The foreign exchange market interventions of the European Central Bank*

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1. The setting

Monetary authorities often try to manage exchange rates in an attempt to cope with the 'open-economy trilemma' which reflects the impossibility to achieve free cross-border capital flows, exchange rate flexibility, and monetar autonomy simultaneously.[1] Active exchange rate management is usually implemented by conducting occasional foreign exchange market interventions or by constraining spot rates to evolve within explicit bands of fluctuation. For example, even after the Bretton Woods System had broken down in 1973 and a system of floating exchange rates had been established, exchange rates were not determined by market forces alone but also by actual or anticipated intervention activities of monetary authorities. The so-called Plaza Communiqué agreed upon by the G-5 central bank governors and finance ministers on September 22, 1985 and the Louvre Accord proclaimed at a G-7 summit held in Paris on February 22, 1987 are examples for political events marking attempts to implement ex-

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[1] See, for example, Obstfeld and Taylor (1998).

change rate systems characterized by occasional interventions. An example for a policy regime aiming at invoking an explicit exchange rate target zone is the former European Monetary System.

Confronted with a significant and lasting devaluation pressure on the euro in the fall of 2000, the European Central Bank (ECB) also tried to influence the dynamics of the exchange rate through foreign exchange market interventions. On September 14, 2000, representatives of the ECB informed the public that the ECB would sell the equivalence of 2.5 billion euro of interest revenues from foreign assets denominated in US dollars as well as Japanese yen "in order to maintain the structure and risk profile of the ECB's balance as it was at the beginning of 1999" (ECB 2000b). Being concerned about a strong US dollar reaching a new historical high against the euro, the ECB intervened again in the foreign exchange market on September 22, 2000. This intervention was coordinated with the Federal Reserve, the Bank of Canada, the Bank of Japan, and the Bank of England. Further interventions with the intention to support the external stability of the euro were initiated solely by the ECB on November 3, November 6, and November 9, 2000.

In this paper, we analyze the effectiveness of the foreign exchange market interventions conducted by the ECB. To set the stage for the empirical analysis, we discuss in Section 2 different theoretical models that describe how interventions may influence exchange rate dynamics. Section 3 reviews results reported in recent contributions to the empirical literature on the effectiveness of central bank interventions. In Section 4, we analyze the effectiveness of the foreign exchange market interventions of the ECB. To this end, we use intradaily exchange rate data to shed light on the short-term effects of the interventions on the dynamics of the spot US dollar/euro exchange rate. We also estimate the effect of the interventions on the volatility of exchange rate returns. In addition, we use an event study methodology and daily exchange rate data to compare the short-term effects of the interventions with their medium-term effectiveness. In Section 5, we summarize the main findings of our empirical research and offer some concluding remarks.

2. The impact of sterilized foreign exchange market interventions on exchange rate dynamics: the theoretical background

Central bank interventions in foreign exchange markets can be defined as sales or purchases of foreign currency by the monetary authorities of a country conducted with the intention to influence the future path of the exchange rate (see Baillie, Humpage and Osterberg 2000 and Schwartz 2000). It is common practice among central banks to sterilize the impact of foreign exchange market interventions on the monetary base. Sterilization is achieved by taking measures which help to neutralize the expansionary or contractionary effects of interventions.[2] Given that the impact of interventions on domestic money supply is typically neutralized, the question arises how sterilized interventions might affect exchange rates. In the academic literature, three main models have been suggested that can be used to describe how sterilized central bank interventions may influence the pricing of foreign exchange: the so-called *signaling model*, the *portfolio balance model* and the *noise trader model*. In addition, recent studies have stressed that the *market microstructure* of foreign exchange markets may be an important determinant of the effectiveness of central banks' foreign exchange market interventions.

A core assumption of the *signaling model* is that the exchange rate is an asset price and that foreign exchange markets are competitive and informationally efficient in the sense that all information relevant for the pricing of foreign exchange is instantaneously embedded in the current realization of the exchange rate. In such a setting, the current exchange rate embodies market participants' expectations regarding the entire integral of discounted future fundamentals. In structural macroeconomic models of exchange rate determination, these fundamentals mainly include relative money supplies, interest rate differentials, output differentials and current account balances. Given the assumptions mentioned above, sterilized interventions affect exchange rates if a central bank succeeds in influencing economic

[2] For studies addressing the question whether central banks tended to sterilize the impact of interventions on money supply, see Obstfeld (1983), Neumann (1984), Mastropasqua, Micossi and Rinaldi (1988), Gaiotti, Giucaa and Micossi (1989), von Hagen (1989) as well as Neumann and von Hagen (1992).

agents' expectations regarding the future evolution of these macroeconomic fundamentals (Mussa 1981).

Since a central assumption of the signaling model is that market participants utilize all publicly available information when pricing foreign exchange, a sterilized intervention can affect the exchange rate only if the central bank has an informational advantage over the market participants. This asymmetric distribution of information implies that central banks have access to information which are not (or only with a certain time-lag) available to the market participants. By intervening in the foreign exchange market, central banks can reveal this information at least partially. Market participants can then process the new information and adjust their expectations regarding the future evolution of fundamentals, which, in turn, implies that the intervention results in a change of the exchange rate.[3]

An important drawback of the signaling model is that it can only be employed to discuss potential exchange rate movements in the aftermath of a publicly known sterilized intervention (Edison 1993). Thus, the signaling model predicts that central banks that aim at increasing the effectiveness of sterilized interventions should always inform market participants about their sales and purchases of foreign currency. However, as pointed out by Dominguez and Frankel (1993a), central banks also carried out secret interventions.[4] Neither does the signaling model provide an answer to the question why monetary authorities use secret interventions to target spot rates nor does the model explain how secret interventions might affect the exchange rate.

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[3] In this context, the question arises why a central bank should resort to interventions in the foreign exchange market rather than to a transparent communication and information policy to disseminate its superior information. To resolve this problem, Mussa (1981) argued that central banks may be beleaguered by credibility problems which can only be resolved by resorting to monetary policy actions like interventions. Such actions underscore that monetary authorities follow a policy of "putting their money where their mouth is" and stand ready to act on the intervention signal.

[4] Dominguez and Frankel (1993a) show that approximately 80% of the interventions of the Fed were reported in the financial press. They argue further that, with respect to the interventions conducted by the Bundesbank, it is not necessary to distinguish between publicly known and secret interventions since the majority of them were carried out in a way so that market participants were aware that the central bank participated in FX trading. For analyses regarding the accuracy of the intervention reports in the financial press, see Osterberg and Wetmore Humes (1993) and Klein (1993).

The *portfolio balance model* describes another channel through which interventions may influence exchange rate dynamics.[5] The central assumption underlying this model is that market participants regard bonds denominated in domestic currency and bonds denominated in foreign currency as imperfect substitutes. This assumption implies that a sterilized intervention can affect the exchange rate because it alters the relative supply of domestic and foreign bonds and, thus, requires an adjustment of the risk premium to balance demand and supply on international bond markets. For example, through buying European bonds for foreign bonds (e.g., US bonds) the European central bank can alter the relative supply of domestic and foreign currency denominated assets. If economic agents are risk averse, so that domestic and foreign assets are imperfect substitutes, this sterilized intervention requires that market participants adjust the structure of their portfolios according to the shift in the relative supply of bonds which has taken place. This portfolio reallocation gives rise to wealth and substitution effects. In the above example of a sterilized ECB intervention (purchase of European bonds/sale of US bonds), these wealth and substitution effects imply that financial market equilibrium is restored by a decline in the risk premium paid for holding euro-denominated assets. As this risk premium effect of the sterilized intervention indicates that the relative attractiveness of European bonds increases, the exchange rate, defined as a unit of domestic currency in terms of foreign currency (US dollar/euro), tends to rise. Thus, the portfolio reshuffling of investors implies that sterilized central bank interventions can affect exchange rates.

