in this account is equivalent to a purchase of U.S. \$ 750 millions.

for the trade weighted exchange rate case, the highest deviation is 0.2 percent and occurs 12 quarters after the intervention. More importantly, the initial increase in the money supply should depreciate the domestic currency. Yet, Figure 1 shows the opposite movement in exchange rates; this last result provides even more compelling evidence for the effectiveness of interventions.

To further confirm the properties of the identification scheme, I compare the reaction of the domestic money supply in the benchmark case with the response of money following a monetary shock. Christiano, Eichenbaum, and Evans (1999) find that the money supply contracts by about 0.8 percent following a contractionary monetary policy shock.[19] Moreover, the response of money is highly persistent; three years after the shock it is still 0.7 percent below its pre-shock levels. In my benchmark case, however, the response of the money supply is anything but persistent. This observation and the highly inertial response of exchange rates to an intervention shock indicate that changes in the monetary aggregate have nothing to do with exchange rate movements under my identification scheme.

3.2 Extending the Benchmark Case

The Exact-Zeros Case

I extend the benchmark case by studying a case in which the zero restriction, money supply is zero after the shock, is imposed exactly at some periods. When the vector Y has dimension 6, the zero condition can be imposed in exactly 4 periods. This identifies the system up to a scale (one coefficient is identified by the condition $||\alpha|| = 1$.) I choose the scale such that the initial point estimate of the dynamic response of the ESF account matches the initial response of that account in the benchmark case.

To illustrate, I impose the zero restriction in periods $1, 7, 14$, and 20 (the choice is completely arbitrary.) For brevity, I present the results only for the DM/Dollar exchange rate. A quick look at Figure 3 reveals that the dollar still appreciates following

[19] The monetary aggregate corresponds to $M2$. I choose this aggregate since it is the closest object in their study to MZM.

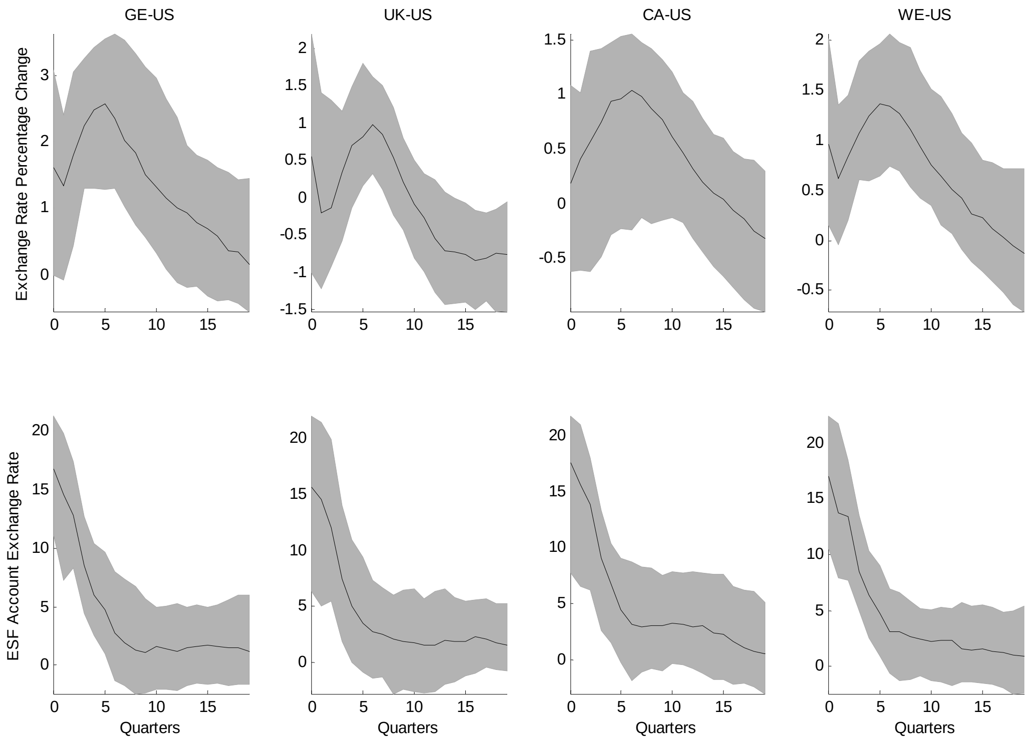

Figure 1: Responses of Exchange Rate and ESF Account to an Intervention Shock

the intervention shock. Upon impact, the point estimate of the exchange rate moves up implying a depreciation of the foreign currencies. Note that this initial appreciation is significant for all bilateral exchange rates but not for the trade-weighted exchange rate. For example, the Deutschmark depreciates roughly 1.2 percent upon impact. Moreover, this depreciation is persistent; even after 1 year the dollar is still above its pre-intervention value. The responses of the ESF account and the interest rates are similar to the benchmark case. In addition, the response of the interest rate is not significantly different from zero.

From the last row in Figure 3, we see that the identification program is successful: the U.S. money supply is zero in periods $1, 7, 14$ and 20. The impulse responses for money are less than 0.01 percent for all cases. Combining this last result with the statistically significant appreciation of the U.S. dollar we may conclude that sterilized

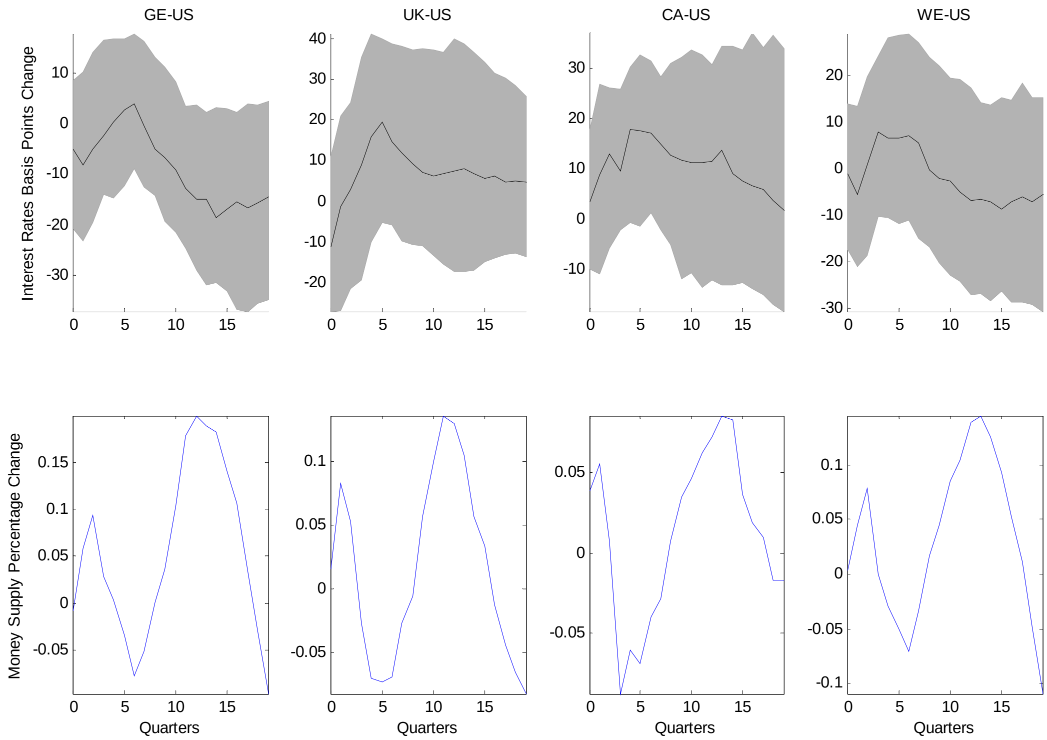

Figure 2: Responses of Interest Rates and Money Supply to Intervention Shock

interventions in favor of the U.S. dollar are likely to appreciate it.

