FOREX Intervention in the Absence of Signaling Channels: Evidence from the Bank of England

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Abstract

A structural vectorautoregression model is constructed to study the effects of secret, sterilized Bank of England interventions on the foreign exchange market in tandem with interest rate effects. The impulse response functions reveal a number of relationships between variables, suggesting the value of a joint analysis. I find that without a signaling channel, exogenous interventions of 500 million USD by the Bank of England do not have a statistically significant impact on the value of the pound after a month. Interest rates tend to fall after a purchase of foreign currency assets, suggesting that signaling would be a viable channel to affect the exchange rate assuming the information could be clearly communicated through interventions.

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1 Overview

This paper attempts to examine a number of issues in tandem surrounding foreign exchange rate interventions. In particular it investigates the effectiveness of sterilized exchange rate intervention, how this works without signaling channels, and how these effects occur in interaction with interest rates set by the central bank. A number of studies have separately addressed issues of interest rate policy responses to exchange rates, and foreign exchange intervention effectiveness, however is it rare that these issues are considered together. Kim (2003) is one of few papers that jointly assesses the effects of foreign exchange intervention and interest rate changes on the exchange rate using a structural vector autoregression method to unify results from past literature that study the effects of these policies in isolation. He finds that a public net monthly purchase of foreign currency depreciates the US dollar, consistent with most theoretical exchange rate models. He also finds evidence of a signaling channel. There is limited research on effects while muting particular mechanisms to try to understand which mechanisms are necessary for intervention to be effective, a gap that this paper aims to fill.

I use a comparable structural VAR analysis to Kim (2003) in the context of *secret* interventions to study whether these effects remain in the absence of signaling channels. The paper makes use of a novel data set of previously unpublished sterilized foreign exchange interventions made by the Bank of England between 1971 and 1987. I consider a data vector made up of the net monthly purchases of pound sterling (FEI), the interest rate (R), the M0 money supply (M), the consumer price index (CPI), the industrial production index (IP), a commodity price index (CP), and the exchange rate of the pound against the US dollar (E). The paper measures impulse response functions of both foreign exchange intervention and interest rate changes by making structural assumptions first argued for by Kim (2003). These assumptions will provide some justification for considering the responses to be causally identified. In Section 3, the literature on this topic is examined and I discuss the myriad strategies used to address endogeneity. I describe my data in Section 4 and my empirical strategy in Section 5. Estimated parameters and impulse responses are detailed in Section 6. In Section 7 the paper considers six alternative specifications as robustness checks in acknowledgement of the sensitivity of structural VARs to identifying assumptions. Finally in Section 8 I discuss some criticisms of Kim (2003) raised by Neely (2005), namely data frequency issues and the rank condition, and the limitations of the structural VAR in this context.

2 Motivation

The effectiveness of foreign exchange intervention is a policy relevant question with important implications for central banking. Whether sterilized interventions work in general is still a matter of debate, despite how regularly these policies are adopted by policymakers. Furthermore, attempts at identifying the mechanism through which they work have achieved mixed results in the literature. From a development standpoint, as FOREX intervention becomes increasingly the domain of central banks in developing nations, it is imperative to study best practices with regard to their implementation in order to lay the foundation for economic development more broadly. While central bankers report confidence that foreign exchange intervention is effective in moving the exchange rate, there is no academic consensus on the matter, especially with regard to interventions that are not communicated to the public. This paper attempts to address this gap by showing that interventions do not work under certain conditions.

I am interested in the mechanism by which sterilized intervention affects the exchange rate. The purchase of domestic currency with foreign reserves by a central bank decreases the supply of that currency which lowers the money supply and vice versa. The change in money supply in turn affects interest rates and prices *ceteris paribus*. To counteract these money supply changes, central banks may sterilize their intervention by purchasing or selling bonds of commensurate value to the original intervention. Early theory suggested that sterilized interventions could not affect the exchange rate. Suppose the Federal Reserve purchases 50 million dollars worth of Euro bonds to depreciate the US dollar and, as a byproduct, increases the US money supply by that amount. A sterilization would require the Federal Reserve to sell Treasuries worth the same amount, bringing the money supply back to what it was prior to the intervention. However, since the relative money supplies of euros and dollars are unchanged, the exchange rate ought to remain the same.

Without the interest rate or price effect, the *portfolio balance* according to Kenen (1982) and the *signalling* channel according to Mussa (1981) have been proposed as ways through which the sterilized intervention might still affect the exchange rate. Portfolio balance theory assumes imperfect substitutability of domestic and foreign assets. In our example, the sterilization does not affect the relative money supplies but it has changed the relative supply of US and European bonds. By affecting these supplies, sterilized intervention makes it so that investors want to be compensated for holding the more numerous bonds with a higher return that must stem from bond prices or exchange rates. The signalling channel argument suggests that interventions signal future monetary policy and exchange rates respond to these signals. The intuition is that the central bank has accessed to privileged information that is too sensitive to share directly with the market, thus requiring indirect signaling via interventions. Kim (2003) showed that with a signalling channel present, intervention can be effective. By measuring the impulse responses with non-public interventions, we can assess whether intervention is still effective without this channel.

3 Literature Review

The interest in intervention effects on exchange rates is not new. However, the seemingly innocuous task of measuring intervention effects on the exchange rate suffers from an endogeneity problem in that intervention often “leans against the wind”. That is, intervention is usually conducted to counteract an opposite movement in the exchange rate. A naive regression analysis will tend to underestimate, or even estimate opposite effects if the market movement is stronger than the intervention, because we lack access to the counterfactual where there was no intervention. Furthermore, exchange rates are determined by many factors, meaning that omitted variable bias is an ever-present threat to identification.

In the past, one method to address the endogeneity issue has been the use of instrumental variables. Dominguez and Frankel (1993) find statistically significant effects of Federal Reserve and Bundesbank interventions using public news as an instrument to test the signalling channel on daily data between 1982 and 1988. They also find evidence for the portfolio balance channels. Naef and Weber (2019) use a similar method, instead with the squared lagged distance from the Bank of England's exchange rate target as an instrument. Alternative methods include Fatum and Hutchinson (2003), who use an event study with sign tests and find similar results. Blanchard et. al (2014) take a cross-country VAR approach to studying sterilized interventions and show that these interventions can stem exchange rate pressues. Kim (2003) uses a structural VAR model with short-run (ie. contemporaneous) restrictions in order to provide a unified framework for understanding the interactions of monetary policy, intervention and exchange rates. I borrow his method because it allows us to look at how monetary policy changes with exogenous intervention shocks for a specific country, offering insight for understanding the signalling channel in addition to whether or not exchange rates are merely impacted.