Another channel through which sterilized central bank interventions may affect exchange rates has been discussed in the strand of the literature concerned with the *noise trader model* of exchange rate determination. Noise traders are financial market participants whose demand for a financial security is not influenced by economic fundamentals alone (Black 1986). Instead, noise traders employ techniques provided by, for example, technical chart analysis to extract buy and

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[5] For early contributions to the strand of the literature using portfolio models to analyze the effectiveness of central bank foreign exchange market interventions, see, for example, Tryon (1983), Boothe *et al.* (1985), Loopesko (1984) and Dominguez and Frankel (1993b). Branson and Henderson (1985) provide a comprehensive discussion of issues related to the modeling of asset markets with portfolio models.

sell signals from historical exchange rate trajectories. In noise trader models of exchange rate determination it is assumed that, at least in the short and medium run, the group of noise traders influences the dynamics of the exchange rate so that the price of this asset can depart from its fundamental value. The empirical relevance of the noise trader model has been confirmed in a number of studies of the structure of foreign exchange markets.[6]

The so-called fundamentalists, who – in contrast to noise traders – resort to economic fundamentals to form exchange rate expectations, play an important role in every noise trader model of exchange rate determination. Fundamentalists recognize that a substantial proportion of short-run exchange rate fluctuations is caused by the behavior of noise traders rather than by changes in economic fundamentals. Thus, fundamentalists utilize the same information set and the same exchange rate model as the central bank and their exchange rate forecasts are more accurate than those of the noise traders. However, their relatively high degree of risk-aversion implies that they do not take positions which exploit and eventually eliminate a deviation of the actual exchange rate from its fundamental value. As demonstrated by DeLong *et al.* (1990 and 1991), in such a situation the mere presence of noise traders creates a so-called noise trader risk. As the major proportion of this risk is borne by noise traders, these traders earn a higher expected return than fundamentalists and are, thus, not driven out of the market. In such an environment, central banks, which are not constrained by liquidity considerations and which typically have a relatively long investment horizon, can use sterilized interventions to initiate stabilizing foreign exchange market speculation. To a certain extent, the central bank thus acts as a risk-neutral fundamentalist who tries to exploit the deviations of the exchange rate from its intrinsic value caused by the trading behavior of chartists (see, e.g., Hung 1997 or Murray, Zelmer and Williamson 1990). If the central bank succeeds in affecting the exchange rate and noise traders respond to these changes, the price impact of noise traders' orders may then account for persistent exchange rate effects of sterilized foreign ex-

[6] See e.g. Allen and Taylor (1990, 1992) and Frankel and Froot (1990). For recent empirical evidence, see Menkhoff (1997, 1998), Lui and Mole (1998), Cheung and Chinn (1999a, 1999b), Cheung and Wong (2000) and Oberlechner (2001).

change market interventions.[7] Thus, in a market in which noise traders participate in the trading process, central banks can try to influence the position-taking of trend-chasing noise traders by using interventions to establish or to break short-run price trends.

Recently, the findings documented in papers devoted to the analysis of the *microstructure of financial markets* have been exploited to describe the effects of sterilized foreign exchange market interventions. For example, Bhattacharya and Weller (1997) use a market microstructure model to analyze why central banks – in contrast to the predictions of the signaling model – often try to influence exchange rates by means of secret rather than publicly known interventions. To construct their model, they assume that a central bank, which has inside information about its preferred exchange rate target, interacts with risk-averse rational market participants on foreign exchange markets. In such an environment, the inside information of the central bank are revealed to the market by an intervention. An important result of the analysis of Bhattacharya and Weller (1997) is that a central bank that wants to increase the effectiveness of its interventions should not inform the public about the volume of its interventions. A further result of their theoretical analysis is that a central bank should in certain situations publicly announce its preferred exchange rate target. Further, they use their model to demonstrate that under certain parameter constellations the exchange rate exhibits a perverse reaction in response to an intervention, i.e., in some situations a purchase (sale) of foreign exchange by the central bank entails an appreciation (a depreciation) of the domestic currency.

A similar asymmetric information model featuring central bank foreign exchange market interventions has been developed by Vitale (1999). He uses the modeling strategy suggested by Bhattacharya and Weller (1997) to develop a model in which the central bank is assumed to resort to interventions in the foreign exchange market in order to establish a central parity for the exchange rate. He further assumes that market participants in the foreign exchange market collect information on buy and sell orders to form and to revise their expectations regarding the fundamental value of the exchange rate. Given

[7] Also note that a central bank that intends to exploit the noise trader channel in order to influence exchange rates using sterilized interventions needs to know the reaction function of the noise trader (Hung 1997 and Aguilar and Nydahl 2000).

these assumptions, he shows that the central bank can try to influence economic agents' exchange rate expectations by placing orders to carry out secret sterilized interventions.

Naranjo and Nimalendran (2000) also use a framework with asymmetric information to develop a market microstructure model in which central banks conduct foreign exchange market interventions. Building on the work of Bossaerts and Hillion (1991), they focus on the effects of interventions on the bid-ask spread in the spot market for foreign exchange and argue that unanticipated interventions normally result in a widening of the bid-ask spread. The economic intuition behind this result is that in their asymmetric information model market participants use the difference between the bid and the ask price of a financial security to neutralize the costs which arise whenever transactions with better informed agents are carried out. The empirical results reported in the paper confirm the predictions of the theoretical model that unanticipated central bank interventions in foreign exchange markets and the magnitude of the bid-ask spread should be positively correlated.

Evans and Lyons (2000) analyze central bank interventions in a market microstructure model featuring both asymmetric information between the central bank and the public and asymmetric information between private speculators. Evans and Lyons also assume that domestic and foreign currency denominated assets are imperfect substitutes. As in the theoretical models described above, the exchange rates moves in their model whenever an order and, thus, an additional piece of information arrives in the market. This is the information effect of an order. Moreover, the assumption that domestic and foreign currency denominated assets are imperfect substitutes implies that portfolio balance effects, which are brought about by price adjustments, are also important determinants of the price effect of orders. The authors use high-frequency data to test their theoretical model and find that both the information effect and the portfolio balance effect should be taken into consideration when the effects of central bank interventions in the foreign exchange market are analyzed.

3. The empirical evidence on the effectiveness of central banks' foreign exchange market interventions

In the literature on the effectiveness of foreign exchange market interventions the debate about the question whether such operations tend to stabilize or destabilize exchange rates or do not affect exchange rates at all has not yet been settled. Most authors contributing to this debate analyze the effectiveness of interventions in terms of either their effect on the level of exchange rates or their effect on the volatility of exchange rates.[8]

3.1. *Evidence on the impact of central banks' interventions on exchange rate levels*

A study of Dominguez and Frankel (1993a) is one of the first empirical investigations in which daily data on central bank interventions are used to assess the effectiveness of foreign exchange market interventions of central banks. Dominguez and Frankel apply a regression approach to analyze the impact of the foreign exchange market operations conducted by the US Federal Open Market Committee and by the Deutsche Bundesbank on exchange rates.[9] In their study, they use the portfolio balance model of exchange rate determination to study whether sterilized interventions affected exchange rates. The portfolio balance model relies on the assumptions that domestic and foreign assets are imperfect substitutes and that investors take expected market returns into account when constructing globally diversified portfolios. An important determinant of expected market returns are expected rates of change of exchange rates. An interesting feature of the study conducted by Dominguez and Frankel is that they use survey data to construct a time series that serves as a proxy for market participants' exchange rate expectations. Their empirical results suggest

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[8] In this section, we survey results reported in recent studies. A survey of earlier research on the effectiveness of foreign exchange market interventions of central banks can be found in Edison (1993). See also Almekinders (1995, chapter 6).

[9] In addition, they analyze the interventions of the Swiss National Bank, which is an example of a central bank of a small open economy.

that the Federal Reserve and the Bundesbank interventions which took place during the mid-Eighties indeed influenced exchange rates.[10]

Eijffinger and Gruijters (1992) provide additional evidence on the effectiveness of US and German interventions. Utilizing daily data covering the period from February 1985 to August 1988 to assess the impact of foreign exchange market interventions on the level of the exchange rate, they demonstrate that central bank interventions were rather ineffective in this respect. Furthermore, they provide evidence that the coordination of interventions tended to influence the effectiveness of this policy instrument positively. As interventions frequently occurred over a series of days, they also test the hypothesis that the first intervention in a series may be more effective than subsequent ones. Eijffinger and Gruijters find some evidence supporting this hypothesis when using data on German interventions but not when using data on US interventions.

