# Is foreign exchange intervention effective?
# Some micro-analytical evidence from Central Europe

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Abstract

We test the effectiveness of the interventions performed by the Czech National Bank in the EUR/CZK within the framework of the Evans-Lyons (*JME*, 2002) microstructure model of the forex market. Employing time-stamped quotes and transactions on the Reuters Spot Matching market, we estimate a two-equation system on the rate change and order flow at hourly intervals. We find a significant impact of order flow on the exchange rate, equal on average to 7.6 basis points per €10 million in the whole sample period, 80 percent of which persists through the day. The existence of distinct subperiods enables us to estimate the potential effects of intervention in three different states of the market. First, the central bank might perform secret interventions in orderly market conditions, when dealers perceive a *low likelihood* of their occurrence. Second, secret interventions might take place in a state characterized by a *high likelihood* of their occurrence. The third state is characterized by the market's *knowledge* that intervention is indeed taking place. Our results lend support to the theoretical model and provide useful insight on the conditions for effective central bank intervention in the future.

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## 1. Introduction[1]

This paper provides an empirical test of the effectiveness of sterilized foreign exchange intervention in the case of a small open economy, the Czech Republic, characterized by a floating exchange rate regime for the local currency, the koruna (CZK).

In recent years several studies have tried to shed light on the efficacy of central banks' interventions within the framework of the microstructure approach to exchange rates (Lyons, 2001), thus adding new perspective into a long-debated issue[2]. Microstructure models generally hinge on two hypotheses that are familiar to macro exchange rate models, namely the portfolio balance or liquidity effect, and the signaling effect. However, unlike in traditional models, information heterogeneity on the part of investors and the information aggregation process crucially enter into play[3] (see Baillie, Humpage and Osterberg, 2000, and Vitale, 2004 for a survey of recent developments). Previous tests of microstructure hypotheses, covering a variety of intervention episodes mainly for the G-10 currencies, have examined the effect of intervention on exchange rate returns and/or volatility at the intraday level (Beattie and Fillion, 1999; Breedon and Vitale, 2004; Cai, Cheung, Lee and Melvin, 2001; Chang and Taylor, 1998; Chari, 2002; Dominguez, 2003a, b; Evans and Lyons, 2001; Fischer and Zurlinden, 1999; Goodhart and Hesse, 1993; Morana and Beltratti, 2000; Neely, 2002; Pasquariello, 2002b; Payne and Vitale, 2003; Peiers, 1997). A broadly shared conclusion is that central banks' activity has significant impact effects on the first two moments of the exchange rate, with some important qualifications. In particular, the analysis of the G-3 interventions between 1987-1995 performed by Dominguez (2003a) reveals that their impact on exchange rate levels depends to a large extent on the state of the market. The intraday effect is larger when interventions are conducted during heavy trading hours, when they occur in the aftermath of macroeconomic announcements and when they are coordinated with other central banks. Payne and Vitale (2003) find that the Swiss National Bank interventions produced a larger impact on the exchange rate when they were concerted and when they were "leaning with the wind".

[1] This study draws from an earlier paper (Scalia, 2003). The research was mainly conducted while the author was visiting the Haas School of Business, University of California at Berkeley. The author is grateful to Rich Lyons for his invaluable support and to Paolo Vitale, Andrea Santorelli, Martin Perina, and seminar participants at the European Central Bank for useful comments on earlier drafts. Thanks are due to Reuters for making available the Spot Matching Market data set, and to Factiva for providing access to the electronic news archive. Stefano Meloni provided excellent research assistance. Any remaining errors are the author's responsibility.

[2] Surveys of the literature on central bank intervention are provided among others by Baillie, Humpage and Osterberg (2000), Catte, Galli and Rebecchini (1994), Dominguez and Frankel (1993), Galati and Melick (2002), Sarno and Taylor (2001).

[3] Theoretical models of intervention and forex market microstructure are developed by Bhattacharya and Weller (1997), Derviz (2003), Dominguez (2003b), Evans and Lyons (2001, 2002a), Pasquariello (2002a), Popper and Montgomery (2001), Vitale (1999). Bacchetta and van Wincoop (2003) provide a model of exchange rate determination with investor heterogeneity.

The conceptual framework for our analysis is provided by the micro portfolio-balance model of Evans and Lyons (2002a, henceforth EL), which provides an insightful link between the agents' rational adjustment to economic news and the working of the market. The basic idea is that, in a world with risk averse traders and dispersed information on the asset's value[4], the arrival of news affects beliefs in two ways: first, through a common-knowledge component, which causes an instantaneous adjustment in price, i.e. before any trading can occur at the old price; second, through a private-knowledge component which induces trades; these in turn reveal the private information, which is gradually impounded in price. Causality then runs from order flow to prices[5], and trades will have more impact on prices when markets are less liquid. Two testable predictions are derived from the model. The arrival of news increases the price impact of trades, since news bring about a major update of agents' dispersed beliefs. Besides, the passing of orders among dealers for the purpose of risk reduction, the so-called "hot potato" trading, produces restrictions on the pattern of returns and order flow. The notion that order flow may have persistent effects on price, in our case the exchange rate, is of course tightly connected with the issue of the efficacy of central bank's intervention in the market.

Based on the EL model, we estimate a two-equation system on the rate change and, respectively, the order flow measured at hourly intervals on the EUR/CZK currency pair. We hypothesize that the news of intervention increases the impact of order flow on currency returns, and provide a simple econometric test of this conjecture.

From a methodological perspective, our investigation innovates over the past studies on the efficacy of central bank intervention in the foreign exchange market. While the existing literature generally employs data on indicative quotes and, when available, on time-stamped interventions, our first motivation is studying the behavior of prices *and* order flow at times of intervention. In this respect, our analysis is akin to the case study of the ECB intervention episodes performed by Breedon and Vitale (2004).

Our second motivation has a policy nature. The Czech Republic, together with Poland, Hungary and other Central European countries, is expected to participate in the ERM II in the coming years, following the entry in the European Union in May 2004 (see ECB, 2004). The key elements of the exchange agreement are the central parity against the euro, the fluctuation band around the central rate and the obligatory interventions at the margin, which are in principle automatic and unlimited. Two additional features are the availability of a short-term financing facility among participating central banks and the possibility to conduct discretionary, intra-

[4] In the foreign exchange market the notion of dispersed beliefs may not be as intuitive as is the case, in particular, for the stock market. However, dispersed beliefs do not necessarily imply that individuals possess "superior" information. Most macroeconomic variables like output, money demand, trade balances, and inflation are themselves aggregations of micro realizations; what matters is that some of these micro realizations may be conveyed to the market through trading.

[5] Several studies argue that this direction of causality is not obvious, depending in the first place on the possibility of trend-chasing behavior. See in particular Froot and Ramadorai (2002).

marginal interventions in order to contain the deviations of the currency from the central parity. The mechanism also foresees the possibility of realignments during the period of participation. The agreement's design is aimed at combining discipline and adjustability in the road to real and financial convergence of a country until the eventual adoption of the euro. Under the ERM II the stability of the participating currencies against the euro will thus be the focus of monetary authorities and market participants. Two key features of Central European currencies, including the Czech koruna, are the relatively low liquidity and high volatility compared to the currencies of other major European countries (see Scalia, 2003). The BIS (2002) survey of foreign exchange activity shows that average daily turnover in the spot CZK market against all other currencies was equivalent to $736 million as of April 2001. The statistics by the Czech National Bank (CNB) on forex market turnover, available for April and October 2002, show the same order of magnitude, with daily average spot transactions corresponding to $708 million and, respectively, $802 million. For the sake of comparison, the BIS survey indicates that total spot transactions on a daily basis for the Danish krone (DKK), currently the major participant in the ERM II with the euro[6], were equivalent to $2,988 million. In 2002 volatility, measured as the annualized standard deviation of daily log rate changes, was equal to 7 percent for EUR/CZK and to 0.8 percent in the case of EUR/DKK[7]. By assessing the effects of foreign exchange intervention in the case of the Czech koruna, the second aim of this paper is to provide insight on the conditions for effective central banks' actions in the future, particularly in view of the discretionary nature of intra-marginal interventions.

We employ two original sources of data. In the first place, we use a new and complete data set of time-stamped orders and transactions on the Reuters Dealing 3000 Spot Matching electronic market in the six-month period from July to December 2002. Reuters is one of the two leading providers of electronic broking services in the foreign exchange market[8], the other being EBS. Reuters Dealing is predominant for transactions in emerging market currencies, and for European currencies in particular. The Reuters Spot Matching system accounts for an estimated 35 percent of all spot transactions involving the Czech koruna; the rest is carried out mainly on the OTC market, both direct and brokered, and on the Reuters Dealing Direct system[9] (not covered by our data set). Owing to transparency, liquidity and efficiency considerations, the Spot Matching market may be considered as the leading segment for the behavior of the

[6] Estonia, Lithuania and Slovenia joined the ERM II in July 2004. Estonia and Lithuania operate a currency board arrangement, Slovenia has adopted a crawling peg to the euro in recent years.

