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Official Intervention in the Foreign Exchange Market: Is It Effective and, If So, How Does It Work?

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1. *Introduction*

OFFICIAL EXCHANGE rate intervention in the foreign exchange market occurs when the authorities buy or sell foreign exchange, normally against their own currency and in order to affect the exchange rate. Whether or not official exchange rate intervention is effective in influencing exchange rates, and the means by which it does so, are issues of crucial policy importance, and they have been the subject of a vast academic and policy-related literature.

Given the policy importance of official intervention, it is perhaps not surprising that this literature has been the venue for a substantial and ongoing economic controversy. Insofar as a consensus is discernible among economists and policy makers concerning the effectiveness and desirability of exchange rate intervention, it appears to have shifted several times over the past quarter of a century. At the time of the collapse of the Bretton Woods adjustable peg exchange rate system in the early 1970s, when the impotence of the authorities to hold the parities in the face of massive speculative attacks had apparently been demonstrated only too well,[2] the profession appeared strongly to favor a pure float, involving zero intervention. The 1970s experience with floating exchange rates among the major industrialized countries, and the ensuing volatility of both nominal and real exchange rates, however, led to a shift in this consensus so that, by the late 1970s, both economists and policy makers—particularly of countries which had suffered a substantial loss in competitiveness—frequently criticized the U.S. authorities for not intervening in support of the dollar.

Nevertheless, partly as a result of the realization of the speed and ease with

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[2] John Williamson (1977, p. 50) notes: "By the time that the adjustable peg was abandoned, capital mobility had developed to the point where the Bundesbank could take in well over $1 billion in an hour when the market had come to expect that another parity change was impending."

which capital could move between developed countries, the prevailing consensus among economists, policy makers and foreign exchange market practitioners during the early 1980s appeared to be that intervention—and in particular sterilized intervention, where the effects of intervention on the domestic money supply are neutralized—was not effective over anything but the very short run. Not only was this view prevalent among academic economists, it also appeared to be the consensus view of policy makers, symbolized by the conclusions of the *Jurgensen Report* (Phillippe Jurgensen 1983) on exchange rate intervention which was commissioned by the 1982 G7[3] Economic Summit of Heads of Government at Versailles.[4]

Following the strong and chronic overvaluation of the U.S. dollar during the early to mid 1980s, and a communiqué issued by the leaders of the G5 industrialized countries at the Plaza Hotel in New York in September 1985 to the effect that concerted intervention would be undertaken to bring down the high dollar, however, the consensus appeared to have shifted once more.[5] Following the decline of the U.S. dollar during the late 1980s, a subsequent meeting of the leaders of the G7 industrialized nations, held at the Louvre in Paris in February 1987, led to the agreement that coordinated exchange rate intervention should be undertaken to stabilize the U.S. dollar within informal "reference ranges," although precise target zone bands were not established.[6]

Following the Plaza and Louvre meetings, official intervention in the markets for the major exchange rates has been regular and at times heavy (Maurice Obstfeld 1990). In addition, exchange rate intervention, together with macro policy coordination, played an important role in the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS) of target zones between European exchange rates.[7]

[3] The Group of 7 or G7 countries are the U.S., Japan, Germany, France, the U.K., Italy, and Canada. The first five countries listed above are the Group of 5 or G5 countries.

[4] The *Jurgensen Report* did not provide very explicit conclusions. The official press release of the finance ministries and central bank governors of the G7 stated, however, that the main results of the *Jurgensen Report* may be summarized as follows: sterilized intervention affects long-run exchange rates much less than nonsterilized intervention; sterilized intervention can influence exchange rates only in the short run; coordinated intervention can be much more powerful relative to official intervention by a single country's authorities.

[5] Some authors argue that this embodiment of a new intervention regime started at the beginning of 1985, since the dollar had its peak in February 1985 and was already depreciating at the time of the Plaza Agreement. In fact, large sales of dollars were operated by some European Central Banks (especially the Bundesbank) in February and March of that year (see Kathryn Dominguez and Jeffrey Frankel 1993a).

[6] The agreement is clearly embodied in the following quotation from the official press release of the Louvre Accord: "The Ministers and Governors agreed that the substantial exchange rate intervention since the Plaza Agreement will increasingly contribute to reducing external imbalances and have now brought their currencies within ranges broadly consistent with underlying economic fundamentals . . . Further substantial exchange rate shifts among their currencies could damage growth and adjustment prospects in their countries."

[7] Following the ERM crisis of 1992–93 and a number of other currency crises during the 1990s, there have been calls from various quarters for measures to be put in place to safeguard against speculative attacks when they are apparently unrelated to the underlying economic fundamentals. In 1994, for example, the Bretton Woods Commission, headed by former Chairman of the Federal Reserve Paul Volcker, recommended that the IMF set up an intervention fund to help countries stave off attacks on their currencies (see e.g., *The Economist* 1995). In a related literature, economists have debated the desirability and feasibilty of imposing capital controls or taxes on foreign exchange transactions as a means of "throwing sand in the wheels of finance" (James Tobin 1969; Barry Eichengreen and Charles Wyplosz 1993; Eichengreen, Tobin, and Wyplosz 1995; Peter Garber and Taylor 1995).

Following the introduction of the euro as the single European currency in January 1999 and its immediate and persistent depreciation against the U.S. dollar, calls for concerted intervention among the industrialized countries to support the euro have at times been quite strong. Indeed, exactly such concerted intervention by the G7 countries did occur in September 2000.[8]

This paper summarizes the present authors' reading of recent research on official exchange rate intervention—what we have learned, what puzzles remain, and where further research progress is most likely to be made. While the survey will be of use to specialists in international finance and macroeconomics, given the policy importance of the issue in hand we also believe that our assessment of the central question motivating our analysis will be of interest to a wider audience of economists and policy makers: is official exchange rate intervention effective and, if so, how does it work?[9]

2. *The Mechanics of Intervention: Nonsterilized versus Sterilized Operations*

Official intervention is said to be sterilized when the authorities—simultaneously or with a very short lag—take action to offset or "sterilize" the effects of a change in official foreign asset holdings on the domestic monetary base. On the other hand, nonsterilized intervention occurs when the authorities buy or sell foreign exchange, normally against their own currency without such offsetting actions. Clearly, nonsterilized intervention will affect directly the domestic money supply and therefore its effect on the exchange rate is contentious only insofar as the effects of changes in the money supply on the exchange rate are contentious—a debate that perhaps belongs more to the area of exchange rate determination (e.g. see Taylor 1995).

In general, a strong consensus exists in the profession that *nonsterilized* intervention can influence the exchange rate similarly to monetary policy by inducing changes in the stock of the monetary base which, in turn, induces changes in broader monetary aggregates, interest rates, market

[8] Calls for concerted intervention appeared to reach a peak at the IMF and World Bank annual meetings in Prague in September 2000, when, at a press conference on September 19, the IMF's Economic Counsellor and Director of the Research Department, Michael Mussa, asked the memorable question, "If not now, when?" The G7 intervention actually occurred a few days later, on September 22.

[9] While there are some other excellent existing surveys on issues related to official intervention, they are all in book form and now require updating—see, for example, Peter Kenen (1988), Dean Taylor (1982), Dominguez and Frankel (1993a), Hali Edison (1993), Keith Pilbeam (1991), and Geert Almekinders (1995). Because of space constraints, we largely confine ourselves to covering the literature which has been published during the last twenty-five years or so since the breakdown of the Bretton Woods system, but devote particular attention to studies published in last decade or so. Important earlier contributions would include John Maynard Keynes (1923) and Kenen (1960, 1965).

Because of space limitations, we also do not discuss the literature relating to the role and effectiveness of intervention in target zone exchange arrangements. On this see, inter alios, Williamson (1985), Paul Krugman (1991), and Williamson and Marcus Miller (1987).

See also the papers in Matthew Canzoneri, Wilfred Ethier and Vittorio Grilli (1996), which cover a number of issues related to "The New Translantic Economy," ranging from transatlantic policy coordination with sticky labor markets to coordinated exchange rate intervention following the Plaza and Louvre agreements in comparison with the experience of the European Monetary System prior to the 1992 crisis, inter alia. For a treatment of exchange rate intervention and related issues in the Pacific Basin, see also Reuven Glick (1998); for a broader treatment of the issues related to central banks' behavior and economic performance, see Sylvester Eijffinger (1997). See Sarno and Taylor (2001) for textbook treatment of all of these issues.

TABLE 1
MONETARY AUTHORITIES' STYLIZED BALANCE SHEET

Assets	Liabilities
Net foreign assets (*NFA*)	*Monetary base* (*M*)
Gold	Total currency in circulation
Foreign	Reserve liabilities to commercial banks
Net domestic assets (*NDA*)	*Net worth* (*NW*)
Government securities	Spending surpluses
Loans on commercial banks	Net interests and capital gains from assets
Other	

expectations and ultimately the exchange rate. The effectiveness of *sterilized* intervention is very controversial, however, and, accordingly, the core of the debate on the effectiveness of official intervention in the foreign exchange market largely relates to sterilized intervention.[10]

Consider table 1, which gives a stylized representation of the balance sheet of a country's monetary authorities (that is, the central bank and exchange-stabilization authorities combined).

