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Is foreign exchange intervention effective?
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by Antonio Scalia

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IS FOREIGN EXCHANGE INTERVENTION EFFECTIVE?

SOME MICRO-ANALYTICAL EVIDENCE FROM THE CZECH REPUBLIC

by Antonio Scalia*

Abstract

I estimate a two-equation system on the Czech koruna-euro exchange rate and order flow at hourly frequency within the framework of Evans-Lyons (JME 2002). I use transactions data from the Reuters Spot Matching market in the second half of 2002, during which the Czech National Bank conducted discreet interventions to stem the appreciation of the domestic currency. I find a significant impact of order flow on the exchange rate, equal on average to 7.6 basis points per €10 million, of which 80 per cent persists throughout the day. The news of intervention increases the price impact of order flow by 3.9 basis points per €10 million, consistently with the notion of intervention efficacy. The order flow equation yields inconclusive results.

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* Bank of Italy, Monetary and Foreign Exchange Policy Department, Via Nazionale 91, 00184 Rome. Tel. +39-0647923390; fax +39-0647923083. Email: antonio.scalia@bancaditalia.it.

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, with a floating exchange rate regime for the local currency, the koruna (CZK). Drawing mainly from the microstructure model of Evans-Lyons (2002a, henceforth EL), I estimate a two-equation system on the rate change and, respectively, the order flow measured at hourly intervals on the CZK/EUR currency pair. My main hypothesis is that the news of intervention should increase the impact of order flow on currency returns. I adopt the following empirical definition of effectiveness, which is directly testable: if the econometric estimates support the above hypothesis, then I claim that intervention was effective.

I employ two original sources of data. First, I 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. The sample period spans a prolonged round of discreet purchases of euros against korunas conducted in the spot market by the Czech National Bank (CNB) on 28 days between July and September. My second data source is the CNB, which kindly disclosed to me the intervention days and its operating practices. Although the exact timing within each day and the daily amounts are not available, I know that these operations were conducted according to the same basic rule: on each intervention day an assessment of the forex market took place in the initial working hours, after which the CNB dealing desk executed the interventions smoothly and in small lots throughout the rest of the day. In spite of the covert nature of the interventions, the CNB desk admits that the market at large learned about the bank's presence very rapidly. This is also confirmed by press reports and anecdotal evidence. The spreading of the intervention news, together with the regularity of the operations, enable me to construct an indicator variable that captures fairly well the market's awareness of intervention at hourly frequency. To my knowledge this is the first study to employ the microstructure approach to

exchange rates (Lyons, 2001), involving order flow data and the intraday frequency, in the analysis of interventions performed by an emerging country.

Several studies have tried to shed light on the efficacy of the interventions conducted on the major international currencies within the microstructure framework, thus adding new perspective into a long standing debate.[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 signalling effect. However, unlike in traditional models, information heterogeneity on the part of investors and the information aggregation process crucially come into play.[3] 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, 2004; Dominguez, 2003, 2005; 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 bank activity has significant 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 (2003) 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's interventions produced a larger impact on the exchange rate when they were concerted and when they were "leaning with the wind".

The extensive IMF survey of emerging markets (Canales-Kriljenko, 2003) shows that the effect of official foreign exchange intervention is usually larger than in developed

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[2] Surveys of the literature on central bank intervention are provided by, among others, Baillie, Humpage and Osterberg (2000), Catte, Galli and Rebecchini (1994), Dominguez and Frankel (1993), Galati and Melick (2002), Sarno and Taylor (2001), Humpage (2003), Vitale (2004).

[3] Theoretical models of intervention and forex market microstructure are developed by Bhattacharya and Weller (1997), Derviz (2003), Dominguez (2005), Evans and Lyons (2001, 2002a), Pasquariello (2002a), Popper and Montgomery (2001), Vitale (1999). Bacchetta and van Wincoop (2005) provide a model of exchange rate determination with investor heterogeneity.