[7] Denmark, in consideration of the historical stability of the currency and the high degree of convergence with the euro area, has adopted a narrow fluctuation band of +/-2.25 percentage points around the central parity, as opposed to a standard fluctuation band of +/-15 percent.

[8] The Reuters Dealing 3000 Spot Matching market, previously denominated Dealing 2000-2, is analyzed by Payne (2003) and Danielsson and Payne (2002).

[9] On the Dealing 3000 Direct market any participating dealer can contact bilaterally a specific counterparty on-screen and propose/execute a deal.

EUR/CZK, which is the currency pair of interest for the Czech monetary authorities[10] (see also Derviz, 2003).

The above sample period spans a prolonged round of foreign exchange interventions, conducted in the spot market by the CNB during July, August and September. Our second data source is the CNB, that kindly provided to us the intervention dates. We are thus in a position to perform an analysis of the response of the EUR/CZK exchange rate and interdealer order flow on the leading market segment on intervention days. The interventions were "leaning against the wind", as they were aimed at reversing the appreciating trend of the koruna, driven by the market's expectation of large foreign capital inflows (see CNB, 2002). This led to the EUR/CZK trading below the level of 30 for the first time ever. The central bank traded mainly with foreign exchange dealers on a bilateral basis, thus generating "private" order flow for the latter. Market practitioners and the press described these episodes as "stealth interventions" because the CNB, with few exceptions, generally declined to make comments. Furthermore, the CNB chose to trade with a restricted pool of counterparties and sought some confidentiality. We observe that this intervention technique, although not accompanied by a transparent communication policy, did convey a clear signal to the interested parties in the market. That these discreet interventions conveyed information to price setting dealers is confirmed by an anecdote. On some occasions the CNB stepped in the market and selected some dealers but not some others, which had been selected in earlier intervention rounds. In those cases it was not infrequent that a left-out dealer later phoned the CNB to complain.

During October-December the tension on the koruna eased considerably, the EUR/CZK remained well above the level of 30 and the market's fear of CNB intervention faded away. In fact, the CNB no longer intervened. On account of the change in the state of the market, the last quarter of 2002 lends itself as a useful control sample for the results obtained from the third quarter, i.e. the intervention period.

Our main finding is a highly significant impact of order flow on the exchange rate, equal to 7.6 basis points per €10 million over the entire sample period. Within our intraday setting, the persistent effect of order flow on the exchange rate corresponds to 80 percent of the within-hour effect. Interestingly, the model allows us to identify and measure three modalities through which intervention may potentially affect the exchange rate level. They correspond to three possible states of the market, which we characterize differently compared to previous studies (notably Dominguez, 2003a, and Payne and Vitale, 2003). Indeed, we identify the state of the market in terms of the perceived likelihood of the central bank's presence. We note that our interpretation holds even if in practice the CNB applied only the third of these modalities. First, the central bank might intervene secretly in orderly market conditions, like those prevailing for the EUR/CZK in the last quarter of 2002, when dealers faced a *low likelihood* of intervention. In

[10] Trading in USD/CZK is also reported, but mainly in the forward market.

such circumstances the impact on the exchange rate would be equivalent to that of ordinary interbank trades, equal to 6.6 basis points per €10 million order flow. The second state of the market is characterized by a *high likelihood* of intervention, like that experienced in July-September of 2002, irrespectively of its occurrence. We estimate that in a tense market the price impact increases by 2.7 basis points, to 9.3, per €10 million order flow, and that in turn can be interpreted as the potential effect of totally secret intervention in those circumstances. The third state is characterized by the market's *knowledge* that the central bank is indeed intervening. We show that the intervention news, the third layer, further augments the impact on the exchange rate by 2.9 basis points, to 12,2, per €10 million order flow.

In the case of the model's second equation, where the endogenous variable is order flow, our results are inconclusive. This might partly be explained by the circumstance that, while the Reuters Spot Matching market plays a crucial role for price discovery on the EUR/CZK exchange rate, still this market covers only a fraction, although sizeable, of total transactions. Hence our order flow variable is only a proxy of total order flow.

We are aware that any inference from the experience of the CNB in the summer 2002 is to be viewed in light of the concurrent policy measures undertaken by the monetary authorities of the country and of the structure of the forex market. Nonetheless, owing also to the clinical nature of our econometric setting, we believe that the episode analyzed in this paper is more generally illustrative of the game played in the market by the central bank and forex dealers in emerging countries.

Section 2 of the paper presents an overview of the empirical model. Section 3 gives some background on the foreign exchange policy regime and intervention technique in the Czech Republic, describes the dealing system and presents summary statistics. Section 4 presents the empirical estimates of the intraday exchange rate and order flow equations. Section 5 concludes.

## 2. Empirical model

The EL model provides the analytical structure for the joint behavior of order flow and returns within a trading day[11]. The model is characterized by the hypothesis that the arrival of news prompts an adjustment in agents' expectations, which is in turn conveyed to the market by order flow. We present an outline of the model using the original notation. The trading day is divided in four periods and the market has two types of risk averse participants: foreign exchange dealers and customers. Foreign exchange, the risky asset, earns a daily random payoff $R_t$ defined as the sum of past payoffs plus an increment $\Delta R_t$. The latter can be naturally thought of as interest rate movements, though it can be understood to represent macro fundamentals more generally.

[11] The full specification of the model is provided by the authors at www.haas.berkeley.edu/~lyons.

In round 1, customers place stochastic orders in the foreign exchange market. The orders, not publicly observable, are driven by portfolio shifts and are affected by whether a news event occurred that morning, in which case the indicator variable $A_t$ takes the value 1. To some customers the news conveys information about the stochastic payoff to be realized later; hence the ensuing order flow will be informative about future payoffs. Each dealer $i$ simultaneously and independently quotes a price, denoted by $P_1^i$. Lastly in round 1 each dealer receives a signed order $C_1^i$, which is executed at the quoted price. The order has a positive sign when it reflects customer purchases and a negative sign when it reflects customer sales of foreign exchange. In round 2 dealers trade among themselves to share inventory risk within a centralized trading mechanism, visible to a large extent to all participants. At the end of round 2 all dealers observe a noisy signal $\Delta x_2$ of total interdealer order flow. In round 3 the payoff increment $\Delta R_t$ is realized and dealers trade among themselves a second time, observing interdealer order flow without noise. Motives for trade will remain, because risk sharing and information aggregation are not yet complete. In round 4, dealers trade again with the public to share overnight inventory risk, under the assumption that the public's capacity to bear risk is much greater relative to the dealers. This round of trading is non-stochastic. Each dealer sets a price, taking into account the fact that the public's demand for foreign exchange is proportional to its the expected return. The dealer's optimizing problem is defined over six choice variables: the four quotes $P_1^i$ - $P_4^i$ to be applied in each round of trading, and the two interdealer trades $T_2^i$ - $T_3^i$. To prevent arbitrage, at any given time all dealers must quote a common price. This price will be conditioned on common information only, which comprises the interdealer order flow $\Delta x_2$, the payoff increment $\Delta R_t$ and the interdealer order flow $\Delta x_3$.

Once translated in an hourly setting, the solution to the dealer's optimization problem yields two estimable equations: one for the log exchange rate change, $\Delta p_h$, and one for order flow, $\Delta x_h$, as follows:

$$\Delta p_h = (\beta_1 + \beta_2 A_{h-1})\,\Delta x_h + \beta_3\,\Delta p_{h-1} + \eta_h^p \qquad (1)$$

$$\Delta x_h = \beta_4\,\Delta x_{h-1} + \beta_5\,\Delta p_{h-1} + \eta_h^x, \qquad (2)$$

where:

$$\eta_h^P = \beta_6\,\Delta R_h$$

$$\eta_h^x = (\beta_7 + \beta_8 A_{h-1})\,C_{1h}$$

$$\beta_1, \beta_2, \beta_4, \beta_5 > 0,\ \ \beta_3 < 0.$$

From equation (1), hourly return $\Delta p_h$ is a positive function of contemporaneous order flow $\Delta x_h$ and a negative function of its own lag[12]. A news event in the previous hour ( $A_{h-1} = 1$) increases the contemporaneous exchange rate impact of order flow by a coefficient $\beta_2$, reflecting the incremental information about $\Delta R_h$ in the flow $C_{1h}$. The mean-reversion of the exchange rate captures the transitory intraday risk premia that arise in the model. The residual term $\eta_h^P$ in the return equation is linked to the arrival of public news in the form of $\Delta R_h$.

From equation (2), interdealer order flow is positively autocorrelated over trading rounds, because dealers pass among themselves the hot potato of exchange rate risk. Order flow is also positively affected by lagged returns, owing to the impact of order flow on price from the previous hour and to the assumption that order flow is measured with noise. The residual term $\eta_h^x$ captures the flow of unmeasured, contemporaneous customer orders.