This paper expands on the existing literature in two ways. Firstly, it attempts to replicate the methodology of Kim (2003) on new, unpublished historical data in order to revisit his findings for a separate country and over a different time period. If the signaling channel is not in fact a crucial channel for intervention effectiveness, the study will act as external validation for Kim's findings. Secondly, Kim's analysis focuses on publicized interventions while the intervention data used here is secret. Thus, this paper examines the unified interactions of conventional monetary policy and sterilized exchange rate interventions on the exchange rate in the absence of a signalling channel. Theory and evidence suggest that signalling is a significant avenue through which sterilized interventions can affect the exchange rate. Muting this effect is important for understanding whether or not sterilization blunts the effect of exchange rate interventions and, if it does not, understanding the mechanism by which sterilized intervention works. Thirdly, the paper responds directly to Neely's criticism of Kim (2003) and proposes areas of further research along those lines.

4 Data

This paper uses a novel time series data set on daily Bank of England interventions on the pound sterling between 1971 and 1987 shared privately with the author. The data is digitized from confidential reports from the Bank of England to the Treasury over this period. The time interval is chosen such that it begins directly after the United Kingdom floats its exchange rate in August 1971, and ends a month prior to the Bank of England beginning an official shadowing of the Deutschmark in January 1987. Data for the other variables of interest are sourced from Global Financial Data. A critical feature of the data is that all interventions were sterilized because they were done through the Exchange Equalization Account (EEA), a government institution managed by the Bank of England. All interventions performed in the EEA had their money supply effects offset by commensurate domestic bond interventions.[1] Another important aspect of the data is that there is strong reason to believe that all interventions were secret. While the secrecy is hard to verify with certainty, policymakers at the Bank were themselves convinced of their success at hiding their intervention activities.[2] Due to the monthly frequency of index data, the daily interventions are aggregated into net monthly purchases.

[1] Allen, William. *The Bank of England and the Government Debt.* 2019.

[2] Archives of the Bank of England, Harry Arthur Siepmann papers, reference C14/1, 1936.

5 Empirical Model

The paper employs a structural VAR model with identifying restrictions on contemporaneous parameters and no restrictions on lagged parameters. That is, it makes assumptions informed by theory about how variables interact in the same period but make no assumptions about how they interact from one period to another, in order to recover the structural model from a reduced form. Endogeneity is addressed by our structural assumptions and the strength of the identification rests upon the validity of these assumptions. First, I assume that the economy can be described by a structural equation of the form:

$$G(L)y_t = \epsilon_t \tag{1}$$

Vectors are denoted with subscripts and scalar matrix entries are denoted with subscripts in brackets. Here y_t is an $n \times 1$ data vector, with n variables of interest and ϵ_t is an $n \times 1$ error vector describing structural shocks. I assume the true structural shocks are uncorrelated so $Var(\epsilon_t) = \Sigma$ where Σ is a diagonal matrix such that the ith diagonal entry is $\Sigma_{(ii)} = Var(\epsilon_{t(i)}) = \sigma^2_{(i)}$. $G(L)$ is a matrix polynomial with lag operator L. The lag operator maps a random variable to its value in the previous period and repeatedly applying L to a random variable X_t k times gives:

$$L^k X_t = X_{t-k}$$

Suppose we have p lags accounted for in this model. $G(L)$ is then:

$$G(L)y_t = G_0 y_t + G_1 y_{t-1} + G_2 y_{t-2} + ... + G_p y_{t-p}$$

G_i is an $n \times n$ matrix of coefficients for all $i \in [p]$. Define $A(L)$ as the coefficient matrix without the contemporaneous matrix G_0. That is:

$$A(L) = \sum_{i=1}^{p} G_i L^i$$

Then the matrix polynomial $G(L)$ can be expressed as:

$$G(L) = G_0 + A(L) \tag{2}$$

We would like to estimate $G(L)$ from the reduced form VAR below:

$$y_t = B(L)y_{t-1} + \mu_t \tag{3}$$

Here $Var(\mu_t) = \Omega$ which can have non-zero off-diagonal elements because they are not necessarily uncorrelated. We can use equation (2) and equation (1) to solve the expression for its reduced form:

$$y_t = -G_0^{-1}A(L)y_t + G_0\epsilon_t$$

Thus we can see that the structural parameters and the reduced form parameters are related by:

$$B(L) = -G_0^{-1}A(L) \tag{4}$$

Similarly the structural shocks and reduced form errors are related by:

$$\mu_t = G_0\epsilon_t \tag{5}$$

This in turn implies that the covariance matrices are related by:

$$\Omega = G_0^{-1}\Sigma G_0^{-1} \tag{6}$$

This helps explain why a reduced form VAR is less useful than a structural VAR when we are trying to understand the effect of policy. Equation (5) shows that the reduced form errors are composites of the structural shocks, meaning a single structural shock can produce effects across many endogenous variables in the reduced form. In other words, we cannot identify the effect of isolated shocks using the reduced form alone.

To estimate a structural VAR, we wish to solve for the structural coefficients by identifying G_0. In general there are infinite possible candidates for G_0 without additional restrictions. With n variables, we need at least $\frac{n^2-n}{2}$ zero restrictions in order to solve the system, sometimes referred to as the *order condition.* One way to address this is to use a recursive VAR which assumes G_0 to be lower triangular. That is, we assume the first variable does not depend on contemporaneous values of other variables, the second depends on contemporaneous values of the first variable and so on. However, this can be quite restrictive. This paper instead makes use of a generalized method proposed by authors such as Sims (1986) and Bernanke (1986) and used by Kim (2003) which still requires contemporaneous restrictions but does not require G_0 to be triangular. I use the following restrictions as per Kim (2003):

$$-A(L)y_t + \epsilon_t = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & g_{16} & 0 \\ g_{21} & 1 & g_{23} & 0 & 0 & 0 & g_{27} \\ 0 & g_{32} & 1 & g_{34} & g_{35} & 0 & 0 \\ 0 & 0 & 0 & 1 & g_{45} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ g_{61} & g_{62} & g_{63} & g_{64} & g_{65} & 1 & 0 \\ g_{71} & g_{72} & g_{73} & g_{74} & g_{75} & g_{76} & 1 \end{bmatrix} \begin{bmatrix} FEI \\ R \\ M \\ CPI \\ IP \\ E \\ PC \end{bmatrix}$$

Let $A(L)_i$ and ϵ_{ti} indicate the ith rows of the matrices in $A(L)$ and ith shock of ϵ_t respectively.