countries. This phenomenon is explained in the first place by a *size effect*. While foreign exchange intervention by the central banks issuing the major currencies accounts for a small fraction of forex market turnover, in developing countries the intervention amounts are large in relation to the level of market turnover, the money base and the stock of domestic bonds, thus adding support for the portfolio balance hypothesis. Furthermore, central banks in developing and transition economies have a greater *information advantage* over market participants. Owing to reporting requirements, central banks may infer aggregate foreign exchange order flow; they can also actively use monetary regulations and operating practices, which may increase the advantage. In some cases the unsterilized nature of the intervention further enhances its effectiveness.[4] Disyatat and Galati (2005) review the empirical studies on foreign exchange intervention in emerging countries, which use time series at *daily* or lower frequency of the exchange rate and the intervention amounts. It is confirmed that the impact of intervention on the exchange rate level depends to a large extent on the monetary policy framework and the communication policy of the central bank, whereas intervention is generally successful in reducing exchange rate volatility. In particular Domaç and Mendoza (2004) examine the experience of Mexico and Turkey, in which, as in the Czech Republic, an inflation targeting regime is adopted and the central bank uses forex intervention to dampen temporary shocks to the exchange rate. The study shows that a central bank's sale in the market of USD 100 million appreciates the peso by 8 basis points and the lira by 20 basis points, respectively. The Czech experience in exchange rate management is described by Holub (2005). It is argued that the round of interventions of July-September 2002 had an important effect, leading to a nominal depreciation of the koruna against the euro by 9 percent at year end compared with the record level of July, and to a relatively weak exchange rate throughout 2003. Disyatat and Galati (2005) perform a regression analysis of the Czech case in the period September 2001-Octobrer 2002. Using an indicator variable for intervention days, their evidence is that the impact of the CNB activity on the CZK/EUR level is only slightly significant.

I seek to further the analysis of the Czech case using primarily the EL micro portfolio-balance model. Its basic idea is that, in a world with risk averse traders and dispersed

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[4] I note, however, that the last effect does not apply to the case examined in this study.

information on the asset's value,[5] 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 the price. Causality then runs from order flow to prices.[6] The arrival of news increases the price impact of trades, since the news brings about a major update of agents' dispersed beliefs.

My second motivation has a policy nature. The Czech Republic, together with Poland, Hungary and other Central European countries, is expected to participate in the European Exchange Agreement, also known as ERM II, in the coming years, following entry in the European Union in May 2004 (see ECB, 2004).[7] 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-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 design of the agreement is aimed at combining discipline and adjustability on the road to the 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. 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 into the conditions for effective central bank actions in the future, particularly in view of the discretionary nature of intra-marginal interventions.

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[5] 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, I note that dispersed beliefs do not necessarily imply that individuals possess "superior" information. Most macroeconomic variables, such as 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.

[6] Several studies argue that this direction of causality is not obvious, depending in the first place on the possibility of trend-chasing behaviour. See in particular Froot and Ramadorai (2005).

[7] Estonia, Lithuania and Slovenia joined the ERM II in June 2004; Malta, Cyprus and Latvia joined in April 2005; Slovakia in November of the same year.

The CNB interventions conducted between July and September aimed to reverse the appreciating trend of the nominal exchange rate of the koruna, driven by the market's expectation of large foreign capital inflows (see CNB, 2002). This led to the CZK/EUR 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 dealers. During October-December the tension on the koruna eased considerably, the CZK/EUR remained well above the critical level of 30 and the market's fear of CNB intervention faded. 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.

My main results are as follows. I find 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 my intraday setting, the persistent effect of order flow on the exchange rate corresponds to 80 per cent of the within-hour effect. I also find that the intervention news significantly increases the price impact of order flow, by 3.9 basis points per €10 million order flow, thus supporting the notion that the CNB interventions were effective. In the case of the order flow equation my results are not statistically significant.

Taking advantage of the change in the perceived likelihood of the central bank's presence in the market during my sample period, I identify three ways in which intervention may in principle affect the exchange rate level, corresponding to different states of the market.[8] First, the central bank might intervene secretly in orderly market conditions, such as those prevailing for the CZK/EUR in the last quarter of 2002, when dealers faced a *low likelihood* of intervention. In 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, irrespective of its occurrence. In such circumstances the ordinary 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 secret intervention in those circumstances. The third state involves the market's *knowledge* that the central bank is

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[8] Other studies, notably Dominguez (2003) and Payne and Vitale (2003), adopt different definitions of the "state of the market".

indeed intervening. 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.

I acknowledge that the possibility of keeping interventions totally secret is rather abstract, so I view the first two modalities above as purely informative. However, I also note that the first method has a different and more intuitive interpretation, that may be quite useful from an operational standpoint: it gives the price impact estimate of non-policy-related transactions that the central bank may want to conduct in the forex market, typically in orderly conditions, e.g. acting as an agent for the government or for reserve management purposes.