We extend equations (1)-(2) in several ways. It is useful to recall that the EUR/CZK exchange rate is defined as the number of Czech korunas per 1 euro, and the EUR/USD exchange rate is expressed as the number of US dollars per 1 euro. The unit transaction size in our market is €1 million for both contracts (see the next section). In the first place, we distinguish two different information sources: (i) public announcements and (ii) private information about the presence of the central bank in the market. We hypothesize that those possessing the latter type of information will (gradually) reveal it not only through their trades but also directly and confidentially to their own customers, like e.g. institutional investors, as part of their working relationships. The news about the central bank's presence should cause the largest possible update of agents' beliefs on the future payoff of foreign exchange or, stated differently, on its fundamental value. Hence, in the empirical implementation the latter type of news should have a larger impact on the exchange rate, through the order flow variable, compared to public news. We thus distinguish two indicator variables: $A_h$, equal to 1 when at least one public announcement occurs in interval $h$, and 0 otherwise; and $INT_h$, equal to 1 when the central bank is known, by at least some dealers, to be in the market in $h$, and 0 otherwise.

Second, we allow for the possibility that additional lags of the foreign currency return $\Delta p$ exert an influence on its current value, implying that mean reversion would last longer than one hour.

Next, we hypothesize that intraday trading activity in the Czech koruna is influenced by contemporaneous order flow in the most liquid contract of the foreign exchange market, the EUR/USD. This choice is admittedly ad hoc. We draw from the intuition and evidence presented in Evans and Lyons (2002b), who find that order flow on the most important currency pair (in their case the DEM/USD) exerts a contemporaneous impact on the order flow of a broad range of third currencies. Their result is motivated in light of information aggregation in a

[12] It is intended that the nominal exchange rate (the price $P$) is defined as the number of units of currency A (in our case, the CZK) that is needed to purchase/sell 1 unit of currency B (the EUR). The unit of measure of order flow $\Delta x$ is defined in terms of currency B (in our market, €1 million). If currency B is bought (sold) then order flow has a positive (negative) sign.

highly integrated market, where investment strategies are aimed at allocating wealth optimally across all currencies, and major portfolio shifts may be first revealed by order flow in the dominant spot market. This hypothesis would seem highly realistic in the case of the Czech koruna. Hence, we will also allow for the possibility that intraday order flow in EUR/CZK is positively affected by contemporaneous order flow in EUR/USD.

To sum up, the regression equations are modified as follows:

$$\Delta p_h = (\beta_{11} + \delta\ A_{h-1} + \gamma\ INT_{h-1})\ \Delta x_h + \beta_{12}\ \Delta p_{h-1} + \beta_{13}\ \Delta p_{h-2} + \beta_{14}\ \Delta x_h^{US} + \eta_h^P \tag{1'}$$

$$\Delta x_h = \beta_{21}\Delta x_{h-1} + \beta_{22}\Delta p_{h-1} + \beta_{23}\Delta x_h^{US} + \eta_h^x\ . \tag{2'}$$

For simplicity of notation we limit the lag length of $\Delta p$ to 2, because we empirically find that longer lags are never statistically significant (see below). We would expect $\gamma > \delta > 0$. Besides, $\Delta x_h^{US}$ is contemporaneous (same hour) order flow in the EUR/USD contract, with a plus indicating net euro purchases and vice versa. Other things equal, we would expect that a net purchase (sale) of euros with US dollars should be associated with a net purchase (sale) of euros with korunas, which implies $\beta_{23} > 0$; such order flow should directly affect the nominal EUR/CZK exchange rate, with $\beta_{14} > 0$.

A vast amount of empirical evidence indicates that the errors in exchange rate equations display (positive) general autoregressive conditional heteroskedasticity, reflecting volatility persistence during the day and across days (see in particular Andersen and Bollerslev, 1998). Furthermore, several studies on foreign exchange interventions have shown that central bank activity is associated with an increase in intraday volatility (Cai et al., 2001; Chang and Taylor, 1998; Chari, 2002; Dominguez, 2003a, b; Pasquariello, 2002b).

The presence of autoregressive conditional heteroskedasticity was also confirmed by preliminary estimates of equation (1') with OLS. This has led us to introduce a parsimonious GARCH effect alongside equation (1'). Allowing for this possibility with hourly time series, however, raises a technical problem. The frequency of the data, sampled at hourly intervals during working hours only (see the next section), is such that our time series are not continuous. Indeed, they display overnight breaks plus weekend breaks; together, these breaks make the estimation of a GARCH model infeasible. We try to circumvent this limitation as follows. We assume for simplicity that conditional variance in the exchange rate equation, $Var(\eta_h^p)$, depends linearly on its own first lag only, i.e. it follows a GARCH(0,1) model (with no ARCH parameters). We compute the hourly series of the unconditional variance (i.e., the square) of exchange rate returns for the regular intervals only (excluding the overnight and weekend intervals). We then go on to estimate jointly the conditional mean and the conditional variance equations, using the lag of unconditional variance as a proxy for its conditional value and dropping the first regular hourly interval of the day, which would have an irregular value for the lag of variance (computed overnight). Consistently with the hypothesis that volatility persists during the day, we expect a positive coefficient.

To test for the presence of the intervention effect on exchange rate volatility, we include the first lag of the intervention variable *INT* in the conditional variance equation.

Lastly, we allow for the possibility that time-varying trading intensity affects the conditional variance of the exchange rate equation. We hypothesize that trading intensity *I*, which we will measure as the number of transactions in the previous interval, is positively correlated with the speed of information aggregation in the market, thus improving the fit of the theoretical model for $\Delta p_h$. Hence we would expect a negative impact on the residuals' variance.

The resulting conditional variance equation is:

$$Var\left(\eta_h^p\right) = \alpha_0 + \alpha_1 \left(\Delta p_{h-1}\right)^2 + \alpha_2 \, INT_{h-1} + \alpha_3 \, I_{h-1} \tag{3}$$

with:

$\alpha_0, \alpha_1, \alpha_2 > 0, \quad \alpha_3 < 0$.

In light of the economic and political developments in the Czech Republic, and considering the time pattern of the EUR/CZK exchange rate during our sample period (see the next section), we conjecture that a structural break in the model has occurred in the middle of the period. This is motivated by the circumstance that in July-September 2002 market dealers had widespread expectations that the central bank might have intervened in the foreign exchange market, whereas such expectations faded away during October-December. Now we hypothesize that, irrespectively of the actual presence of the central bank, the change in the likelihood of intervention in itself may have affected the micro-working of the market, captured by the parameters of equation (1'), (2') and (3). In particular, we would expect that, other things equal, a high probability of intervention should cause an increase in the ordinary responsiveness of the exchange rate to order flow, $\beta_{11}$, and an increase in the conditional mean reversion coefficient $\beta_{12}$, the latter motivated by a higher intraday risk premium.

## 3. Market and data

### *3.1 Background*

Since 1998 the Czech Republic has combined an inflation targeting strategy with a floating exchange rate regime, in a context of liberalized capital movements. Foreign exchange interventions have been occasionally undertaken to avoid excessive volatility of the koruna.

If we restrict our attention to the four-year period from the launch of the euro, in January 1999, to the end of our data sample, we notice that the koruna experienced an initial depreciation against the euro, with the EUR/CZK exchange rate moving from 35 up to 38.5 in April of 1999 (Graph 1)[13]. From then onwards the koruna has moved along an appreciating trend *vis-à-vis* the euro. The strengthening became particularly evident from end-2001 to mid-2002, following large capital inflows related to the privatization process. At the beginning of the summer 2002 the EUR/CZK was trading slightly above 29. In our sample period (July-December 2002), and based on the daily reference rates published by the ECB, the average EUR/CZK exchange rate was equal to 30.54 and it fluctuated in the range +3.6/-5.2 percent around that average.

In the second half of 2003 the monetary authorities spelled out their plans for the process of monetary integration. In particular, the CNB recommended that the koruna stay outside the ERM II for some time after its entry in the EU, owing mainly to the calendar for fiscal consolidation and the need for structural reforms. The CNB stated that it would be undesirable to stay in the ERM II for longer than the minimum required period of 2 years. Therefore, the adoption of the euro by the Czech Republic is not likely to occur before 2009-2010.