Then in scalar form, we have the following system of equations as our model:

$$FEI_t + g_{16}E_t = -A(L)_1 y_t + \epsilon_{t1} \tag{7}$$

$$R_t + g_{21}FEI_t + g_{23}M_t + g_{27}PC_t = -A(L)_2 y_t + \epsilon_{t2} \tag{8}$$

$$M_t + g_{32}R_t + g_{32}CPI_t + g_{32}IP_t = -A(L)_3 y_t + \epsilon_{t3} \tag{9}$$

$$CPI_t + g_{45}IP_t = -A(L)_4 y_t + \epsilon_{t4} \tag{10}$$

$$IP_t = -A(L)_5 y_t + \epsilon_{t5} \tag{11}$$

$$E_t + g_{61}FEI_t + g_{62}R_t + g_{63}M_t + g_{64}CPI_t + g_{65}IP_t = -A(L)_6 y_t + \epsilon_{t6} \tag{12}$$

$$PC_t + g_{71}FEI_t + g_{72}R_t + g_{73}M_t + g_{74}CPI_t + g_{75}IP_t + g_{76}E_t = -A(L)_7 y_t + \epsilon_{t7} \tag{13}$$

As per equation (7), we assume the central bank conducts foreign exchange intervention only in contemporaneous response to the exchange rate itself. Intervention can still react indirectly to other variables since all but the commodity price are assumed to affect the exchange rate in the same period as per equation (12). Equation (8) indicates that the interest rate is assumed not to respond to production or overall price levels from this period because this information is not available within the month. This is in line with past studies like Sims and Zha (2006) except with addition of contemporaneous responses to intervention, allowing for the possibility of an imperfectly sterilized sale or purchase of currency affecting the policy rate. Equations (9) through (13) are also from Sims and Zha (2006) as well as Kim and Roubini (2000). Equation (9) reflects the money demand equation, which responds to the output indicated by the industrial production and the interest rate. Equations (10) and (11) assume that the real economy has a delayed response to changes in policy and exchange rates, motivated by the fact that firms cannot easily change output and prices. The final two equations (12) and (13) are arbitrage equations that stem from financial market equilibriums for the foreign exchange market and the commodities market.

6 Results

The model was estimated with six lags. Table 1 reports the estimates for the structural parameters of the contemporaneous coefficient matrix, rounded to the nearest thousandth. Note that positive contemporaneous coefficients imply negative relationships and vice versa because we subtract from both sides of the relevant scalar equation above to solve for the outcome variable of interest. It is immediately worth observing that while many parameters fit the direction implied by macroeconomic theory, a few parameters have opposite signs to what we would expect. For example, it makes sense that $g_{61} > 0$ because it implies that purchasing foreign currency assets decreases the amount of dollars that can be bought with one pound. However, $g_{62} < 0$ suggests that the value of the pound tends to fall with contemporaneous increases in interest rates, a counterintuitive result. Another puzzling implication comes from $g_{32} < 0$, suggesting that the money supply rises with higher interest rates. On the other hand, $g_{23} > 0$ suggests the opposite, which is the direction implied by money supply and demand models.

Table 1: Estimated contemporaneous structural parameters

$$-G_0 y_t + \epsilon_t = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & -25.957 & 0 \\ 0.429 & 1 & 0.277 & 0 & 0 & 0 & 21.971 \\ 0 & -1.283 & 1 & -26.141 & 2.815 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0.028 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0.064 & 0.130 & 47.860 & 37.600 & 6.070 & 1 & 0 \\ 0.363 & 0.416 & -2.549 & -6.173 & -9.692 & 28.924 & 1 \end{bmatrix} \begin{bmatrix} FEI \\ R \\ M \\ CPI \\ IP \\ E \\ PC \end{bmatrix}$$

Figure 1 reports the impulse responses to a unit shock in foreign exchange intervention and interest rates respectively, where the unit for intervention is a 500 million dollar purchase of US dollars and the unit for interest rates is one percent. To put the intervention shock size in perspective, the mean magnitude (absolute value) of net monthly intervention over this period was 368.56 million and the standard deviation was 619.49 million. Dashed lines represent 90% probability bands or 1.65 standard errors. We observe no statistically significant changes in the money supply over 12 periods in response to foreign exchange intervention, supporting the claims that these interventions were sterilized. The exchange rate tends to depreciate about 0.9% in the same period in response to 500 million USD foreign asset purchases but quickly appreciates back to its original value within a month. This makes sense since buying US dollars ought to reduce the amount of US dollars that can be purchased per pound. The responses are not statistically significant past the initial period, suggesting a muted-to-negligible response. An issue of note is that error bands produced by the Statsmodels package used for this paper do not show any error in the contemporaneous period despite the fact there should be some. As such we direct attention to the error bands for the first period to get a sense of what the error is in the zero-th period. It is entirely possible that the depreciation we observe in the exchange rate is not statistically significant at all, implying that without signaling, there is little to no effect of intervention on the exchange rate.

The interest rate does not respond contemporaneously despite allowing for this interactions in the assumptions, again supporting the fact that these interventions were sterilized. However, the interest rate does tend to fall after a purchase of foreign assets, which by models like Mundell-Fleming ought to depreciate a currency. This result does become significant about a half year later. This suggests that interest rates move in line with signaling channel predictions and that there would be something to signal should the central bank decide to, assuming this information could be accurately conveyed and correctly interpreted by the market. A conflicting result is the slight depreciation and general lack of response to the interest rate by the exchange rate in Figure 2. This stems from the $g_{62} < 0$ concern discussed earlier. If signaling is to work through monetary policy expectations, a lack of exchange rate response to monetary policy is puzzling.