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

2. Market and data

2.1 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.

A picture of exchange rate developments in the Czech Republic is provided by Holub (2005). If we restrict our attention to the four-year period from the launch of the euro, in January 1999, to the end of the data sample, the koruna experienced an initial nominal depreciation against the euro, with the CZK/EUR exchange rate moving from 35 to 38.5 in April of 1999 (Graph 1).[9] Since then the koruna has moved along an appreciating trend vis-à-vis the euro. The strengthening was particularly evident from end-2001 to mid-2002, following large capital inflows related to the privatization process. At the beginning of the

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

summer of 2002 the CZK/EUR 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 CZK/EUR exchange rate was equal to 30.54 and it fluctuated in the range +3.6/-5.2 per cent 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, mainly owing 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. In August 2005 the government made public that it sees 2010 as the target year for entry in the euro zone, implying that it would pursue entry in the ERM II towards the end of 2007 or the beginning of 2008.

Two key features of Central European currencies, including the Czech koruna, are the relatively low liquidity and high volatility compared with the currencies of other major European countries. 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 in April 2001.[10] For the sake of comparison, the BIS survey indicates that spot transactions on a daily basis for the Danish krone (DKK), currently the major participant in the ERM II with the euro, were equivalent to $2,988 million. During 2002 volatility, measured as the annualized standard deviation of daily log rate changes, was equal to 7 per cent for CZK/EUR and to 0.8 per cent in the case of DKK/EUR.[11]

Derviz (2003) reports detailed information on the structure of the interbank forex market for the koruna. The number of domestic banks licenced as market makers in the koruna is 18, including local branches of leading international banks; the most active players, with a market share above 5 per cent each, number 8. Licenced banks can execute spot, forward and other derivative transactions. The CZK/EUR is the leading pair in the spot

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[10] The CNB statistics 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 $802 million respectively.

[11] Denmark, in view of the historical stability of its 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 per cent.

market, while the swap market is mainly done in the CZK/USD. A large volume of koruna transactions take place offshore, and many of the trades executed by licenced banks in Prague are initiated by a parent bank outside the Czech Republic. The major international players in korunas include banks form Germany, the Netherlands, the UK and the US. I have separate evidence on the relevance of offshore spot transactions in the CZK/EUR pair. Based on our dataset (see below), which records the country of establishment of the party that initiates a trade, I note that the largest share is from the United Kingdom (37 per cent), followed by the Czech Republic (32 per cent), Austria (14 per cent), Germany and the US (5 per cent each).

2.2 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 for a total €1.3 billion.[12] 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 again stepped into the market purchasing the euro in a round of discreet interventions. These operations were accompanied by a rebound of the CZK/EUR, which moved away from the critical level of 29. On July 25, against the backdrop of a favourable inflation outlook, the CNB cut its key rate by 0.75 percentage points, setting the 2-week repo rate at 3 per cent, below the value of the ECB key rate at 3.25 per cent. The move, larger than anticipated by market participants (CNB, 2002), was accompanied by a further rise in the nominal level of the CZK/EUR. Besides, official statements reinforced the market's confidence in 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 appreciation of the koruna was interrupted by the government crisis. The political uncertainty contributed to set the Czech currency on a slightly depreciating trend, which continued until December, the end of our sample period.

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[12] The CNB publishes the monthly figures of intervention amounts on its website.

Until April 2002 the CNB used to announce publicly the conduct of interventions. This practice was changed in July of the same year. Market practitioners and the press described the CNB's operations of the summer of 2002 as "stealth interventions" because the Bank, with few exceptions, declined to make comments. Furthermore, the CNB chose to trade with a restricted pool of counterparts and sought some confidentiality. During July-September the Czech financial press, commenting the pattern of the CZK/EUR exchange rate, had a number of morning briefings about the market's expectation of central bank interventions. Afternoon commentaries often reported "market sources" saying that the CNB had indeed been seen in the market. That these discreet interventions conveyed information to price setting dealers is confirmed by an anecdote. On some occasions the CNB stepped into the market and selected some dealers but not others, who 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. Not surprisingly, no press reports about the presence of the CNB in the market 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, and €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, equivalent to 5 per cent of daily total spot transactions of koruna against other currencies.