The monetary base comprises currency and deposit liabilities to banks. Net worth of the financial authorities includes accrued spending surpluses, accumulated net interest receipts and capital gains on their holdings of net domestic and foreign assets. From table 1, it follows that:

$$M \equiv NFA + (NDA - NW) \equiv NFA + DC \quad (1)$$

where DC, defined as net domestic assets less net worth ($DC \equiv NDA - NW$), represents the stock of domestic credit made available by the monetary authorities.

Foreign exchange market intervention by the monetary authorities involves a purchase or sale of foreign assets. When official intervention is nonsterilized, the purchase (sale) of foreign currency by the authorities leads to an increase (decrease) in NFA and an equivalent increase (decrease) in M. Therefore, nonsterilized intervention has the same impact on monetary liabilities as an open market operation, and the only difference between the two is that by a nonsterilized intervention operation the monetary authorities alter M through a change in foreign asset holdings rather than through a change in domestic asset holdings.

On the other hand, if intervention is fully sterilized then domestic credit is altered so that

$$\Delta DC = -\Delta NFA \quad (2)$$

which implies

$$\Delta M = \Delta NFA + \Delta DC = 0 \quad (3)$$

where Δ denotes the change in the relevant stock. Normally, intervention would be sterilized by sales or purchases of domestic-currency bills or bonds by the monetary authorities so that the effects on the monetary base of changes in the holdings of net foreign assets are in fact offset one-for-one by the effects of changes in net domestic asset holdings:

$$\Delta NDA = -\Delta NFA. \quad (4)$$

We now turn to analyzing the two channels of influence of official exchange rate intervention and explain

[10] For an early elegant description of the mechanics of exchange rate intervention, see Donald Adams and Dale Henderson (1983).

how, in theory, these channels work. In section 4 we will evaluate the empirical evidence to date as to *whether* they work *in practice*.

3. *How Does Intervention Work in Theory*?

A standard and useful taxonomy for analyzing how sterilized intervention may affect the exchange rate is by reference to two channels of influence of such intervention operations: the portfolio balance channel and the expectations or signalling channel (see Michael Mussa 1981).

3.1 *The Portfolio Balance Channel: Theory*

The effects of official intervention through the portfolio balance channel can be analyzed within the framework of a portfolio balance model (PBM) of exchange rate determination in which investors balance their portfolio among the assets of various countries on the basis of their relative expected returns.[11]

In the PBM, the assumptions which underlie both the flexible price and the sticky price monetary model of the exchange rate, i.e. that domestic and foreign assets are perfect substitutes and that the wealth effects of a current account imbalance are negligible, are relaxed. The PBM may be seen as a dynamic model of exchange rate determination based on the interaction of international asset markets, current account imbalance (reflecting net foreign asset accumulation or decumulation) and the exchange rate (see e.g. Branson 1983, 1984; Michael Dooley and Peter Isard 1983; Taylor 1995).

After the authorities have intervened in the foreign exchange market and then sterilized the intervention there can, by definition, be little or no effect on domestic interest rates since the level of the money supply has remained constant. What has altered, however, is the *composition* of agents' portfolios, since the authorities will have bought or sold domestic assets in their sterilization operations. The spot exchange rate must therefore shift in order to affect the domestic value of foreign bonds and the expected return for holding them. This occurs as agents try to rebalance their portfolios by buying or selling foreign assets. For example, an increase in the supply of euro-denominated assets in the hands of the public relative to the supply of dollar-denominated assets necessitates a fall in the relative price of euro-denominated assets. This is how, in theory, intervention affects the exchange rate through the portfolio balance channel.

If domestic and foreign assets are regarded by agents as perfect substitutes, however, sterilized intervention may have no significant effect on the exchange rate through the portfolio balance channel. This follows because agents will be indifferent as to the relative amounts of domestic and foreign assets they are holding—they will care only about the total amount and hence no change in market-clearing prices or quantities is required. Suppose, for example, that the authorities purchase foreign exchange and carry out an open market sale of domestic bonds in order to sterilize the effect of a rise in official reserves on the money supply. If domestic and foreign bonds are perfect substitutes in private agents' portfolios and agents' portfolios were initially in stock equilibrium, then investors will sell foreign bonds one for one with the increase in domestic bonds. Thus, the private sector will sell the same amount

[11] For space constraints, we do not outline analytically the PBM here. For a formal discussion of the PBM, see, for example, Kenen (1982), William Branson and Henderson (1985), and Taylor (1995).

of foreign currency that the authorities bought, and there will be a zero net effect on the level of the exchange rate.

In a world of high-speed capital flows one might suspect that financial assets denominated in the currencies of the major industrialized countries may indeed be highly substitutable in domestic portfolios, and—as we shall see below—this issue has been addressed by researchers.

At a theoretical level, it should also be noted that in a Ricardian world, where private agents offset expected future tax payments (which will be required to service extra government debt) against currency holdings of domestic bonds (Robert Barro 1974), imperfect substitutability would no longer be a sufficient condition for sterilized intervention to influence the current exchange rate. If Ricardian equivalence does not hold, however, and domestic and foreign bonds are less than perfectly substitutable, official intervention will in theory have a net effect on the level of the exchange rate through the portfolio balance channel.[12]

3.2 *The Signalling Channel: Theory*

Even if perfect substitutability of domestic and foreign assets holds, sterilized intervention can still in theory be effective through the signalling or expectations channel (Mussa 1981). The basic idea here is that agents may view exchange rate intervention as a signal about the future stance of policy. Because the exchange rate is a forward-looking variable, a shift in expectations concerning future movements in variables affecting the exchange rate—such as relative money supplies—will affect the level of the exchange rate now.

In essence, the signalling channel assumes that intervention affects exchange rates by providing the market with new relevant information, under the implicit assumption that the authorities have superior information to other market participants and that they are willing to reveal this information through their actions in the foreign exchange market. More precisely, the effect of sterilized intervention through the signalling channel occurs because private agents change their exchange rate expectations either because they change their view with regard to the likely future actions of the monetary authorities or because they change their view with regard to the *impact* of certain actions of the monetary authorities.

Notice that, since unsuccessful intervention is costly, if official intervention is expected to be effective through the signalling channel, there is an incentive for the authorities to manifest clearly their policy intentions. In this sense, it is perhaps something of a mystery as to why monetary authorities often maintain secrecy of intervention operations. As Kenen (1988, p. 52) puts it: "The rules for exchange rate management should be as transparent as possible. That is to maintain credibility, not by studied ambiguity, which breeds disagreement and distrust." At any time, however, a government will be pursuing many macroeconomic policy goals and the trade-offs amongst these will be highly complex, hence complicating significantly the judgement of other market agents about the time consistency of a certain announced exchange rate policy.

Some influential theoretical literature has analyzed these issues in the context of a framework in which market agents have incomplete information about the authorities' utility trade-off between the exchange rate target and a domestic policy target. Within this framework,

[12] See also Frankel (1979), Obstfeld (1982), David Backus and Patrick Kehoe (1989).

for a policy to be time consistent, the authorities must announce a *range* for the future exchange rate since the announcement of any *precise* target may not be credible. More generally, the monetary authorities of many major industrialized countries tend to adopt exchange rate policies which are consistent with the fulfillment of preannounced targets of the growth rate of monetary aggregates (see Jeremy Stein 1989).

The trade-off between the attainment of a target level of money stock (m_t^T) and a target level of the exchange rate (s_t^T) may be formalized in a simple fashion using a quadratic loss function for the monetary authorities of the form:

$$£_t = (m_t - m_t^T)^2 + \omega(s_t - s_t^T)^2, \qquad (5)$$

where $£_t$, m_t and s_t denote the loss to the monetary authorities, the domestic monetary base and the nominal exchange rate (domestic price of foreign currency) at time t respectively, while $\omega \geq 0$ is the relative weight attached to the monetary and exchange rate targets by the monetary authorities. If the authorities only care about the attainment of the preannounced monetary target—say in order to build their reputation and hence benefit by relatively lower inflation expectations and wages claims from trade unions—then $\omega = 0$ in equation (5). If $\omega = 0$ and no official intervention policy is undertaken by the monetary authorities, however, the exchange rate has to bear entirely the burden of adjustment: any expected appreciation of the domestic currency will induce speculators to buy the currency, hence generating the actual appreciation of the currency itself. Alternatively, the monetary authorities may use sterilized intervention which can effectively induce the independence of exchange rates and monetary targets ($\Delta NDA = -\Delta NFA$), ultimately generating only a change in the composition of the private sector's portfolio (see Almekinders 1995 and the references therein). Note, however, that this independence is contingent upon adequate foreign exchange reserves being available—an issue brought into stark relief by the literature on speculative attacks, as discussed below.