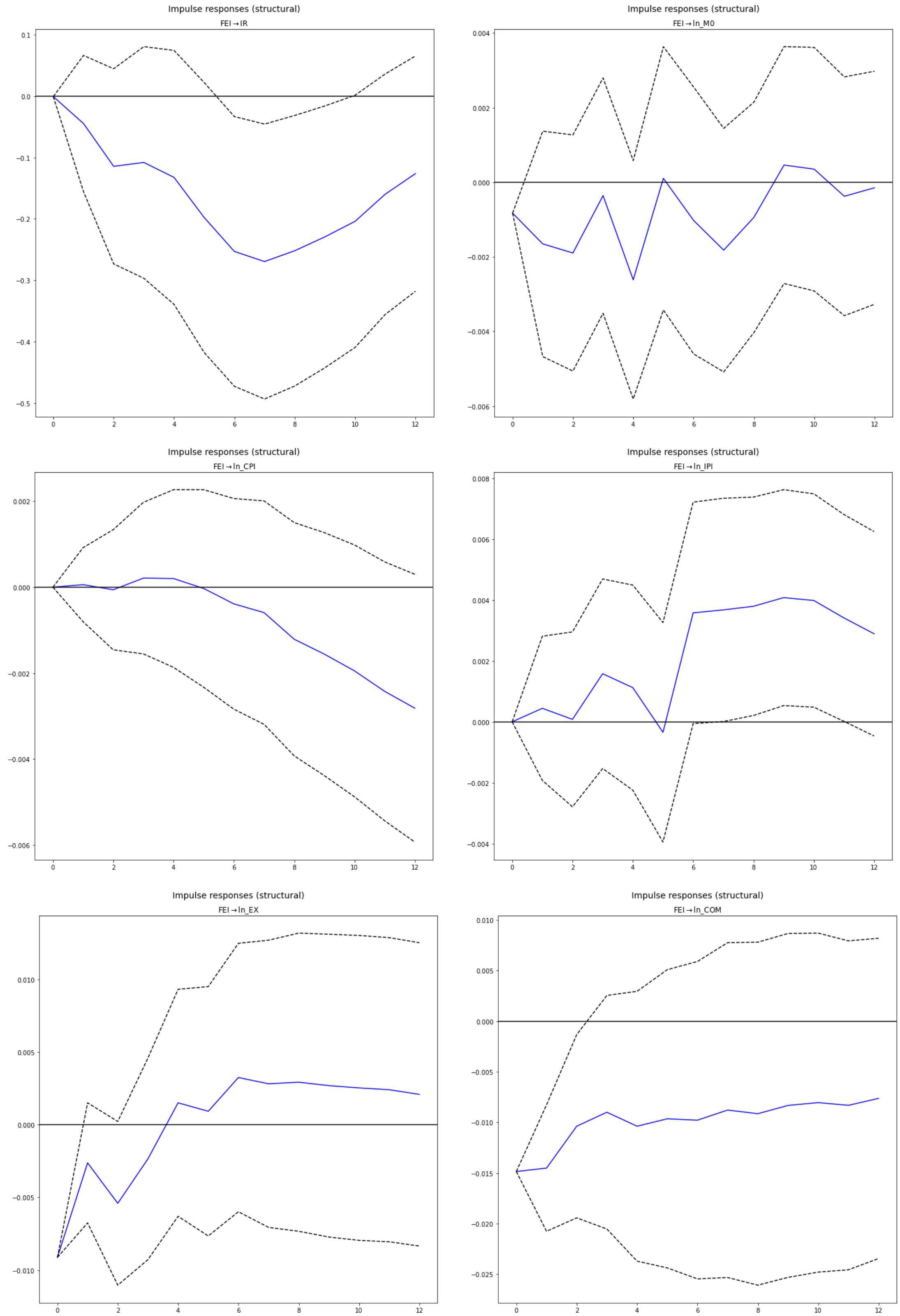

Figure 1: Impulse responses to 500 million USD intervention shocks

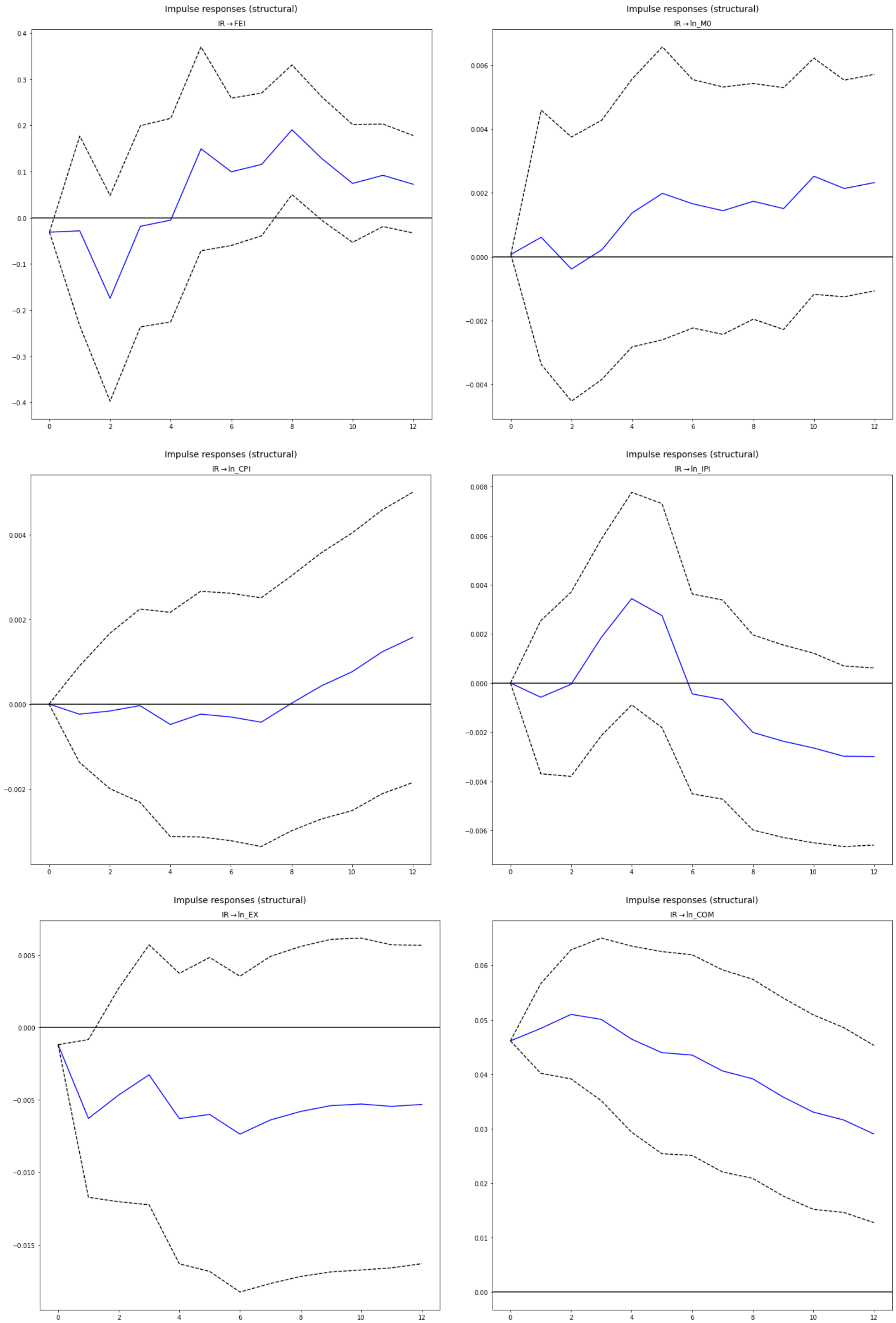

Figure 2: Impulse responses to 1% interest rate shock

7 Alternate Specifications

7.1 Reaction Function Restrictions

We now consider alternative restrictions on the central bank's contemporaneous policy response to the exchange rate. That is, we consider three alternate assumptions about the contemporaneous reaction of the intervention or the interest rate to the exchange rate. These specifications are (1) restricting intervention response to exchange rate in the same period where $g_{16} = 0$ and $g_{26} > 0$, (2) allowing both intervention and interest rates to respond to the exchange rate in the same period where $g_{16} > 0$ and $g_{26} > 0$, and (3) restricting both intervention and interest rate response to the exchange rate in the same period such that $g_{16} = 0$ and $g_{26} = 0$. These are shown in Figures 3, 4 and 5 respectively. For brevity we exclude impulse responses of the various price index controls. From left to right, the response variables are the other policy (either interest rates or intervention), exchange rates, and monetary aggregates.