Identification in the exact-zeros case seems more successful than the benchmark program. Money supply is far less sensitive in the former case than in the latter case. Money supply oscillates around zero indicating that the reaction of the monetary aggregate to the intervention shock is spurious.

Including Foreign Interest Rates

Now I include a foreign interest rate in Y; including the foreign interest rate tries to incorporate the theoretical models of Dornbusch, and Mundell and Fleming. For the sake of exposition, four cases are considered in Figure 4: the bilateral exchange rates between the U.S. Dollar and the Deutschmark, the British Pound, the Canadian

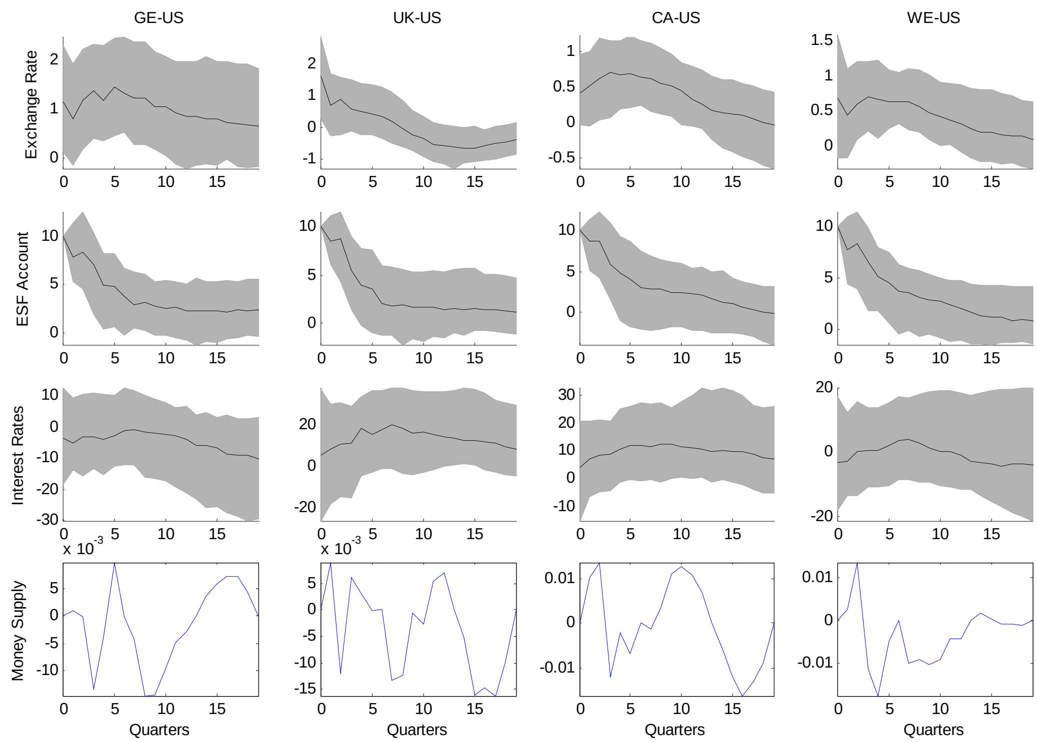

Figure 3: Responses to a Sterilized Shock in the Exact-Zeros Case

Dollar, and the Yen. The foreign interest rate corresponds to the Treasury Bill Rate in the International Financial Statistics database.

As in the benchmark case, a sterilized intervention leads to a statistically significant Dollar appreciation with respect to the Deutschmark. This appreciation is present even one year after the intervention; however, it vanishes in the long term. Similarly, the Yen depreciates significantly with respect to the Dollar. The other two currencies, the Pound and the Canadian dollar do not significantly depreciate. The fact that the ESF is mainly composed of Deutschmark- and Yen-denominated assets is likely to lie behind the pronounced depreciation of those currencies.

The second regularity apparent from Figure 4 is the significant response of the ESF following the intervention shock. For example, total holdings of U.S. assets in the ESF increase by 12 percent for the Deutschmark-U.S. Dollar case. This change in the ESF is temporary; typically lasting about 5 quarters.

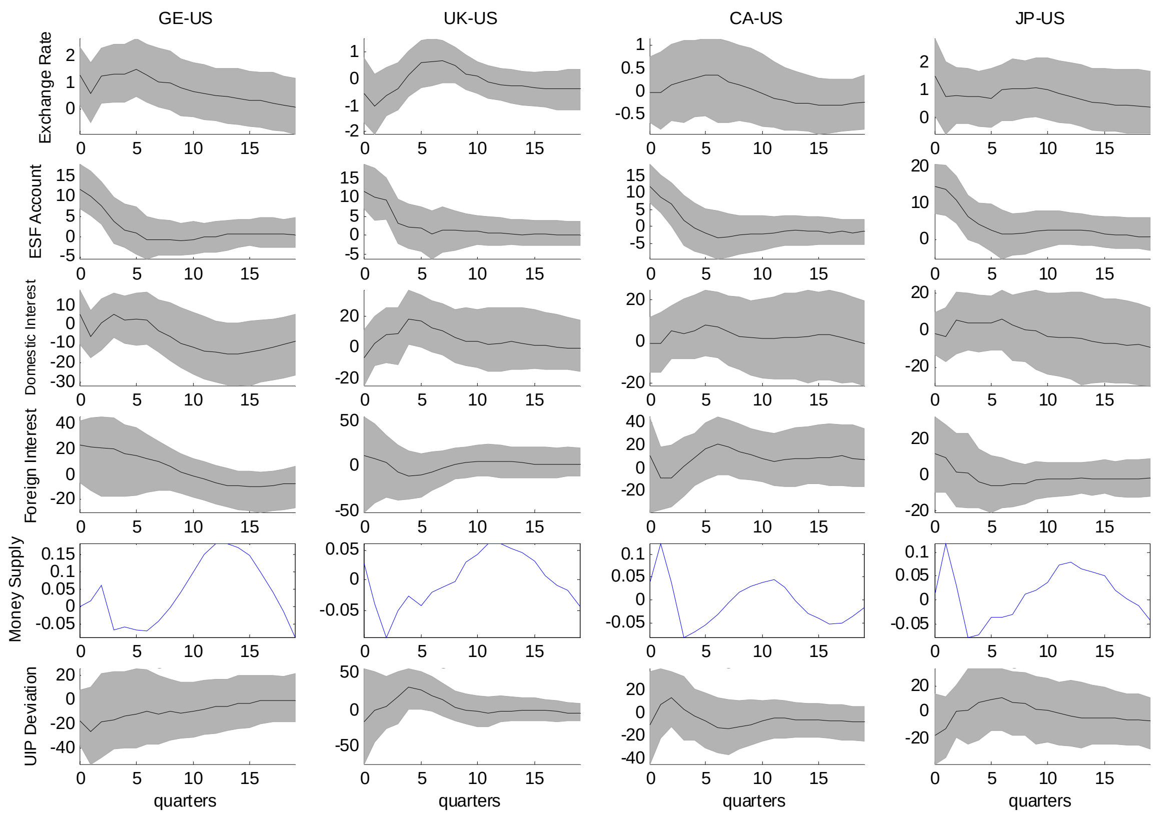

Figure 4: Impulse Responses when the Foreign Interest Rate is included

We also observe that neither the domestic nor the foreign interest rates are significantly different from zero. Furthermore, the confidence intervals are wide implying that we cannot reject the null hypothesis of zero effect on interest rates. Similarly, the response of the money supply is not different from zero. The initial response of money is typically less than 0.05 percent, which indicates that program P.1 successfully identifies a shock to the ESF that is orthogonal to money supply. Moreover, money supply response is not to different zero in the long run.

The final panel in Figure 4 displays deviations from the uncovered interest rate parity condition. According to this panel an intervention shock leads to persistent deviations from uncovered interest parity in favor of foreign currency investments. This persistent deviation, however, is not statistically significant except for the U.S. Dollar-Deutschmark market. A decline in the return on dollar investments relative to foreign-currency investments is accompanied by an expected dollar appreciation. The former effect dominates the latter so that the uncovered interest rate parity condition is no longer satisfied. As a consequence, there is no forward premium following an intervention. This result is at variance with Eichenbaum and Evans (1995) who find UIP violations satisfying the forward premium puzzle after a monetary shock.

