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A Survey on the Effects of Sterilized Foreign Exchange Intervention

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Abstract

In this paper we survey prominent theories that have shaped the literature on sterilized foreign exchange interventions. We identify three main strands of literature: 1) that which advocates the use of sterilized interventions; 2) that which deems sterilized interventions futile; and 3) that which requires some market friction in order for sterilized interventions to be effective. We contribute to the literature in three important ways. First, by reviewing new theoretical models that have surfaced within the last decade. Second, by further penetrating into the theory of interventions in order to analyze the key features that make each model distinct. And third, by only focusing on sterilized operations, which allows us to sidestep the effects induced by changes in the stock of money supply. Additionally, the models that we present comprise both a macro and micro-structure approach so as to provide a comprehensive view of the theory behind exchange rate intervention.

Key Words: Sterilized foreign exchange intervention, impossible trinity, portfolio balance channel, signaling channel, uncovered interest rate parity

JEL Codes: E52, E58, F31

1 Introduction

The breakdown of the Bretton Woods system in the early 1970's marked the beginning of the greatest exchange rate liberalization in history. Major currencies were allowed to float, while others fluctuated within narrow bands. Decades later, during the aftermath of the European exchange rate crisis of the 1990s, countries steered away from intermediate schemes towards either hard pegs or fully flexible rates. It was during this time that the "corner hypothesis" (Eichengreen, 1994) or the "fix or float" proposition (Obstfeld and Rogoff, 1995) became conventional wisdom. This idea quickly spread to emerging markets, intensely reinforced by the East Asia crises of 1997-1998, and the failure of Argentina's currency board in 2001. Since then, central banks have allegedly opted for monetary policy autonomy where inflation targeting plays a leading role.

Notwithstanding, the empirical evidence has shown that most countries have been reluctant to relinquish control over the value of their currencies. In fact, industrialized countries have led concerted initiatives to affect the value of major exchange rates, some of which include the Smithsonian Agreement (December 1971), the Plaza Accord (September 1985), the Louvre Accord (February 1987), the Chiang Mai Initiative (May 2000) and the Pittsburg Agreement (December 2009). Similarly, emerging markets have conducted frequent and large-scale interventions (although in less coordinated fashion), to the extent of becoming an empirical regularity (see Calvo and Reinhart, 2002). But allowing for free capital flows while having autonomous monetary policy and a managed exchange rate is an impossible trinity due to arbitrage by foreign investors. In principle, this trinity limits the effects of policy.

In this paper we survey prominent theories that have shaped the literature on sterilized foreign exchange interventions (i.e. purchases or sales of foreign currency, intended to affect the exchange rate, but without altering the monetary base). While there has been a wide array of empirical surveys on the effectiveness of central bank interventions, few have elucidated the mechanisms through which they affect the economy. To the best of our knowledge, less than a handful of non-empirical surveys exist that center on the various propagation mechanisms of interventions; for instance, Sarno and Taylor (2001), Evans (2005) and Lyons (2006). However, these surveys either provide a descriptive reading of how interventions affect the exchange rate, or predominantly focus on a micro-structure approach. Hence, our paper contributes to the literature in three important ways: (i) by reviewing new theoretical models that have surfaced within the last decade; (ii) by further penetrating into the theory of interventions in order to analyze the key features that make each model distinct; and (iii) by only focusing on sterilized operations, which allows us to sidestep the effects induced by changes in the stock of money supply. Additionally, the models that we present comprise both a macro and micro-structure approach so as to provide a comprehensive view of the theory behind exchange rate intervention.

We identify three main strands of literature. In Section 2 we present the works that advocate the use of sterilized interventions (rendering the impossible trinity possible). A key underlying assumption of models pertaining to this strand of literature is that agents are not indifferent to holding different currency-denominated assets. Thus, in the event of a sterilized intervention, agents require a change in either the relative rates of return or the value of domestic currency in order to offset changes in their portfolio composition.

In Section 3 we present the views that deem interventions futile (where the impossible trinity is ever binding). Generally, this strand of literature employs no-arbitrage conditions, such as the uncovered interest rate parity, but with no risk premium. Hence, agents are indifferent between holding foreign and domestic assets as long as they guarantee the same level of consumption in each state of the economy. As a consequence, sterilized interventions do not affect equilibrium prices nor do they represent an additional monetary instrument for central banks.

Finally, in Section 4 we present models that require the inclusion of market frictions in order for sterilized interventions to be effective. In essence, these frictions explain why assets are imperfect substitutes and limit arbitrage opportunities that would have been otherwise exploited. Most of these works consider capital controls, currency risks, differences in return distributions (when agents are risk averse), and default risks as the main constituents of market constraints. This section also comprises the most recent literature on central bank intervention.

We acknowledge the ample empirical literature that exists on the effectiveness of central bank intervention. However, in this paper we intend to cover only the theoretical framework of interventions, both new and mainstream. For a thorough compilation of empirical findings we refer readers to Dornbusch (1980), Meese and Rogoff (1988), Dominguez and Frankel (1993), Edison (1993), Dominguez (2003), Fatum and Hutchison (2003), Neely (2005), and Menkhoff (2010). We do, however, present a compilation of empirical findings in Appendix B. In sum, the general consensus indicates that interventions have a small and short-lived effect on exchange rates. This result has remained valid ever since the Economic Summit at Versailles in June 1982, when the Jurgensen Group declared that "the role of intervention can only be limited."[1] Nonetheless, authors who do not find any significant effects have increased in number over the past decade. Examples include Fischer (2001a), Fischer (2001b), Blanchard (2013), and Villamizar (2014).

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[1]See last paragraph of Jurgensen (1983).

2 Impossible trinity might not be impossible

The literature that supports a managed exchange rate regime identifies two main channels through which interventions affect the exchange rate, even when opting for monetary policy autonomy and allowing for free capital flows. The first channel is known as the *signaling channel* and conveys information regarding the future value of money supply and interest rates. Thus, forward-looking markets affect the exchange rate today. The second channel is known as the *portfolio balance channel* and comprises the supply of assets denominated in different currencies. If assets are imperfect substitutes, changes in expected returns induce agents to re-balance their portfolios. And, since the money supply and interest rates remain unchanged (as is the nature of sterilized interventions), the exchange rate then absorbs any alteration in expected returns.