The results are broadly consistent with the original specifications except under the second specification when we have both contemporaneous restrictions on interest rate and intervention responses. Under this assumption the impulse responses suggest a strong appreciation of the exchange rate upon purchasing foreign assets, which is the opposite of the central bank's intention. This model also shows an interest rate response to the foreign exchange intervention with stronger statistical significance than the original specification. While counterintuitive, this result is borne from assumptions that are both much stronger and less plausible than the initial specification, giving us reason to question the underpinnings of the second model. The original data included daily interventions in response to previous day exchange rate changes, challenging the view that intervention responds to the exchange rate with a one month lag. Otherwise, the impulse responses are not significantly altered by reasonable changes to the assumptions we made about how the central bank responds to changes in the exchange rate, providing additional support for our original results.

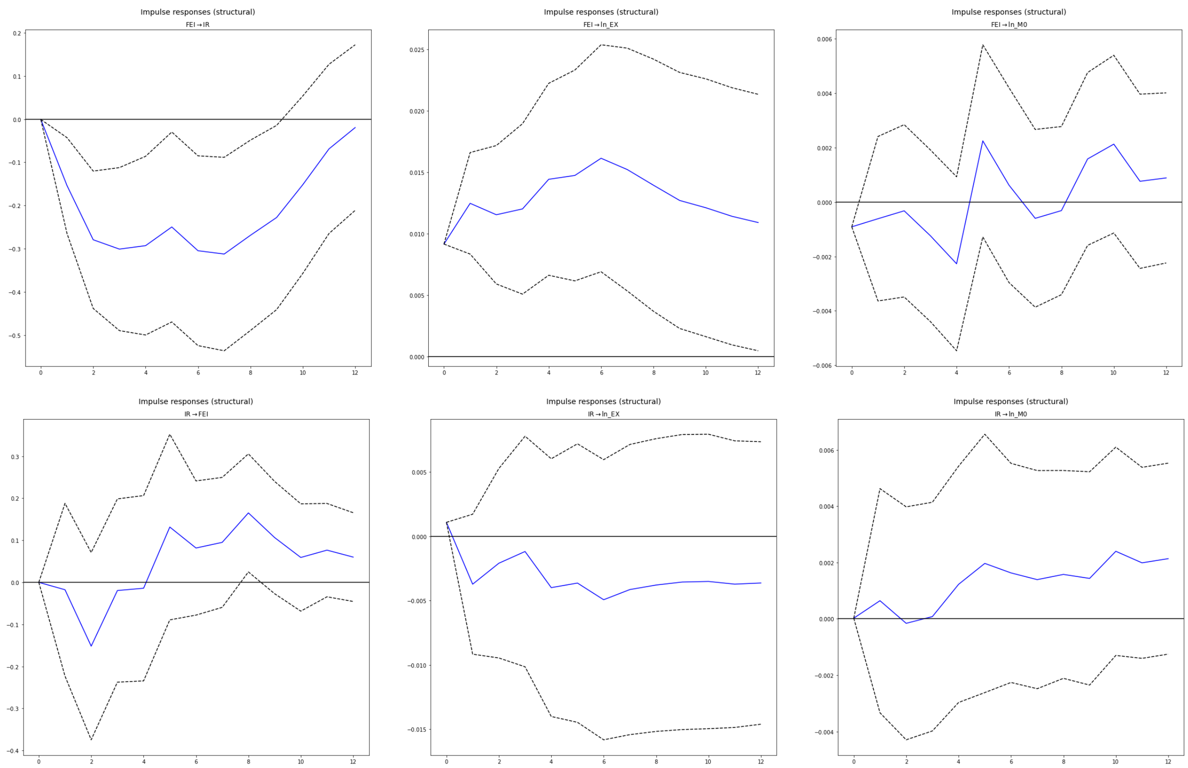

Figure 3: Impulse responses to FEI (top row) and IR (bottom row) when $g_{16} = 0$ and $g_{26} > 0$

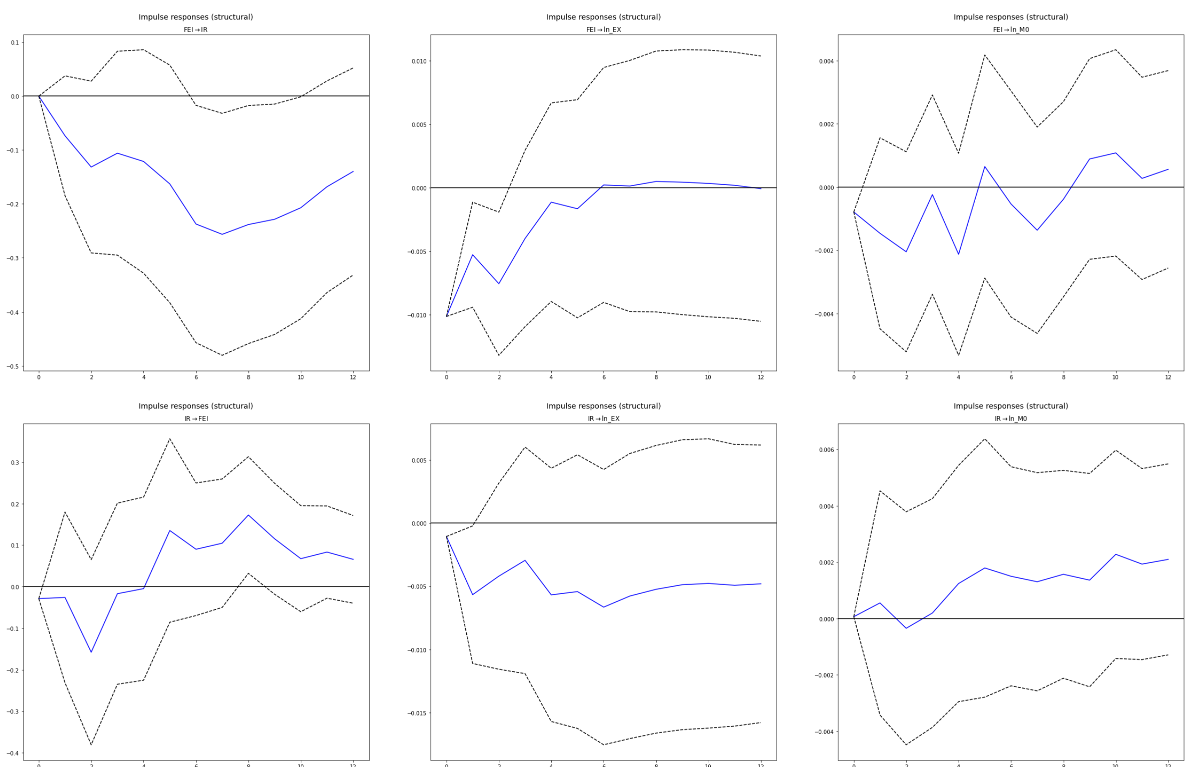

Figure 4: Impulse responses to FEI (top row) and IR (bottom row) when $g_{16} > 0$ and $g_{26} > 0$