An Alternative-Weighting Matrix

Although it makes sense to consider a minimization program with declining weights over time as in program P.1, its choice was completely arbitrary. Let us consider a generalized version of our initial program:

$$\alpha = \arg\min_{\widetilde{\alpha}} r'_{m,esf} V r_{m,esf}, \tag{P.1'.}$$

$$\begin{aligned} \text{subject to } ||\alpha|| &= 1, \\ r_{esf,esf}(1) &\geq 0, \end{aligned}$$

where $r_{m,esf}$ is a K dimensional vector containing the time 1 to time K dynamic responses of money coming from equation 2. V is a weighting matrix that was initially the identity matrix.

A simple way to control the response of money is to force it to cross zero frequently.[20] To that end, I choose a matrix V that penalizes responses that do not cross zero in two consecutive periods. The results of this approach are displayed in the right panel

[20]By controlling the size and cycle of money supply we want it to look similar to white noise and therefore orthogonal to the intervention shock.

of Figure 5. The effect of weighting is evident as the money supply declines upon impact; it crosses zero more frequently than in the benchmark case. Moreover, the responses are about the same size as in the exact-zeros case. The overall response of the exchange rates is weaker compared to the benchmark case. More importantly, the responses are less statistically significant. Yet the shape and persistence of exchange rates are pretty much the same as in the benchmark case. For example, the Canadian Dollar stays depreciated even two years after the sterilized shock. The reason behind the weak response of exchange rates might lie in the small reaction of the ESF account. According to Figure 5, the immediate response of the ESF is around 7 percent; almost half the response in the benchmark case.

In general, we conclude that sterilized interventions as defined in this paper are effective at least in the short term. Moreover, the dynamic responses of exchange rates show that this effect is persistent over eighteen months following the intervention by the Central authority. The effect is more pronounced if we consider either the trade weighted exchange rate or the DM/US Dollar exchange rate.

The Signaling Channel

Mussa (1981) argues that interventions affect exchange rates by providing market participants with new information about future actions by the monetary authority. This hypothesis can be easily implemented in my formulation as a variant of the exact zero case. To do so, I restrict the money supply not to react, for example, during the first four quarters following the intervention; it can freely move thereafter.

Figure (6) presents the results from this new identification scheme. First, money supply does not change for the first four quarters and then increases. This rise in money in turn should depreciate the U.S. dollar. Yet, the first row in that figure indicates that the U.S. dollar actually appreciates following the intervention. The initial appreciation is statistically significant not only for the Deutschmark-Dollar rate but also for the Pound-Dollar relation. We can attribute the subsequent depreciation of the dollar to the future increase in the money supply. In this sense, the signaling hypothesis is

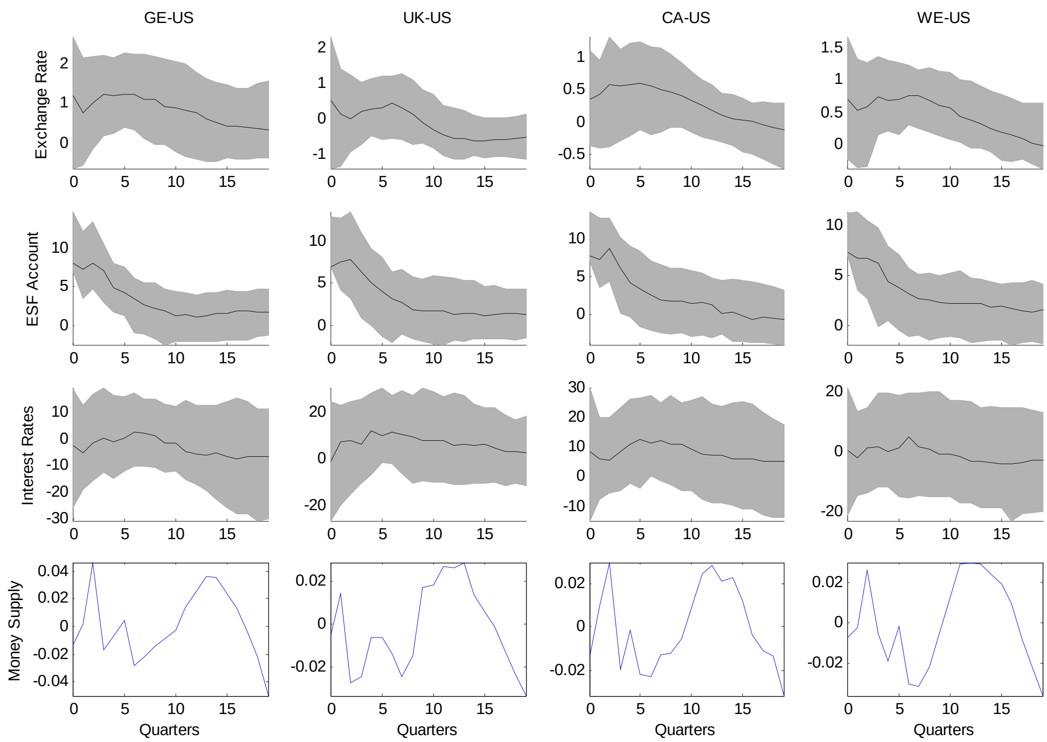

Figure 5: Responses to a Sterilized Shock using an Alternative-Weighting Matrix

partially correct in describing the post intervention dynamics of the exchange rate. However, the evidence just presented suggests that the sterilized interventions indeed affect exchange rates independently of what the money supply does.

We also note that following the intervention the change in interest rates is negligible and statistically indifferent from zero. As with the previous cases, the initial response of the ESF account is statistically significant and around 10 percent upon impact.

3.3 Relation to the Literature

It is informative to compare the results from this section with those reported in recent papers supporting the effectiveness of sterilized interventions: Dominguez and Frankel (1993a), Kearns and Rigobon (2005) and Kim (2003). First of all, the second paper finds that for Australia a $100 million purchase of Australian dollars will appreciate