The theory of the signalling channel of official intervention has attracted renewed interest in recent years. In particular, some researchers have used simple two-country models to examine the theoretical implication of the signalling channel of foreign exchange market interventions that sterilized interventions represent signals of future monetary policy and hence affect exchange rate expectations. Within a game-theoretic framework which allows for partial credibility and nonrational expectations, both noncooperative and cooperative policies of exchange rate management can be studied formally. These models predict that, in order to maintain credibility in the future, sterilized interventions must be accommodated by corresponding subsequent changes in the money supply, implying that official intervention does not represent an instrument independent of monetary policy. This framework also indicates that the implied trade-off between internal and external policy objectives makes the coordination of official intervention operations advantageous, even in the case of conflicting exchange rate targets (see Silke-Fabian Reeves 1997, 1998).

3.3 *International Coordination and the Channels of Influence*

Coordinated (or concerted) official intervention in the foreign exchange market occurs when two or more central banks intervene simultaneously in the market in support of the same

currency, according to an explicit or implicit international agreement of cooperation.[13]

The rationale for international coordination of official intervention stems from the observed existence of significant spillover effects of domestic policies across countries. For example, under a floating exchange rate system, official intervention in one country may be expected to change the value of the domestic currency with respect to other currencies, thereby affecting trading partners' economies. Standard economic theory suggests that, in an interdependent world economy, a Pareto-optimal outcome may be achieved by taking into account the spillover effects of macroeconomic policies and by forming policies which exploit the existence of these cross-country interdependencies for the mutual benefit of the participants of the coordinated intervention (Ralph Bryant 1995).[14]

[13] Some researchers use a more restrictive definition of concerted intervention which does not include operations which would have been undertaken by the individual central banks even in the absence of any coordination (e.g. Kenneth Rogoff 1984, 1985). In practice, however, concerted official intervention in the foreign exchange market among the major industrialized nations has largely consisted of information sharing and discussions with small modifications of the individual intervention operations.

[14] The theoretical literature investigating the implications of policy coordination among interdependent economies typically adopts a game-theoretic approach which is commonly referred to as "policy-optimization" analysis. In a typical game the rational agents are national governments, whose preferences are formalized using a loss function biased toward domestic welfare. Cooperative and noncooperative games can then be analyzed and the outcomes from the two types of games can be compared in order to infer the optimal strategy for governments. In choosing their loss-minimizing strategy, each national government also takes into account the preferences and the reactions of the other governments (e.g., Willem Buiter and Jonathan Eaton 1985; Richard Cooper 1985; Bryant 1995). See also the papers in Clas Wihlborg, Michele Fratianni, and Thomas Willett (1991).

With regard to nonsterilized intervention, the benefits from coordination of nonsterilized operations are identical to the benefits from monetary policy coordination. Nevertheless, the advantage of coordination of nonsterilized official intervention relative to monetary policy coordination is that the former, unlike the latter, creates an explicit incentive to coordinate monetary policies consistent with exchange rate targets for the countries involved (see Dominguez and Frankel 1993a).

The advantages of coordination for sterilized exchange intervention are less straightforward. In fact, the effectiveness of sterilized intervention through the portfolio balance channel is totally independent of monetary policy effectiveness and, therefore, countries can design concerted official intervention without relinquishing sovereignty over domestic monetary policy. If sterilized intervention works through the signalling channel, however, there may be gains from coordinating official intervention. This is because the coordination of multiple signals is more likely to convince speculators that the signalled policy is credible relative to an individual signal, implying that sterilized official intervention coordination may help central banks with relatively low reputation or credibility (Kenen 1988, ch. 6; Dominguez and Frankel 1993a; Isard 1995, ch. 12).

A recent formal treatment of these issues is provided by Marc Flandreau (1998) in the context of a model where several target zones co-exist and parities are defended by manipulating money supplies in participating countries. As a result, interventions aimed at one given exchange rate also affect other exchange rates, implying that shocks on each fundamental affect the whole range of exchange rates involved, intramarginal interventions

arise endogenously and the stationary distributions of exchange rates and fundamentals are influenced by the "rules of the game" regarding currencies used in intervention and sterilization procedures. The model ultimately predicts large gains from international coordination for all participating countries since "intramarginal targets" are generated to which exchange rates tend to return and their location is shown to depend on the intervention-sterilization mix adopted by monetary authorities.

Overall, therefore, the existence of significant gains from international coordination of official intervention relative to individual intervention and the enhancement of the effectiveness of intervention through the signalling channel as an effect of coordination appear to be accepted theoretical results.

3.4 *Optimal Exchange Rate Management: Theory*

The theoretical literature on optimal exchange rate management to date is enormous (e.g. see, inter alia, the work of Michael Artis and David Currie 1981; Jagdeep Bhandari 1985 and the papers therein; Stephen Turnovsky 1987; Kenen 1988; Glick and Michael Hutchison 1989). The conventional theoretical analysis mainly focuses on designing an exchange rate policy which minimizes the variance of output around its natural rate.[15] Also, the traditional approach taken by this literature is based on a flow model of the exchange rate which accounts for three types of currency flows: flows generated, respectively, by current account transactions (CA), net flow demand for domestic currency through the capital account of the balance of payments (ΔK) and currency flows generating directly from central bank intervention in the market (INT) (e.g. see Stanley Black 1985). The market-clearing condition involving those three currency flows may be written at time t as :

$$INT_t = CA_t + \Delta K_t \tag{6}$$

where the left-hand side and the right-hand side of the equation describe the net supply of and the net demand for domestic currency respectively. The current account is assumed to be a function of measures of competitiveness such as the real (i.e. relative price level adjusted) exchange rate. A function for the net flow demand for domestic currency through the capital account of the balance of payments may be derived, for example, using the framework of speculative dynamics models developed by Stein (1987) and J. Bradford De Long, Andrei Shleifer, Lawrence Summers, and Robert Waldmann (1990). According to these models, the net international demand for domestic currency will be a function of a set of factors including deviations from uncovered interest parity, the degree of risk aversion of investors and the conditional variance of the next period spot rate (see Almekinders 1995).

The theoretical literature in this context essentially models official intervention by assuming a particular central bank loss function from which, given a particular process governing exchange rate movements, estimatable central bank reaction functions can be derived. Several authors assume, for example, that the central bank has a single-period, quadratic, symmetric loss function of the deviation of the current exchange rate from its target level, and that there are costs of intervening in

[15] This implicitly assumes, however, that the main concern of the monetary authorities is to choose the optimal degree of *non*sterilized intervention in response to idiosyncratic shocks and therefore, in some sense, this approach neglects the fact that the monetary authorities widely use sterilized intervention.

the foreign exchange market (e.g., see Almekinders 1995).[16]

While this class of models provides useful insights on the strategic behavior of the monetary authorities and allows researchers to derive reaction functions which can be easily estimated, they do suffer, however, from some drawbacks. In particular, these models treat the central bank on the same terms as other market participants, who, therefore, do not have any informational gain from monitoring the actions of the central bank. It may be more appropriate to withdraw this assumption in future studies. Central banks should have a larger information set at least because they know more about their own future actions relative to other market participants.[17,18]

An important move in this direction is due to Utpal Bhattacharya and Paul Weller (1997), who build an asymmetric information model of sterilized intervention where the equilibrium is characterized by a situation in which the central bank has inside information about its exchange rate target whereas risk-averse speculators have inside information about future spot rates. In that framework, circumstances may arise in which "perverse" responses to intervention may occur and ultimately the model provides a rationale for secrecy not only with regard to the scale but also to the target of official intervention (see also Paolo Vitale 1999a).

Game-theoretic approaches have also been undertaken by researchers. Typically, these models analyze the interaction between the central bank and private rational speculators in the foreign exchange market in the event of a shock observed by both parties. The central bank wishes to counterbalance the effect of the shock and stabilize the exchange rate. Given the fact that the scale of official intervention is not very significant relative to the daily turnover in the market, the central bank has an incentive to use secret intervention in order to surprise private speculators and increase the effectiveness of the intervention operation. Rational agents will expect, however, a higher volume of intervention and, therefore, the ultimate result of the game between the central bank and the private speculators is the generation of some sort of "intervention bias." Clearly, the preferences of the central bank and the shape of its

[16] These costs may be, for example, bureaucratic costs incurred during the decision-making process for designing the optimal intervention strategy or financial losses caused by a purchase (sale) of foreign currency which is not followed by future appreciation (depreciation) of the domestic currency. While in the absence of intervention costs the central bank counteracts to every single idiosyncratic shock, in the presence of positive costs of intervention, the decision to respond to a shock with sterilized intervention is based on a cost-benefit analysis of foreign exchange intervention (see Almekinders 1995).