### *3.2 Interventions*

Throughout the first half of 2002 the Czech koruna appreciated strongly, and the CNB intervened to stem this pressure several times in January and April, buying euros with korunas by a total €1.3 billion. The summer months saw a reversal of this trend. The key facts were as follows. After the continuing appreciation of June and the beginning of July, the CNB stepped again in the market selling the koruna in a round of discreet interventions. These operations were accompanied by a rebound of the EUR/CZK, which moved away from the critical level of 29. At the end of July, against the backdrop of a favorable inflation outlook, the CNB cut its key rate by 0.75 percentage points, setting the 2-week repo rate at 3 percent, below the value of the ECB key rate at 3.25 percent. The move, larger than anticipated by market participants (CNB, 2002), was accompanied by a further rise in the nominal level of the EUR/CZK. Besides, official statements reinforced the market's confidence on the agreement between the CNB and the government on the sterilization of privatization proceeds. In August, as a consequence of the floods that struck the country, the koruna was again spurred by the anticipation of transfers of funds from foreign insurance companies to local companies. The discreet koruna sales of the CNB went on during August and September. At the end of September the koruna appreciation

[13] The exchange rate for the Czech koruna is expressed as the number of CZK per 1 euro, and the unit transaction size is 1 million of euros.

was interrupted by the government crisis. The political uncertainty contributed to set on a slightly depreciating trend for the Czech currency, which remained in place until December, the end of our sample period.

During July-September the Czech financial press, commenting the pattern of the EUR/CZK exchange rate, had a number of morning briefings about the market's expectation of central bank's interventions. Afternoon commentaries often reported "market sources" saying that the CNB had indeed been seen in the market. Not surprisingly, no such reports are available for October-December.

According to the figures published on the CNB website, total intervention operations amounted to €444 million in July, €104 million in August, €406 million in September. The CNB was in the market on 28 days in the quarter, of which 11 days in July, 6 days in August and 11 days in September; the lower frequency of interventions in August was partly related to the disruption in the Czech market caused by the heavy floods. The daily average size of intervention was thus equal to €34 million. In light of the above, it would seem fair to categorize these interventions as not large in absolute value. Still, one has to bear in mind the size of the EUR/CZK spot market.

We do not know the daily breakdown of the interventions, nor do we know the exact timing within the day. However, owing also to the discreet nature of the CNB operations, the time schedule of events was rather smooth. The CNB Board performed an assessment of market developments at its regular weekly meetings, and occasionally during ad hoc meetings. Such assessment produced among other things a decision whether to conduct forex interventions in the following days, accompanied by general instructions on the total amount and/or the preferred rate level. The intervention instructions were passed on for execution to the dealing desk, which had some leeway on the best timing of the operations. We understand that, within a given day, the interventions were preceded by some assessment of market conditions at the CNB dealing desk level in the early trading hours. Once started, the interventions were then carried out in small tickets distributed over the remaining working hours. Thus, it seems plausible to assume that on intervention days market dealers would have learned the news about the presence of the CNB, either directly or through rumors, not in the early trading rounds but some time later[14].

In the empirical estimation of equation (1'), we will generally assume that the news of intervention becomes known to (at least some) dealers in the market starting from 10:00 on intervention days; thus, by the lag structure, the effect on the exchange rate is felt from 11:00 onwards. We will also provide the results under different assumptions.

[14] The hypothesis that the market at large learns with some delay after the central bank has started intervening is also in line with the evidence of previous studies; see for example Dominguez (2003a).

*3.3 The Reuters Spot Matching data set*

The Reuters Dealing 3000 Spot Matching system is a multilateral trading platform operated as an electronic limit order book, that is a system where dealers can place either orders with a price limit (limit orders) or orders to be executed at the best outstanding quotes (market orders), for a wide range of currency pairs. All orders are firm and they are automatically matched against the best available quotes (i.e., limit orders), up to the threshold set by the bilateral credit lines. The system updates the order book and shows the best quotes to all dealers together with the flow of quotes and trades. Reuters operates also a different facility, the Dealing 3000 Direct, whereby any dealer can contact a specific counterparty on-screen and propose/execute a deal. Our data set does not cover the latter trading facility.

The data set includes all incoming orders and trades executed during the entire day, between 1 July and 31 December 2002. Each record (quote or trade) includes the date, time and currency pair. In addition each quote record shows the side of the quote plus the firm price and quantity, the latter in millions of euros or dollars. Each transaction record gives the price and quantity with a bought/sold indicator. Although trading can take place 24 hours a day, 7 days a week, activity in the Czech koruna is strongly concentrated in the interval 8:00 a.m.-5:00 p.m. local time, corresponding to Central European Time (CET), Monday through Friday. Therefore we restrict our analysis to the sub-sample of data in that date/time interval[15].

Summary statistics on a daily basis for the EUR/CZK are shown in Table 1. The sample includes 128 working days. The order flow statistics refer to "signed" transactions, whereby any filled buy (sell) market order is attributed a + (-) sign[16]. Daily turnover on EUR/CZK is €169.6 million. Average order flow is equal to € +5.9 million, indicating net euro purchases against the koruna over the sample period. The arithmetic average of daily returns for the koruna is 6.2 basis points, indicating a tendency to depreciate against the euro over the sample period. Volatility, measured as the squared daily return, is relatively large on average, at 0.23 basis points.

The data set does not record when a given quote has been matched or cancelled by the proponent. Hence, the bid-ask spread at any point in time cannot be directly observed but must instead be estimated on the basis of some assumptions about the "life" of each quote. We took a simple stance and, in view of the relatively low liquidity of the EUR/CZK and of casual inspection, we assumed that each quote expires after 5 minutes, if it has not been previously

[15] Local time is GMT+1 plus Daylight Saving Time, when applicable. We also discarded all trades/quotes on national festivities plus 24 and 31 December, when afternoon trading was negligible.

[16] Analogously, when a limit order finds an automatic match against an outstanding quote on the opposite side, the former gives the sign of the trade. We employ actual quantities, unlike past studies (e.g. Evans and Lyons, 2002a) that measure order flow as the difference between the number of buyer-initiated and seller-initiated trades.

matched (something we detect from order flow[17]). At discrete, high frequency points in time we thus obtain an estimate of the prevailing inside spread, given by the difference between the best outstanding ask and the best outstanding bid, under the condition that quotes are available on both sides[18, 19].

The lower section of Table 1 gives the cross correlation between the above market variables. An important fact stands out: signed order flow and returns display a large positive correlation, equal to 0.49. This is consistent with the notion that order flow has a direct impact on exchange rate changes.

Table 2 provides similar statistics as in the previous table, at hourly intervals within each day. To construct the hourly time series of the exchange rate we employ the last available mid-quote in each hourly interval. We also provide the serial correlation coefficients for the two key variables of the empirical analysis, return and order flow[20]. The intraday data confirm that the cross correlation between order flow and return is high, at 0.47. The spread displays positive correlation with volatility, equal to 0.18[21]. Turnover and (unconditional) volatility are positively correlated. We observe that the latter finding does not necessarily contradict the hypothesis that

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[17] We also discard a quote if a new quote arrives on the opposite side, that would open up an arbitrage opportunity.

[18] Indeed, the above assumption enables us to track the entire limit order book.

[19] Let us clarify why we are making this digression on the spread, which is not directly relevant in our analytical framework. We have a practical reason. Indeed, on account of the relatively low market turnover, we would have some difficulty in constructing the intraday series of EUR/CZK rates if we were to use uniquely the record of actual transactions. That happens because in many cases the hourly intervals in the sample period have a low number of trades or no trades at all. That would blur the measurement of hourly return. We could alleviate the problem if we took indistinctly all trades on both sides of the market, but we would then introduce a bid-ask bounce effect. To overcome these concerns, and owing to the much higher frequency of orders compared to actual trades, we construct a reliable estimator of the spread within the day, as we described in the previous paragraph. For the construction of the hourly time series of the exchange rate we then employ the last available mid-quote in each hourly interval. In this sense, our intraday series of the exchange rate is akin to one that might be derived from Reuters' FXFX data, although in our case we use firm, not indicative, quotes.

The daily spread is a weighted average of the intraday spreads, where the weights are given by the inverse of the time elapsed between entry of the first quote and entry of the opposite quote; this reflects the idea that the longer the time elapsed, the higher is the probability that the first quote has indeed been withdrawn from the market. For comparison with other currencies, the spread is normalized and expressed as a percentage of the exchange rate times 100, i.e. in basis points. The EUR/CZK average spread is equal to 7.5 basis points.

[20] In the serial correlation statistics, we pay attention to construct regularly spaced, same-day-only lags. In other words, when computing first (second) order serial correlation we drop the observation for the first (two) hourly interval(s) of the day, which would otherwise take as first (second) lag an irregular interval going from 17:00 of the previous day to 8:00 of the current day. The same procedure is applied throughout the rest of the paper, with a small loss of degrees of freedom.

[21] Positive correlation between spread and volatility in emerging market currencies is documented by Galati (2000).

turnover and *conditional* volatility are negatively correlated within the framework of equations (1') and (3).

Serial correlation is absent in the case of order flow, while the log rate change displays significant mean-reversion, equal to –0.15[22].