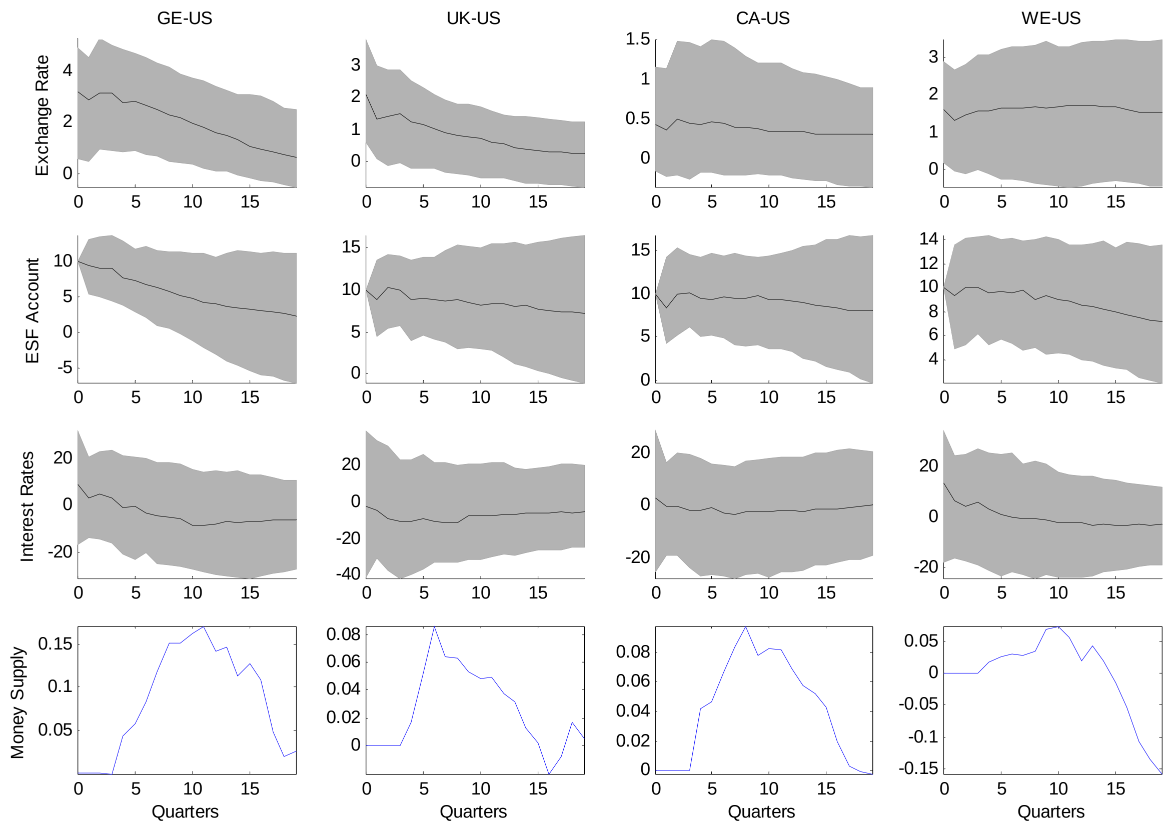

Figure 6: The Signaling Channel Hypothesis

the exchange rate by between 1.3 and 1.8 percent. Similarly, Dominguez and Frankel report that an intervention supporting the U.S. dollar appreciates the exchange rate by roughly 1 percent. According to the benchmark specification, the U.S. dollar appreciates by roughly 1.5 percent after a sterilized intervention; a result that is well within the margins reported in the above papers.

Second, both papers estimate that the effects of sterilized interventions are short lived; typically lasting less than a week. My estimates from the most complete specification (see Figure 4) indicate that interventions are statistically significant upon impact, but they are marginally significant 1 year after the initial shock. The response of the ESF account to intervention is highly persistent. In contrast, Dominguez and Frankel's

(1993a) study consider the effects of a one-time intervention, i.e. their intervention variable is not persistent. We conclude that the persistent appreciation I find is driven by the ESF's inertial response. It would interesting to repeat Dominguez and Frankel's simulation using a persistent process similar to the one reported for the ESF.

Kim (2003) finds that following a sterilized sell of foreign currency by the U.S. Treasury, the U.S. dollar appreciates by 1.5 percent. Further, the dollar stays appreciated even one year after the intervention. My approach seems more successful than his in identifying a sterilized intervention shock as the U.S. money supply is less responsive and less persistent in my study. Even though our identification strategies differ considerably, we arrive to similar results not only in the initial response of exchange rates but also in their persistence.[21]

The results in this paper have also consequences for theoretical models of exchange rate determination. In the appendix, I show that a version of Lucas (1982) that allows for transaction costs and incomplete markets can account for the initial appreciation of the dollar following a sterilized intervention. The model, however, fails to deliver the hump-shaped response of exchange rates. A promising way to capture such response is the rational inattention framework developed in Baccheta and van Wincoop (2005). However, such analysis is left for future research.

3.4 Variance Decomposition

In this section I compute the fraction of the variance of the k-step ahead forecast revision $E_t[Y_{t+k}] - E_{t-1}[Y_{t+k}]$ in the bilateral exchange rates accounted for by the sterilized intervention shock. To achieve this, I define the fraction of the variance of this forecast

[21] He uses a structural VAR, and a measure for foreign interventions obtained from the Board of Governors. His identification strategy has the disadvantage of not allowing him to directly infer the effects of sterilized interventions. His scheme identifies a shock that leaves unchanged the money supply only in the period immediately after the intervention. Consequently, some of his results may be driven by the future change in the money supply; an issue that is directly addressed in my formulation.

revision for the exchange rate by:

$$\phi_k = \frac{(r_{exrate,esf}(k))^2}{\sum_{i=1}^{m}(r_{exrate,i}(k))^2},$$

where $r_{exrate,esf}$ and $r_{exrate,i}$ are the impulse responses of the exchange rate to a sterilized intervention shock and a Cholesky decomposition shock, respectively (see Section 2 and Uhlig 2005 for more details). The results from the benchmark case are plotted in Figure 7 with the solid line representing the median estimate while the shaded area corresponds to one standard deviation intervals.[22]

According to the median estimates, sterilized intervention shocks explain between 10% and 20% of the total variation in the Deutschmark-U.S. Dollar and the Trade Weighted-U.S. Dollar exchange rates at all horizons; the largest contribution happens roughly one and a half years after the intervention. Moreover, the variance contribution tends to vanish after 2 and a half years. For the other two exchange rates, the contribution is smaller than 10%, which is not surprising given the highly Deutschmark-denominated portfolio held at the Exchange Stabilization Fund.

The second panel in Figure 7 displays the fraction of the variation in the U.S. interest rate caused by the intervention shock. For all cases, the contribution to the variability of interest rates is less than 10% (it is even less than 5% for a significant portion of the simulation sample) and smaller than the variability of exchange rates. This result is expected since by definition sterilized interventions affect only exchange rates while leaving interest rates and the money supply unaffected. Therefore, the variance decomposition of interest rates provides indirect evidence that program $P.1.$ successfully identifies a sterilized intervention shock.

[22] For brevity, I only consider the benchmark case. It is straightforward to compute the variance decomposition for the other cases. They are omitted as the results are similar.

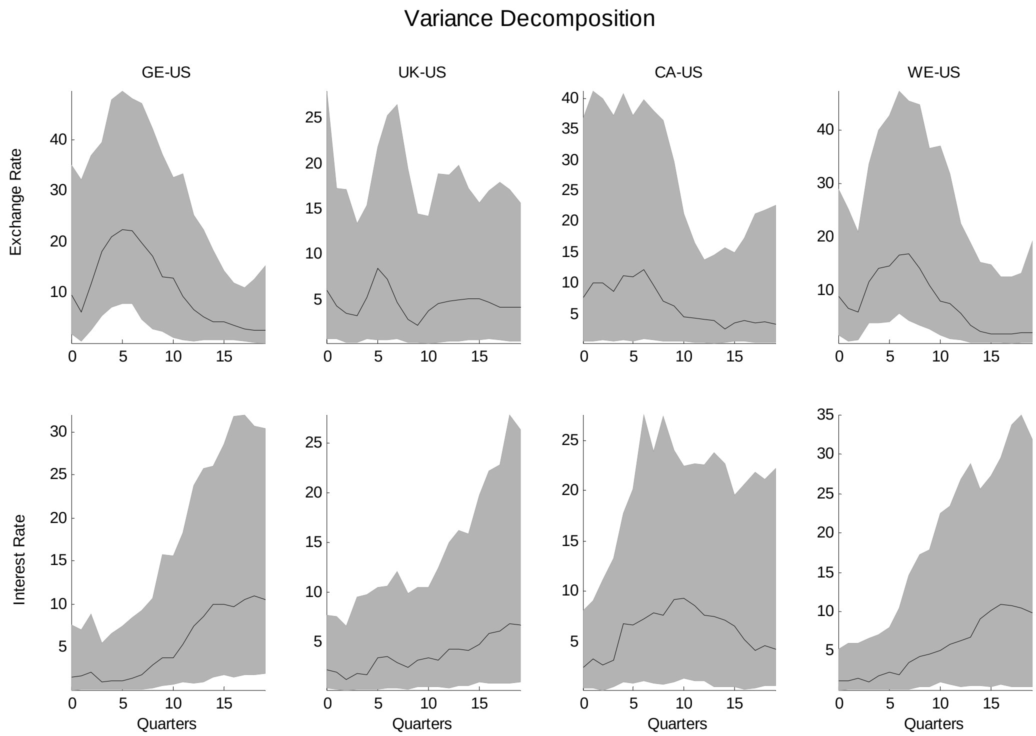

Figure 7: Fraction of the exchange rate and interest rate variance attributed to the sterilized intervention shock.