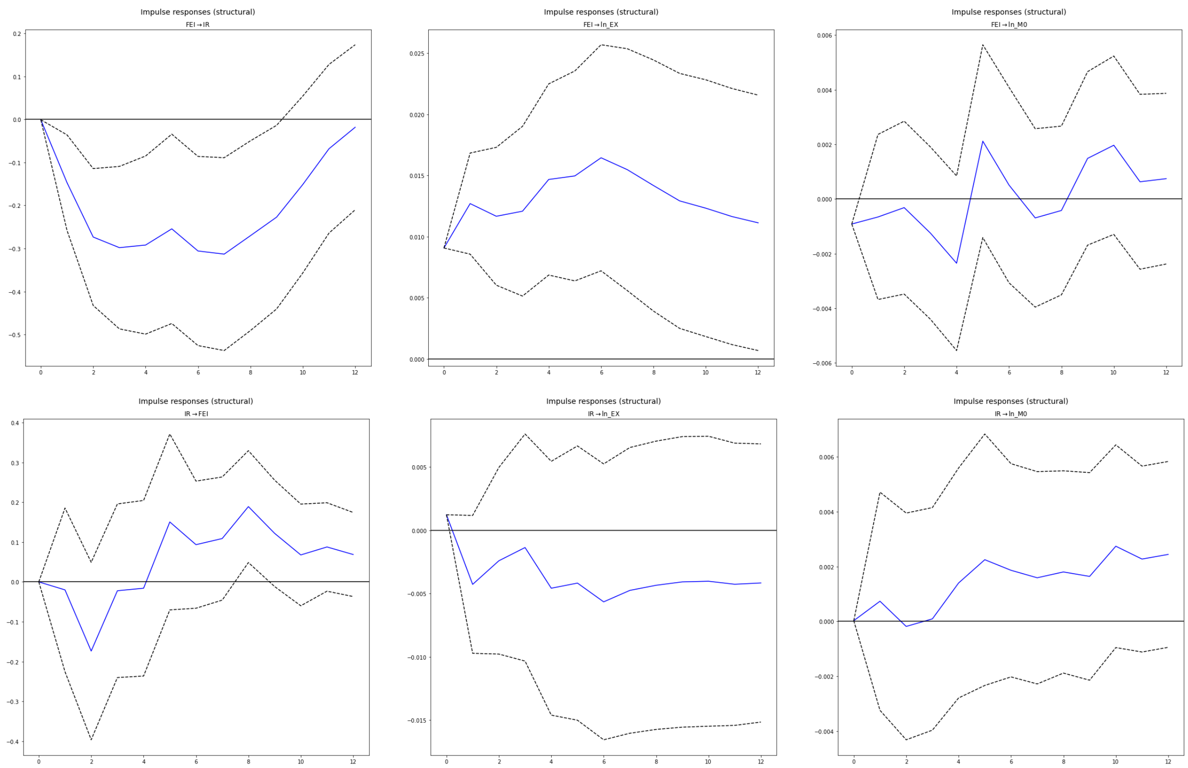

Figure 5: Impulse responses to FEI (top row) and IR (bottom row) when $g_{16} = 0$ and $g_{26} = 0$

7.2 Policy Interaction Restrictions

Next we consider alternative restrictions on how the two kinds of policies react to each other. That is, we consider various assumptions about the contemporaneous relationship between intervention and interest rates. These specifications are (1) restricting intervention response to interest rates in the same period and vice versa where $g_{12} = 0$ and $g_{21} = 0$, (2) allowing both intervention and interest rates to respond to each other in the same period where $g_{12} > 0$ and $g_{21} > 0$, and (3) restricting only interest rate response to exchange rate interventions in the same period but not the other way around such that $g_{12} > 0$ and $g_{21} = 0$. These are shown in Figures 6, 7 and 8 respectively. In this case the impulse responses are nearly identical to those in the original specification save for a slightly larger depreciation of the pound in the contemporaneous period. In the first and third models the depreciation is about 1.1% as opposed to the 0.9% observed in the original model, a marginal difference.

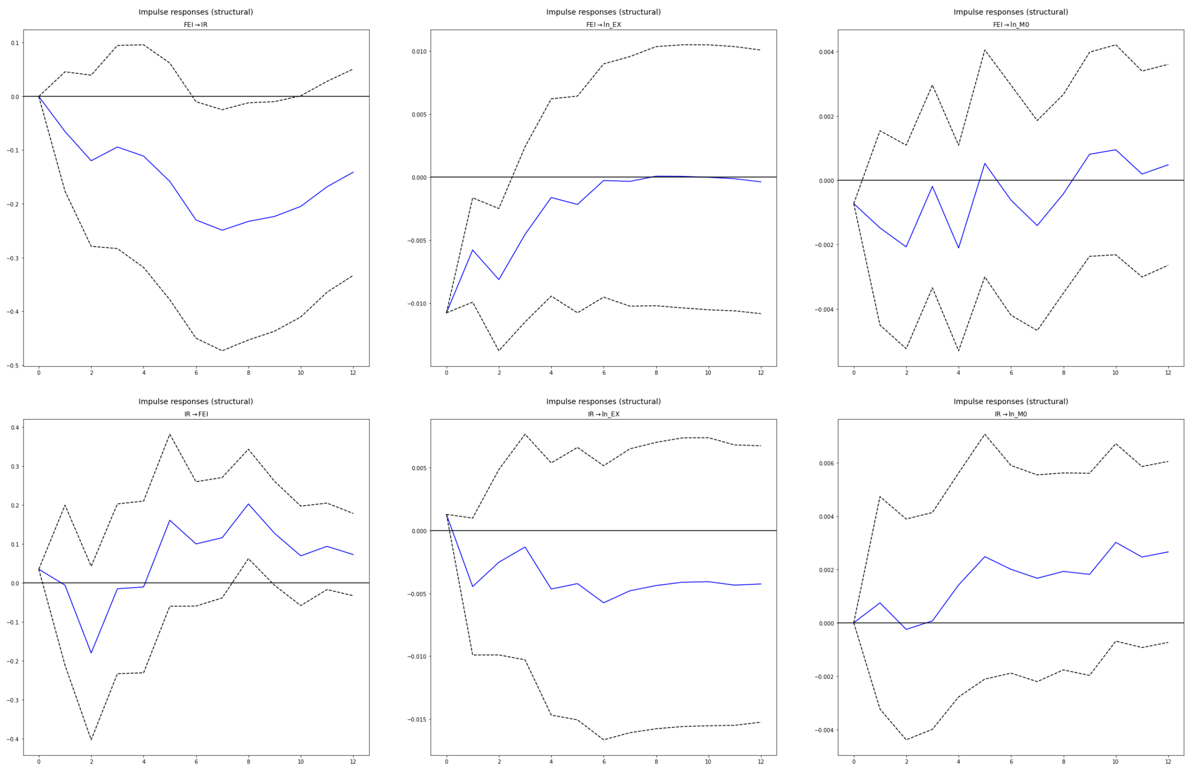

Figure 6: Impulse responses to FEI (top row) and IR (bottom row) when $g_{12} = 0$ and $g_{21} = 0$