*3.4 News*

The construction of the public news variable $A_h$ that may in principle affect the EUR/CZK is not straightforward. We made two simplifying assumptions. First, we took into consideration news that are specific to the Czech economy, leaving aside the news that may have an impact on the euro economic area. This choice reflects the idea that the euro is the "central" currency for the koruna and that the latter news source should not cause an update of beliefs on the EUR/CZK (but rather on the EUR/USD or EUR/JPY). Second, in analogy with previous studies of intraday market behavior, we decided to focus on intraday news releases, without considering daily news sources, like the press. Against that background, the obvious candidate source is the on-line Czech Reuters News Service, issuing articles from Prague. The articles are in English, and this circumstance makes them visible to most potential counterparties in the EUR/CZK, even outside the Czech Republic. We therefore collected all Reuters Czech news in the sample period. For each working hour we considered all macroeconomic news (macro data releases, decisions of the monetary authorities, surveys of macroeconomic conditions, etc.), all major political news (e.g. reported public comments of leading government members) and all microeconomic news (those regarding specific companies or industries)[23]. We constructed two hourly news variables: the indicator variable $A_h$, as defined above, and the news count variable $N_h$, equal to the number of news releases in hour *h*. The latter is a variation of $A_h$, which will be used in the empirical section for comparative purposes. The frequency distributions of $A_h$ and $N_h$ are highly concentrated: 77 percent of total hourly intervals has no news, 19 percent has 1 news item, 3.5 percent has 2 items, 0.5 percent has 3 items.

## 4. Results

*4.1 Exchange rate*

In the first place we ran regression (1') with robust estimators for the standard errors. We found a relatively good fit; the LM test revealed however the presence of autoregressive conditional

[22] This phenomenon cannot be related to the bid-ask bounce, since hourly return is measured on the last available mid-quote in each interval. The mid-quote does not reflect actual transactions; therefore the presence of unconditional mean reversion does not necessarily imply market inefficiency.

[23] We filtered out the articles that did not reflect a genuine real-time news event, like summaries of press articles, statistical boxes, market reports, research alerts, etc.

heteroskedasticity. Therefore we turned to the joint estimation of equations (1') and (3). The results are shown in Table 3a[24].

Lines *a-b* give the results for the base version, which covers the entire sample period. We assume that the intervention news variable *INT* turns on from 10:00 am onwards on intervention days, which implies that the impact of intervention on the exchange rate, if any, is felt from 11:00 am onwards on those days. From line *a* we notice in the first place that all coefficients show the correct sign and are significant, with the exception of the effect of public news, equal to 0.097 and insignificant. Therefore line *b* gives the results obtained by dropping the public news variable $A_{h-1}$. The ordinary exchange rate impact of order flow, measured by $\beta_{11}$, is equal to 0.761 and highly significant. This implies that a net purchase of euro with koruna by €10 million brings about a 7.6 basis points rise on EUR/CZK[25]. In nominal terms, this translates into a +23 pips move of the exchange rate, e.g. from 30.540 to 30.563. This estimate is directly comparable with that obtained within the same analytical framework by Evans-Lyons (2002a) for the DEM/USD. These authors find that the exchange rate impact of order flow is equivalent to 0.6 basis points per $10 million[26], therefore our estimate is over twelve times as large as the EL estimate. Froot and Ramadorai (2002) provide projections of order flow[27] on exchange rate returns for the G-10 currencies against the US dollar at various frequencies. For the daily frequency, the highest available, these projections lie in a range between 0.5 basis points per $10 million order flow, for the Canadian dollar, and 2.4 basis points, for the Australian dollar, with Euroland at 0.9 basis points. The big difference between our estimates and those from previous studies seems clearly related to the different degree of liquidity of the EUR/CZK contract compared to the major currency pairs.

We estimate a highly significant effect for the intervention variable, with a value of $\gamma$ equal to 0.387. With a one-hour delay from the start of intervention, as postulated by the model, the additional impact of order flow normalized by €10 million is thus equal to 3.9 basis points. Summing the ordinary effect $\beta_{11}$ to $\gamma$, at times of intervention a net purchase of euro with koruna by €10 million causes a within-hour nominal change in the EUR/CZK of +35 pips, e.g.

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[24] The coefficient estimates and standard errors from the robust estimation of equation (1') alone are substantially similar to the ones obtained under the joint estimation. The former results, not reported for simplicity, are available from the author upon request.

[25] In consideration of the overall market size and the CNB intervention size, taking €10 million as yardstick for the measurement of hourly price impact seems the most reasonable choice. In particular, we considered that average hourly turnover is equal to €18 million, whereas the standard deviation of hourly order flow is €10 million (from Table 2). Furthermore, the average daily size of CNB intervention is €34 million. For the same reasoning, we observe that the issue of possible non-linearity in the response of the exchange rate to order flow has little practical relevance.

[26] EL use data of a different type, namely bilateral interdealer trades from the Reuters Dealing Direct system, in a period without foreign exchange interventions.

[27] Order flow is computed from cross border transactions channeled through one of the world's largest global asset custodians, not from the forex interdealer market.

from 30.540 to 30.575. We observe that, by the model's construction, such effect would apply indifferently to order flow that derives directly from the central bank as well as to order flow stemming from commercial dealers.

Conditional mean reversion is present at the first and second lag, respectively equal to –0.170 and –0.083. The sum of $\beta_{12}$ and $\beta_{13}$ is slightly larger than the cumulative unconditional mean reversion effect (equal to -0.20, from Table 2). Additional lags of $\Delta p$ proved to be insignificant. The cross effect of order flow on the EUR/USD is equal to 0.020, with the expected sign. In view of the much bigger size of the EUR/USD market, in this case it seems more intuitive to measure exchange rate impact from this source per €100 million. In percentage terms, €100 million worth of net euro purchases with dollars cause a rise in the EUR/CZK exchange rate by 2.0 basis points in the same hourly interval, equivalent to 6 pips. It is not possible to compare directly our results with the Evans-Lyons (2002b) estimates of cross order flow effects, owing to the different definition of the variables. However, we could think of the ratio between the outside-order-flow coefficient and the own-order-flow coefficient as a rough measure of the degree of international integration of the local currency market. In our case this ratio is equal to (0.020/0.761=) 0.03, whereas from the cited study we generally obtain much larger figures, like 0.2 for the British pound, 0.5 for the Swiss franc and 4 for the Swedish krona[28].

We show the results for conditional variance on the right hand side of each line, after the results for equation (1'). From line *b* we notice that the lag of volatility is positive and significant as expected[29]. The effect of intervention is positive, with $\alpha_2$ equal to 0.031. The hypothesis that trading intensity dampens the residuals' variance is also confirmed, with $\alpha_3$ equal to –0.007.

An interesting issue is whether "expected" interventions have a different impact on market conditions compared to "unexpected" interventions. In empirical tests, this question can in principle be tackled in different ways. For example, Pasquariello (2002b) exploits the knowledge of the exact timing of central bank operations and computes an expectation indicator based on the intraday quotes surrounding the intervention. The nature of our model, as well as the limitations in the available data, suggested to us a different approach. As we argued, the nominal level of the EUR/CZK in July-September and the policy reaction of the CNB were such that all the intervention episodes in that period can be safely deemed as highly likely ex ante. We do not attempt to measure how likely they were. Rather, we take the major political event of the government crisis of end-September as a clear turning point in the outlook for the koruna exchange rate. We simply assume that the market's expectation of intervention switched from

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[28] These figures are purely indicative. We take as the numerator in the Evans-Lyons ratios the price impact of order flow on the DEM/USD pair, viewed as the leading "outside" contract. The denominator is the price impact of order flow on the domestic currency traded against the US dollar, not the Deutsche mark.

[29] The addition of further lags of volatility yielded insignificant results.

high to low at the beginning of October and remained as such until December. Therefore we set out to check whether this change in the state of the foreign exchange market has affected its micro-structural behavior, by running equations (1') and (3) in the two sub-samples. As we argued in section 2, we would expect that when the probability of intervention is high $\beta_{11}$, the exchange rate impact coefficient, and $\beta_{12}$, the mean reversion coefficient, should both increase compared to the low probability state.

We report the estimates of the base equations (1') and (3) in the first subperiod in lines *c-d* of Table 3a. Line *c* shows the results for the complete model. The $\delta$ coefficient is again not statistically different from 0. A number of coefficients are also not significant at the usual confidence levels: the intervention coefficient $\gamma$ (equal to 0.230) and the EUR/USD order flow effect $\beta_{14}$, in the exchange rate equation; the intervention effect $\alpha_2$ and the coefficient of trading intensity $\alpha_3$, in the variance equation. A specification search led to an alternative regression equation, where we retained the intervention effect in the exchange rate equation and dropped the remaining terms which previously were insignificant. The results are given in line *d*. We find that the ordinary price impact effect is equal to 0.931, i.e. over 20 percent larger than for the entire sample period (from line *b*). The differential impact of actual intervention, given by $\gamma$, is equal to 0.293. The sum of the two effects is 1.224, as against 1.148 during July-December. We also find that mean reversion is substantially larger compared to the entire period: the sum of $\beta_{12}$ and $\beta_{13}$ is now equal to –0.345, against –0.253. Turning to the variance equation, the GARCH effect is lower, with $\alpha_1$ equal to 2.896, against 4.308 in the entire period.