3.5 Intervention versus Monetary Shocks

In this section I compare how my results on exchange rates compare to those derived from monetary policy shocks. To that end, I take the Deutschmark-Dollar exchange rate in my benchmark formulation, and the results in Eichenbaum and Evans (1995) as the reference points.

Eichenbaum and Evans report that the maximal appreciation of the U.S. Dollar against different currencies after a monetary contraction equals 3%. This appreciation happens 3 years after the monetary shock indicating that the effect is highly persistent. In Figure 1 the Deutschmark reaches its maximum depreciation of 2.5% roughly 1 year after an intervention favoring the U.S. dollar. Moreover, the initial depreciation has completely vanished 2 years after the shock. Similarly, the Pound-Dollar exchange rate is more responsive and persistent after a monetary shock than after an intervention shock.

Uhlig (2005) finds that between 5% and 15% of the total variation in the T-bill interest rate is caused by a monetary shock. The effect is highly persistent; the monetary shock explains almost 10% of the interest rate variability even 5 years after the shock. In contrast, an intervention shock explains less than 10% of this variability (see Section 3.4) although the effect is still present after 3 years.

These results confirm the belief that monetary policy is the most effective way to appreciate or depreciate a currency with the drawback that changes in inflation have short-term effects on economy activity. On the other hand, my study shows that sterilized interventions have the desired effect on exchange rates; although this change is small and of short duration, it has the advantage of leaving unaffected inflation and interest rates.

4 Conclusion

This paper has explored the consequences of sterilized interventions using a VAR framework. The main conclusion is that sterilized interventions have an effect on the exchange rate, which is statistically significant lasting for about 1 year or so. The Deutschmark-Dollar exchange rate is the most affected by intervention thanks to the bias in the Exchange Stabilization Fund towards Deutschmark-denominated securities. Similar to monetary shocks, sterilized interventions are a source of UIP deviations in the short run. However, intervention shocks deliver smaller and less persistent effects on the exchange rate than monetary shocks.

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5 Appendix: A simple model

Evidence supporting the effectiveness of sterilized interventions is relatively new: Frankel and Dominguez's results (the first showing concrete evidence) only date from 1993. Central bankers, however, have been actively intervening in the exchange market since the collapse of the Bretton-Wood system. A natural question economists should answer is: What model, if any, can support central bankers' actions?

Instead of searching for all possible models that provide an answer to the last question, I investigate sufficient conditions for sterilized interventions to be effective in a specific general equilibrium framework. To that end, I use Backus and Kehoe (1988) as the baseline because their model is the classic theoretical reference against the effectiveness of interventions. My formulation, however, differs from theirs in two dimensions. First, nominal bonds denominated in both domestic and foreign currencies are the only assets available to households. Second, every time households trade in the bond market, they must pay a per-unit transaction cost. A consequence of this assumption is that the uncovered interest rate parity condition (UIP) includes a variable premium which depends on the specifics of the cost.[23]

Consider a symmetric world composed of two countries: home and foreign. Each country is populated by a representative agent who receives utility from consuming a composite good, c_t, and from holding real money balances, M/P. Consumption services are produced by combining tradable (C^T) and nontradable (C^N) goods according to the CES technology:

$$c_t = \left[a_1^{1/\theta} \left(C_{T,t}\right)^{\frac{\theta-1}{\theta}} + a_2^{1/\theta} \left(C_{N,t}\right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} . \tag{4}$$

Here, θ controls the elasticity of substitution between C^T and C^N. Let P_t^T and P_t^N denote the domestic currency prices of the tradable and nontradable goods, respectively.

[23] As will become clear, my formulation is a general equilibrium version of Branson's (1985) portfolio theory frequently cited to support the effectiveness of interventions. His model has been criticized for ignoring feedback effects present in general equilibrium models (Backus and Kehoe 1988).

Then the price of consumption services is given by:

$$P_t = \left[a_1 \left(P_t^T\right)^{1-\theta} + a_2 \left(P_t^N\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{5}$$

The law of one price implies $P^T = P^{*T}/s$, where P^{*T} denotes the foreign currency price of the tradable good and s is the foreign currency price of domestic currency. To simplify the analysis, I assume that households are endowed with one unit of each good per period.[24] Domestic households trade nominal bonds denominated in domestic and foreign currency with prices, q_t and q_t^*, respectively. Bonds are redeemed at face value next period.

The representative agent in the home country solves the following problem:

$$\max E_t \sum_{j=0}^{\infty} \beta^j \left[U(c_t) + L(M_t/P_t)\right] \tag{6}$$

subject to

$$\begin{aligned} P_t^N C_t^N + P_t^T C_t^T + q_t \Theta_{1,t} B_{h,t} + q_t^* \Theta_{2,t} B_{h,t}^*/s_t + M_t \quad \leq \quad & B_{h,t-1} + B_{h,t-1}^*/s_t + \\ & M_{t-1} + P_t^T y_t^T + P_t^N y_t^N + T_t + \pi_t. \end{aligned}$$

where T is a lump-sum transfer from the government; B_h and B_h^* are holdings of domestic and foreign bonds, respectively; E_t is the expectations operator conditional on information available at time t; finally Θ_1 and Θ_2 are the variable transaction costs paid with $\Theta_i > 0$ and $\Theta_i' > 0$ for $i = 1, 2$. Following the literature, I assume that this costs are proportional to the real value of the bonds held by households: $\Theta_2 = \Theta_2(B_{h,t}^*/P_t^*)$, $\Theta_1 = \Theta_1(B_{h,t}/P_t)$ and that they are equal to 1 in steady state. For simplicity, I assume that these costs are collected by a trader and then rebated to households through the term π. Laxton and Pesenti (2003) justify the presence of these transaction costs solely on technical grounds. The idea is that transaction costs in the presence of incomplete

[24] Following Backus and Kehoe (1988), I choose an endowment economy to concentrate on the money and bond markets.

markets guarantee the existence of a stationary steady state which does not depend on initial conditions.[25] As will become clear, the presence of these costs is crucial in the model. Therefore, I will devote a separate section to discuss their plausibility and consequences.

Households in the foreign country solve a similar problem. For notational purposes, their choices are indexed by f; for example, foreign holdings of domestic bonds is denoted by $B_{f,t}$. Similarly, the transaction costs are defined by $\Theta_1^* = \Theta_1^*(B_{f,t}^*/P_t^*)$ and $\Theta_2^* = \Theta_2^*(B_{h,t}/P_t)$.

5.1 Fiscal Authority

The fiscal authority receives seigniorage revenues from the monetary authority, rebates lump-sum transfers to households, and issues bonds in domestic and foreign currencies. At any time, the government's budget constraint must hold:

$$T_t + B_{g,t-1} + B_{g,t-1}^*/s_t = M_t^a - M_{t-1}^a + q_t B_{g,t} + q_t^* B_{g,t}^*/s_t. \tag{7}$$

A similar budget constraint holds for the foreign country. For simplicity, I have assumed that governments issue debt without incurring costs.

5.2 Monetary Authority

I assume that both the domestic and foreign monetary authorities set the money growth rate to zero: $M_t^a = M$. This assumption allows us to concentrate on the pure effects of sterilized interventions ignoring indirect effects due to monetary policy followed by the monetary authorities.

[25] Other examples include Schmitt-Grohe and Uribe (2003), Benigno (2001), and Bacchetta and van Wincoop (2005).