A study arguing in favor of the effectiveness of G-3 foreign exchange market interventions is presented by Catte, Galli and Rebecchini (1992). They document that episodes during which interventions took place were often periods during which turning points of the US dollar/Deutsche Mark exchange rate could be observed. Though it is tempting to conclude from this observation that G-3 central banks effectively helped to break trends in the US dollar/Deutsche Mark exchange rate, Weber (1996) emphasizes that it is also possible to identify a substantial number of turning points in the path of this exchange rate which do not fall into periods characterized by central bank interventions. To analyze the impact of interventions on the level of exchange rates, Weber (1996) estimates a vector autoregression and finds that the foreign exchange market interventions of the G-3 observed during the period 1985-92 were ineffective in the sense that they did not help to stabilize exchange rates in the long-run.

Recent evidence presented by Humpage (1999) suggests that interventions conducted by the US central bank during the Louvre period effectively smoothed the US dollar/Deutsche Mark and the US dollar/yen exchange rates. Using a binary dependent variable model, he reports that the probability of a successful US intervention was

[10] Additional evidence on the effectiveness of interventions can be found in a related study by Dominguez and Frankel (1993b).

higher whenever the Federal Open Market Committee coordinated foreign exchange market operations with other major central banks. According to the binary success criterion which is applied in his study, foreign exchange market interventions are identified as effective if a sale (a purchase) of foreign currency was either followed by an appreciation (a depreciation) or a smaller rate of depreciation (appreciation) of the domestic currency.

In a recently published work, Fatum (2000) uses an event study technique to assess the effectiveness of the foreign exchange market interventions of the US central bank and the Bundesbank. He uses intervention data for a period ranging from September 1985 to December 1995. Fatum rates an intervention as effective if the central banks *i*) succeeded in moving the exchange rate in the direction intended by the foreign exchange market operation, or *ii*) succeeded in weakening an exchange rate trend prevailing before the intervention.[11] The results he reports in his study suggest that the interventions conducted by the US central bank and by the Bundesbank in the Deutsche Mark/US dollar market were effective. In particular, he finds that a coordination of the foreign exchange market interventions tended to influence the effectiveness of interventions positively.[12]

Kaminsky and Lewis (1996) also report that interventions affected exchange rates. The empirical research strategy adopted by these authors is particularly suited to test the hypotheses that sterilized interventions mainly affect the exchange rate through the signaling channel. The signaling model implies that interventions allow economic agents to gain information regarding the future stance of monetary policy. Kaminsky and Lewis study the effectiveness of the interventions conducted by the US central bank in the US dollar/Deutsche Mark and the US dollar/yen market during a period beginning in 1985 and ending in 1990. In contrast to the predictions of the signaling model, the authors find that US interventions conveyed information that future monetary policy moves in the opposite direc-

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[11] When using an exchange rate trend to trace out the effectiveness of central bank interventions it is also necessary to discriminate between "blowing-with-the-wind " and "leaning-against-the-wind" interventions in order to avoid biased results (Fatum 2000, pp. 9-10).

[12] As regards this latter finding, it should be taken into account that "about one half of the studies find that coordinated intervention is more effective than non-coordinated intervention, the other half find no special significance to the difference between regimes" (Edison 1993, p. 35).

tion suggested by the sign of the intervention. Consequently, they also find that interventions tended to induce an exchange rate change in the opposite direction indicated by the sign of the intervention.[13]

3.2. *Do interventions affect exchange rate volatility?*

Bonser-Neal and Tanner (1996) use volatilities implicit in foreign currency options to analyze whether interventions reduced market participants' expected future volatility of exchange rates. Controlling for the influence of macroeconomic announcements, they find that both US and Bundesbank interventions conducted during the period 1985-91 in the US dollar/Deutsche Mark and US dollar/yen market either did not affect or contributed to inflate volatilities implicit in foreign currency.

Madura and Tucker (1991) also use volatilities implicit in foreign currency options to study the impact of interventions on exchange rate volatility. They find that interventions conducted during the years following the Louvre agreement did not dampen exchange rate volatility. Their findings thus corroborate the results documented by Bonser-Neal and Tanner (1996).

Baillie and Osterberg (1997) resort to a consumption based intertemporal asset pricing model to argue that central banks' foreign exchange market interventions may affect the risk-premium on foreign exchange.[14] To perform empirical tests of the predictions of their model, they use daily data on the interventions conducted by the US central bank, the Bundesbank and the Bank of Japan during the Plaza and the Louvre period. Estimating a GARCH model to depict the evolution of the risk premium over time, they report that, in particular, dollar purchases of the Federal Reserve Bank had a significant positive impact on the size of the Deutsche Mark/US dollar and the yen/US dollar risk premium. The empirical evidence they present also suggests that the risk premium did not react significantly to a coordination of interventions. All in all, Baillie and Osterberg conclude

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[13] For additional evidence on the signaling model of central bank interventions, see Ghosh (1992), Fatum and Hutchison (1999) and the references cited therein.

[14] In their model, a cash-in-advance constraint implies that central banks' holdings of foreign currency reduce the amount of that currency available for purchases in the goods market.

that the empirical evidence they present in their paper supports the notion that interventions tended to increase rather than to decrease the variability of exchange rates.

Taking a noise trader approach, Hung (1997) points out that the impact of interventions on exchange rate volatility may have changed over time. Using data on US interventions in the US dollar/Deutsche Mark and in the US dollar/yen market covering the period April 1985-December 1986 as well as the Louvre period ranging from March 1987 to December 1989, she finds that interventions during the mid-eighties, which were intended to depreciate the strong US dollar, tended to decrease volatility. In contrast, the interventions conducted in the Louvre period, that were aimed at stabilizing exchange rates around prevailing levels, raised exchange rate volatility. Hung motivates her results economically by resorting to arguments put forward by the noise trader literature. According to her line of argumentation, volatility decreasing interventions serve to foster the demand for foreign currency of noise traders who use the trend or moving average of exchange rates to derive investment signals. In contrast, volatility increasing interventions enhance trading uncertainty and contribute to make such trend-based trading strategies less appealing to foreign exchange market participants. These arguments imply that even interventions which raise exchange rate volatility can be viewed as effective as long as *i*) these interventions are intended to stabilize exchange rates around a prevailing fundamental level and *ii*) noise traders drive a wedge between the spot rate and this fundamental level.

Dominguez (1998) uses a GARCH model and volatilities implicit in foreign currency options to examine the impact of central banks' interventions on the level and the volatility of exchange rates empirically.[15] Her empirical study covers the period 1987-94. She examines the effectiveness of the interventions conducted by the Fed, the Bundesbank and the Bank of Japan. Although the results differ across central banks and sub-periods, defined to account for the Plaza Communiqué and the Louvre Accord, the general impression which emerges from her study is that interventions tended to increase ex-

[15] Fatum and Hutchison (1999) employ a similar technique to assess the informational role of US foreign exchange market interventions as a signal of future monetary policy. They estimate the effect of interventions on federal funds futures price changes. In their analysis, the coefficients in the conditional variance equation are significant and positive.

change rate volatility. In addition, the positive impact of central banks' foreign exchange market interventions on exchange rate volatility can be attributed to the presence of a central bank rather than to the volume of an intervention. Interestingly, secret interventions tended to exert a particularly strong increasing impact on exchange rate volatility.

In a recent study, Aguilar and Nydahl (2000) extend the framework of analysis employed by Dominguez (1998). They study the impact of the interventions of the Swedish central bank on the level and on the volatility of the Swedish krona/US dollar and the Swedish krona/Deutsche Mark exchange rate. The sample period analyzed in this study covers a period beginning in 1993 and ending in 1996. Aguilar and Nydahl set up a multivariate GARCH framework which renders it possible to model the impact of interventions on the level and the conditional volatility of exchange rates within a unified framework. The results from estimating this multivariate GARCH model as well as the findings of supplementary exercises relying on options implied volatilities provide only weak evidence that the interventions of the Swedish central bank influenced exchange rate volatility. When they reestimate the model for certain sub-periods, they find that interventions tended to dampen (increase) the volatility of the krona/US dollar exchange rate in 1995 (in 1993). In addition, weak empirical evidence for an increasing impact of interventions on the krona/Deutsche Mark exchange rate volatility is found for the year 1994.