This section provides an in-depth analysis of these channels. Section 2.1 portrays thier effects in the light of asset markets and goods and services. Section 2.2 centers on the portfolio balance channel. Specifically, Section 2.2.1 presents the first acknowledged portfolio balance model introduced by Weber (1986) and expands on some key results that are not explicitly derived in his paper. Section 2.2.2 comments on a model by Canzoneri and Cumby (2013) which offers a non-conventional interpretation as to why different currency-denominated assets are imperfect substitutes; mainly due to liquidity premiums. Section 2.2.3 reviews one of the earliest works on the portfolio balance channel by Evans and Lyons (2001), under a micro-structure approach. Finally, Section 2.3 describes the signaling channel, based on Vitale (1999), who is also a pioneer on micro-structured models applied to the foreign exchange market.

Most of the models presented in this section consider a world with 2 countries, *home* (h) and *foreign* (f). We denote the exchange rate, $e_t^{i,j}$, as the units of country i's currency per unit of country j's currency at time t. Hence, $e_t^{i,i} = 1$ for all periods. Furthermore, let $e_t^{h,f} \equiv e_t$. Additional notation will be presented in each model.

2.1 Assets and Goods market

2.1.1 Asset market approach

In essence, the asset market approach is based on the Uncovered Interest rate Parity condition (UIP), exemplified in equation (1):[2]

$$E_t[e_{t+1} - e_t \mid \Omega_t] = i_t^h - i_t^f - rp_t. \tag{1}$$

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[2]See Kearns and Rigobon (2002) and Almekinders and Eijffinger (1996).

In this equation e is the log exchange rate, Ω_t is the relevant information set at time t, rp is the risk premium,[3] and i^h and i^f correspond to domestic and foreign returns, respectively. Contemporaneous and past exchange rate interventions, INT, are included in Ω_t, so that $\{INT_i\}_{i=-\infty}^{t} \subseteq \Omega_t$.

A useful representation of UIP that lends itself to the interpretation of policy effects is shown in equation (2). It is constructed by iterating equation (1) forward:

$$e_t = \sum_{j=0}^{T-t-1} E_t \left[i_{t+j}^f - i_{t+j}^h + rp_{t+j} \mid \Omega_t \right] + E_t[e_T \mid \Omega_t]. \tag{2}$$

For instance, under the portfolio channel, the rebalancing of domestic and foreign bonds operates through the term $E_t[rp_{t+j} \mid \Omega_t]$. Under the signaling channel, the term $E_t[i_{t+j}^h \mid \Omega_t]$ conveys changes in the expected future policy rate. This channel also contains exchange rate expectations captured by the term $E_t[e_T^{h,f} \mid \Omega_t]$ which are often pinned down by the Purchasing Power Parity condition (PPP). In sum, all terms can be expressed as a function of exchange rate interventions so that $e_t = e_t(INT_t)$.

In this setup, a sterilized intervention implies that both i_t^h and i_t^f remain unchanged. Therefore, the exchange rate can be affected by: i) signals on future monetary policy, ii) changes in the expected future exchange rate, and iii) movements in the contemporaneous and future values of the risk premium.[4] In order to pin down the exchange rate, some authors, such as Almekinders and Eijffinger (1996), consider a central bank's loss function, L_t, in order to capture deviations of the exchange rate from a moving target, as expressed in equation (3).[5] This helps to determine the optimal exchange rate, as characterized in equation (4).

$$L_t = [e_t(INT_t) - \bar{e}_t]^2 \tag{3}$$

$$e_t(INT_t^*) = \bar{e}_t. \tag{4}$$

Additionally, if central banks find interventions to be costly, they might decide to conduct foreign exchange operations only when the loss function exceeds some threshold $(\overline{INT} > 0)$.

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[3]Intuitively, the risk premium can be thought of as the difference between a risk-free investment (domestic asset) and a risky investment (foreign asset) subject to unexpected exchange rate changes. Thus, if agents are risk averse, the risk premium takes on positive values in order to compensate for the increased uncertainty of the risky asset.

[4]A change in the risk premium (rp_t) is possible provided that assets are imperfect substitutes.

[5]In empirical applications, the exchange rate target $(\bar{e})$ is usually taken to be the moving average of past exchange rate values (i.e. $\bar{e}_t = \frac{1}{n} \sum_{j=1}^{n} e_{t-j}$).

Formally,

$$INT_t = \mathbf{1}_{\{|INT_t^*| \geq \overline{INT}\}} INT_t^*, \tag{5}$$

where $\mathbf{1}$ represents an indicator function. Consequently, equations (2), (4) and (5) fully describe the system of equations that determine the optimal level of interventions and its corresponding exchange rate value. In related literature, some authors such as Kearns and Rigobon (2002) find a substantial effect of interventions, especially during the day in which they are conducted. Most authors however, find scant evidence of any significant effects.

2.1.2 Goods market approach

The goods (and services) market approach is generally linked to the exchange rate behavior in the long run. As such, many central banks follow this methodology, albeit with different techniques, to decide over equilibrium levels of exchange rates. We follow Mussa (1976) and Frenkel (1976) to further analyze this approach but focusing only on the effects of sterilized interventions.

In the long run, currencies should have equal purchasing power so the "generalized law of one price" (or PPP) is expressed as

$$e_t = p_t^h - p_t^f, \tag{6}$$

where e_t again corresponds to the log exchange rate and p^i denotes the price (in logs) of a representative basket of goods and services in country i. The model now turns to the real money market where money supply equals demand. In the literature, this equilibrium is typically expressed as

$$m_t - p_t = \alpha y_t - \beta i_t, \tag{7}$$

where m_t is the money supply, y_t corresponds to real output, and i_t is the short-term interest rate (all variables in logs). By substituting equation (7) and the UIP condition of equation (1) into equation (6), we obtain

$$e_t = (m_t^h - m_t^f) - \alpha(y_t^h - y_t^f) + \beta(E_t[e_{t+1} - e_t \mid \Omega_t] + rp_t) \tag{8}$$

Finally, iterating equation (8) forward and defining $\lambda \equiv \frac{\beta}{1+\beta}$ yields:

$$e_t = \sum_{j=0}^{\infty} \left(\frac{\lambda^j}{1+\beta} \right) E_t[(m_{t+j}^h - m_{t+j}^f) - \alpha(y_{t+j}^h - y_{t+j}^f) + \beta rp_{t+j} \mid \Omega_t]. \tag{9}$$

As it turns out, equation (9) differs in two main aspects with respect to the flexible-price model of equation (2). The first difference is the effect of the money supply (as opposed to asset returns). Thus, a sterilized intervention in this case implies that m_t^h and m_t^f remain unchanged. The second difference is the newly effect of real output. In this sense, macroeconomic variables complement monetary policy in exchange rate determination. In sum, a sterilized intervention can affect the exchange through: i) signals on future money supply, ii) changes in the expected future exchange rate, iii) movements in the contemporaneous and future values of the risk premium, and iv) changes in the expected value of output growth.[6]