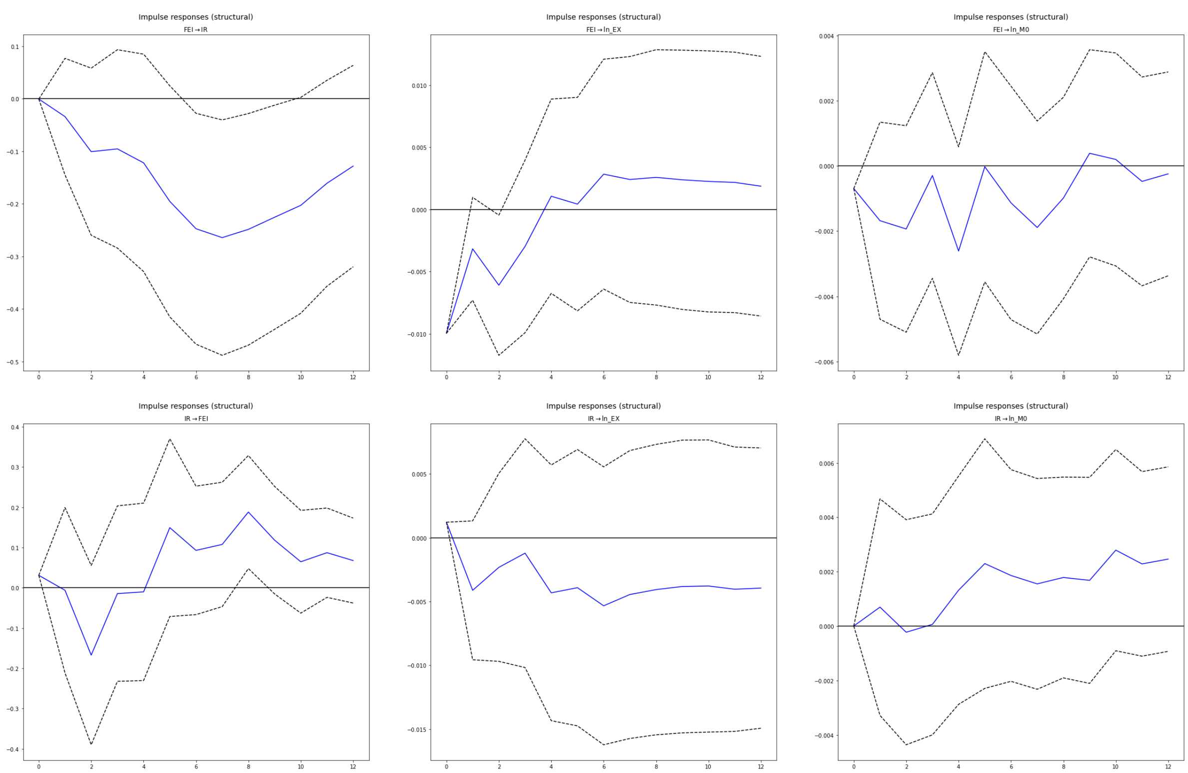

Figure 7: Impulse responses to FEI (top row) and IR (bottom row) when $g_{12} > 0$ and $g_{21} > 0$

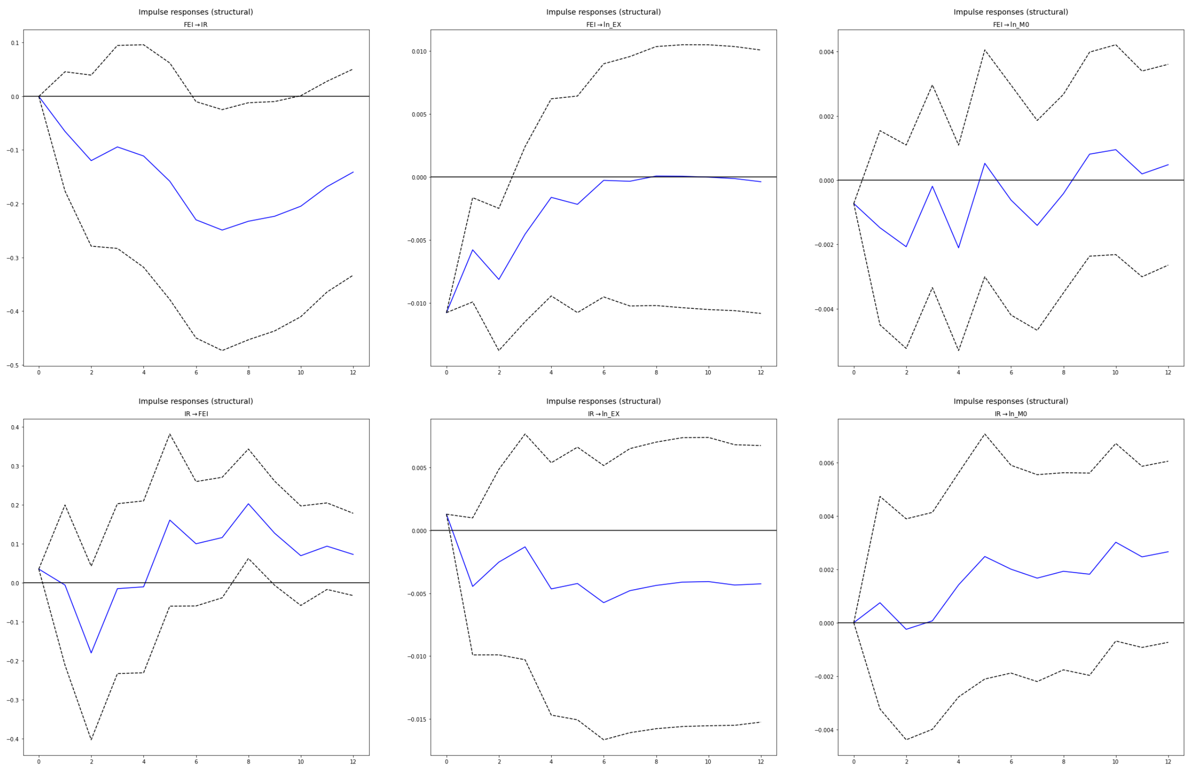

Figure 8: Impulse responses to FEI (top row) and IR (bottom row) when $g_{12} > 0$ and $g_{21} = 0$

8 Discussion

In general, a major weakness of structural vectorautoregressions is their sensitivity to alternate identifying restrictions. In this case, the results are highly robust to a number of different plausible specifications. When not robust, it happens to be the case that the specification itself is implausible. However, Neely (2005) raises two other concerns with this method of evaluating exchange rate intervention effectiveness. The first is the potential presence of high-frequency interactions, possibly at weekly, daily or even hourly time frames, which are missed by monthly data. Authors such as Fischer and Zurlinden (1999) as well as Payne and Vitale (2003) have instead used data with time stamped interventions, showing effectiveness over very short term periods even within a day. However, in defense of considering monthly periods, studying interactions between many variables allows us to include price indices that are only available at these intervals, which helps correct for omitted variable bias. Trying to do so in tandem high frequency data would incorrectly suggest spikes in the consumer price index at the start of each month and any correction methods (for example a linear interpolation) would require additional justification. Furthermore, there are cases where the effect we are interested in is not an hour-long or day-long adjustment of the exchange rate but effectiveness over longer time horizons, in which case the minute interactions are of less concern. As such, the trade-off between a rigorous causal identification and policy-relevant insights continues to be a trade-off. It is not clear that high-frequency data sets alone can answer whether secret sterilized interventions are effective in a way that is useful for central banking.