5.3 Equilibrium

An equilibrium for this economy is a sequence of allocations $\{C_t^T, C_t^N, C_t^{T*}, C_t^{N*}, B_{h,t}, B_{h,t}^*, B_{g,t}, B_{g,t}^*, B_{f,t}, B_{f,t}^*, B_{g^*,t}, B_{g^*,t}^*, M_t, M_t^*, M_t^a, M_t^{a*}, T_t, T_t^*\}$ and prices $\{P_t^T, P_t^N, P_t^{T*}, P_t^{N*}, q_t, q_t^*, s_t\}$ such that:

1. The allocations solve the maximization problem of both domestic and foreign residents given prices and cost functions,

2. The allocations satisfy the resource constraints for the economy.

$$\begin{aligned} c_t + c_t^* &= y^T + y^{T*}, \\ c^N &= y^N; c^{*N} = y^{*N}, \\ B_{h,t} + B_{f,t} &= B_{g,t} + B_{g^*,t}, \\ B_{h,t}^* + B_{f,t}^* &= B_{g,t}^* + B_{g^*,t}^*. \end{aligned}$$

Definition 1 *Let* $\tau_t = [M_t, T_t, B_{g,t}, B_{g,t}^*]$ *denote a domestic government policy which satisfies its budget constraint . Given an initial policy* $\tau_{1,t}$, *a sterilized intervention by the domestic government is a new policy* $\tau_{2,t}$ *which only differs from* $\tau_{1,t}$ *in the composition of the domestic government debt, i.e.* $\tau_{1,t} = [M_t, T_t, B_{g,t}, B_{g,t}^*]$ *and* $\tau_{2,t} = [M_t, T_t, B_{g,t}', B_{g,t}^{*\prime}]$.

To simplify the following proofs, I will temporarily assume that the tradable good is the only one available so that $c_t = C_t^T$ and $P = P^T$. Then the optimal conditions and resource constraints imply the following log-linearized equations (a variable with a hat represents percentage deviations from its non-stochastic steady state):

$$\widehat{q}_t + \Theta_1' \frac{B_h}{P}\left(\widehat{B}_{h,t} - \widehat{P}_t\right) + E_t\widehat{P}_{t+1} - \widehat{P}_t - \rho E_t\left(\widehat{c}_{t+1} - \widehat{c}_t\right) = 0, \tag{8}$$

$$\widehat{q}_t^* - \widehat{q}_t + \Theta_2' \frac{B_h^*}{sP}\left(\widehat{B}_{h,t}^* - \widehat{s}_t - \widehat{P}_t\right) - \Theta_1' \frac{B_h}{P}\left(\widehat{B}_{h,t} - \widehat{P}_t\right) = -E_t\widehat{s}_{t+1} + \widehat{s}_t, \tag{9}$$

$$-\lambda\widehat{\lambda}_t + \beta\lambda E_t\widehat{\lambda}_{t+1} + L'' \frac{M}{P^2}\left(\widehat{M}_t - \widehat{P}_t\right) - \frac{L'}{P}\widehat{P}_t = 0, \tag{10}$$

$$
\begin{aligned}
\widehat{P}_t + \widehat{s}_t - \widehat{P}_t^* &= 0, && (11)\\
\widehat{c}_t + \widehat{c}_t^* &= 0, && (12)\\
B_h \widehat{B}_{h,t} + B_{h^*} \widehat{B}_{h^*,t} &= B_g \widehat{B}_{g,t} + B_{g^*} \widehat{B}_{g^*,t}, && (13)\\
B_h^* \widehat{B}_{h,t}^* + B_{h^*}^* \widehat{B}_{h^*,t} &= B_g^* \widehat{B}_{g,t}^* + B_{g^*}^* \widehat{B}_{g^*,t}^*. && (14)
\end{aligned}
$$

The first three equations correspond to the optimal choices of domestic bonds, foreign bonds, and money held by home residents; λ is the budget constraint multiplier and ρ is the risk aversion coefficient. Specifically, (9) is an extended version of UIP allowing for a risk premium measured by the derivatives of the transaction costs: Θ_1' and Θ_2'. Equation (11) is purchasing power parity condition. Finally, the last three conditions describe the resource constraints in the goods and bond markets, respectively. To save space, I have omitted the foreign resident's conditions as they are similar to those of the domestic resident.

Lemma 2 *(On the Irrelevance of the Government Debt Part I) Suppose households can freely trade in the bond markets:* $\Theta_i = \Theta_i^* = 0$ *and* $\Theta_i' = \Theta_i^{*\prime} = 0$ *for* $i = 1, 2$. *In addition, assume that the initial policy is* $\tau_{1,t} = [M, T, B_g, B_g^*]$ *for* $t < 0$. *Then a sterilized intervention in favor of the domestic currency,* $\tau_{2,t} = [M, T, B_{g,t}, B_{g,t}^*]$ *such that* $B_{g,t}^* > B_g^*$, *has no effect on the world economy, i.e. there is a unique equilibrium in which* $\widehat{c}_t = \widehat{c}_t^* = 0$, $\widehat{q}_t = \widehat{q}_t^* = 0$, *and* $\widehat{P}_t = \widehat{P}_t^* = \widehat{s}_t = 0$.

Proof. A sterilized intervention imposes the following restriction in the domestic government's budget:

$$
B_{g,t-1} + \frac{B_g^*}{s}\left(\widehat{B}_{g,t-1}^* - \widehat{s}_t\right) = qB_g\left(\widehat{q}_t + \widehat{B}_{g,t}\right) + \frac{q^* B_g^*}{s}\left(-\widehat{s}_t + \widehat{q}_t^* + \widehat{B}_{g,t}^*\right), \ t \geq 0. \quad (15)
$$

To simplify the analysis, I assume that the government issues domestic debt according to the autoregressive process: $\widehat{B}_{g,t} = \mu \widehat{B}_{g,t-1} + \varepsilon_t$, chooses its foreign debt to satisfy equation 15, and that the foreign government does not react to the domestic intervention. Next, I impose the price restrictions $\widehat{q}_t = \widehat{q}_t^* = 0$, and $\widehat{P}_t = \widehat{P}_t^* = \widehat{s}_t = 0$

and then show that the only allocations compatible with these prices are those leaving consumption unchanged.

Equation (8) and its foreign counterpart imply that $\widehat{c}_t = 0$ and $\widehat{c}_t^* = 0$. As a consequence, marginal utility is zero and so is the multiplier: $\widehat{\lambda}_t = 0$; then (10) is trivially satisfied. Finally, (13) and (14) form a system of two equations in four unknowns from which one can derive the levels of private domestic and foreign bond holdings consistent with the equilibrium in which interventions are ineffective. One possibility is $\widehat{B}_{h,t} = \widehat{B}_{g,t}$ and $\widehat{B}_{h,t}^* = \widehat{B}_{g,t}^*$.

The equilibrium is unique since issuing debt only affects (13) and (14) without modifying the remaining equilibrium conditions. ■

The proof relies exclusively on the assumption that trading bonds is costless. A by product of this assumption is that UIP holds; but this is exactly the arbitrage condition in the irrelevance result derived in Backus and Kehoe (1988). Therefore, lemma 1 extends their theorem to the incomplete markets case in which only two bonds are available.

Lemma 3 *(On the Irrelevance of the Government Debt Part II) Suppose households can trade in their domestic bond markets freely:* $\Theta_1' = \Theta_1^{*\prime} = 0$ *but they must pay a positive fee in the foreign market:* $\Theta_2' = \Theta_2^{*\prime} > 0$. *In addition, assume that the initial policy is* $\tau_{1,t} = [M, T, B_g, B_g^*]$ *for* $t < 0$. *Then a sterilized intervention in favor of the domestic currency,* $\tau_{2,t} = [M, T, B_{g,t}, B_{g,t}^*]$ *such that* $B_{g,t}^* > B_g^*$, *has no effect on the world economy, i.e. there is a unique equilibrium in which* $\widehat{c}_t = \widehat{c}_t^* = 0$, $\widehat{q}_t = \widehat{q}_t^* = 0$, *and* $\widehat{P}_t = \widehat{P}_t^* = \widehat{s}_t = 0$.