2.2 Portfolio Balance Channel

2.2.1 Weber (1986)

Weber considers the case in which the impossible trinity is not impossible, provided that bonds denominated in different currencies are not perfectly interchangeable. In the related literature, this is attributed to a variety of reasons including the risk of enacting currency controls, default risks, liquidity premiums and various forms of capital market imperfections. Essentially, anything that sustains a non-zero risk premium (rp_t), as presented in the UIP condition of equation (1), is sufficient for assets to be imperfect substitutes. Weber's portfolio balance model assumes perfect capital mobility across countries and monetary independence in each country. The general framework is as follows:

There are no financial intermediaries in the economy so the assets of the central bank of country i are the claims that it holds from country j, denoted by $b^{i,j(CB)}$. Also, each central bank's only liability is the money supply (M^i), which is assumed to be exogenously determined as follows:

$$M_t^i = \sum_{j \in \{h,f\}} e_t^{i,j} b_t^{i,j(CB)}. \tag{10}$$

The model also assumes that the total stock of home and foreign bonds are exogenously

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[6]Changes in the expected value of output would, most likely, only enhance the effects of the other channels, assuming that output responds to an effective depreciation.

determined and equal to $\bar{b}_t^h$ and $\bar{b}_t^f$, respectively. This implies that

$$\bar{b}_t^j = \sum_{i \in \{h,f\}} \left[b_t^{i,j(CB)} + b_t^{i,j(H)} \right], \tag{11}$$

where $b^{i,j(H)}$ denotes the claims that the household (H) of country i has on country j.[7] The model next assumes that each household can only hold currency of the country in which it resides and uses its (exogenous) wealth to hold currency and bonds as shown in equation (12):

$$W_t^i = M_t^i + \sum_{j \in \{h,f\}} e_t^{i,j} b_t^{i,j(H)}. \tag{12}$$

The household's demand for assets depends on the level of aggregate wealth and on the expected rates of return of each type of asset. Differences in the latter indicate the degree of substitutability between bonds. Consequently, reduced-form demands for bonds are expressed as

$$e_t^{i,j} b_t^{i,j(H)} = g^{i,j} \left(\tilde{r}_t^{i,h}, \tilde{r}_t^{i,f}, W_t^i \right), \tag{13}$$

for a given function g. In equation (13), $\tilde{r}^{i,j}$ is the return of bonds issued by country j in terms of country i's currency. Formally, $\tilde{r}^{i,j} \equiv r^j + \pi^{i,j}$ where $\pi^{i,j}$ is the expected change in the exchange rate: $\pi_t^{i,j} \equiv E_t[e_{t+1}^{i,j}]/e_t^{i,j}$. Demand for bonds is assumed increasing in both the household's wealth and the return of the home bond and decreasing in the return of the foreign bond. Since demands for bonds are modeled as reduced forms, to solve the model Weber (1986) performs a first-order linear approximation. The idea is to express the expected depreciation, $\pi^{i,j}$, in terms of bond holdings of the home country's central bank.[8]

There are four markets in the economy: money supply (M^i) and bonds $(\bar{b}^i)$ which are supplied and issued by each country. By Walras' we need only to consider the market clearing condition for both types of bonds and the home country's money supply. The mechanics are as follows: we first perform a linear approximation of $g^{i,j}$ around (0,0,0). We then solve for $b^{i,h(CB)}$ in equation (10) and substitute into equation (11). Finally, we use equation (12) for $i = h$ to obtain

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[7]Without loss of generality, we assume that each country has one household with wealth W^i.

[8]Weber (1986) assumes that e_t does not depend on exogenous variables. One alternative is to assume that exchange rate expectations $E_t[e_{t+1}]$ are formed rationally.

$$\pi_t^{h,f} = \alpha_0 + \alpha_1 \bar{b}_t^h + \alpha_2 e_t \bar{b}_t^f + \alpha_3 M_t^h - \alpha_1 e_t M_t^f + \alpha_4 W_t^h + \alpha_5 e_t W_t^f + \tag{14}$$
$$(\alpha_1 - \alpha_2) e_t \left[b_t^{h,f(CB)} + b_t^{f,f(CB)} \right].$$

All coefficients in (14) depend on the derivatives of $g^{i,j}$ with respect to its arguments. However, since these functions are not made explicit, the signs are undetermined. Nonetheless, equation (14) is useful to analyze the effects of a sterilized intervention. In this sense, we consider the case in which the central bank of the home country sells $b_t^{h,f(CB)}$ and purchases $b_t^{h,h(CB)}$ (i.e. bond swap) without offsetting the money supply. That is,

$$\Delta b_t^{h,h(CB)} = -\Delta e_t^{h,f} b_t^{h,f(CB)}. \tag{15}$$

Consequently, the sign of $\alpha_1 - \alpha_2$ determines the effect of the sterilized intervention on the exchange rate, as seen in equation (14). In particular, sterilized interventions will have no effect if $\alpha_1 = \alpha_2$. A key contribution of Weber (1986) is to show that a sufficient condition for $\alpha_1 = \alpha_2$ is for assets to be perfect substitutes. We explain this result as follows:

Let $g_k^{i,j}$ be the derivative of $g^{i,j}$ with respect to its k-th argument evaluated at $(0,0,0)$. Then

$$\alpha_1 = \frac{1}{H} \left[\left(g_1^{h,h} + g_1^{h,f} \right) \left(g_2^{h,f} + e_t^{h,f} g_2^{f,f} \right) - \left(g_1^{h,f} + e_t^{h,f} g_1^{f,f} \right) \left(g_2^{h,h} + g_2^{h,f} \right) \right]$$
$$\alpha_2 = \frac{1}{H} \left[\left(g_2^{h,h} + g_2^{h,f} \right) \left(g_1^{h,h} + e_t^{h,f} g_1^{f,h} \right) - \left(g_2^{h,h} + e_t^{h,f} g_2^{f,h} \right) \left(g_1^{h,h} + g_1^{h,f} \right) \right],$$

where

$$H \equiv e_t^{h,f} \left(g_2^{h,h} + g_2^{h,f} \right) \left[\left(g_1^{h,f} + e_t^{h,f} g_1^{f,f} \right) \left(g_1^{f,h} + g_2^{f,h} \right) - \left(g_1^{h,h} + e_t^{h,f} g_1^{f,h} \right) \left(g_1^{f,f} + g_2^{f,f} \right) \right]$$
$$+ \left(g_1^{h,h} + g_1^{h,f} \right) \left[\left(g_2^{h,h} + e_t^{h,f} g_2^{f,h} \right) \left(e_t^{h,f} g_1^{f,f} - g_2^{h,f} \right) - \left(g_2^{h,f} + e_t^{h,f} g_2^{f,f} \right) \left(e_t^{h,f} g_1^{f,h} - g_2^{h,h} \right) \right].$$

We next assume that households are indifferent to holding home and foreign bonds, as long as they have the same return. Formally, $g_k^{i,j} = g_{k'}^{i,j'}$, for $i, j, j' \in \{h, f\}$, $k \in \{1, 2\}$, $j \neq j'$ and $k \neq k'$. Notice that in this case $\alpha_1 = \alpha_2$.