[17] On the one hand, if official intervention is to work through the signalling channel, then ideally every intervention operation of the central bank in the foreign exchange market should be announced publicly since the announcement increases the chance of the operation being successful. On the other hand, however, some theoretical models (e.g. Alex Cukierman and Alan Meltzer 1986; Nathan Balke and Joseph Haslag 1992) show that a necessary condition for official intervention to be effective is the maintenance of the informational advantage. In this sense, public announcements of *future* official intervention by central banks may heavily undermine the effectiveness of the intervention operation.

[18] A recent paper which conflicts with this presumption is due to Owen Humpage (1997), who investigates the forecast value of U.S. interventions in the foreign exchange market. The rationale is that evidence of superior forecasting skill would imply that the U.S. monetary authorities act with better information than the market and that intervention could alter foreign exchange traders' expectations about exchange rates. The analysis presented by Humpage (1997) shows, however, that this was not the case for U.S. official intervention during the period 1990–97, and official transactions by U.S. monetary authorities do not seem to improve the efficiency with which the foreign exchange market obtains and uses information.

loss function, in addition to the degree of central bank independence, are crucial in determining the final outcome of the game between the central bank and the rational speculators in the market in these models (see Rogoff 1985; Cukierman 1992; Eijffinger and Eric Schaling 1993; Guy Debelle 1993; and George Alogoskoufis 1994).

3.5 *Intervention, Speculative Attacks and Currency Crises*

There is a large theoretical literature in international macroeconomics on speculative attacks and currency crises. Although this literature does not explicitly address the effectiveness of intervention, we believe that there are some strands of it which do yield important insights into intervention operations, and that some of the models might be usefully adapted to analyze specific intervention issues.

There are three main strands of this literature.[19] The first strand—often referred to as the first-generation currency crisis approach—starts with the seminal article by Krugman (1979) and the subsequent article by Flood and Garber (1984). The key characteristic of first-generation models is that the authorities are pursuing a fiscal policy which is inconsistent with the exchange rate peg. As such, intervention is doomed to ultimate failure primarily because exchange rate policy is incompatible with the underlying stance of monetary and fiscal policy, so that exhaustion of a finite stock of reserves is inevitable. In addition, the effects of sterilized intervention through the portfolio balance channel are precluded by assuming a simple underlying monetary model of the exchange rate, which assumes perfect substitutability between domestic and foreign assets (so only nonsterilized intervention is considered), and the signalling effects of intervention are ruled out because agents know that the authorities' monetary policy is ultimately unsustainable. The central insight on intervention operations from these models, however, is that they must be ultimately unsuccessful if they are inconsistent with the general stance of macroeconomic policy.[20]

In second-generation models, the emphasis is generally on policy rule nonlinearities, such as a shift in domestic monetary policy conditional on whether or not there is a speculative attack (Obstfeld 1994, 1996). A key feature of second-generation models is an escape clause in government policy, whereby there is a fixed penalty for abandoning the exchange rate peg and switching to a floating regime. The authorities then intervene to support the peg so long as the value of their loss function under this regime is less than the value of the loss with a switch to a float, including the fixed penalty for invoking the escape clause. Because there is a simultaneity between the value of the loss involved in each regime and whether or not a speculative attack is

[19] For more comprehensive discussions and surveys of this literature, see Pierre-Richard Agénor, Bhandari and Robert Flood (1992), Garber and Lars Svensson (1995), Olivier Jeanne (1996), and Flood and Nancy Marion (1999).

[20] The implicit assumption of perfect substitutability between domestic and foreign assets has been relaxed in some modified first-generation models (e.g. Flood, Garber and Charles Kramer 1996; Flood, Robert Hodrick, Isard and Kramer 1996; Flood and Marion 2000). These models allow a role for sterilized intervention by introducing a risk premium—itself a function of domestic and foreign bond holdings—into the uncovered interest rate parity condition. Moreover, Flood and Marion's (2000) analysis shows how introducing nonlinearity into the model and relaxing the perfect foresight assumption generates multiple solutions and opens up the possibility of self-fulfilling speculative attacks. These features are, in fact, key characteristics of so-called second generation-speculative attack models, so that the Flood-Marion model may be seen in some respects as bridging the "generation gap."

launched, the model admits multiple equilibria. Interestingly, it is possible to show that by increasing the penalty of invoking the escape clause and abandoning the peg, the probability of an attack being launched is actually *increased*, which—at least prima facie—appears counter-intuitive (see Flood and Marion 1997a, 1999). One way of making this result more intuitive, and at the same time seeing the link with exchange rate intervention, is as follows. Although the cost of invoking the escape clause and abandoning the peg is usually interpreted as the authorities' loss of credibility or as a deadweight loss to society, a more immediate interpretation is to view it as the transfer of wealth which is made from the authorities to private speculators following a successful speculative attack. Thus, the more prolonged and intense the defense of the peg—i.e. the more the authorities intervene—the greater will be the profit that accrues to speculators and the greater the incentive they will therefore have to attack. Under this interpretation of second-generation models, therefore, intervention has the perverse effect of making the collapse of a currency more probable. This is an interesting theoretical result which warrants empirical investigation.

A large and growing literature on third-generation models of currency and financial crises has developed recently in the wake of the 1997–98 East Asian financial and currency crisis. These models were developed primarily because the East Asian crisis appeared not to be characterized by the fiscal deficits which typically trigger a crisis in first-generation currency crisis models, nor did there appear to be any strong temptation for the authorities to abandon a fixed exchange rate system in order to pursue a more expansionary monetary policy, as one might expect in a second-generation model. In fact, these third-generation models are really models of financial sector crisis rather than models of speculative attack or currency crisis per se. As such, however, third-generation models have few implications for the effectiveness or otherwise of intervention policies. The implicit assumption is that a massive capital flight following the collapse of domestic asset market bubbles will swamp intervention operations, leading to a collapse of the currency.[21]

Clearly, the three strands of literature on speculative attacks and currency crises offer rather different—albeit related—views of the mechanics of a currency crisis. Intervention only has a major role in the context of first- and second-generation models. First-generation models tell a simple, stark story about intervention policies which are inconsistent with the underlying stance of monetary and fiscal policy, namely that they are doomed to ultimate failure. Some of the second-generation models, however, tell a rather more sophisticated story in which prolonged intervention may in certain circumstances actually increase the probability of a successful attack on the currency. It is perhaps worth conjecturing that such models may shed some light on why monetary authorities so often deem it necessary or desirable to intervene in secret, contrary to the intuition which follows from thinking in terms of a simple signalling channel framework. It may be that the authorities in these cases are attempting to

[21] For further discussion of third-generation models, see e.g. Ronald McKinnon and Huw Pill (1996), Amar Bhattacharya, Stijn Claessens, Suwati Ghosh, Leonardo Hernandez, and Pedro Alba (1998), Edison, Pongsak Luangaram, and Miller (1998), Krugman (1998), Giancarlo Corsetti, Paolo Pesenti, and Nouriel Roubini (1999), Menzie Chinn, Dooley, and Sona Shrestha (1999), and Sarno and Taylor (1999).

influence the exchange rate through the portfolio balance channel without the danger of triggering a self-fulfilling speculative attack on the currency. At present, however, this remains a conjecture of the present authors, but one which we feel would repay further research.

4. *Does Official Intervention Work in Practice*?

So far, our discussion of the mechanics and effectiveness of intervention has been almost exclusively theoretical. We now turn our attention to the vexed questions of whether and how intervention works in practice.

4.1 *Data on Official Exchange Rate Intervention and Exchange Rate Expectations*

The early empirical literature on exchange rate intervention was handicapped by the lack of data on two crucial variables: data on intervention itself and data on market participants' exchange rate expectations. An attempt was often made to circumvent the first lacuna by inferring intervention activity from movements in the authorities' international reserves, while the assumption of rational expectations (often with the auxiliary assumption of uncovered interest rate parity) was generally invoked to cope with the second gap in the data.

Monthly and quarterly data on monetary authorities' international reserves are given in most central banks' statistical publications, while quarterly data are available, for example, from the *International Financial Statistics* database of the International Monetary Fund. Movements in these data, however, represent a very inaccurate proxy for intervention activity since monetary authorities' international reserves may change for a number of reasons different from and often not related to official intervention. Reserves increase, for example, with interest receipts on official portfolio holdings, and fluctuate widely with valuation changes on existing reserves. Most tellingly, reserves do not include transactions that are in fact intervention operations, such as the so-called hidden reserves, which may be seen as changes in official deposits of foreign currency with domestic currency and are regularly used by a number of central banks—in particular, they are very frequently adopted by the Bank of Japan (see Edison 1993; Dominguez and Frankel 1993a).[22]

The issue of data availability on actual intervention operations is obviously closely linked to the issue of why secrecy—or omission of a detailed report—of official intervention is often maintained by monetary authorities, even after the event. While arguments may exist in favor of the secrecy of official intervention, it is unclear why central banks have not been interested for a long time in releasing data to researchers ex post.