4. The effectiveness of the intervention of the ECB

In this part of the paper, we analyze the effects of the interventions conducted by the ECB in September and November 2000 on the level and the volatility of the US dollar/euro. To determine the immediate effects of the intervention, we utilize intraday US dollar/euro exchange rate data. Our primary data set consists of ten-minute bid and ask prices for the US dollar/euro exchange rate reported by Deutsche Bank for the Frankfurt inter-bank market. The sample period ranges from September 1, 2000 to November 30, 2000. We calculate the period t US dollar/euro exchange rate as the average of the bid and

ask price observed in period *t*.[16] We also use daily exchange rate data to shed some light on the medium-term and longer-term effectiveness of the interventions of the ECB.

4.1. *What do exchange rate plots tell us about the intervention effects?*

It is instructive to begin the empirical analysis with a graphical examination of the US dollar/euro exchange rate path on the intervention days as well as on the day before and the day after an intervention day. To this end, Figures 1a-1e depict the dynamic evolution of the exchange rate on a 10-minute basis. The exchange rate is shown in index form with a value of unity representing the exchange rate at 6:00 a.m. on the day before an intervention.

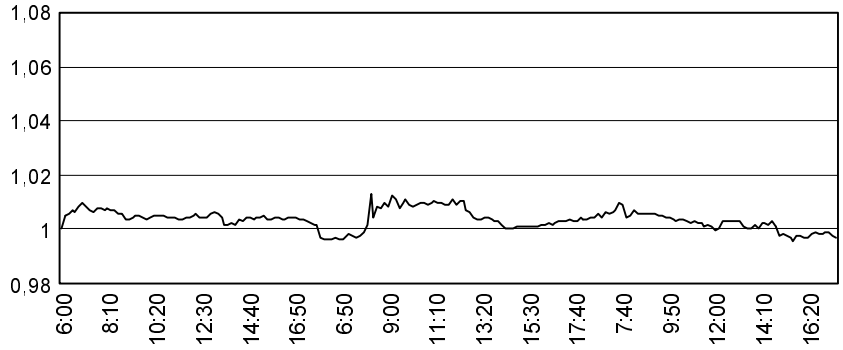
Figure 1a depicts the impact of sales of interest income on foreign exchange reserves against euros by the ECB on September 14, 2000.[17] The graph demonstrates that this policy action had only a very

FIGURES 1

INTRA-DAY EFFECTS OF THE INTERVENTIONS OF THE ECB ON THE LEVEL OF THE US DOLLAR/EUR SPOT RATE

FIGURE 1A

INTERVENTION ON SEPTEMBER 14, 2000

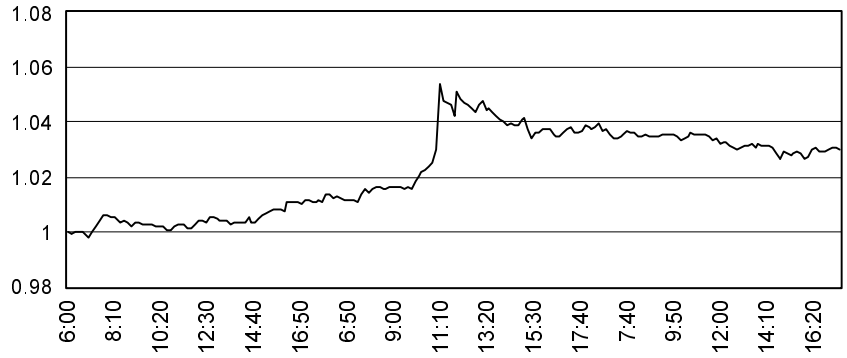


[16] If a bid or ask quote is missing, we take the average of the preceding and the following bid and ask quotes to close this gap.

[17] At the beginning of 1999, the ECB held foreign currency reserves equivalent to euro 39.5 billion. These reserves increased between early 1999 and mid-2000 due to interest income by about euro 2.5 billion. See ECB (2000b).

FIGURE 1B

INTERVENTION ON SEPTEMBER 22, 2000



moderate (if any) impact on the evolution of the US dollar/euro exchange rate. Because the ECB did not label this sale of foreign exchange reserves explicitly as an intervention, it is possible to argue that the tranquil conditions prevailing on the foreign exchange market on September 14 were in line with the interest of the ECB. According to this argument, the ECB's action can be rated as effective. Yet, one should also take into account that the ECB started its sales of interest income at a time when the euro was extremely weak as compared with the US dollar. Hence, a critical observer might be tempted to object that the timing of the sale of interest income was influenced by the developments on the foreign exchange market. The theoretical underpinning of this line of argumentation could be seen in the portfolio balance model which stipulates that selling interest income can have, in principle, the same effect on exchange rates as a regular central bank intervention. Hence, if the main objective of the sales of interest income was to support the external stability of the euro rather than to restructure the ECB's balance sheet, the empirical evidence presented in Figure 1a strongly suggests that this operation was not effective in breaking the depreciation trend of the euro.

As depicted in Figure 1b, a noticeable response of the exchange rate to the intervention conducted of the ECB occurred on September 22, 2000. This intervention was carried out by the ECB jointly with the Federal Reserve, the Bank of Japan, the Bank of England and the

Bank of Canada. It can, thus, be classified as a coordinated intervention. In addition, the ECB left no doubt that the euro purchases were conducted this time with the objective to strengthen the common European currency. Figure 1b shows that this intervention of the ECB and its partner central banks had a major short-term impact on the foreign exchange market. The intervention began at 11:11 a.m. (Fed 2000). Immediately following the intervention, the exchange rate firmed from 0.8745 US dollar/euro at 11:10 a.m. to 0.8944 US dollar/euro at 11:20 a.m., which corresponds to an appreciation by 2.28%. However, on the following trading day, the exchange rate exhibited a tendency to return to its pre-intervention level. Thus, while the immediate response of the exchange rate to the news of a coordinated foreign exchange market intervention was significant, the intervention did not exert a persistent effect on the level of the exchange rate.[18]

A further interesting fact revealed by Figure 1b is that the euro exhibited a slight tendency to appreciate even before the news of the intervention reached the market. On the one hand, this result may reflect the time-lag between the beginning of the intervention and the diffusion of the information that central bank participated in foreign exchange trading. On the other hand, the behavior of the exchange rate may reflect that some market participants had been aware of the intervention of the central banks even before this information was quoted by professional news providers like Reuters or Bloomberg. This latter argument can best be explained by taking into consideration the results of a recent study by Peiers (1997). She analyzes the microstructure of the foreign exchange market and uses intra-day data to determine the impact of Bundesbank interventions on the price formation process. The objective of her study is to show how the information of a central bank intervention spreads within the banking sector and how it is processed by different market participants. Applying causality tests, she shows that some market participants had an

[18] Thus, confronting the immediate exchange rate effect with the effect over the following days shows that there was an overshooting in the response of the spot rate following the arrival of intervention news. This kind of overshooting behavior of the exchange rate due to a central bank intervention has also been described by Dominguez (1999, p. 21), who labels this kind of effect with the term "intra-daily mean reversion".

informational advantage over their competitors in the sense that they were aware of the intervention even before the central bank informed the public about its activities. She finds that in Germany especially the Deutsche Bank seemed to have been better informed about the actions taken by the Bundesbank than other market participants. Peiers argues that due to the fact that the Deutsche Bank was a market maker in the US dollar/Deutsche Mark market, the Bundesbank used the Deutsche Bank to conduct its interventions.[19] Her finding suggests that the Deutsche Bank was able to take the right position in the market roughly 60 minutes before the information regarding a Bundesbank intervention was published.[20]

With respect to the coordinated intervention that took place on September 22, some commentators suspected that some American banks had obtained the information that central banks stood ready to step into the market some hours before the central banks started purchasing euros.[21] It was stated that Citibank, a leading market maker in the US dollar/euro market, heavily sold dollars in the morning of the intervention day. The link between the Citibank and the Federal Reserve was seen in the fact that Robert Rubin, who was co-chairman of Citigroup at the time of the intervention, had formerly been the Treasury Secretary.

Figures 1c, 1d and 1e depict the dynamics of the exchange rate around three further interventions of the ECB. Neither on November 3 nor on November 6 or November 9, 2000, an effect of the interventions lasting longer than approximately one day was achieved. Also note that the intervention which took place on November 6 is special insofar as the ECB already had stepped into the foreign exchange market on November 3, the previous trading day. However, even though the ECB intervened on successive trading days, the exchange rate path shown in the Figures 1 indicate that the depreciation

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[19] Neely (2000) finds, for a panel of central banks, that monetary authorities often use domestic commercial banks to conduct interventions. Thus, it is reasonable to conjecture that some commercial banks are able to achieve an informational advantage over other market participants with respect to the timing of foreign exchange market interventions of central banks.