Proof. The proof is exactly the same as for Lemma 1. The only distinction is that the deficit of domestic bonds is be absorbed by domestic residents whereas foreigners purchase the surplus of foreign debt issued the domestic government. Moreover, the new equilibrium is characterized by: $\widehat{B}_{h,t} = \widehat{B}_{g,t}$ and $\widehat{B}_{f,t} = \widehat{B}_{g,t}^*$. We observe this pattern because it is costless for domestic residents to buy (sell) domestic debt. Similarly, foreigners buy (sell) foreign bonds freely. ■

To shed light on the results from Lemmas 1 and 2, let us solve (9) forward:

$$\widehat{s}_t = -E_t \sum_{j=0}^{\infty} \alpha^{j+1} \left[\widehat{q}_{t+j} - \widehat{q}^*_{t+j} + \Theta_1' \frac{B_h}{P} \left(\widehat{B}_{h,t+j} - \widehat{P}_{t+j} \right) - \Theta_2' \frac{B_h^*}{sP} \left(\widehat{B}^*_{h,t+j} - \widehat{P}_{t+j} \right) \right], \tag{16}$$

which is a valid solution for the difference equation as long as $\alpha = (1 + \Theta_1' \frac{B_h}{P})^{-1} < 1$. From (16) is quite clear that a necessary condition for sterilized interventions to be effective is that Θ_1' and Θ_2' be different from zero. Note that if this is the case, even announcements of future sterilized interventions may have an effect on exchange rates. A second interesting consequence of (16) is that a sterilized intervention supporting the domestic currency, which is completely absorbed by domestic residents, appreciates the domestic currency; this is exactly what we expect following this type of interventions.

Are the conditions $\Theta_1' > 0$ and $\Theta_2' > 0$ also sufficient? With these restrictions the model is more complicated. Even if these conditions are sufficient, it is unclear whether they will have a significant effect on exchange rates. I rely on simulations to study the effects of non-zero transaction costs on the exchange rates in the model that includes both tradable and non-tradable goods.

5.4 Simulations

For simulation purposes, I use the following functional forms and parameter values:

$$\begin{aligned} U(c) &= \frac{c^{1-\rho}}{1-\rho}, \quad L(M/P) = \psi \frac{(M/P)^{1-\sigma}}{1-\sigma}, \\ \beta &= 0.99, \rho = 2, \psi = 1e^{-4}, \sigma = 10. \end{aligned}$$

In addition, I choose the following parameter values: $a_1 = 0.2$, $a_2 = 0.8$, and $\theta = 0.4$. These numbers are consistent with home bias in consumption and the empirical literature on tradable and nontradable goods.[26] The values for β and ρ are quite standard in the business cycle literature while the values for the money-in-the-utility

[26] See, for example, Stockman and Tesar (1995).

term are taken from Christiano, Moto, and Rostagno (2004). I choose the coefficient μ and the standard deviation of ε_t in the process $\widehat{B}_{g,t} = \mu \widehat{B}_{g,t-1} + \varepsilon_t$ to match the impulse response of the ESF account for the Deutschmark-Dollar case illustrated in Figure 1. In the model, B_g corresponds to the total domestic debt issued by the government whereas the domestic assets included in the ESF account represents only 2 percent of the total domestic debt in U.S. Furthermore, I assume that the foreign monetary authority does not react to the domestic intervention. However, the foreign fiscal authority might modify the composition of its liabilities to satisfy the balanced budget restriction at all times.

I assume that the total public domestic debt is roughly 4 percent of real GDP in steady state. This figure is consist with the recent experience of the U.S. Domestic residents in steady state hold 80 percent of their net assets in domestic denominated currency whereas the remaining 20 percent corresponds to foreign currency bonds in steady state. This calibration captures the home-bias puzzle reported in Lewis (1995). Θ_1' and Θ_2' are set such that the maximum between them implies a variable cost of 0.3% outside steady state; this is a mild cost compared to the fees charged by financial intermediaries, see next section.

Figures 8 and 9 display the impulse responses of several variables following an intervention shock in favor of the domestic currency. The most important prediction given by the model is that no matter what the relative transaction costs are, the domestic currency appreciates following a sterilized intervention supporting the domestic currency (see the first row in Figure 8). If, for example, the relative transaction cost is $\Theta_2'/\Theta_1' = 2.5$, the exchange rate of the domestic currency increases by 1 percent. Even 4 quarters after the intervention, the domestic currency is still 0.25 percent above steady state.

The model also predicts some unexpected results after the initial shock. The decline in the total supply of domestic bonds is accompanied by an increase in their price; immediately after the intervention, domestic interest rates go down by roughly 5 basis points. In contrast, the foreign interest rate increases by 1.2 basis points. These changes in interest rates and the appreciation of the domestic currency suggest that both domestic and foreign households request a smaller compensation for holding domestic assets. According to Figure 9, the risk premium on domestic bonds declines by 0.4 percent upon impact and is persistent; even one year after the intervention, the risk premium is 0.2 percent below its pre-shock value. The model's predictions are well within one-standard deviation of the impulse responses displayed in Figure 4.

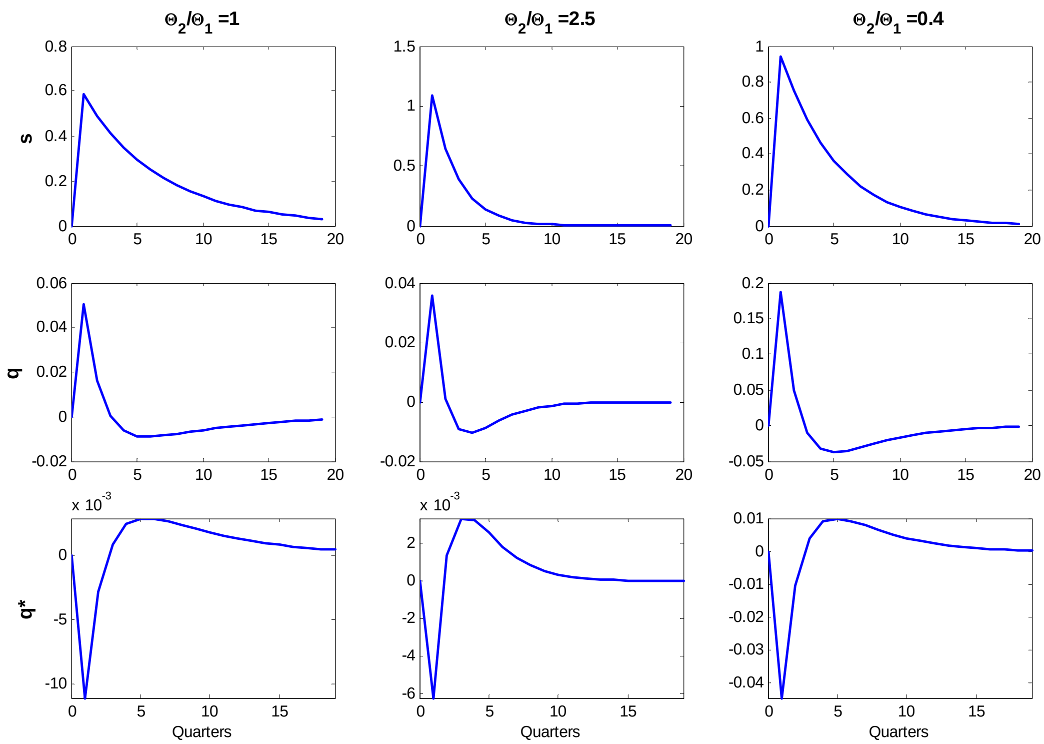

Figure 8: Impulse responses after a sterilized intervention shock

As displayed in Figure 10, domestic households' wealth net of bond purchases increases after the intervention shock.[27] Because of home bias, domestic residents prefer to spend the extra money on domestic nontradable goods. These goods, however, are in fixed supply implying that their price rises to restore equilibrium. On the other hand, tradable goods bought abroad are cheaper thanks to the domestic currency; this last

[27]Net wealth is defined as $NW_t = B_{h,t-1} + B^*_{h,t-1}/s_t - q_t\Theta_{1,t}B_{h,t} - q^*_t\Theta_{2,t}B^*_{h,t}/s_t + M_t$.

effect drives the domestic price of tradable goods down. Since 80 percent of domestic consumption comes from nontradable goods, the combined effect of these price changes drives domestic inflation up. By analogy, we expect that the foreign price level declines upon impact the intervention shock.