A change in this practice has been made, however, by the U.S. authorities, and U.S. daily data for intervention are now available, following the authorization of the U.S. Treasury to the Board of Governors of the Federal Reserve System to release them in the early 1990s. Germany and Japan have recently followed the example of the United States. The other G7 countries have not followed this practice yet and, therefore, the process of gathering

[22] Ideally, a study on official intervention attempting to be infomative on both short- and long-term effectiveness of official intervention should use minute-by-minute data, since this is the time scale on which intervention of the monetary authorities in the foreign exchange market occurs. Nevertheless, daily data may represent a sufficiently good approximation.

intervention data still requires the reconstruction of the operations of the monetary authorities on the basis of reports of the financial press which, however, is not expected to be comprehensive of every secret operation, especially small ones which may not be identified even by traders in the foreign exchange market.[23]

In addition to the recent availability of data on official exchange rate intervention, survey data on exchange rate expectations also became available for utilization during the late 1980s. These data are very useful for modelling expectations mechanisms and testing the signalling or expectations channel.

Hence at the beginning of the 1990s the empirical literature on intervention was able to address the question of whether official intervention is effective more seriously than the corresponding literature of the 1980s. The handicaps that researchers in the 1980s worked under were essentially removed. In particular, as discussed below, a series of studies by Dominguez and Frankel in the early 1990s significantly raised the standard of the analysis by using both intervention data and survey data on expectations.

4.2 *The Portfolio Balance Channel: Evidence*

In order to analyze the effectiveness of sterilized official intervention through the portfolio balance channel, various studies have focused on the traditional formulation of the PBM under the assumption that the Ricardian equivalence theorem does not hold. In that framework, investors allocate their wealth among different assets in proportions that are assumed to be increasing functions of the expected return on each asset. Also, under the assumption that investors are risk averse and that rates of return are uncertain, investors maximize expected profits by diversifying their portfolios.

The PBM has not attracted a large empirical literature relative to other models of exchange rate determination and in particular relative to monetary models, mainly because several problems are encountered in mapping the theoretical framework of the PBM into real-world financial data. In particular, the choice of non-monetary assets to be considered in the empirical model is difficult and data are not always available on a bilateral basis.[24] In general, however, two types of tests have been conducted by the relevant empirical literature. The first type is based on estimating a reduced form solution of the PBM in order to measure its explanatory power—this approach is often called the direct demand approach. The second type of test of the PBM focuses on solving the PBM for the risk premium and testing for perfect substitutability of bonds denominated in different currencies—this is the inverted demand approach.

In testing the portfolio balance model using the inverted asset demand approach, researchers typically estimate an equation where the risk premium (say ρ) is a function of domestic and foreign bond holdings (B and B^*) (and, in more complex formulations, of income and wealth):

$$\rho_t = \theta_1 B_t + \theta_2 B_t^* \qquad (7)$$

where θ_1 and θ_2 are parameters and where, for simplicity, we have assumed a linear static specification. Typically, the

[23] See Dominguez and Frankel (1993a) for a more extensive discussion of these issues, and Diana Weymark (1997a,b) for a discussion of methods of constructing indices of intervention activity on the basis of observed data.

[24] See Taylor (1995) for a discussion of the econometric issues involved in estimating the PBM.

risk premium is measured by deviations from uncovered interest parity, either assuming rational expectations or employing survey data. Under the null hypothesis that assets are perfectly substitutable at home and abroad, the coefficients on the bond holdings variable should all be zero. On the other hand, if the portfolio balance channel hypothesis holds, then the coefficients on bond holdings should be statistically significant (see e.g. Taylor 1995).

In general, in the late 1970s and in the 1980s, the empirical literature on testing the PBM suggested that sterilized intervention is effective at most in the very short term, while the joint hypothesis of rational expectations and perfect substitutability of domestic and foreign assets was regularly rejected. Also, much of this literature suggests that the exchange rate effects of intervention through the portfolio balance channel are very small in size—see Edison (1993) for a review of the empirical studies on testing the portfolio balance channel in the 1980s.

Some post-1980s support in favor of significant portfolio balance effects is provided by Atish Ghosh (1992). The approach taken involves using a forward-looking monetary model of the exchange rate in order to capture signalling effects. Since the monetary model implies that the exchange rate is a function of expected future monetary fundamentals, the monetary policy signalling effects must be captured. This then allows the researcher to test for the effects of sterilized intervention through channels other than the signalling channel. Using monthly data for the U.S. dollar-German mark rate over the period 1980–88, Ghosh provides evidence for a weak, but statistically significant portfolio influence on the exchange rate. The model also performs well in forecasting, displaying a very high correlation between the actual and fitted values of the exchange rate and outperforming an alternative random walk model in out-of-sample forecasting. In a sense, this approach is mildly "schizophrenic" (Ghosh 1992, p. 217), in that a significant portfolio balance effect implies rejection of the monetary model, but various indicators of the monetary model's performance, such as in-sample fit and predictive performance, indicate that "the model provides a reasonable filter for removing the influence of agents' expectations of future policies" (ibid).[25]

The conventional wisdom of official intervention ineffectiveness through the portfolio balance channel has been strongly challenged by Dominguez and Frankel (1993b). Using survey data on U.S. dollar-German mark and U.S. dollar-Swiss franc exchange rate expectations in the mid-1980s to construct measures of the risk premium as the deviation from uncovered interest rate parity and also taking account of potential simultaneity bias using appropriate instrumental-variable estimation, Dominguez and Frankel (1993b) find that intervention variables have statistically significant explanatory power in a regression for the risk premium. Their study provides strong support in favor of a significant portfolio balance effect (with mean-variance optimization) and, therefore, effectiveness of intervention, and

[25] Interesting evidence on the relationship between exchange rates, interest rates and current account news is also provided by Costas Karfakis and Suk-Joong Kim (1995), using Australian data for the period from July 1985 to December 1992. The Australian dollar is found to depreciate over the sample examined, while interest rates are found to rise as a result of an announcement of a larger than expected current account deficit. These results may be interpreted as consistent with the view that market participants expected a foreign exchange market intervention sale of the Australian dollar by the Reserve Bank of Australia and they used a portfolio balance model when responding to news.

especially coordinated intervention. Their results lead the authors to state that

> Until recently, there was an unusual degree of consensus among economists that intervention by central banks in the foreign exchange market did not offer an effective or lasting instrument for affecting the exchange rate. . . . the theoretical case against the effectiveness of intervention is not as clear as a reading of the economics literature might suggest. (p. 1356)

4.3 *The Signalling Channel: Evidence*

The empirical literature investigating the significance of the signalling channel is relatively recent but growing rapidly, especially due to the release of daily data on intervention from the U.S. authorities in the early 1990s. Given the comprehensive review of the 1980s and earlier literature by Edison (1993), we focus here—with one exception—on studies published during the 1990s.

The single exception is the unpublished doctoral thesis of Dominguez (1987). This is an empirical investigation of the ability of the monetary authorities to signal monetary policy intentions and affect market expectations of the future exchange rate, executed using weekly U.S. data for the February 1977–February 1981 period. Estimation of regressions of the intervention variable on money surprises (constructed using publicly available preannounced money supply forecasts) produces results suggesting that money supply surprises are positively associated with intervention during periods of high reputation and credibility of the monetary authorities. Also, estimation of regressions of exchange rate changes on intervention, aimed at testing the signalling channel hypothesis, suggests that in periods of high reputation and heavy sterilized official intervention the monetary authorities are able to influence exchange rate changes, which are found to be positively related to intervention. Overall, this study provides some evidence supportive of the signalling hypothesis.[26]

Interesting evidence has also been produced through the estimation of inverted portfolio balance equations with the risk premium as the dependent variable, generally under the assumption of rational expectations (e.g. Dominguez 1990). This approach has often been seen as providing information on the effectiveness of sterilized intervention through the signalling channel rather than the portfolio balance channel because the explanatory variable used in the estimated regression is typically actual intervention rather than cumulated intervention, the more common variable used by the literature. Formally, the estimated regression is of the following form:

$$\rho_t = \gamma_0 + \gamma_1 INT^C_{t-1} + \gamma_2 INT^{NC}_{t-1} + \omega_t, \quad (8)$$

where ρ_t is the risk premium, INT^C_t and INT^{NC}_t are defined as coordinated and noncoordinated actual intervention, and ω_t is a white noise error. As a representative study of this literature, for example, Dominguez (1990) provides results for five subperiods, using daily data for the Japanese yen-U.S. dollar and the German mark-U.S. dollar from January 1985 to December 1987. For the first

[26] Another important early contribution is due to Obstfeld (1990). This is an examination of the effectiveness of foreign exchange intervention after the 1985 Plaza Hotel announcement by the G5 countries. At that time, a substantial realignment of exchange rates occurred and, at the same time, foreign exchange market intervention—mainly concerted and sterilized—was undertaken on a scale not seen since the early 1970s. The evidence produced indicates that sterilized intervention had played a relatively minor role in promoting exchange rate realignment, while shifts in the patterns of monetary and fiscal policy were the main factors determining currency values during the late 1980s. Similar results are obtained by several other studies (e.g. see Humpage and William Osterberg 1990; Eijffinger and Noud Gruijters 1991a,b).

two subperiods, the estimation produces significant and correctly signed coefficients on the intervention variables, while in the remaining subperiods the coefficients are either significant but wrongly signed or correctly signed but not statistically significantly different from zero at conventional significance levels. Interestingly, different effects are found for coordinated and noncoordinated intervention for various subperiods and, in general, the coefficient on coordinated intervention is found to be relatively more strongly statistically significant.