In the empirical literature, some studies estimate the demand functions for bonds to establish whether or not different currency-denominated bonds are perfect substitutes. Other studies estimate equation (14) directly. Finally, some works determine whether a no-arbitrage condition holds (i.e. $r_h(t) = r_f(t) + \pi(t)$). As mentioned in Section 1, most of the recent evidence seems to be consistent

with $\alpha_1 = \alpha_2$.

2.2.2 Canzoneri and Cumby (2013)

There have been several extensions to the portfolio balance model introduced by Weber (1986), along with various interpretations of the underlying asset risk-structure. However, few studies rely on a liquidity premium to explain why assets are imperfect substitutes. Such is the case of Canzoneri and Cumby (2013) for which we sketch their central argument as follows:

The authors present a model with standard features of New Open Economy Models (NOEM). They assume that the home country uses both home bonds and a key currency bond to facilitate trade. Additionally, money is introduced but assumed to be an imperfect substitute for bonds. The model then prices one bond with no liquidity services (denoted as the CCAPM bond) with a higher return. Portfolios in each country need not be symmetric. Namely, foreign residents hold claims on home firms while home residents hold foreign bonds. Also, foreign residents earn the CCAPM rate on foreign equity, while home residents earn a liquid bond rate on foreign holdings. It turns out that, since liquid assets carry a liquidity premium, foreign investors earn a higher return on foreign assets than what they pay for their foreign liabilities.

The model uses a Taylor rule to control for inflation while concurrently allowing for foreign exchange interventions.[9] Results show that sterilized interventions (i.e. bond swaps) have a lesser effect on output and inflation than when allowing for the monetary base to change (i.e. open market operations). Nonetheless, the authors show that interventions (even when sterilized) have a significant impact on economic variables.

2.2.3 Evans and Lyons (2001)

The model by Evans and Lyons (2001) constitutes one of the earliest works on the portfolio-balance channel under a micro-structure approach. Similar to Vitale (1999), the authors estimate a partial equilibrium model in which the trading process reveals information contained in order flows. This information, in turn, is sub-categorized into two types according to their lasting effects on portfolio balances: *temporary* and *persistent*. While the former refers to the price compensation that risk-averse dealers demand for holding positions that they would otherwise not hold, the latter refers to the compensation that the market as a whole demands for holding positions that it would otherwise not hold. Temporary effects dissipate once the dealer positions are known by market participants. Alternatively, persistent effects remain active because all risks are shared at the market level.

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[9]Empirical studies that center on simultaneous monetary policies include Ostry et al. (2012) and Villamizar (2014).

Sterilized foreign exchange interventions do not reveal any additional information. Nonetheless, they can potentially affect the exchange rate by altering the total order flow (i.e total number of trades that dealers execute within a given period). In this sense, the effect on prices is a direct consequence of imperfect substitutability, and not of asymmetric information, as in Kyle (1985). The general framework of the model is as follows:

There are three types of agents: N dealers, a continuum of customers and one central bank. There are also two assets, one of which is risky (the foreign exchange) with an observed return of e. Four rounds of trading occur within each period. In the first round, dealers trade with the central bank and with the customers. The model assumes that the central bank trades are: sterilized, secret and convey no information about future monetary policy.[10] In the second trading round, dealers trade among themselves. At this stage the temporary portfolio-balance effects appears to compensate the dealers, which are risk averse. Thus, the size of this effect depends on the size of the exercised orders. In the third round, e_t is realized and the dealers trade among themselves once again. Finally, in the fourth round dealers pass positions onto the customers. The risk associated with these positions cannot be fully insured, generating persistent effects.

Formally, at the beginning of period t, each dealer i quotes a price P_1^i for the foreign exchange that is bought (sold) from (to) the public and the central bank. In round 2, dealer i quotes a price P_2^i to other dealers. At this point agents observe a noisy signal denoted by X_2 of inter-dealer order flow that depends on trades (T_2^i) such that $X_2 = \mathbb{E}\left[\sum_{i=1}^{N} T_2^i\right]$. At the beginning of round three, e_t is realized. Then, similar to the dynamics of round 2, dealer i quotes a price P_3^i to other dealers. At the end of this round all agents observe the inter-dealer flow (X_3) such that $X_3 = \sum_{i=1}^{N} T_3^i$. Finally, in round four each dealer i quotes foreign exchange to the public at price P_4^i.

An equilibrium in this model consists of market quotes P_j^i and trades T_k^i, for $j \in \{1, 2, 3, 4\}$, $k \in \{2, 3\}$ and $i \in \{1, \ldots, N\}$ such that each dealer maximizes its expected utility at the end of round four, subject to: i) the fact that outstanding positions at the end of each period must remain unchanged, and ii) new information is revealed at each round (order flow). In equilibrium, all dealers post equal quotes in each round so that

$$P_{2,t} = P_{1,t} = P_{4,t-1}$$
$$P_{3,t} = P_{2,t} + \lambda_{2,t} X_{2,t}$$
$$P_{4,t} = P_{3,t} + \lambda_{3,t} X_{3,t} + \delta_t \left(e_t - e_{t-1}\right) - \phi_t \left(P_{3,t} - P_{2,t}\right),$$

where $\lambda_{2,t}, \lambda_{3,t}, \delta_t, \phi_t > 0$. Intuitively, the price change between each round depends on the new information available. No information is revealed after the first round since trades are not made

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[10]Evans and Lyons (2001) state that this last condition is equivalent to assuming that the exchange rate floats.

public. Only between the second and third rounds is the inter-dealer order flow ($X_{2,t}$) publicly observed. Similarly, between the third and fourth rounds, dealers observe the inter-dealer order flow ($X_{3,t}$) and the corresponding change in the exchange rate ($e_t - e_{t-1}$). The second order flow between dealers has more information than $X_{2,t}$ since it is observed without noise. Moreover, the change in the exchange rate is persistent, and therefore priced. Finally, $P_{4,t} - P_{3,t}$ takes into account part of the price change between the second and third rounds. It dissipates because dealers transfer some of the risk onto customers.