The second concern raised by Neely (2005) is more technical, which is the failure of Kim's model to meet the *rank conditions* necessary for a unique estimation of the coefficients and thus impulse responses. What follows is a brief overview of this condition from Hamilton (1994). We wish to recover the contemporaneous coefficient matrix G_0 and the structural covariance matrix Σ from the reduced form covariance matrix Ω using Equation (6). Let n denote the number of variables of interest and let θ_G and θ_Σ be $(n_G \times 1)$ and $(n_\Sigma \times 1)$ sized vectorized versions of the parameters to be estimated in G_0 and Σ respectively:

$$\theta_G = \begin{bmatrix} g_{16} \\ g_{21} \\ \vdots \\ g_{76} \end{bmatrix}, \quad \theta_\Sigma = \begin{bmatrix} \sigma_1^2 \\ \sigma_2^2 \\ \vdots \\ \sigma_7^2 \end{bmatrix},$$

Define the function vech(X) as the "half-vectorization" of an $n \times n$ matrix X, which creates a column vector out of the lower triangular part of X:

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nn} \end{bmatrix} \implies \text{vech}(X) = \begin{bmatrix} x_{11} \\ x_{21} \\ \vdots \\ x_{n1} \\ x_{22} \\ \vdots \\ x_{n2} \\ \vdots \\ x_{nn} \end{bmatrix}$$

Note that by Equation (6), $\text{vech}(\Omega) = f(\theta_G, \theta_\Sigma)$ is some function f of θ_G and θ_Σ. Hamilton shows that the matrix of derivatives of this function J is an $(n \times [n_G + n_\Sigma])$ matrix equal to:

$$J = \begin{bmatrix} \frac{\partial \, \text{vech}(\Omega)}{\partial \theta_G^T} & \frac{\partial \, \text{vech}(\Omega)}{\partial \theta_\Sigma^T} \end{bmatrix}$$

The rank condition states that the $n_G + n_\Sigma$ columns of J must be linearly independent. The intuition is that J roughly describes how the reduced form covariance matrix Ω (that we already have) changes with respect to the parameters we want to estimate. If the parameters in θ_G and θ_Σ can be changed without affecting Ω, it means that other estimates of these parameters are also consistent with the same reduced form model, making ours non-unique. This is akin to saying there exists some non-zero vector v we can add to $[\theta_G^T, \theta_\Sigma^T]^T$ without changing Ω, which is equivalent to saying v is in the null-space or kernel of J. According to Neely (2005), the model used here and by Kim (2003) suffers from this issue. This criticism is more serious than the data-frequency critique because it means that the estimates for G_0 and Σ are consistent with the data but not unique. However, without a theorem that describes what demands the rank condition imposes on our assumptions about G_0, the only way to check the rank condition is by initializing different guesses for the parameters and checking J manually, a feature which is unavailable for the Statsmodels vectorautoregression packages. This makes it difficult to find a specification that we know *ex ante* will satisfy the rank condition. It is notable that since our results are robust to so many specifications that it may be that our impulse responses and their corresponding estimates are unique in their consistency with every specification. However, much more work would be required to verify this hypothesis.

The data-frequency critique is a legitimate concern if our only priority is to assert strong causally identified impulse responses, regardless of policy significance. However, in light of the need to understand intervention effectiveness over both short and long time horizons, as well as the desire to include price index controls to reduce the risk of omitted variable bias, there is reason to adopt a monthly approach even at the risk of within-month endogeneity. With regard to the rank condition, additional work is required to find restrictions that satisfy both the rank and order conditions for structural VAR identification, while simultaneously being theoretically sound. An avenue for study might be examining if and how we can specify different restrictions on G_0 such that the derivative matrices for our k specifications $J_1, J_2, ..., J_k$ satisfy $\ker(J_1) \cup \ker(J_2) \cup ... \cup \ker(J_k) = \emptyset$. If there is a way to find specifications so that no vector can be in the null space of every J_i simultaneously and the impulse responses happen to be similar in each specification as they are in our case, it would mean the overarching impulse response functions are robust even if the individual models fail the rank condition. In the meantime, we can say there is a lack of evidence to suggest that intervention was successful without signaling for the Bank of England over this period.

Neely's critiques take issue with the modeling choices in Kim (2003) that also apply here, which I have now discussed at length. However, on the issue of whether or not the signaling channel is actually salient which is specific to this paper, it is worth noting my results cannot be directly juxtaposed with those in Kim (2003) to claim that signaling channels are required. There are likely differences between Kim's Federal Reserve context and the Bank of England context studied here that may account for why we do not observe statistically significant impulse responses here while we do for the Federal Reserve from 1974 to 1996. In other words, our study does not represent a true signaling-absent counterfactual for Kim's. One ought to be cautious drawing the conclusion that signaling was the key difference between these two countries in these time periods. The best we can say is that we have circumstantial evidence to suggest signaling might be important because these results are consistent with such a hypothesis.

9 Conclusion

This paper develops a structural VAR model to study the interactive effects of monetary policy and secret sterilized foreign exchange intervention using data from the Bank of England between 1971 and 1987. I am interested in the impact of the intervention because the unpublished nature of the interventions allows us to study how the exchange rate responds when the signaling channel is muted. I find that there is a slight depreciation of the pound upon a 500 million dollar purchase of foreign currency assets and that this result is not statistically significant past the initial period. Thus we cannot reject the claim that it was ineffective altogether. Additionally, I observe interest rate responses after interventions that are consistent with signaling hypothesis in that interventions meant to lower the value of domestic currency tend to lower interest rates. These results have some statistical significance in later periods. However, I do not observe significant impulse responses from the exchange rate due to interest rate changes, which muddies the narrative that signaling might work.

The results are generally robust to six different specifications about how the central bank responds to the exchange rate and how different policies interact. However, the failure to meet the rank condition for structural VAR parameter identification weakens the confidence with which we can claim a lack of evidence for intervention effectiveness in the absence of signaling. Further research on this topic is required to clarify some of the above issues and to simplify the process of making contemporaneous assumptions while satisfying all necessary conditions for unique identification.

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