[20] Chang and Taylor (1998) report that the volatility of the yen/US dollar-exchange rate increased significantly one hour before the news of a central bank intervention was broadcast via Reuters.

[21] See, e.g., *Frankfurter Allgemeine Zeitung* (2000, p. 31).

of the euro tended to continue on the trading days following the interventions. Hence, we conclude that these interventions had no significant persistent effect on the path of the US dollar/euro exchange rate and can, thus, not be classified as effective.

FIGURE 1C

INTERVENTION ON NOVEMBER 3, 2000

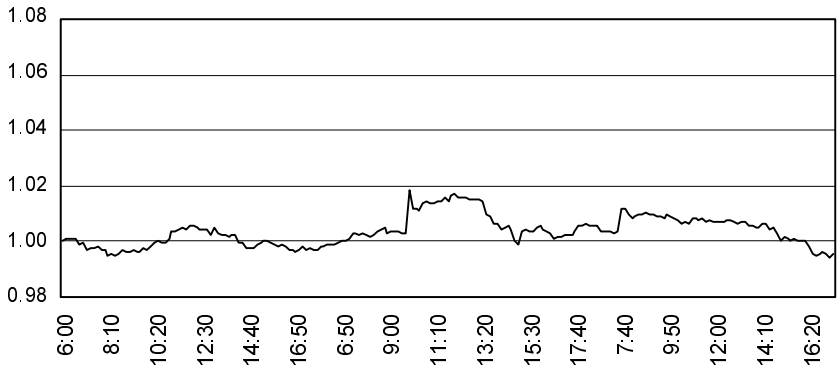
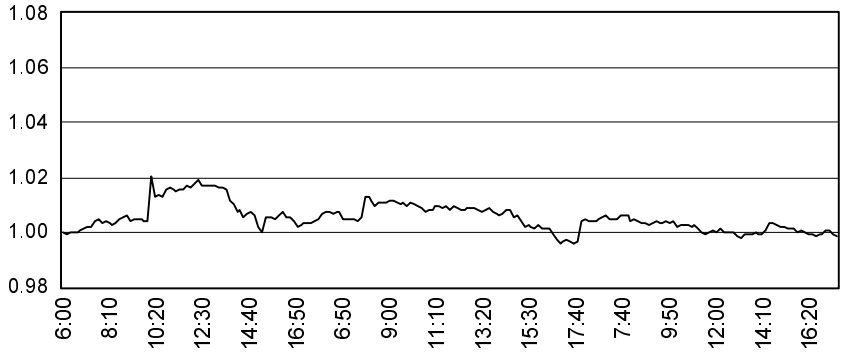


FIGURE 1D

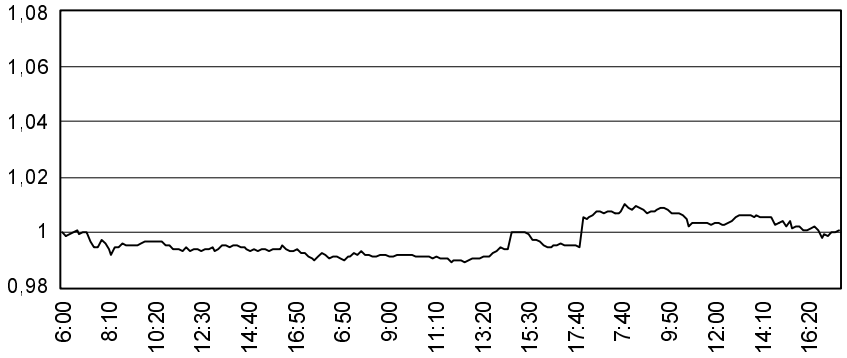
INTERVENTION ON NOVEMBER 6, 2000



In contrast to the intervention conducted on September 22, the Federal Reserve and other major central banks did not participate in the foreign exchange market interventions carried out by the ECB in November 2000. Taking this fact into consideration, Figures 1a-1e suggest that central banks interventions tend to exert a stronger impact on the exchange rate whenever monetary authorities coordinate

FIGURE 1E

INTERVENTION ON NOVEMBER 9, 2000



their interventions. Thus, as the unilateral ECB interventions had only a minor effect on the exchange rate path, one might be tempted to conclude that the ECB should back its actions by getting support from other major central banks. The conclusion that coordinated intervention activities have a stronger impact on the exchange rate than unilateral interventions is in the line with the empirical findings of Eijffinger and Gruijters (1992), Humpage (1999, 2000) and Fatum (2000). The results reported by these authors suggest that, according to the signaling theory, coordinated interventions have a relatively stronger impact on the expectations of foreign exchange market participants and, therefore, on the exchange itself because coordinated interventions signal that all intervening central banks share the same judgment that exchange rates are misaligned. However, such an interpretation is not supported by the results documented in other studies on the relative effectiveness of unilateral versus multilateral interventions. For example, neither Humpage (1989) nor Humpage and Osterberg (1992) find a significant difference between the effectiveness of coordinated and non-coordinated interventions. Notwithstanding the ambiguous findings documented in the existing empirical literature, we conclude from Figures 1 that the interventions carried out by the ECB exerted a stronger temporary impact on the US dollar/euro spot rate when the intervention was coordinated with other major central banks.

4.2. *A quantitative analysis of the effect of the ECB interventions on exchange rate returns*

In this section, we analyze whether the effects of the interventions of the ECB on the dynamics of the US dollar/euro exchange rate documented in Figure 1 are statistically significant. In our empirical analysis, we use ten-minute exchange rate returns for the US dollar/euro spot exchange rate. Exchange rate returns are defined as changes in the logarithm of the exchange rate E_t between time $t - 1$ and time t, $r_t \equiv \ln(E_t) - \ln(E_{t-1})$. To analyze the influence of the ECB interventions on the returns of the US dollar/euro exchange rate, we use an 'event study' approach.[22]

To this end, we construct in a first step a set of dummy variables. The notation is such that a dummy variable denoted *lead _ x* (*lag _ x*) is equal to one exactly x minutes before (after) an intervention and zero otherwise. In a second step, we use ordinary least squares (OLS) to estimate the 'event study' regression given below (see also Dominguez 1999):

$$(1) \qquad r_t = \beta_0 + \Sigma_x \beta_{lead\_x} lead\_x + \Sigma_x \beta_{lag\_x} lag\_x + \varepsilon_t$$

Here, ε_t is a disturbance term, β_0 is a constant, β_{lead_x} and β_{lag_x} are the coefficients of the various lead- and lag-dummies, respectively. Because all interventions of the ECB in 2000 consisted of selling foreign currency, an intervention policy that successfully supports the euro in the short run would imply that at least some of the estimates of the coefficients β_{lead_x} and β_{lag_x} have a positive sign.[23] To estimate equation 1, we use ten-minute US dollar/euro returns data that include only the days on which the ECB intervened in the foreign exchange market.

The estimation results are summarized in Table 1. As can be seen in the Table, the sum of the coefficients of dummy variables that are significantly different from zero implies that the interventions of

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[22] To implement the quantitative models estimated in this paper we used the software package EViews 3.1.

[23] Also note that the fact that the ECB always intervened to support the euro implies that we do not need to distinguish between interventions consisting of purchases and interventions consisting of sales of foreign currency when estimating equation 1.