The results for the second subperiod are given in lines *e-f*. In the full regression of line *e* a number of coefficients are not significant, hence we provide a streamlined version in line *f*. Ordinary price impact is equal to 0.660, corresponding to 70 percent of the estimate for July-September (from line *d*). Based on a $\chi^2$ test, the former coefficient is significantly different from the latter. First-order mean reversion is equal to –0.124, and statistically smaller than the value of –0.230 for July-September. The cross-effect of euro/dollar order flow, which disappeared in the third quarter, is equal to 0.031. The GARCH coefficient is equal to 3.968.

The evidence presented so far prompts some remarks. In the first place, we fail to detect a significant incremental effect of public news arrival on exchange rate impact. This might partly be attributed to the nature of the public news variable which, in spite of our efforts, is rather difficult to measure. Second, we have estimated a highly significant impact of order flow on the exchange rate, equal to 7.61 basis points per €10 million over the entire sample. Furthermore, if we take into account the effect of the lagged endogenous variables, the persistent effect of order flow on the exchange rate is equal to (1/1.253), or 80 percent, of the within-hour effect.

Third, based on our hypothesis that a structural break took place in the micro working of the market, our evidence accords fully with the model's predictions. We have empirically estimated the parameters of a rather tense market in the first sub-period. Dealers' behavior appears smoother in the second sub-period, where we estimate that both exchange rate impact and conditional mean reversion, the latter related to the intraday risk premium, decline substantially. In addition, order flow on the "outside" foreign exchange market, captured by EUR/USD order flow, displays a bigger effect on the EUR/CZK, by over 50 percent, consistently with the notion that the domestic conditions matter less.

Fourth, from a policy perspective, regressions *d* and *f* enable us to measure the effectiveness of intervention under three possible states of the market. The period-2 estimate of $\beta_{11}$ reflects the dealers' perception of a low likelihood of intervention. As argued by Evans and Lyons (2001) in their study of secret intervention, that parameter can also be viewed as an indirect measure of the potential effectiveness that central bank intervention would have if it were kept completely secret, as if it were conducted entirely through one discreet intermediary. These authors estimate a within-hour price impact of 44 basis points per \$1 billion. We note that this type of measure has a symmetric property, because it would apply to central bank operations on either side of the market. Such measure has also a different interpretation, because it gives the price impact of transactions unrelated to exchange rate policy that the central bank may wish to carry out on the forex market, e.g. acting as agent for the government or to rebalance its foreign reserve assets[30].

The second layer for the effectiveness of central bank interventions is related to the mere likelihood of their occurrence. We know that in period 1 the market had widespread expectations of the central bank stepping into the market and selling the koruna *vis-à-vis* the euro. We can thus think of the difference between $\beta_{11}$ in period 1 and in period 2 as the incremental impact that is self-generated by the market under the credible, and one-sided, threat of intervention. Thus, by analogy with the previous reasoning, $\beta_{11}$ in period 1 tells the central bank how effective its intervention would have been *if* it had been kept completely secret.

The third layer is the incremental effect that the interventions had precisely because they were *not* kept secret, but became known to the interested parties. This is directly measured by the $\gamma$ value in period 1. The following chart summarizes our estimates of the effect on the EUR/CZK that a €10 million net sale of koruna would have had based on regressions *d* and *f*.

[30] These operations would typically be conducted discreetly and in an orderly market, to avoid sending unintended signals to forex dealers. Although interventions may have the same technical form of policy unrelated transactions, it is safe to say that market dealers would understand very well the intentions of the central bank, based both on market conditions and the type of conversation that accompanies each spot trade by the central bank. Transactions not related to exchange rate management are sometimes viewed as a subgroup of a very broad definition of central bank "interventions", encompassing any operation carried out by the central bank on the forex market (see for example Dominguez and Frankel, 1993).

| | *Same-hour exchange rate impact per €10 million order flow* | *Persistent effect* |
|---|---|---|
| *1) The central bank intervenes secretly (either side), the likelihood of intervention is low* | *6.60 basis points (20 pips)* | *89 percent* |
| *2) The central bank intervenes secretly, the likelihood of intervention is high* | *9.31 basis points (28 pips)* | *74 percent* |
| *3) The central bank intervenes discreetly, the likelihood of intervention is high and the market learns about it* | *(9.31+2.93=) 12.24 basis points (37 pips)* | *74 percent* |

Overall, we interpret the above evidence as providing support for the EL model of the foreign exchange market.

To check for the robustness of our results, we performed alternative regression estimates covering the full sample period with modifications of the explanatory variables. We report these alternative estimates in Table 3b[31]. The first check aims to test whether the assumption that the news of intervention spreads from 10:00 a.m. onwards on intervention days has any effect on the results. Lines *g* and *h* provide the estimates under the alternative assumption that the switching time is 9:00 a.m. and, respectively, 11:00 a.m. (we rule out additional switching times for the reasons given in the previous section). In the first case, from line *g* we notice that the intervention effect $\gamma$ declines slightly, to 0.340, compared to the base case (Table 3a, line *b*), while the remaining coefficients of both the mean equation and the variance equation are virtually unchanged. In the second case, it is noteworthy that $\gamma$ almost vanishes, to 0.059, and becomes statistically insignificant. Correspondingly we observe an increase of the ordinary price impact, to 0.872, and of $\alpha_2$, the intervention effect on the variance equation, which doubles to 0.063 (compared to 0.031, see line *b*). We recall that, by the model's lag structure, the last case rests on the assumption that the intervention news hits the market from 11:00 a.m. and its effect on mean and volatility is felt starting one hour later.

The above evidence clearly indicates that on intervention days the initial trading hours are those when most of the intervention effect takes place on the exchange rate level. This finding is qualitatively similar to the evidence provided by Fischer and Zurlinden (1999), who document that the exchange rate response to interventions is significant for the initial trading hours of the day. In this respect, we have found that choosing 9:00 a.m., as opposed to 10:00, for the initial

[31] In additional checks, not reported for simplicity, we employed additional lags of the explanatory variables and alternative definitions of variables, including for the conditional variance equation. The results of these checks were generally in line with the base case. As concerns the public news variable, we also distinguished macro news, political news, and micro news. None of the sub-categories improved our results.

spreading of the news does not alter substantially the results. We have also shown that if we move the switching time to 11:00 then the intervention effect becomes econometrically undistinguishable from the ordinary price impact coefficient. These findings seem consistent with our understanding of the time sequence of events during intervention days, which laid the ground for the estimates of Table 3a. Hence, the conclusions based on the evidence from that table remain valid.

The second check adopts a slight variation for the public news variable, motivated also by the poor performance of the 0/1 indicator variable employed so far. In line *i* we show the estimates of equations (1') and (3) using the news count variable $N_h$. Even in this case the public news variable remains insignificant.

The last robustness check is done mainly for comparability with the existing literature. A number of empirical studies on market microstructure, notably Hasbrouck (1991) and Evans and Lyons (2002a, b), measure order flow in a slightly different fashion compared to what we did so far. Owing also to the nature of the available data, they compute order flow as the difference between the *number* of market buys and the number of market sales within a given time interval, obtaining a good proxy of net order size. We thus re-estimated the exchange rate equation using the same order flow variable as the one employed in those studies, i.e. as a net "order count" variable. Incidentally, we observe that in the case of Reuters Spot Matching the market's technical arrangement suggests that order count may be a relevant variable, as well as order flow. We refer to the fact that the market screen flags to all dealers in real time the occurrence of every market buy or sale in a dedicated field, without providing the transaction size. This feature of the market corroborates the theoretical model's assumption that interdealer trading is to a large extent visible to all dealers.

The estimates are shown in line *j*. All in all, we observe that the main results of the base case carry through to the alternative specification of order flow. In particular, the ordinary impact coefficient is equal to 0.953, while the intervention effect coefficient is equal to 0.651, and both are highly significant. It is interesting to note that the ratio between the incremental effect of intervention and the ordinary price impact increases if compared to the base case of line *b*, from roughly 50 percent to 68 percent. If we take the view that what really matters on the Reuters Spot Matching market is the trade count, and not so much the actual trade size, the last estimates enhance the support to the underlying model when it predicts a specific role for the news of intervention.

### *4.2 Order flow*

In Table 4 we report consistent estimates of equation (2'). Line *a* shows the base case. We find that lagged order flow and lagged rate change are both insignificant. The contemporaneous effect of EUR/USD order flow is positive and mildly significant. The sign is as expected: buying of euros with dollars is accompanied by buying of euros with korunas, and vice versa.