More recently, Dominguez and Frankel (1993a) employ an alternative estimation procedure, different from all previous studies, as they test both channels of influence without assuming rational expectations of exchange rates; indeed, the expected future U.S. dollar-German mark exchange rates used in the estimation are weekly and biweekly survey data on market forecasts. Dominguez and Frankel estimate a two-equation system where one of the equations defines the expectations formation mechanism and the other equation is an inverted portfolio balance equation which allows for mean-variance optimization.[27] Also, the estimated model allows for all of the fundamentals suggested by traditional exchange rate determination models as explanatory variables, thereby providing a more carefully specified reduced form regression for the exchange rate relative to previous studies. Intervention is defined in three different ways: one-day intervention (occurring at the end of the day before the survey), one-week or two-weeks intervention (cumulated between survey forecasts) and cumulated intervention (cumulated from the beginning of the sample period). The authors also distinguish, in some of the many regressions estimated in their study, between public and secret intervention.

Overall, the monograph of Dominguez and Frankel (1993a) provides strong statistical evidence supportive of the effectiveness of sterilized intervention through both the portfolio balance channel *and* the signalling channel. It is also shown that, for certain parameter values and under the two assumptions that interest rates are constant and that expectations are neither adaptive nor extrapolative, the quantitative effects of sterilized intervention may be substantial. These results are arguably the most supportive of the effectiveness of official intervention in the relevant literature. The use of survey data, the bilateral basis of the estimated regression (rather than multilateral), the sample period considered (only data for the 1980s) and the constraint of mean-variance optimization imposed in the inverted portfolio balance equation all represent potential factors that may have influenced the findings of Dominguez and Frankel (1993a), and further work to investigate the specificity of their results is therefore warranted. The authors conclude their monograph eliciting a view—shared by the present authors—characterized by a certain degree of optimism:

> Our results suggest that intervention can be effective, especially if it is publicly announced and concerted. It may be that sterilized intervention can only have effects in the short term. But if "short-term effects" include the bursting of a nine-month bubble

[27] More precisely, the expectations formation mechanism is described by an equation where the investor's forecast of the expected future exchange rate is the dependent variable and the explanatory variables are the difference between the contemporaneous and the lagged exchange rate and three different dummies for information on intervention reported in newspapers, actual intervention operated by the Bundesbank, and actual intervention by the Federal Reserve reported in the newspapers.

> earlier than it would otherwise have burst, then such an effect may be all that is needed . . . Our specific recommendations are quite modest: that the authorities make their interventions public, that an interagency process regularly consider exchange rate developments in light of developments in the fundamentals, and the G7 discussions on macroeconomic policy and exchange rates be integrated. (p. 140)

In a further complementary study, using survey data on dollar-mark exchange rate expectations, Dominguez and Frankel (1993c) provide evidence that official announcements of exchange rate policy and reported intervention significantly affect exchange rate expectations and that, overall, the effectiveness of intervention, in terms of significantly affecting both weekly and daily exchange rate changes, is very much enhanced if it is publicly announced.[28]

Using publicly available data on U.S. foreign exchange rate intervention, an interesting literature examines the relationship between foreign exchange market intervention and monetary policy, testing the hypothesis that official intervention signals changes in future monetary policy as well as the hypothesis that changes in monetary policy may induce leaning-against-the-wind interventions. This literature provides persuasive supportive evidence for both hypotheses, suggesting that official intervention may predict monetary policy variables and vice versa (e.g. see Lewis 1995 for a study of the period from 1985 to 1990). This literature also examines the prediction of the signalling channel hypothesis that central banks signal a more contractionary monetary policy in the future by buying domestic currency today and, therefore, that expectations of future tighter monetary policy make the domestic currency appreciate, even though the current monetary effects of the intervention are typically offset by sterilization. This expectation presumes that central banks in fact back up interventions with subsequent changes in monetary policy, and the literature provides ample evidence in favor of this presumption (Graciela Kaminsky and Karen Lewis 1996).

Another interesting contribution in this context, due to Catherine Bonser-Neal, V. Vance Roley, and Gordon Sellon (1998), re-examines the relationship between the Federal Reserve monetary policy actions, U.S. interventions in currency markets and exchange rates using an alternative measure of monetary policy actions—the Federal Reserve's federal funds interest rate target. The authors find that the exchange rate generally responds immediately to U.S. monetary policy actions and that this response is usually consistent with Rudiger Dornbusch's (1976) exchange rate overshooting hypothesis. The authors also find evidence of signalling and leaning against the wind in U.S. intervention policies over the sample period.

A closely related strand of the literature has recently addressed the question of whether there is a link between central bank intervention and the volatility of foreign exchange rates. Bonser-Neal and Glenn Tanner (1996), for example, examine the effects of central bank intervention on the ex ante volatility of the U.S. dollar-German mark and the U.S. dollar-Japanese yen from 1985 to 1991, estimating ex ante volatility using the implied volatilities of currency option prices and also controlling

[28] The literature identifies a number of episodes of coordinated intervention over the 1985–91 period across the G3 countries (the U.S., Germany, and Japan), all of which may have been successful in reversing the trend in the dollar, presumably through the signalling channel (Pietro Catte, Giampaolo Galli, and Salvatore Rebecchini 1994). For a recent study of intervention in the context of the European Monetary System, see Peter Brandner, Harald Grech, and Helmut Stix (2001).

for the effects of other macroeconomic announcements. Bonser-Neal and Tanner find little support for the hypothesis that central bank intervention is associated with a positive change in ex ante exchange rate volatility or with no change.[29]

More recently, the standard of the analysis has been raised using intraday data. The first intraday study of intervention is due to Bettina Peiers (1997), who examines Reuters reports of intervention in dollar-mark by the Bundesbank over the period October 1, 1992 to September 30, 1993 and finds that Deutsche Bank was a "price leader" up to sixty minutes prior to intervention reports. By the time the reported intervention appears on the Reuters money-market headline news screen, one observes two-way causality and the "normal" sort of price interactions among traders, implying that intervention is signaled via the counterparty banks used by the central bank. The market has learned of the intervention through trading rather than the public news shown on the Reuters news screen. By the time the headline news screen reports the intervention, it is no longer news to the interbank market. Such informational leads should be taken into account by researchers investigating the "news" effects of intervention. Yuanchen Chang and Stephen Taylor (1998) examine the effects of intervention by the Bank of Japan again using intraday data over the same period as that analysed by Peiers (1997) and news related to the Bank of Japan intervention in the dollar-yen market retrieved from Reuters reports. They find that dollar-yen volatility varies significantly differently across periods from one before to one after Reuters' intervention reports. Using autoregressive conditional heteroskedasticity models, Chang and Stephen Taylor find that their intervention proxy has the largest effect on high frequency volatility 30 to 45 minutes prior to Reuters' reports of intervention.

4.4 *The Secrecy Puzzle*

Most actual intervention operations in the foreign exchange market have been—and still are—largely secret, not publicly announced by monetary authorities. This secrecy of official intervention is difficult to explain, however, given that the signalling channel is expected to work through altering the expectations of other market agents through policy announcements by monetary authorities.

The traditional relevant literature identifies three types of arguments in favor of secrecy of official intervention: arguments based on the central bank's desire to minimize the effects of an unwanted intervention operation (for example because the decision has been taken outside the central bank, e.g. by the Treasury), arguments based on the perceived risk and volatility in the foreign exchange market which might be exacerbated by an announcement of official intervention, and portfolio adjustment arguments (Dominguez and Frankel 1993a). A further explanation may be that although monetary authorities intervene in order to target the value of a foreign currency, since the fundamentals of the foreign currency are not necessarily equal to this objective, the monetary authorities do not have an incentive to reveal their intervention operations and no announcement on their activities will be credible (see Bhattacharya and Weller 1997; Vitale 1999a,b,c).

[29] The link between intervention and exchange rate volatility has also been formally rationalized in some recent theoretical studies, generally in the context of multi-country intertemporal asset pricing models (e.g. see Richard Baillie and Osterberg 1997).