TABLE 1

ECB INTERVENTIONS AND THE RETURNS
OF THE US DOLLAR/EURO EXCHANGE RATE

Dependent variable: r_t		
Variable	**Coefficient**	**t-statistic**
β_0	-0.000235	-1.744424*
lead_90	0.000479	0.480084
lead_80	2.66E-05	0.026621
lead_70	-0.000246	-0.242240
lead_60	0.001085	1.068064
lead_50	0.000802	0.803496
lead_40	0.000757	0.757669
lead_30	0.000258	0.258579
lead_20	0.001322	1.323741
lead_10	0.008734	8.745538***
lead_0	-0.002041	-2.043857**
lag_10	0.005325	5.332599***
lag_20	-0.001645	-1.647318*
lag_30	0.001237	1.238835
lag_40	6.40E-05	0.064055
lag_50	-0.000525	-0.526127
lag_60	0.001821	1.823053*
lag_70	-0.000942	-0.943287
lag_80	-8.39E-05	-0.084043
lag_90	0.000396	0.396311

Method	OLS	Number of observations	365
Adjusted R-squared	0.218852	Durbin-Watson statistic	2.12404
Sum squared residual	0.001684	F-statistic	6.35267

Notes: The Table gives the estimation results for a regression of US dollar/euro returns on a constant and various intervention dummies. The notation is such that the dummy denoted *lead*_30 (*lag*_30) assumes the value one thirty minutes before (after) an intervention. The equation was estimated over intervention days with ten-minute exchange rate returns. *,** and *** denote significance at the 10, 5 and 1% level respectively. In the case of the ECB interventions which took place on September 14, 2000 and on November 3, 6 and 9, 2000, Bloomberg quotes were used to determine the time of the day at which the news that the ECB intervened in the foreign exchange market was released. The respective news were disseminated by Bloomberg at 8:32, 10:24, 8:12 and 15:04 Greenwich Mean Time. The ECB intervention which took place on September 22, coordinated with interventions of other major central banks, began at 11:11 Greenwich Mean Time (see Fed 2000).

the ECB resulted in an immediate and statistically significant appreciation of the euro *vis-à-vis* the US dollar. In addition, the insignificance of most of the other dummy variables indicates that this effect persisted to a certain extent on the intervention day. Thus, the interventions of the ECB led to an instantaneous appreciation of the euro that was not entirely reversed during the hours following the interventions. This confirms the results of the graphical analysis contained in Section 4.1.

We now turn to the question of whether the effect of the ECB interventions on the US dollar/euro exchange rate persisted for even a longer period of time. To address this question, Table 2 contains a further quantitative assessment of the relationship between the ECB interventions and the US dollar/euro exchange rate. The Table presents the percentage change in the exchange rate on intervention days as well as on the days before and after intervention days.[24]

TABLE 2

CHANGE IN THE LEVEL OF THE EXCHANGE RATE IN THE EVENT WINDOW

	Day before intervention 6:00-18:00	Night before intervention 18:00-6:00	Intervention day 6:00-18:00	Night after intervention 18:00-6:00	Day after intervention6: 6:00-18:00
1	9/13/2000	9/13/2000 – 9/14/2000	9/14/2000	9/14/2000 – 9/15/2000	9/15/2000
	0.19%	–0.53%	0.66%	0.09%	–0.73%
2	9/21/2000	9/21/2000 – 9/22/2000	9/22/2000	9/22/2000 – 9/25/2000	9/25/2000
	1.10%	0.24%	2.27%	0.20%	–0.83%
3	11/2/2000	11/2/2000 – 11/3/2000	11/3/2000	11/3/2000 – 11/6/2000	11/6/2000
	–0.30%	0.14%	0.52%	0.20%	–1.03%
4	11/3/2000	11/3/2000 – 11/6/2000	11/6/2000	11/6/2000 – 11/7/2000	11/07/2000
	0.52%	0.20%	–1.03%	0.76%	–0.52%
5	11/8/2000	11/8/2000 – 11/9/2000	11/9/2000	11/9/2000 – 11/10/2000	11/10/2000
	–0.89%	0.17%	0.22%	1.03%	–0.41%

[24] Fatum (2000) uses a similar event study methodology to analyze the effectiveness of the intervention policy of the Fed and the Bundesbank.

The results reported in Table 2 reveal that the exchange rate showed no regular pattern on the days or during the nights before the interventions (see first and second column). The middle column of the Table highlights that in all but one case the euro appreciated on the day of the intervention. Thus the results in the fourth column of Table 2 show that the ECB was able to influence the exchange rate path of the euro in the intended direction, which reinforces the findings shown in Table 1. As already pointed out in the discussion of Figure 1, the coordinated intervention on September 22, 2000 had the strongest impact on the US dollar/euro exchange rate. The euro appreciated by 2.27% on this intervention day. The Table further shows that in each of the five cases of foreign exchange market intervention, the euro depreciated on the day following the intervention (see last column in Table 2). Hence, this strongly suggests that the effect of the interventions of the ECB on the US dollar/euro exchange rate was not persistent but was basically reversed on the trading day following an intervention.

To shed additional light on the effects of ECB's interventions on exchange rate returns, we apply *t*-tests and Wilcoxon-Mann-Whitney rank tests. These tests allow the hypothesis that the exchange rate returns of two different categories of days are not significantly different from each other to be tested.[25] More specifically, we compare the returns on days without intervention activities with the returns on interventions days, on days before intervention days, and on days after intervention days.[26] Table 3 reports the results of these tests. The test results indicate that one cannot reject the null-hypothesis that exchange rate returns observed on days before intervention days were equal to the returns on other non-intervention days. In addition, the Wilcoxon test suggests that the hypothesis that the returns on non-intervention days are equal to the returns on intervention days can be rejected at a 10% significance level. This is consistent with our prior findings according to which interventions had an effect on the US dollar/euro exchange rate on intervention days. Finally, the test results given in the last column of Table 3 suggest that the exchange rate

[25] See, e.g., DeGroot (1989) for a description of these tests.

[26] Here, 'days without interventions' or 'non-intervention days' are defined as business days that do not classify as pre-intervention days, intervention days, or days following intervention days.

returns on days following interventions were different from the return on non-intervention days. Taking into account the signs of the returns on the intervention and post-intervention days as shown in Table 2 the latter results implies that the intervention effects were short-lived.

TABLE 3

A COMPARISON OF INTERVENTION DAYS WITH NON-INTERVENTION DAYS

Test statistic	Non-intervention days as compared to the days before intervention days	Non-intervention days as compared to intervention days	Non-intervention days as compared to the days after intervention days
t-test	−0.53	−1.10	4.34***
Wilcoxon-Mann-Whitney U-Rank-test	0.66	1.39*	2.44***

Note: * and *** denote significance at the 10 and 1% level respectively (one-sided test).

How can the results of this section be summarized? An important point to note is that only five observations were available to assess the impact of the interventions of the ECB on the level of the exchange. This, of course, implies that one should not stretch the interpretation of the results of the quantitative analyses too far. Nevertheless, as the results of this section confirm the conclusions derived from Figures 1a-1e, the general impression emerges that the interventions of the ECB did not exert a persistent impact on the level of the US dollar/euro exchange rate.

4.3. *The effects of the ECB interventions on the volatility of exchange rate returns*

We now examine the impact of the interventions conducted by the ECB on the volatility of the US dollar/euro exchange rate. In a first step, we compute the absolute returns of the US dollar/euro rate. To this end, we use intra-daily exchange rate data from September 1, 2000 to November 30, 2000. In a second step, we construct 72 (=(12h·60min/h)/10min) dummy variables to account for potential intra-daily seasonal patterns in the absolute returns (see Baillie and

Bollerslev 1991).[27] In a third step, the absolute returns are regressed on these dummy variables and on six lagged realizations of absolute returns. The latter are included in the regression to control for the autocorrelation in the absolute returns series. In a fourth step, we compute a new series containing the absolute fitted values of this regression. We take this series as our measure of exchange rate volatility V_t.[28] In a fifth and final step, we follow Dominguez (1999) and estimate an 'event study' regression of the format:

$$(2) \qquad V_t = \beta_0 + \Sigma_x \beta_{lead\_x} lead\_x + \Sigma_x \beta_{lag\_x} lag\_x + \varepsilon_t \, .$$

In equation 2, we use the same notation as in equation 1. The exchange rate volatility data include only the days on which the ECB intervened in the market.

We present the estimation results in Table 4. The coefficient of the dummy variable *lead_0* is significantly different from zero and positive. A similar result holds for the coefficients of the dummy variables *lead_20* and *lead_30*. These findings suggest that the volatility of the US dollar/euro exchange rate returns peaked immediately after an intervention had taken place. The significance of the coefficients of the lag-dummies implies that the interventions of the ECB caused exchange rate volatility to increase again with a time lag of roughly 20 minutes. The fact that the coefficients of all other lag-dummies are not significantly different from zero indicates that the interventions of the ECB did not have a lasting impact on the volatility of US dollar/euro exchange rate returns.