In view of the poor performance of the regression, we made some specification checks. First, we split up the sample period as we did in the case of equation (1'). From lines *b* and *c*, we note no significant change in the performance of equation (2') in either subperiod. We then tried the order count variable as an alternative measure for the left-hand side of the equation (see line *d*). Again, we found no improvement in the results[32].

One possible reason why we fail to detect positive serial correlation in order flow, as predicted by the model, is the fact that our order flow variable covers Reuters Spot Matching, excluding OTC transactions and other market mechanisms.

## 5. Conclusions

We have failed to find support for the EL model from the estimates of the intraday order flow equation. In particular, we do not detect the positive serial correlation in order flow that would be consistent with "hot potato" trading on the EUR/CZK. This might in part be attributed to the fact that our data set does not include OTC transactions, which account for a considerable share of the market.

However, consistently with the view that the Reuters market does play a crucial function for price discovery, the estimates of the exchange rate equation are clearly in line with the model's predictions. We estimate a highly significant same-hour exchange rate impact of order flow on the exchange rate, equal to 7.6 basis points per €10 million on average, of which 80 percent persists over time. We also document the presence of conditional mean reversion in the exchange rate, that is linked to the existence of an intraday risk premium. The difficulty to disentangle econometrically the effect of public information, as released by news agencies, does not hinder our conclusions.

We identify a structural break in the micro working of the foreign exchange market. This enables us to estimate the model's parameters in two distinct periods characterized by a high ex ante probability of central bank intervention and, respectively, by a low probability of intervention. We interpret these estimates as providing measures of the potential effect of intervention under different states of the market. The first state occurs when the central bank intervenes secretly, on either side of the market, and market dealers do not expect that presence. The second state occurs when the central bank still manages to conceal the intervention, but the market has some fear of it and knows its possible direction. The third state occurs when the

[32] In additional checks we included longer lags of the predetermined variables. We had no improvement, and do not report the results for simplicity.

market expects the intervention and the central bank cannot (or does not want to) avoid that the news spreads among dealers.

Our investigation does not tackle the issue of the long run efficacy of foreign exchange intervention which, owing to the chosen methodology and the limitation in the data sample, goes beyond the scope of this paper. However, we note an important reason why our evidence has a bearing also on that issue. By corroborating the EL model, we lend support to the general view held by the microstructure approach to exchange rates, that new and dispersed bits of information on economic fundamentals are impounded in order flow and, consequently, the latter has permanent price effects. Under the hypothesis that economic agents view intervention as key information on the future intentions of the central bank and hence on the value of the domestic currency, something we believe EUR/CZK dealers did in our case, the evidence of this paper suggests that the role of central bank intervention on the forex market may be long-lived.

When conducting intervention, central banks are first and foremost interested in the short and medium term market developments, the assessment of which is done in continuous time at the dealing desk level. From a policy viewpoint, the long term efficacy of intervention is obviously a key concern, but it is mitigated in practice by the awareness that in the longer run the central bank should be prepared to back its exchange rate policy with the powerful leverage of monetary policy or, put differently, to change the fundamentals, like the CNB did in our sample period. With this important caveat in mind, the findings of this paper provide an argument in favor of the role of central banks in the foreign exchange markets of Central Europe at present and, in the future, within the ERM II.

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**Graph 1**
**EUR/CZK exchange rate**

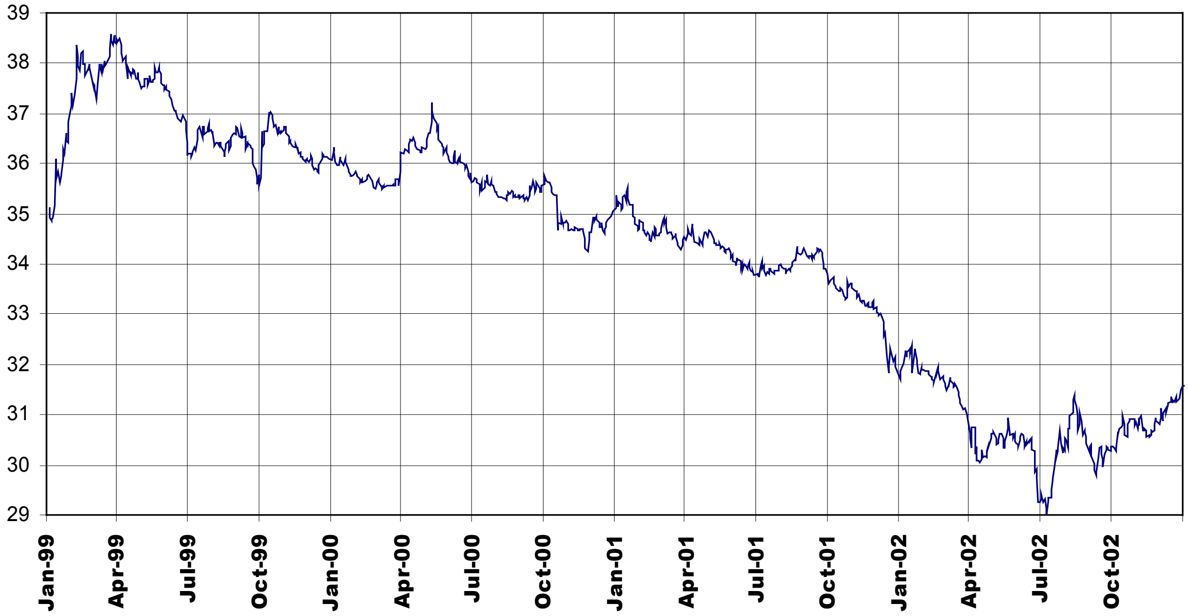

Table 1

EUR/CZK transactions on the Reuters Spot Matching market
Summary statistics – Daily data (July-December 2002)

*Summary statistics*

| | Obs. | Mean | Std. dev. | Sum | Min. | Max. |
|---|---|---|---|---|---|---|
| Turnover | 128 | 169.6 | 79.0 | 21713 | 33 | 429 |
| Order flow | 128 | 5.9 | 31.4 | 752 | -82 | 89 |
| Log rate change | 127 | 6.2 | 47.4 | 792.8 | -99.0 | 142.4 |
| Volatility | 127 | 0.23 | 0.37 | | 0 | 2.03 |
| Spread | 128 | 7.5 | 2.9 | | 3.0 | 22.6 |

*Cross correlation*

| | Order flow | Log rate change | Volatility | Spread |
|---|---|---|---|---|
| Log rate change | 0.49 *** | | | |
| Volatility | 0.30 *** | 0.49 *** | | |
| Spread | 0.03 | 0.01 | 0.18 ** | |
| Turnover | 0.24 *** | 0.29 *** | 0.49 *** | -0.10 |

Notes: Turnover and order flow are in millions of euros. The log rate change is multiplied by 10,000. The daily rate is given by the last traded rate before 5 pm Central European Time. Volatility is the squared log rate change multiplied by 10,000. The spread is given by the average intraday inside spread divided by the rate level and multiplied by 10,000, i.e. in basis points. *** denote significance of correlation at the 1 percent level, ** denote significance at the 5 percent level, * denotes significance at the 10 percent level.

Table 2
EUR/CZK transactions on the Reuters Spot Matching market
Summary statistics – Hourly data (8:00-17:00 CET)

*Summary statistics*

| | Obs. | Mean | Std. dev. | Min. | Max. |
|---|---|---|---|---|---|
| Turnover | 1130 | 18.1 | 17.9 | 1 | 166 |
| Order flow | 1130 | 0.5 | 10.1 | -42 | 73 |
| Log rate change | 1058 | 0.17 | 18.82 | -73.5 | 136.3 |
| Volatility | 1056 | 0.04 | 0.10 | 0 | 1.9 |
| Spread | 1147 | 8.1 | 8.3 | 0.01 | 150.8 |

*Cross correlation*

| | Order flow | Log rate change | Volatility | Spread |
|---|---|---|---|---|
| Log rate change | 0.47 *** | | | |
| Volatility | 0.12 *** | 0.30 *** | | |
| Spread | -0.01 | 0.03 | 0.10 *** | |
| Turnover | 0.14 *** | 0.17 *** | 0.37 *** | -0.13 *** |

*Serial correlation*

| | First order | Second order |
|---|---|---|
| Log rate change | -0.15 *** | -0.05 |
| Order flow | 0.04 | -0.01 |

Notes: Turnover and order flow are in millions of euros. The log rate change is multiplied by 10,000. The hourly rate is given by the last mid-quote available at the end of each hour. Volatility is the hourly squared log rate change multiplied by 10,000. The spread is given by the average hourly inside spread divided by the rate level and multiplied by 10,000, i.e. in basis points. *** denote significance of correlation at the 1 percent level, ** denote significance at the 5 percent level, * denotes significance at the 10 percent level.