2.3 Signaling Channel

2.3.1 Vitale (1999)

Vitale (1999) is one of the pioneering works to study the effects of foreign exchange market intervention using a micro-structured approach. Through the signaling channel, Vitale examines how central banks' private information regarding the fundamental value of domestic currency affects exchange rate expectations, via order flows. Recall from Section 2.1.1 that under a sterilized intervention, the signaling channel consists of: i) signals on future monetary policy and ii) changes in the expected future exchange rate.

As opposed to Mussa (1981) who favors announced interventions in order to publicly reveal what the fundamental vale of the exchange rate is, Vitale (1999) favors unannounced or "secret" methods of intervention. The main reason is that secrecy allows for strategic behavior, especially when the central bank's objective differs from the fundamental value. As such, monetary authorities advantageously transmit wrong signals to traders and dealers. We refer readers to Lyons (2006) for an in-depth discussion on announced vs. secret interventions.

Most authors who follow a micro-structure approach, including Vitale (1999) and Evans and Lyons (2001), present alterations to the work-horse model proposed by Kyle (1985). Given its impact on the recent literature, we present a sketch of Kyle's batch framework in Appendix A. In essence, a dealer (often referred to as the market-maker) receives quotes from liquidity traders and the central bank before prices are determined. The dealer then determines the market-clearing price based on these orders. Hence, the model's central argument centers on the dealer's inability to distinguish between informed and uninformed traders.

Formally, the exchange rate's fundamental value, e_0, is assumed to be normally distributed with mean s_0 and variance Σ_0^f. Only the central bank observes the realization of e_0, which occurs in period 0. In period 1, the central bank and traders place their quotes, x and ϵ, respectively.[11]

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[11]The model also assumes that traders' orders, ϵ, are normally distributed and independent of e_0, with zero mean

The dealer then fixes the exchange rate and executes all orders. Perfect market competition coupled with risk neutrality on the dealer's behalf enforces a semi-strong efficiency condition that results in zero-expected profits. Therefore, the exchange rate in period 1 is expressed as

$$e_1 = E\left[e_0 \mid \Omega_1\right], \tag{16}$$

where Ω_1 is the relevant information set in period 1. Concurrently, the central bank chooses its market order x to minimize its loss function:

$$L = (e_1 - e_0)x - q(e_1 - \bar{e})^2, \tag{17}$$

where $\bar{e}$ is the central bank's target rate, which is common knowledge, and $q > 0$ is the commitment to $\bar{e}$. Intuitively, the first term captures the cost of intervention while the second term captures the cost of missing its target.

In light of restricting our analysis to the effects on the exchange rate (and sidestepping the effects on market efficiency and liquidity), we next highlight two of Vitale (1999) relevant propositions:

Proposition 1: If the central bank's target rate $\bar{e}$ is common knowledge, then there is a unique Nash equilibrium in which the central bank is incapable of targeting the value of domestic currency. That is, the dealer is able to filter out the wrong signal emitted by the central bank.

Proposition 2: If the central bank's target rate $\bar{e}$ is secret, then there is a unique Nash equilibrium in which the central bank is capable of targeting the value of domestic currency. Namely, the dealer is able to only partially filter out the wrong signal emitted by the central bank.

Consequently, in both these cases the exchange rate is affected by sterilized foreign exchange interventions.[12]

3 Impossible trinity remains impossible

In contrast to the works presented in the previous section, we now focus on the strand of literature that deems interventions futile, when faced with the monetary "trilemma". In the models that follow, agents are indifferent between holding foreign and domestic assets as long as they guarantee the same level of consumption in each state of the economy. As a consequence, sterilized interventions

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and variance σ_1^2.

[12]Other propositions and proofs are found in Vitale (1999).

do not affect equilibrium prices nor do they represent an additional monetary instrument for central banks.

This section proceed as follows: Section 3.1.1 analyzes Backus and Kehoe (1989) and uses their model as benchmark. We believe that most of the works that encompass the "trilemma" share similar features, or in some cases, are directly derived from their model. Finally, Section 3.1.2 presents the central argument of Cunha (2013), for which fiscal policies conflate with exchange rate effects.

3.1   Free Capital Flows

3.1.1   Backus and Kehoe (1989)

Backus and Kehoe (1989) show that, as long as there is perfect capital mobility, sterilized interventions have no effect on equilibrium prices and quantities. The basic setup of their model is as follows:

There are two countries, *home* (h) and *foreign* (f), each represented by a consumer and a government. Consumers face a cash-in-advance constraint and maximize their utility by choosing consumption of the final good of both countries, c, currency, M, and bond holdings, b. Additionally, they purchase bonds issued in each country and receive an endowment of the final good of the country where they reside.[13] Finally, each government issues bonds and determines the domestic money supply.[14]

The consumer of country i solves the problem

$$\max_{c^{i,j}, M^{i,j(H)}, b^{i,j(H)}} \sum_{t=0}^{\infty} \beta^t u^i \left(c_t^i \right) \tag{18}$$

subject to the following two constraints:

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[13]We simplify the setup that is explained in Backus and Kehoe (1989) since the main result that we want to highlight does not change. Backus and Kehoe consider an economy where households in each country supply labor that is used as input to produce the final good and get utility from leisure. Additionally they also assume that the government in each country levies taxes on production. Moreover we describe a setup where there is only one possible state per period. On the other hand, Backus and Kehoe consider a finite number of possible states in each period. Their result does not rely on the assumption of complete markets.

[14]Backus and Kehoe (1989) claim that the result does not change if the government of country i is restricted to issuing bonds denominated in the currency of country i.

$$p_t^j c_t^{i,j} \le M_t^{i,j(H)} \tag{19}$$

$$A_t^i = \sum_{j \in \{h,f\}} e_t^{i,j} M_t^{i,j(H)} + \sum_{j \in \{h,f\}} e_t^{i,j} \frac{b_{t+1}^{i,j(H)}}{1 + r_{t+1}^j}, \tag{20}$$

where $\beta \in (0,1)$, c^i is the total consumption from goods produced in both countries, p^j is the price of the good produced in country j, $M_{i,j}^H$ are money holdings of currency of country j, and $b^{i,j(H)}$ denotes bond holdings in currency j and with return r^j.[15] Finally, consumer claims are defined as

$$A_t^i \equiv \sum_{j \in \{h,f\}} e_t^{i,j} b_t^{i,j(H)} + p_t^i y_t^i + \sum_{j \in \{h,f\}} e_t^{i,j} \left[M_{t-1}^{i,j(H)} - p_{t-1}^j c_{t-1}^{i,j} \right], \tag{21}$$

where y^i is the endowment of the final good of country i.