The fact that equation 2 suggests that the interventions of the ECB unfolded their impact on exchange rate volatility immediately after the interventions had begun implies that a link between interventions and the volatility of exchange rate returns should show up mainly in intra-day data but should be rather modest when daily data are used. To analyze whether this is indeed the case, we change the sample frequency of our data and use daily US dollar/euro returns data to study the link between the interventions of the ECB and ex-

[27] Anderson and Bollerslev (1998) and Chang and Taylor (1998) discuss alternative techniques which render it possible to control for intra-daily seasonal effects in financial market data.

[28] Our volatility measure is similar to the one used by Schwert (1989).

change rate volatility. Instead of the regression model described in equation 2 above, we use now a GARCH model to shed light on the impact of interventions on conditional exchange rate volatility.[29] To rule out that possible systematic day-of-the-week effects distort the estimation results, we regress in a first step the exchange rate returns (i.e., the change in the natural logarithm of the exchange rate) on five day-of-the-week dummies. In a second step, we use the residuals of this regression to estimate a standard GARCH(1,1) model. The conditional variance equation of this model is of the format:

$$(3) \qquad h_t = \beta_0 + \beta_u u_{t-1}^2 + \beta_h h_{t-1} + \delta \text{dummy}_t \, .$$

Here, the conditional variance is given by h_t and u_t are the residuals from the mean equation. The important economic feature of this GARCH model is that the conditional variance depends also on the foreign exchange market interventions of the ECB as measured by the variable $dummy_t$. This dummy variable is equal to one whenever the central bank is present in the market and is zero otherwise. From the significance level of the coefficient δ we can infer whether the interventions of the ECB dampened or increased exchange rate return volatility or did not affect the volatility of the exchange rate at all on average.

To estimate the model, we use a series of daily US dollar/euro exchange rate data for the period January 5, 1999, through December 29, 2000. Table 5 summarizes the estimation results as well as several diagnostic tests, which we perform to check for the adequacy of the model. The results indicate that all coefficients of the GARCH model are significantly different from zero. Moreover, the sum of the ARCH and the GARCH terms entering into the conditional volatility equation is significantly smaller than one, suggesting that the unconditional variance exists. The Q-statistic indicates that it is not possible to reject the null hypothesis of no remaining autocorrelation in the standardized residuals. The ARCH-test suggests that the null hypothesis of no further GARCH effects in the squared standardized re-

[29] Surveys of the strand of the literature dealing with issues related to the construction and the estimation of GARCH models include Bollerslev, Chou and Kroner (1992) and Bera and Higgins (1993). The seminal papers on the specification and estimation of ARCH and GARCH models are Engle (1982) and Bollerslev (1986).

TABLE 4

ECB INTERVENTIONS AND THE VOLATILITY
OF THE US DOLLAR/EURO EXCHANGE RATE

Dependent variable: V_t		
Variable	**Coefficient**	**t-statistic**
β_0	0.000528	6.551817***
lead_90	–0.000319	–0.531989
lead_80	–8.58E-05	–0.143250
lead_70	–0.000249	–0.408270
lead_60	–9.93E-05	–0.162948
lead_50	–0.000217	–0.362343
lead_40	0.000619	1.034282
lead_30	0.000139	0.231792
lead_20	2.83E-05	0.047174
lead_10	0.000150	0.250647
lead_0	0.001943	3.243577**
lag_10	0.000866	1.445704
lag_20	0.004907	8.191885***
lag_30	0.005817	9.711208***
lag_40	0.000506	0.845417
lag_50	0.000455	0.760146
lag_60	0.000369	0.615552
lag_70	0.000533	0.889915
lag_80	0.001506	2.514420**
lag_90	0.000385	0.642924

Method	OLS	Number of observations	365
Adjusted R-squared	0.302556	Durbin-Watson statistic	1.91585
Sum squared residual	0.000608	F-statistic	9.31083

Notes: The Table presents the estimation results for a regression of US dollar/euro volatility on a constant and various intervention dummies. The notation is such that the dummy denoted *lead*_30 (*lag*_30) assumes the value unity exactly thirty minutes before (after) an intervention. The equation was estimated for intervention days with ten-minute exchange rate returns. The notation *, ** and *** indicates significance levels of 10, 5 and 1% respectively. In the case of the ECB interventions, which took place on September 14, 2000, and on November 3, 6 and 9, 2000, Bloomberg quotes were used to determine the time of the day at which the news that the ECB intervened in the foreign exchange market was released. The respective news were disseminated by Bloomberg at 8:32, 10:24, 8:12 and 15:04 Greenwich Mean Time. The ECB intervention which took place on September 22, which was coordinated with interventions of other major central banks, began at 11:11 Greenwich Mean Time (see Fed 2000).

siduals of the GARCH (1,1) framework cannot be rejected. However, the significance of the Jarque-Bera-statistic indicates that it is not possible to retain the assumption that the standardized residuals of the GARCH model are standard normally distributed. To account for this departure from normality, we use robust standard errors, computed by implementing the quasi-maximum likelihood method developed by Bollerslev and Woolridge (1992), to assess the significance of the coefficients. As a final exercise, we also test for significant leverage effects in the conditional volatility of exchange rate returns by estimating the asymmetric Threshold-GARCH model suggested by Glosten, Jagannathan and Runkle (1993) and by Rabenmananjara and Zakoian (1993). However, as shown in Table 5, the corresponding T-GARCH coefficient is not significantly different from zero.

Taken together, the evidence summarized in Table 5 indicates that the baseline GARCH (1,1) model captures the dynamics of conditional exchange rate returns volatility well. This means that we can use the estimated GARCH model to analyze the effects of the interventions of the ECB on the volatility of the US dollar/euro exchange rate returns.

TABLE 5

MODELING CONDITIONAL EXCHANGE RATE RETURNS VOLATILITY

Variance equation				T-GARCH
Constant[a]	ARCH-coef.[b]	GARCH-coef.	dummy	coefficient
0.00001* (2.66)	0.15** (2.30)	0.60*** (3.32)	0.000008 (0.17)	0.05 (0.51)
Diagnostic tests	Q(4) 2.03	ARCH(4) 3.99	JB 115.26***	LL[c] 1869.39

[a] Figures in brackets are standard normally distribuded z-statistics computed as the ratio of the respective coefficients and the corresponding standard deviations. Robust standard errors have been obtained by implementing the technique of Bollerslev and Woolridge (1992). *, ** and *** denote significance at the 10, 5 and 1% significance level.

[b] Abbreviation fot coefficient.

[c] LL denotes te value of the maximized log likelihood function.

From the economic point of view, the most interesting result reported in Table 5 is that the coefficient δ of the intervention dummy is not significantly different from zero. The marginal probability value of the t-statistic used to test the null hypothesis $\delta = 0$ strongly suggests that the intervention dummy has only negli-

gible explanatory power for exchange rate volatility. Thus, we are able to reject the hypothesis that the interventions of the ECB influenced on average the dynamics of the volatility of the US dollar/euro spot rate returns.[30]

To summarize this section, the fact that significant effects of the interventions of the ECB on exchange rate volatility can be found when intra-daily data but not when daily data are used indicates that the effect of the interventions of the ECB on exchange rate volatility mainly unfolded immediately after the interventions had begun. Of course, as mentioned earlier, one should again not stretch the interpretation of this results too far, given the fact that we only have five intervention days in our sample.

4.4. *Medium-term effects of the ECB interventions on the level of the exchange rate*

So far, we have been concerned with the short-term effects of the intervention of the ECB. However, it may be the case that the interventions of the ECB had medium-run effects on the level of the US dollar/euro exchange rate that are not identified when focusing on high-frequency data. Therefore, we now enlarge the width of the event windows and examine whether taking a broader perspective yields different results concerning the effectiveness of the intervention policy of the ECB.

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[30] We also analyzed the robustness of the result that the intervention dummy has only negligible explanatory power for conditional exchange rate volatility. To this end, we used volatilities implicit in foreign currency options to study the impact of the ECB's interventions on (expected) exchange rate volatility. The results of this study indicated that, depending upon the specification of the estimated quantitative model, the interventions had either an insignificant or a slightly positive impact on volatilities implicit in options on the US dollar/euro exchange rate. Hence, all in all, these results reinforced the results obtained for the 'event study' regression presented in equation 3. Furthermore, because we use a sample containing only approximately 500 trading days to estimate the highly nonlinear GARCH model, we also computed the squared returns to analyze whether the conditional variance series extracted from the estimated GARCH model is economically reasonable. Visual inspection showed that the dynamics of the squared returns and the dynamics of the conditional variance obtained from the GARCH model are similar to each other. In particular, both series show peaks during the same periods. We then used an 'event study' regression to study the influence of the intervention dummy on the squared returns. The results of this analysis also reinforced the conclusion which can be drawn from the GARCH model with respect to the link between exchange rate volatility and the interventions of the ECB.