Table 3a
Exchange rate equation

*Conditional mean (eq. 1')* $\Delta p_h = (\beta_{11} + \delta\, A_{h-1} + \gamma\, INT_{h-1})\, \Delta x_h + \beta_{12}\, \Delta p_{h-1} + \beta_{13}\, \Delta p_{h-2} + \beta_{14}\, \Delta x_h^{US} + \eta_h^P$

*Conditional variance (eq. 3)* $Var(\eta_h^P) = \alpha_0 + \alpha_1\, (\Delta p_{h-1})^2 + \alpha_2\, INT_{h-1} + \alpha_3\, I_{h-1}$

| | Conditional mean | | | | | | Conditional variance | | | | Wald test p-value | Obs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\beta_{11}$ | $\delta$ | $\gamma$ | $\beta_{12}$ | $\beta_{13}$ | $\beta_{14}$ | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | | . |
| *July-December 2002* | | | | | | | | | | | | |
| *a)* | 0.742 | 0.097 | 0.371 | -0.170 | -0.083 | 0.020 | 5.379 | 4.307 | 0.031 | -0.007 | 0.00 | 777 |
| | (11.58) | (0.77) | (2.65) | (-4.28) | (-2.38) | (1.94) | (57.81) | (10.05) | (1.90) | (-2.30) | | |
| *b)* | 0.761 | | 0.387 | -0.170 | -0.083 | 0.020 | 5.378 | 4.308 | 0.031 | -0.007 | 0.00 | 777 |
| | (12.29) | | (3.02) | (-4.26) | (-2.36) | (1.93) | (45.26) | (6.87) | (1.98) | (-2.96) | | |
| *July-September 2002* | | | | | | | | | | | | |
| *c)* | 0.904 | 0.068 | 0.230 | -0.210 | -0.105 | 0.017 | 6.654 | 3.684 | 0.027 | -0.007 | 0.00 | 409 |
| | (9.43) | (0.44) | (1.48) | (-3.88) | (-2.19) | (1.14) | (67.78) | (8.39) | (1.77) | (-1.75) | | |
| *d)* | 0.931 | | 0.293 | -0.230 | -0.115 | | 5.606 | 2.896 | | | 0.00 | 413 |
| | (9.65) | | (2.01) | (-4.28) | (-2.34) | | (26.51) | (3.53) | | | | |
| *October-December 2002* | | | | | | | | | | | | |
| *e)* | 0.580 | 0.169 | | -0.091 | -0.032 | 0.020 | 5.002 | 5.997 | | -0.011 | 0.00 | 368 |
| | (6.19) | (0.72) | | (-1.44) | (-0.85) | (1.54) | (22.53) | (3.90) | | (-1.16) | | |
| *f)* | 0.660 | | | -0.124 | | 0.031 | 4.926 | 3.968 | | | 0.00 | 438 |
| | (6.88) | | | (-2.69) | | (2.58) | (38.72) | (2.45) | | | | |

Notes: Heteroskedasticity-consistent *t*-statistics are reported in parentheses. The estimates are based on hourly data from 8:00 am to 5:00 pm CET on working days. $\Delta p_h$ is the hourly change in the log spot exchange rate, using the last available mid-quote in each interval, times 10,000. $A_h$ is an indicator variable equal to 1 if one or more public news event occur in hour *h*, and 0 otherwise. $INT_h$ is an indicator variable equal to 1 from 10:00 am onwards on intervention days, and 0 otherwise. $\Delta x_h$ is hourly interdealer order flow in millions of euros (negative for net seller-initiated trades). $\Delta x_h^{US}$ is interdealer order flow in the EUR/USD contract on the Reuters Spot Matching system in millions of euros. $I_h$ is turnover in interval *h*, measured as the number of trades.

Table 3b
Exchange rate – robustness checks

*Conditional mean* $\Delta p_h = (\beta_{11} + \delta\, A_{h-1} + \gamma\, INT_{h-1})\ \Delta x_h + \beta_{12}\, \Delta p_{h-1} + \beta_{13}\, \Delta p_{h-2} + \beta_{14}\ \Delta x_h^{US} + \eta_h^P$

*Conditional variance* $Var(\eta_h^P) = \alpha_0 + \alpha_1\ (\Delta p_{h-1})^2 + \alpha_2\ INT_{h-1} + \alpha_3\ I_{h-1}$

| | Conditional mean | | | | | | Conditional variance | | | | Wald test p-value | Obs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\beta_{11}$ | $\delta$ | $\gamma$ | $\beta_{12}$ | $\beta_{13}$ | $\beta_{14}$ | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | | . |
| *g) Intervention news after 9:00* | 0.751<br>(10.71) | | 0.340<br>(2.78) | -0.167<br>(-4.05) | -0.083<br>(-2.36) | 0.020<br>(1.89) | 5.389<br>(34.26) | 4.346<br>(4.27) | 0.028<br>(1.89) | -0.007<br>(-1.64) | 0.00 | 777 |
| *h) Intervention news after 11:00* | 0.872<br>(12.73) | | 0.059<br>(0.40) | -0.151<br>(-3.76) | -0.074<br>(-2.24) | 0.020<br>(2.02) | 5.374<br>(38.38) | 4.666<br>(6.19) | 0.063<br>(3.76) | -0.008<br>(-2.41) | 0.00 | 777 |
| *i) News count var.* $N_h$ | 0.718<br>(10.50) | 0.191<br>(1.30) | 0.361<br>(2.62) | -0.172<br>(-4.28) | -0.083<br>(-2.36) | 0.020<br>(1.94) | 5.378<br>(42.35) | 4.286<br>(5.94) | 0.029<br>(1.75) | -0.007<br>(-2.33) | 0.00 | 777 |
| *j)* $\Delta x, \Delta x^{US}$ *defined as order count* | 0.953<br>(12.27) | | 0.651<br>(3.92) | -0.156<br>(-3.47) | -0.076<br>(-2.11) | 0.033<br>(1.78) | 5.328<br>(29.03) | 4.348<br>(2.25) | 0.033<br>(1.98) | -0.006<br>(-0.93) | 0.00 | 777 |

Notes: Heteroskedasticity-consistent $t$-statistics are reported in parentheses. The estimates are based on hourly data from 8:00 am to 5:00 pm CET on working days. $\Delta p_h$ is the hourly change in the log spot exchange rate, using the last available mid-quote in each interval, times 10,000. $A_h$ is an indicator variable equal to the number of public news events in hour *h*. $INT_h$ is an indicator variable equal to 1 after 10:00 am (except in lines *g* and *h*) on intervention days, and 0 otherwise. $\Delta x_h$ is hourly interdealer order flow in millions of euros (negative for net seller-initiated trades). $\Delta x_h^{US}$ is interdealer order flow in the EUR/USD contract on the Reuters Spot Matching system in millions of euros. $I_h$ is turnover in interval *h*, measured as the number of trades.

Table 4
Order flow equation

*Equation (2')* $$\Delta x_h = \beta_{21}\Delta x_{h-1} + \beta_{22}\Delta p_{h-1} + \beta_{23}\Delta x_h^{US} + \eta_h^x$$

| | $\beta_{21}$ | $\beta_{22}$ | $\beta_{23}$ | $R^2$ | Autocor p-value | Hetero p-value | ARCH p-value | Obs. |
|---|---|---|---|---|---|---|---|---|
| $\Delta x$, $\Delta x^{US}$ *defined as order flow* | | | | | | | | |
| *a) July-December2002* | -0.003<br>(-0.08) | 0.032<br>(1.33) | 0.012<br>(1.92) | 0.007 | 0.759 | 0.884 | 0.028 | 904 |
| *b) July-September 2002* | -0.024<br>(-0.40) | 0.044<br>(1.47) | 0.017<br>(2.00) | 0.012 | 0.712 | 0.562 | 0.154 | 472 |
| *c) October-December 2002* | 0.028<br>(0.50) | 0.011<br>(0.28) | 0.002<br>(0.29) | 0.002 | 0.467 | 0.109 | 0.123 | 432 |
| $\Delta x$, $\Delta x^{US}$ *defined as order count* | | | | | | | | |
| *d) July-December2002* | -0.009<br>(-0.19) | 0.024<br>(1.27) | 0.018<br>(2.07) | 0.007 | 0.925 | 0.163 | 0.077 | 903 |

Notes: Heteroskedasticity-consistent *t*-statistics are reported in parentheses. The estimates are based on hourly data from 8:00 am to 5:00 pm CET on working days. $\Delta p_h$ is the hourly change in the log spot exchange rate, using the last available mid-quote in each interval, times 10,000. In lines *a-c* (alternatively *b*) $\Delta x_h$ is hourly interdealer order flow (count) in millions of euros (in number of trades). $\Delta x_h^{US}$ is the corresponding variable for the EUR/USD contract on the Reuters Spot Matching market. The Autocor column shows the *p*-value of LM test on the absence of first-order serial correlation in the residuals. The Hetero column shows the *p*-value of the test on constant residuals' variance. The ARCH column gives the *p*-value of the LM test on the absence of ARCH effects.