Equation (19) corresponds to the cash-in-advance constraint for buying goods in both countries. Equation (20), on the other hand, is the budget constraint: the household uses the endowment of final good, the currency left over from the previous period (i.e. not used in purchasing goods), and the return on securities from the previous period to acquire currency and securities issued by both countries.

The government of country i issues bonds, $b^{i,j(G)}$, and determines monetary policy, $M^{i(G)}$. It funds itself by issuing currency and bonds, and uses these resources to pay for bonds issued in previous periods as well as to support the currency of the previous period. The government's budget constraint of country i is specified as follows:

$$\sum_{j \in \{h,f\}} e_t^{i,j} \frac{b_{t+1}^{i,j(G)}}{1 + r_{t+1}^j} + M_t^{i(G)} = \sum_{j \in \{h,f\}} e_t^{i,j} b_t^{i,j(G)} + M_{t-1}^{i(G)}. \tag{22}$$

An equilibrium in this economy is defined as a set of allocations $Q_i \equiv \{n_i, (c_{i,j}, M_{i,j}^H, b_{i,j}^H)_{\text{J}\{f,h\}}\}$, prices $P = \{p_i, e_i, (r_{i,j})_{j \in \{f,h\}}\}_{i \in \{f,h\}}$ and government policies $\Pi_i \equiv \{M_i^G, (b_{i,j}^G)_{j \in \{f,h\}}\}$, such that given P, Q_i is a solution to (18) and Π_i satisfies (22) for $i \in \{f, h\}$. Also, the markets for goods, assets and money must clear for each period t. That is,

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[15] u^i is assumed concave and increasing.

$$\sum_{i \in \{h,f\}} c_t^{i,j} = y_t^j$$

$$\sum_{i \in \{h,f\}} b_t^{i,j(H)} = \sum_{i \in \{h,f\}} b_t^{i,j(G)}$$

$$\sum_{i \in \{h,f\}} M_t^{i,j(H)} = M_t^{i(G)}.$$

The main result of Backus and Kehoe (1989) is that any change in bond policies of country i, such that total bond holdings remain unchanged, does not affect equilibrium prices or quantities. In particular, consider a sterilized foreign exchange intervention where the home government is selling foreign currency. In the context of the model, this is equivalent to selling foreign assets. Since the intervention is sterilized, there must be a purchase of assets issued by the home country in the same quantity of home currency. Now, if the change in the home government portfolio is done through the home household (the home government sells foreign assets to and buys home assets from the home household), then the budget constraints of the agents in the model are not affected. Hence, the new allocations and the prices before the intervention are still an equilibrium. In particular, the sterilized foreign exchange intervention does not affect the exchange rate.

This result depends on an extended state-contingent version of the UIP condition as shown in equation (23).

$$\frac{1 + r_{t+1}^i}{1 + r_{t+1}^j} = \frac{e_{t+1}^{i,j}}{e_t^{i,j}}. \tag{23}$$

As can be observed, the fact that there is no risk premium follows from bonds being perfect substitutes.

3.1.2 Cunha (2013)

Cunha (2013) proposes a model of indeterminacy in the currency denomination and maturity structure of public debt. In the model, a floating exchange rate policy is able to support any competitive equilibrium induced by a fixed exchange rate regime. Also, an exchange rate policy (where the government intervenes every period) can decentralize any allocation and prices induced by a floating exchange rate. Thus, a competitive equilibrium only pins down the total government debt but not its composition. This result holds whenever the term structure of the discount rates satisfies certain spanning conditions. In particular, a sterilized foreign exchange intervention is ineffective, since the same allocations and prices can be achieved under a floating exchange rate

regime.

4   From trinity to binity: The effect of market constraints

The middle ground that exists between the literature presented in Sections 2 and 3 consists of models that require some market friction, such as capital controls, in order for interventions to be effective. In other words, the impossible trinity ceases to be binding given that countries do not allow for free capital flows.[16] As a result, home and foreign assets are no longer perfect substitutes. Thus, market constraints generate a wedge for exchange rate maneuverability. However, market frictions should be considered as necessary (but not sufficient) for interventions to have a significant impact.

This section comprises the most recent literature on central bank intervention. Section 4.1.1 lays out the central argument of Kumhof and van Nieuwerburgh (2007) and Kumhof (2010) for which exogenous fiscal shocks cannot be financed thorough lump-sum taxes. Section 4.2 centers on the effects of capital controls, based on Kuersteiner et al. (2014) and Jeanne (2012). Finally, Section 4.3 reviews recent work on financial constraints. Specifically, Section 4.3.1 presents a model where sterilized foreign exchange intervention can relax financial frictions in the economy. To conclude, Section 4.3.2 provides a sketch of the central argument found in Cardozo et al. (2015), which centers on banking limits that exist on the total amount of foreign currency; a somewhat unexplored terrain in the context of sterilized interventions with market frictions.

4.1   Fiscal Constraints

4.1.1   Kumhof and van Nieuwerburgh (2007) and Kumhof (2010)

Kumhof and van Nieuwerburgh (2007) and Kumhof (2010) argue that the composition of different currency-denominated assets matters, at least for fiscal policies. Both models assume exogenous fiscal shocks that cannot be financed through lump-sum taxes.[17] As a result, taxes do not change when these shocks are realized. The exchange rate then adjusts in order to re-balance the government's nominal liabilities (and pins down a portfolio composition). Within this setup, a sterilized foreign exchange intervention results in a depreciated nominal exchange rate. Moreover, the relationship between the return on different currency-denominated assets depends on the outstanding stock of government bonds.

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[16]Intuitively, economies now choose a specific vertex on the "trilemma" simplex.

[17]According to Kumhof and van Nieuwerburgh (2007) and Kumhof (2010), this assumption is supported by empirical evidence.

4.2 Capital Constraints

4.2.1 Kuersteiner et al. (2014)

Kuersteiner et al. (2014) consider a world with two countries, *home* and *foreign*, where UIP holds. Thus, the central bank can affect either the interest rate or the exchange rate, but not both. Given some demand for funds to invest, equilibrium in financial markets is fully determined once the central bank of each country sets its policy rate. Similarly, the market for foreign exchange requires net capital outflows to be balanced with net exports in the current account.