In Figure 2a, we depict the US dollar/euro exchange rate for the period January 1999-January 2001 on a daily basis. Due to the fact that there was no significant inflation differential between Euroland and the US, we focus on the nominal exchange rate. Figure 2a shows that during the entire period under investigation, the euro depreciated against the US dollar. This overall trend was only deterred during the period May-July 2000, when the euro appreciated slightly. However, in fall 2000, the overall depreciation trend against the euro again gathered momentum. As Figure 2a shows, the central bank interventions of September 2000 did not result in a break – not to mention a reversal – of this trend.

Yet, starting in November 2000, it seems as if the euro reached a historical minimum and was able to gain some strength again thereafter. Despite the fact that the exchange rate of the euro *vis-à-vis* the US dollar was significantly lower at that time as compared to the beginning of EMU in early 1999, the euro was in an upward trend since early 2001. This finding suggests that the interventions conducted by the ECB at the beginning of November 2000 had a major impact on the exchange rate path and were very effective in the medium term. To test this hypothesis, we present in Figure 2b an enlargement of Figure 2a which makes it possible to analyze the exchange rate path in November 2000 in more detail. Figure 2b allows to address the question whether the turnaround of the euro observed in November 2000 can be attributed to the intervention policy of the ECB. In contrast to the impression that emerges from the relatively broad exchange rate development shown in Figure 2a, we can see in Figure 2b that the deprecation trend of the euro stopped at the end and not at the beginning of November 2000. Therefore, it is questionable that the appreciation of the euro after November 2000 was caused by the ECB's interventions at the beginning of that month. Indeed, from Figure 2b we can see that the time period between November 9 and November 27, 2000 was characterized by an overall trend of an euro depreciation which had already existed before the ECB decided to step into the market. For this reason, we conclude that the appreciation trend of the euro, which began at the end of November and continued during the whole month of December, was not caused by the intervention activity of the ECB.

To summarize, the analysis of the medium-term effects of the intervention activity reinforces the results derived above. We there-

FIGURES 2

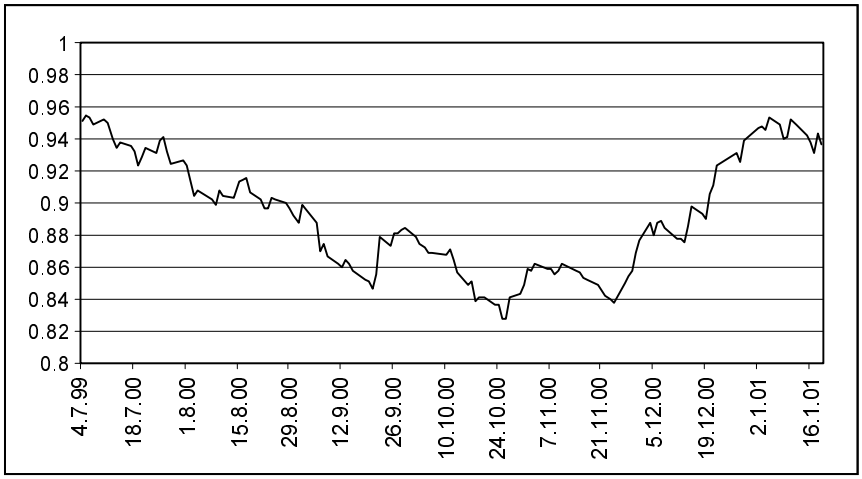
MEDIUM TERM EFFECTS OF THE ECB INTERVENTIONS *

FIGURE 2A

MEDIUM TERM EXCHANGE RATE PATH

FIGURE 2B

ENLARGEMENT OF FIGURE 2A FOR THE PERIOD JULY 2000-JANUARY 2001



* Dates are denoted as DD/MM/YY.

fore conclude that the foreign exchange market interventions conducted by the ECB in the fall of 2000 were rather ineffective as they did not help to stop or to reverse the depreciation of the euro *vis-à-vis* the US dollar.

5. Conclusions

In this paper, we analyzed the short and medium term effects of the foreign exchange market interventions conducted by the ECB in September and November of 2000. On the basis of a review of the theoretical literature, we discussed the channels through which central banks' interventions in foreign exchange markets potentially influence exchange rate dynamics. Because of the fact that the ECB has only a short-term intervention record, we also examined the empirical evidence on the effectiveness of the interventions policy of other central banks.

The results of our empirical analysis suggested that the interventions of the ECB were not effective. Although we were able to detect some effects of the interventions on the level of the exchange rate when using intra-daily exchange rate data, those effects were only minor and tended to be reversed on the trading day following the intervention. All in all, the analysis showed that the ECB was able to influence the exchange rate in the intended direction only on the actual intervention day. An analysis of the medium-term effects of the interventions corroborated this result.

One possible explanation for the lack of effectiveness of the interventions of the ECB may be seen in the failure to conduct coordinated interventions on a regular basis.[31] For the signaling model to work, one prerequisite is that a central bank sends unambiguous and clear signals through its information policy. Such signals should ideally be backed by an internationally coordinated intervention policy. One possible explanation for the lack of effectiveness of the intervention activities may thus be seen in the fact that the ECB did not succeed in conducting coordinated interventions on a regular basis. While the intervention on September 22, 2000 was a coordinated one, all other interventions were conducted unilaterally. This change in

[31] The ECB had apparently hoped to achieve such coordination for some time. The ECB reflected in its *Monthly Bulletin* of October (p. 5) on the September intervention and stated: "The ECB and its partners will continue to monitor developments closely and to co-operate in the foreign exchange markets, as appropriate". However, in its December *Monthly Bulletin* (p. 58), the ECB conceded: "In early November, developments in foreign exchange markets were characterized by unilateral ECB interventions in support of the euro, and concerns about the global and domestic again repercussions of the exchange rate of the euro".

the intervention policy suggests that it was not possible to reach an international consensus on coordinated interventions in November 2000 among major central banks.

According to the signaling model, the effectiveness of an intervention can also be influenced by the ability of a central bank to convince the general public that its interventions signal a coming change in the stance of monetary policy. Taking this argument into consideration, the fact that the ECB emphasized that *i*) the effects of the intervention on money supply were sterilized[32] and *ii*) that there would be no change in monetary policy[33] suggests that the ECB did not want to utilize its interventions as a means to signal a change in its monetary policy.

Finally, it can be argued that the ineffectiveness of the FX market interventions carried out by the ECB can be attributed to the fact that the ECB's information policy was not only at odds with the signaling theory of exchange rate determination but was also inconsistent with the noise trading theory of foreign exchange market interventions. Following Hung (1997), central banks should always conduct secret intervention activities when the intervention objective is to break or reverse an exchange rate trend. The ECB interventions analyzed in this paper were always publicly announced by the ECB via a press release confirming the intervention activity. Although one can argue that these statements were released some time after the intervention had been carried out, they nevertheless revealed the intervention activity shortly after it had taken place. Therefore, the ECB signaled to market participants that a short-term strengthening of the euro realized immediately after an intervention was caused by a temporary exogenous shock rather than be a turnaround in the market's speculative activity. As a result, the ECB could not convince market

[32] See the announcement of the president of the ECB – Willem Duisenberg – during the discussion in the aftermath of the press conference on October 5, 2000. With respect to the question, whether the effect on the money supply was sterilized via the following open market operations, the president answered that the size of the intervention had been taken into account when the size of the next open market operations had been determined. See ECB (2000c).

[33] The ECB emphasized that the slowdown in M3 growth rates, seen from the second quarter of 2000 onwards, probably reflected the progressive tightening of monetary policy in the euro area since November 1999 and is therefore unrelated to the intervention behavior of the ECB. See *Monthly Bulletin* of the ECB (2000a, December, pp. 9-12).

participants that the speculative trend against the euro had been reversed.

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