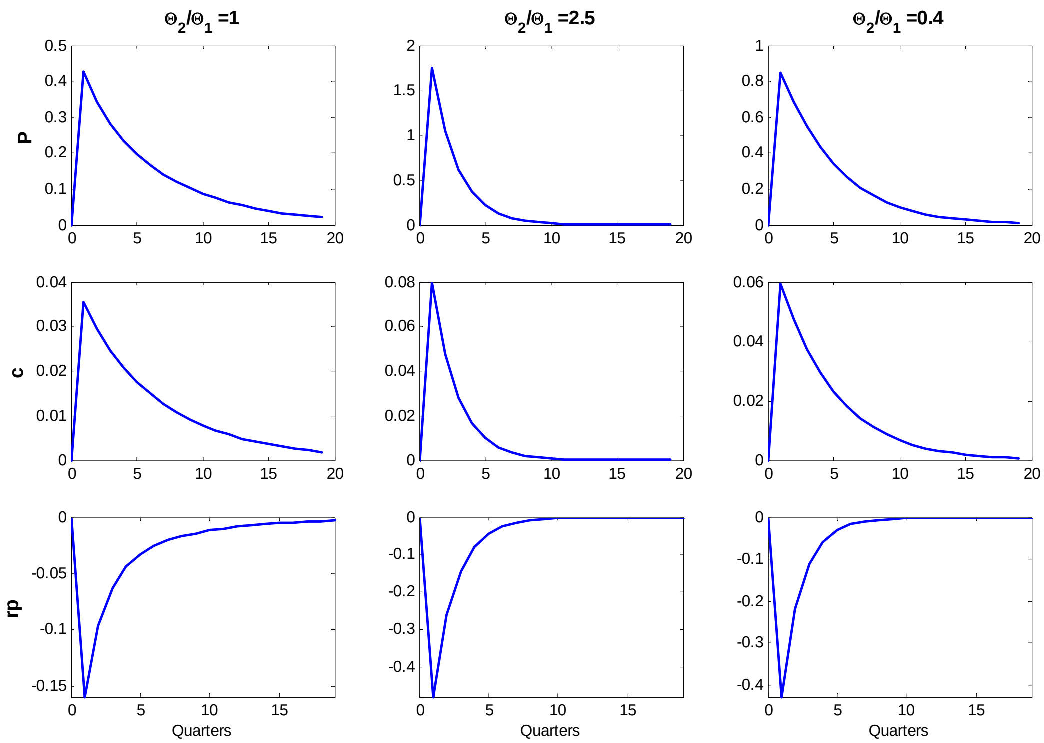

Figure 9: Impulse responses after a sterilized intervention shock.

Cheaper domestic-currency tradable goods and higher net wealth raise domestic consumption, c_t. This conclusion is confirmed by the impulse responses in Figure 9. Since households live in an endowment economy, the raise in domestic consumption comes at the expense of foreigners who see a decline in their consumption basket.

To an outsider, the results in this section may look like the consequence of an expansionary monetary shock: the domestic price index goes up, domestic interest rates decline, and consumption rises. However, these results are solely due to a sterilized intervention.

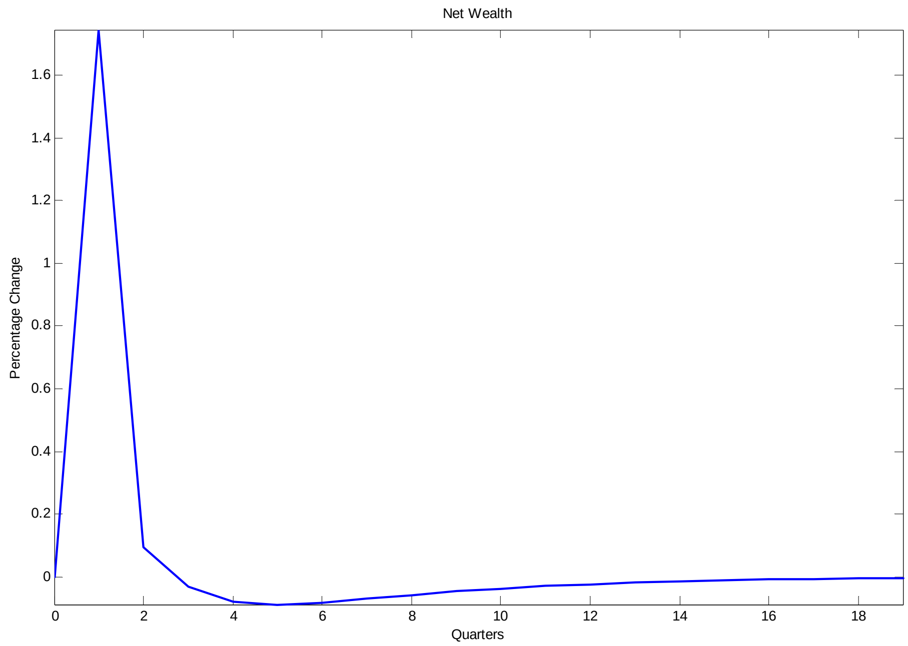

Figure 10: Net Wealth after an intervention shock

5.5 The Role of Transaction Costs

As highlighted by Lemmas 1 and 2, the key ingredient in the model is the presence of transaction costs in the bond markets. Then one may ask to what extent, if any, this assumption makes sense. I explore the answers to this question from two different perspectives: practitioners and scholars.

Swensen (2000) argues that active management in the stock/bond markets is a tough business which demands large sums of money and the skills of intelligent and motivated asset managers.[28] He observes that managers must choose portfolio allocations that generate sufficient returns to cover management fees, transaction costs, and market impact. Moreover, ... *investors face well-entrenched fee arrangements, ranging from asset-based fees for management of efficiently priced marketable securities to a combination of fees and incentive payments for less efficiently priced asset types ...*

[28] David Swensen is Yale University's Chief Investment Officer.

As an example of such transaction costs, Swensen mentions that *Barclays Global Investors's fee schedule for the S&P 500 Index Fund starts at 15 basis points on the first $15 million, moving to 10 basis points on the next $35 million, and 1 basis point on the next $450 million. For amounts over $500 million, the firm charges 8/10 of 1 basis point.* Similarly, hedge funds use fee schedules which usually involve a fix cost of 20% of the amount invested plus 2% of the profits generated from such investments.

Lewis (1995) shares Swensen's view that acquisition of securities is costly. She recognizes that even in the presence of fully integrated capital markets, there are at least brokerage fees and costs associated with gathering information about the domestic and foreign countries. In a related study, Vissing-Jorgensen (2001) reports that households face two types of transaction costs: first, there is a fixed cost representing the time/money spent understanding the basic investment principles as well as acquiring enough information to determine the optimal portfolio allocation between risky and risk-free assets. Second, households incur a per-period cost which represents the time value to determine if trading is optimal. Using data from the PSID, Vissing-Jorgensen estimates a median per-period participation cost of $500 for 1989. This cost is enough to explain why 75% of households do not participate in the stock market.

The evidence reported in this section can justify the presence of transaction costs in modeling the bond market. Figure 8 shows that sterilized interventions are more effective when trading foreign bonds is more costly. Larger costs in the foreign bond market can be linked to the difficulties in learning and assessing the foreign economy.