While some of these arguments may apply some of the time, none of them seems to explain fully the widespread practice of secret intervention operations, and further study is required to analyze these issues further and improve our understanding. As we have conjectured above, further analysis of second-generation currency crisis models may ultimately shed some light on this puzzle: secrecy of intervention may be an attempt to affect the exchange rate through the portfolio balance channel without triggering a self-fulfilling attack on the currency. For the moment, however, the secrecy of much official intervention remains something of a puzzle.

4.5 *The Empirics of Central Bank Reaction Functions*

The empirical literature on central bank reaction functions has typically reported rather simple functions in an attempt to shed light on the behavior of central banks in the foreign exchange market and to test certain theoretical predictions concerning intervention.[30] While the dependent variable in these reaction functions is always some measure of official intervention, the explanatory variables considered vary across studies. In most cases, however, exchange rate changes and deviations of the actual exchange rate from its target level are included. A fairly typical reaction function takes the following form:

$$INT_t = \beta_0 + \beta_1(s_t - s_t^T) + \beta_2 \Delta s_t + \zeta X_t + \nu_t, \qquad (9)$$

where INT_t is the amount of intervention at time t, β_0, β_1 and β_2 are scalar parameters, X_t is a vector of economic factors which may influence official intervention (e.g. lagged intervention or the country's trade balance position), ζ is a corresponding vector of parameters, s_t and s_t^T denote the actual and target level of the exchange rate (domestic price of foreign currency) at time t (in logarithms), Δs_t is the (percentage) change in the exchange rate, and ν_t is an error term.[31] The sign of β_1 is expected to be negative if intervention is stabilizing in the sense that the volume of intervention is inversely related to the deviations of the actual exchange rate from its target level, whereas β_2 is unconstrained and an estimated negative (positive) sign indicates that the central bank sells (buys) foreign exchange (domestic currency) when the currency has depreciated (appreciated), implying that the central bank pursues a policy of leaning against (with) the wind.[32]

The main results recorded by the relevant literature on estimating reaction functions of the form (9) or variants of it, largely carried out in the 1980s and applied to some of the central banks of the major industrialized nations, may be briefly summarized as follows:[33]

[30] There is by now a very large and still growing body of empirical literature on the reaction functions of central banks. The literature especially focuses on monetary policy reaction functions or "Taylor rules"—see, for example, Giuseppe Tullio and Marcio Ronci (1997), and Richard Clarida, Jordi Gali, and Mark Gertler (1998, 1999) and the references therein. The focus of this section is, however, specifically on reaction functions designed to examine exchange rate management.

[31] Although some researchers estimate equations like (9) by ordinary least squares, instrumental variable estimation is strongly advised given the endogeneity of the variables in (9).

[32] The traditional approach to the estimation of sterilization equations has often been criticized on various grounds. In particular, one may argue against the ad hoc specification of the reaction function of the monetary authorities typically employed by this literature. An alternative analytical model where the sterilization equations are derived from an explicit maximization problem solved by the monetary authorities would be more rigorous. In such a model, the optimal intervention and sterilization policies of the monetary authorities are likely to be a function of the different disturbances hitting the economy and the preferences of the monetary authorities (e.g. see Roubini 1988).

[33] For a list of the numerous studies in this context see Edison (1993).

a) the Bundesbank's main objective of exchange rate intervention was smoothing changes in the exchange rate by following a policy of leaning against the wind;

b) the Bank of Japan adopted a policy of leaning against the wind and responded more strongly to exchange rate changes than to deviations of the exchange rate from its target level;

c) the Swiss central bank also adopted a policy of leaning against the wind and mainly targeted deviations of the actual exchange rate from its target level, although both β_1 and β_2 were found to be statistically significant and correctly signed;

d) the Bank of England intervened mainly for smoothing exchange rate movements, but did not target the level of the exchange rate.[34]

Note that this strand of the empirical literature assumes that central banks tend to sterilize their interventions in the foreign exchange market. The question whether central banks fully sterilize their intervention operations is, however, also addressed explicitly by some researchers. The standard approach followed is to estimate a regression with domestic credit or the monetary base as dependent variable and changes in net foreign reserves, contemporaneous output gap and inflation as explanatory variables.[35] The following two forms of reaction functions have been considered and estimated by some studies in this literature:

$$\Delta DC_t = \mu_1 \Delta NFA_t + \mu_2 (y - y^*)_t + \mu_3 \pi_t + \omega_{1t} \quad (10)$$

$$\Delta MB_t = \nu_1 \Delta NFA_t + \nu_2 (y - y^*)_t + \nu_3 \pi_t + \omega_{2t} \quad (11)$$

where DC_t denotes domestic credit, NFA_t denotes net foreign assets, $(y - y^*)_t$ is the gap between current output and its natural level, π_t denotes inflation, MB_t represents the domestic monetary base, Δ represents a change in a stock, and ω_{1t} and ω_{2t} are error terms. Information with regard to the degree of sterilization used by central banks is provided by estimates of the coefficients μ_1 and ν_1. In particular, the estimated μ_1 coefficient is expected to be negative. If it is not statistically significantly different from –1, sterilization is full, while if it is greater than –1 and less than zero, sterilization is only partial. The interpretation of ν_1 is different in the sense that full sterilization is consistent with an estimated value for ν_1 which is not significantly different from zero.

Also, note the econometric difficulty in separately identifying a reaction function from private behavior. For example, equation (10) could be inverted to show the "offset" of domestic monetary operations through endogenous capital flows which affect *NFA*.[36]

The relevant empirical literature indicates that the Bundesbank has in the past tended to sterilize at least partially foreign exchange intervention operations, although the degree of sterilization varies over time (see the references in Edison 1993). Similarly, using Japanese data, researchers generally provide evidence suggesting that the Bank of Japan sterilized its intervention operations, although sterilization is found to be full in some studies but varying over time and decreasing during the post-Bretton Woods period in other studies (e.g. Shinji Takagi 1991; Edison 1993).

[34] Interestingly, the empirical evidence suggests that the response to exchange rate changes is asymmetric for various central banks, and often in different directions (see Edison 1993).

[35] Again, given the endogeneity of these variables, instrumental variables estimation is required.

[36] This issue was first discussed by Pentti Kouri and Michael Porter (1974) in the context of an open-economy general equilibrium model of international capital flows determination where capital flows are essentially seen as the mechanism by which a domestic excess demand for money is removed.

More recently, a novel approach to deriving a central bank intervention reaction function has been proposed by Almekinders and Eijffinger (1996). In particular, this is a model of exchange rates that captures generalized autoregressive conditional heteroskedasticity, such that intervention is allowed to have an effect on both the mean and the variance of exchange rate returns. An intervention reaction function is obtained by combining the exchange rate model with a particular loss function for the central bank. The estimation results of Almekinders and Eijffinger suggest that both the Bundesbank and the Federal Reserve largely adopted a leaning-against-the-wind policy and have often reacted to increases in the conditional variance of daily German mark-U.S. dollar returns.[37]

Overall, therefore, the empirical literature on central bank reaction functions provides fairly mixed results and certainly represents an important potential avenue for future research, especially in the light of the greater data availability in recent years. Evidence to date, however, suggests that central banks appear to use largely a policy of leaning against the wind, to react to both changes of the exchange rate from the target and to exchange rate movements, and to sterilize—at least partially—their intervention operations.[38]

4.6 *Profitability of Intervention Operations as a Test of the Effectiveness of Official Intervention*

According to Milton Friedman's (1953) view on official intervention, a central bank which is successful in stabilizing the exchange rate should make a profit at the expense of speculators, implying that if official intervention is not profitable it is not effective. This is the rationale for measuring the profitability of intervention as a means of evaluating the effectiveness of official intervention.

Empirical studies focusing on the profitability of intervention operations are, however, relatively sparse, presumably because of the significant difficulties encountered in trying to calculate profits and losses in this context. Researchers typically measure central banks' profits from official intervention on the basis of equations of the form:

$$z_t = \sum_{k=1}^{t} \left[fx_k(S_t - S_k) + S_k(i_k^* - i_k) \sum_{j=1}^{k} fx_j \right] \tag{12}$$

where z_t denotes profits, fx_k denotes purchases of foreign exchange at time k, S_t and S_k are end-of-period nominal exchange rates (domestic prices of foreign currency) at times t and k respectively, and i_k and i_k^* denote the domestic and foreign interest rates respectively at time k. According to equation (12), profits are

[37] The evidence on reaction functions of central banks in developing countries and transition economies is still very sparse, perhaps because the economic and political environment has been much more unstable in these countries and, most importantly, because data are less reliable and often not available. Two studies are, however, worth noting. Ronci and Tullio (1996) find a very stable reaction function for the Central Bank of Brazil during the high inflation period from 1980 to 1993. More recently, Tullio and Victor Natarov (1999) estimate a daily reaction function for the Central Bank of Russia using daily data for the period from October 1, 1996 to October 1, 1997. The authors find a systematic and significant reaction of the Bank to changes in market yields, to deviations of the market exchange rate from the central rate of the narrow rouble-U.S. dollar corridor, to changes in the regulations concerning repatriation of foreign capital and to changes in the differential between yields on taxable and nontaxable Treasury bills.