If one country enacts capital controls, UIP no longer holds. Kuersteiner et al. (2014) consider a proportional tax on capital inflows for one period at rate τ. This type of control generates two types of capital: i) *incumbent capital*, which has remained in the home country beyond the enactment of capital controls, and ii) *new capital*, which is traded after controls have been enforced. Consequently, two different no-arbitrage conditions emerge and thus a discontinuity in the supply of capital. Equations (24) and (25) describe the UIP conditions for incumbent and new capital, respectively.

$$(1 + i_t^h) = \frac{E_t[e_{t+1}]}{e_t}(1 + i_t^f) \tag{24}$$

$$(1 + i_t^h)(1 - \tau) = \frac{E_t[e_{t+1}]}{e_t}(1 + i_t^f), \tag{25}$$

where e_t corresponds to the exchange rate (in levels), and i^h and i^f correspond to the interest rates of the home and foreign country, respectively. In sum, incumbent capital will remain as long as the gross return (not including taxes) to investing in the home country does not fall below the return of investing in the foreign country. But new capital will not flow in immediately if the return to capital increases. This will only occur if the return to investing in the home country (net of taxes) exceeds the return to investing in the foreign country.

As noted, there is a middle range in which the return to investing in the home country is sufficiently high so that incumbent capital will not flow out, but not high enough for new inflows to compensate the newly imposed tax. The resulting wedge plays out as a supply curve with a jump (i.e. a vertical portion in which monetary authorities can manage the exchange rate while still maintaining the equilibrium interest rate). Formally, finite but positive capital inflows occur when

$$\left(\frac{1 + i_t^f}{1 + i_t^h}\right) E_t[e_{t+1}] \leq e_t \leq \frac{(1 + i_t^f)E_t[e_{t+1}]}{(1 + i_t^h)(1 - \tau)}. \tag{26}$$

However, starting from an equilibrium without capital controls, the discretion of the central bank is not symmetrical. That is, the exchange rate can either remain constant or increase without affecting the policy rate.[18] In the nature of sterilized foreign exchange interventions, this means that central banks can affect the exchange rate as long as the inequality in (26) holds. It follows that higher controls on capital (a higher τ) generate a larger wedge of maneuverability for the central bank to affect the exchange rate.

Kuersteiner et al. (2014) also consider an alternative version of equation (25) in which inflows incur in a unit cost, proportional to the aggregate amount of inflows V_t. Formally:

$$(1 + i_t^h) - \tau(V_t) = \frac{E_t[e_{t+k}^{h,f}]}{e_t^{h,f}}(1 + i_t^f). \tag{27}$$

The main difference with equation (25) is that the exchange rate now depends on the amount of flows. However, the mechanics of the model and results remain the same.

4.2.2 Jeanne (2012)

Jeanne (2012) presents a model where a small open economy can appreciate its real exchange rate through restrictions on capital mobility. In the model only the government is able to access foreign assets. This allows the government to control the level of net foreign assets, and, therefore, control the current account balance. Consequently, the government also obtains control over the trade balance, and is able to determine the real exchange rate. In particular, when the government accumulates foreign assets, while concurrently issuing domestic bonds (i.e. sterilized intervention), the real exchange rate depreciates.[19]

4.3 Financial Constraints

4.3.1 Céspedes et al. (2012)

Céspedes et al. (2012) develop a small open economy model where banks intermediate resources from abroad to firms. In this model banks can borrow up to a collateral constraint, which depends on the real exchange rate. When the constraint binds, sterilized foreign exchange interventions have an effect on equilibrium.

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[18] Equivalently, the central bank can only conduct monetary tightening while maintaining the same exchange rate value.

[19] Jeanne (2012) does not incorporate monetary policy, but adding it will not affect the model's mechanisms.

In this model there is no currency, but rather the exchange rate is given by the price ratio between tradable and non-tradable goods. In this sense a sterilized foreign exchange intervention is an (exogenous) injection of tradable goods into the economy in exchange for non-tradables, that is offset by credit to firms or banks. When the constraint on banks is binding, the sterilization of the intervention is actually resources that the banks can use to relax their constraint, and thus are able to provide more credit to the economy. As a result, the real exchange rate appreciates and production and welfare increase. It is important to highlight that the intervention only has an effect when the collateral constraint binds. That is, this financial friction plays a crucial role in the success of the intervention. If the constraint doesn't bind, or there is no constraint at all, then there is no effect on the real exchange rate.

4.3.2   Cardozo et al. (2015)

Cardozo et al. (2015) construct a general equilibrium model to analyze whether sterilized foreign exchange interventions have an effect on the equilibrium exchange rate in Colombia. The authors explore banking limits that exist on the total amount of foreign currency that banks in Colombia can hold (which effectively work as controls on capital). As a result, the UIP does not hold. Instead, interest rate differentials between domestic and foreign bonds depend on the expected exchange rate and a non-zero risk premium, which in turn is a function of (relative) foreign bond holdings. The model's predictions are then empirically tested, using proprietary data that include daily interventions by the Colombian Central Bank in the foreign exchange market, as well as bond holdings by market participants.

5   Concluding Remarks

Since the East Asia crises of 1997-1998 and the failure of Argentina's currency board in 2001, central banks have allegedly opted for monetary policy autonomy. However, the empirical evidence has shown that most countries have been reluctant to relinquish control over the value of their currencies. In fact, industrialized countries have led concerted initiatives to affect the value of major exchange rates, some of which include the Smithsonian Agreement (December 1971), the Plaza Accord (September 1985), the Louvre Accord (February 1987), the Chiang Mai Initiative (May 2000) and the Pittsburg Agreement (December 2009). Similarly, emerging markets have conducted frequent and large-scale interventions (although in less coordinated fashion), to the extent of becoming an empirical regularity. But allowing for free capital flows while having autonomous monetary policy and a managed exchange rate is an impossible trinity due to arbitrage by foreign investors. In principle, this "trilemma" limits the effects of policy.

In this paper we bring together prominent theories that have shaped the literature on sterilized foreign exchange interventions (i.e. purchases or sales of foreign currency, intended to affect the exchange rate, but without altering the monetary base). Generally, central banks adopt this method of intervention when targeting the exchange rate while avoiding inflationary pressures induced by movements in the money supply. However, the effects of sterilized interventions often conflict with other monetary instruments, such as the policy rate, and in some cases, their effects offset each other.

Paradoxically, in spite of the ample empirical literature that exists on the effectiveness of central bank intervention, little is known about the mechanisms through which they affect the economy. Hence, we contribute to the literature in three important ways. First, by reviewing new theoretical models that have surfaced within the last decade. Second, by further penetrating into the theory of interventions in order to analyze the key features that make each model distinct. Third, by only focusing on sterilized operations which allow us to sidestep the effects induced by changes in the stock of money supply. Additionally, the models that we present comprise both a macro and micro-structure approach so as to provide a comprehensive view of the theory behind exchange rate intervention.