[38] Indeed, this conclusion is consistent with the recent findings by Christopher Neely (2001), who used survey data based on questionnaires sent to the monetary authorities of 44 countries.

determined by two factors: (a) the differential between the end of period exchange rate at time t and the exchange rate at which the foreign currency was purchased at time k; and (b) the interest rate differential between the two countries whose currencies are involved in the intervention operation, and hence the interest rate costs of the intervention.

The empirical evidence provided by researchers on the profitability of intervention in the 1980s, well surveyed by Edison (1993), Richard Sweeney (1997) and Neely (1998), suggests that profits from intervention operations may vary significantly according to the sample period considered but, in general and in the long run, central banks make profits.

A general fundamental drawback, however, of this strand of the literature is concerned with the implicit assumption that the profitability of intervention represents a valid criterion by which to measure the effectiveness of official intervention. As clearly shown by—among others—Edison (1993), it is possible to think about very realistic situations in which stabilizing (effective) official intervention may not be profitable and, vice versa, situations in which official intervention may be destabilizing but profitable. The argument is that, if the authorities were to purchase foreign exchange when its price was low and sell it when its price was high, then abstracting from interest-rate considerations, intervention would be profitable even if the purchases and sales had no significant effect on exchange rates. If the central bank can earn profits on intervention that has no effect on exchange rates, then it is difficult to argue that those profits imply that intervention has a stabilizing effect on exchange rates. In general, therefore, profitability of intervention is *not* a test of its effectiveness in moving exchange rates.

Nevertheless, central bank intervention losses or profits vary widely, with some studies reporting substantial losses, others substantial profits. In most cases, however, estimated profits are not risk-adjusted, although risk adjustment may have a very significant effect. Also, profit estimates involve time series which are generally found to be integrated of order one (hence nonstationary), implying that test statistics in this context are likely to have nonstandard distributions; very few studies take this factor into account. Estimates of risk-adjusted profits for the U.S. and the Swedish central banks, computed allowing for nonstandard distributions, suggest that none of these central banks had made losses and may even have made significant profits (see Sweeney 1997).

A different but related recent literature focuses on the relationship between central bank intervention and trading rule profits in foreign exchange markets. Studies in this context often examine moving average trading rules, which are utilized in both futures and spot foreign exchange markets to show that substantial profits can be earned for various currencies (Taylor and Helen Allen 1992). Also, central bank intervention is usually found to be strongly associated with the profitability of trading returns for these major currencies and partially explains returns (Andrew Szakmarky and Ike Mathur 1997). However, this literature largely focuses on investigating whether simple rules used by traders have some predictive value over the future movement of foreign exchange rates in connection with central bank activity, with the main objective of finding out to what extent foreign exchange predictability can be confined to periods of central bank activity in the foreign exchange market. The emerging stylized fact

from the relevant literature seems to be that, after removing periods in which the central bank has been particularly active in the foreign exchange market, exchange rate predictability is dramatically reduced (Blake LeBaron 1996).

5. *Conclusion: Towards a Third Channel of Influence?*

Is official exchange rate intervention effective and, if so, how does it work?

Overall, the evidence on the effectiveness of official intervention, through either the portfolio balance channel or the signalling channel, is still mixed on balance, although the more recent literature does suggest a significant effect of official intervention on both the level and the change of exchange rates. Nevertheless, it is perhaps fair to say that the studies of the 1990s, which are largely supportive of the effectiveness of intervention, should perhaps be given more weight than the studies of the 1980s, which largely rejected the effectiveness of intervention. This is because of the removal of the two major handicaps characterizing the empirical studies of the 1980s, namely the lack of data on intervention and the lack of survey data on exchange rate expectations. Thus, the evidence provided by Dominguez and Frankel (1993a,b,c) and subsequent studies using these high-quality data seems to us to be sufficiently strong and econometrically sound to allow us to conclude cautiously that official intervention can be effective, especially if the intervention is publicly announced and concerted and provided that it is consistent with the underlying stance of monetary and fiscal policy. Nevertheless, further empirical work in this area is clearly warranted, especially given the increasing availability of high-quality daily data on intervention.

Of the two traditional channels of influence, it is tempting to conjecture that the portfolio balance channel will diminish in importance over time—at least among the major industrialized countries—as international capital markets become increasingly integrated and the degree of substitutability between financial assets denominated in the major currencies increases. This suggests that, if intervention in the major currencies is effective at all through either of the traditional channels of influence, it will in future be effective primarily through the signalling channel, particularly if it is internationally concerted.[39] Another argument for the relatively lesser importance of the portfolio balance channel is that the typical size of intervention operations is a very tiny fraction of total foreign exchange market turnover.[40] On the other hand, it is perhaps misleading to compare the scale of official intervention to market turnover, since turnover relates to *gross* market activity, whereas it may be more relevant to compare the actual or desired *net* change in traders' end-of-day stock positions. This would certainly be much smaller than overall turnover but, unfortunately, we have no measure of it.

[39] The view that intervention is most effective through the signalling channel and when it is internationally concerted also appears to be a widely held view of policy makers and influential policy advisors. For example, at a press conference on September 19, 2000, held at the annual meetings of the IMF and World Bank, Michael Mussa said the following of official intervention: "It does tend to be significantly more effective when that intervention is coordinated among the major countries and when those countries, in effect, send the signal that it is their joint judgment that markets have taken exchange rates substantially away from fundamentals and that some correction is warranted. I think it also tends to be significantly more effective when there is some signal that monetary policy in one or more of the major areas is likely to be supportive of the intervention."

[40] Writing in the early 1990s, Dominguez and Frankel (1993a, pp. 88–89) argue that, at $200 million dollars per day, the typical intervention operation is dwarfed by the worldwide volume of trading of some $1,000 billion.

If, however, the signalling channel is taken seriously, then an important "secrecy puzzle" emerges: many actual intervention operations in the foreign exchange market are secret. Given that the signalling channel is expected to work through altering the expectations of other market agents through policy announcements by monetary authorities, this is something of a puzzle which has not yet been adequately resolved in the literature. We conjectured above that further analysis of second-generation currency crisis models may ultimately shed some light on this puzzle, in that secrecy may reflect an attempt by the authorities to affect the exchange rate through the portfolio balance channel without triggering a self-fulfilling attack on the currency. Given our conclusion that the portfolio balance channel is likely to be of less importance than the signalling channel and is likely to further diminish in importance in the future, however, this raises the issue of whether or not major monetary authorities are in fact using the intervention tool optimally. Further work on this issue is clearly required.

Finally, it is perhaps worth mentioning a third possible channel of influence for intervention which has, to date, received very little attention in the literature. This is through its role in remedying a coordination failure in the foreign exchange market. One way to think about this is as follows. First, the foreign exchange market may be subject to irrational speculative bubbles brought about by important noneconomic factors such as chartist or technical analysis which are known to have a significant effect on the market and which may impart swift movements of the exchange rate away from the level consistent with the underlying economic fundamentals (Frankel and Kenneth Froot 1990; Taylor and Allen 1992). Once the exchange rate has moved a long way away from the fundamental equilibrium, it may be very hard for individual market agents to act to bring about a reversion of the exchange rate, even though they may strongly believe it to be misaligned, because of a coordination failure. If all of the "smart money" traders were to act simultaneously so as to sell the currency which is overvalued according to the economic fundamentals, then the bubble would be pricked. In practice, once the exchange rate gets stuck into a trend—perhaps because of the widespread use of trend-following trading rules (Taylor and Allen 1992)—it takes a great deal of courage for an individual trader to attempt to buck the market. Publicly announced intervention operations can here be seen as fulfilling a coordinating role in that they may organize the "smart money" to enter the market at the same time. This route for the effectiveness of intervention might be termed the "coordination channel." The mid-1980s dollar overvaluation provides a clear case study of the coordination channel: contemporary commentaries reveal a clear consensus in the dollar overvaluation yet it apparently took the publicly announced Plaza Agreement of the G5 countries to successfully puncture the bubble.

The coordination channel is implicit in Dominguez and Frankel's (1993a) discussion of intervention, and belief in its importance appears to form an important part of policy makers' views on intervention (see e.g. Sushil Wadhwani 2000; Stephen Cecchetti, Hans Genberg, John Lipsky, and Wadhwani 2000). Nevertheless, it has received scant attention in the academic literature to date. In our view, further theoretical and empirical work on the coordination channel is likely to be a very important avenue for future research in this area.

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