We are able to identify three main strands of literature based on their different monetary implications: 1) that which advocates the use of sterilized interventions (rendering the impossible trinity possible); 2) that which deems interventions futile (where the impossible trinity is ever binding); and 3) that which requires some market friction, such as capital controls, in order for interventions to be effective. We believe that a better understanding of the different theoretical frameworks will help design more effective monetary policy regimes. It will also help us understand the reasons and conditions under which central banks intervene in the foreign exchange market today.

Most of the key topics in international economics are extensively discussed. Some include the degree of asset substitutability, the effects of market constraints, and the various channels through which interventions affect economic variables. Thus, we provide a comprehensive and up-to-date survey that can be used for ongoing and future work.

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Appendix A Kyle (1985)

Kyle (1985) models the trading strategy of an insider in a dynamic model of efficient price formation. Specifically, the model shows how the characteristics of a liquid market can be obtained in this setup. Additionally, the model examines how much information prices carry and the value of private information to an insider.

There are three types of agents in the model: a single risk neutral insider, random noise traders and competitive risk neutral market makers. Agents trade a risky asset for a riskless asset. While the insider knows about the liquidation value of the risky asset, noise traders trade randomly. Also, market makers set prices efficiently, conditional on the total quantity traded by other agents (i.e. order flow). Therefore, price fluctuations are a direct consequence of innovations on order flows.

Formally, the insider is the only trader that observes the liquidation value of the risky asset, denoted by $\tilde{v}$. He chooses how much to trade, $\tilde{x}$, in order to maximize expected profits. In doing so, he internalizes how his decision affects the price set by market makers, $\tilde{p}$, after the insider and the noise traders have chosen quantities to trade. Noise traders trade a quantity $\tilde{u}$, which is random and independent from $\tilde{x}$. Market makers determine $\tilde{p}$ by observing the order flow, $\tilde{x} + \tilde{u}$. Thus, profits of the informed trader are given by $(\tilde{v} - \tilde{p})\tilde{x}$. An equilibrium in this economy is defined as a pair (X, P), defined implicitly as $\tilde{x} = X(\tilde{v})$ and $\tilde{p} = P(\tilde{x} + \tilde{u})$, such that the informed trader maximizes profits and the market is efficient, in the sense that $\tilde{p}(X, P) = X[\tilde{v}|\tilde{x} + \tilde{u}]$.

Now consider a model where there are a sequential number of rounds of trading, or auctions. The informed trader now chooses how much to trade taking into account the prices from the previous auctions, as well as $\tilde{v}$. The prices set by market makers will now depend on the order flows of all auctions up to that point. Nonetheless, a result of the model is that the price of a given auction will be that of the previous auction plus a term that depends on the order flow innovation.

The model is extended to an environment where auctions occur continuously. In this setup, Kyle shows that the insider trades in such a way that his private information is incorporated into prices at a constant rate. Additionally, all the insider's information is incorporated onto prices by the end of trading. Furthermore, the continuous auction equilibrium results in a market that has similar characteristics to those found in a liquid market.

Appendix B   Compilation of Empirical Works

Table 1: Selected Works on the Effects of Sterilized Interventions

Author	Country	Period	Methodology	Effects on exchange rate
Adler and Tovar (2011)	15 developing countries	2004-2010 (Intra-day)	2SIV	NO
Aguilar and Nydahl (2000)	Sweden	1993-1996 (Daily)	GARCH	NO
Baillie and Osterberg (1997)	US, Germany, Japan	1985-1990 (Daily)	GARCH	YES (only on volatility)
Beattie and Fillion (1999)	Canada	1993-1995 (Intra-day)	GARCH	YES (short lived)
Beine et al. (2002)	US, Germany, Japan	1985-1995 (Daily)	FIGARCH	YES (opposite sign)
Bonser-Neal and Tanner (1996)	US, Germany, Japan	1985-1991 (Daily)	GARCH	YES (only on volatility)
Chang and Taylor (1998)	Japan	1992-1993 (Intra-day)	ARCH	YES (only on volatility)
Danker et al. (1987)	Germany, Japan, Canada	1982-1987 (monthly)	2SLS	NO
Dominguez (1993)	US, Germany, Japan	1977-1994 (Daily)	GARCH	YES
Dominguez and Frankel (1993)	US, Germany	1982-1988 (Daily)	2SIV	YES
Echavarría et al. (2013)	Colombia	1999-2012 (Daily)	PGARCH	YES (small)
Eijffinger and Gruijters (1990)	US, Germany	1985-1988 (Intra-day)	AR	YES (limited)
Fatum and Hutchison (1999)	US	1989-1993 (Daily)	GARCH	YES (only on volatility)
Fatum and Hutchison (2003)	US, Germany	1985-1995 (Daily)	EVENT STUDY	YES (short-lived)
Guimaraes and Karacadag (2005)	Mexico, Turkey	1997-2003 (Daily)	GARCH	NO (small)
Huang (2007)	US, Germany, Japan	1978-1995 (Daily)	GARCH	YES
Humala and Rodriguez (2010)	Peru	1994-2007 (Daily)	GARCH	YES (small)
Humpage (1999)	US, Germany, Japan	1987-1990 (Daily)	LOGIT	YES

Source: Authors' compilations. 2SIV corresponds to two-stage instrumental variables, 2SLS corresponds to two-stage least squares, AR corresponds to Auto-Regressive processes, ML corresponds to maximum-likelihood, and MS corresponds to Markov-switching models.

Table 2: Continuation of Table 1

Author	Country	Period	Methodology	Effects on exchange rate
Kamil (2008)	Colombia	2004-2007 (Daily)	2SIV-TOBIT -GARCH	YES (short-lived)
Kaminsky and Lewis (1993)	US	1985-1990 (Daily)	ML	YES
Kim et al. (2006)	Australia	1983-1997 (Daily)	PROBIT	YES (sustained and large)
Obstfeld (1988)	US, Germany, Japan	1976-1986 (Quarterly)	AR	YES small
Payne and Vitale (2003)	Switzerland	1985-1995 (Intra-day)	EVENT STUDY	YES
Rincón and Toro (2010)	Colombia	1993-2010 (Intra-day)	GARCH	YES (only w/capital controls)
Rogoff (1984)	US, Canada	1973-1980 (Weekly)	2SLS	NO
Taylor (2004)	US, Germany	1985-1998 (Daily)	MS Switching	YES (short-lived)
Toro and Julio (2005)	Colombia	2004-2005 (Intra-day)	GARCH	YES
Villamizar (2014)	Colombia	1999-2012 (Daily)	BI-TOBIT	NO

Source: Authors' compilations. 2SIV corresponds to two-stage instrumental variables, 2SLS corresponds to two-stage least squares, AR corresponds to Auto-Regressive processes, ML corresponds to maximum-likelihood, and MS corresponds to Markov-switching models.