I do not know the daily breakdown of the interventions, nor do I know the exact timing within the day. However, partly owing to the discreet nature of the CNB operations, the time schedule of events was smooth. The CNB Board performed an assessment of market developments at its regular weekly meetings and occasionally during ad hoc meetings. This assessment produced among other things a decision whether to conduct forex interventions in the following days, accompanied by general instructions on the trigger level of the CZK/EUR exchange rate and the total amount. The intervention instructions were passed on for execution to the dealing desk, which had some leeway on the best timing of the operations. Within a given day, the interventions were preceded by an assessment of market conditions at the CNB dealing desk 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 learnt the news about the presence of the CNB, either directly or through rumours, not in the early trading rounds but some time later.[13]

In the empirical estimation of the exchange rate equation (see Section 4.1) I will assume that the news of intervention becomes known to (at least some) dealers in the market from 10:00 onwards on intervention days; thus, owing to the lag structure of the econometric specification, the effect on the exchange rate is felt from 11:00 onwards. I will also provide the results under alternative assumptions.

2.3 The Reuters Spot Matching data set

Reuters is one of the two leading providers of electronic broking services in the foreign exchange market,[14] 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 per cent of all spot transactions involving the Czech koruna; the rest are carried out mainly on the OTC market, both direct and brokered, and on the Reuters Dealing Direct system.[15] Owing to transparency, liquidity and efficiency considerations, the Spot Matching market may be considered the leading segment for the behaviour of the CZK/EUR, which is the currency pair of interest for the Czech monetary authorities (see also Derviz, 2003).[16]

The Reuters Dealing 3000 Spot Matching system is a multilateral trading platform operated as an electronic limit order book, i.e. 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 limit orders up to the threshold set by the

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[13] 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 (2003).

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

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

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

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 also operates a different facility, the Dealing 3000 Direct, whereby any dealer can contact a specific counterpart 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 -17:00 local time, corresponding to Central European Time (CET), Monday through Friday. Therefore I restrict my analysis to the sub-sample of data in that date/time interval.[17] It is useful to recall that the CZK/EUR exchange rate is defined as the number of Czech korunas per 1 euro and the unit transaction size in the market is €1 million.

Summary statistics on a daily basis for the CZK/EUR 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.[18] Daily turnover in CZK/EUR is €169.6 million. Average order flow is equal to +€5.9 million, indicating net euro purchases against the koruna over the sample period. Volatility, measured as the squared daily return, is equal to 0.23 basis points.

The data set does not record when a given quote is 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. I took a simple stance and, in view of the relatively low liquidity of the CZK/EUR and of casual inspection, I assumed that each quote expires after 5 minutes, if it has not been

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

[18] 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. I 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.

previously matched (something I detect from order flow).[19] At discrete, high frequency points in time I 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.[20, 21]

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 to the previous table at hourly intervals within each day. To construct the hourly time series of the exchange rate I employ the last available mid-quote in each interval. I discard a small number of hourly intervals (2 per cent) where the absence of quotes on both sides did not allow the computation of the exchange rate. We are thus left with 1,130 valid hourly intervals. Market turnover is zero in 13 intervals and its average value is €18.1 million. 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.[22] Turnover and (unconditional) volatility are positively correlated. I observe that the latter finding does not necessarily contradict the hypothesis that turnover and

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[19] I also discard a quote if a new quote arrives on the opposite side, which would open up an arbitrage opportunity.

[20] Indeed, the above assumption enables me to track the entire limit order book.

[21] Let me clarify why I am making this digression on the spread, which is not directly relevant to our analytical framework. I have a practical reason. Indeed, on account of the relatively low market turnover, I would have some difficulty in constructing the intraday series of CZK/EUR rates if I used uniquely the record of actual transactions. This happens because in several cases the hourly intervals in the sample period have a low number of trades or no trades at all, which would blur the measurement of hourly return. I could solve the problem if I took indistinctly all trades on both sides of the market, but I would then introduce a bid-ask bounce effect. To overcome these concerns, and owing to the much higher frequency of orders compared with actual trades, I construct a reliable estimator of the spread within the day, as described in the text. For the construction of the hourly time series of the exchange rate I 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 I 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 CZK/EUR average spread is equal to 7.5 basis points.

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

conditional volatility are negatively correlated (see below equations 3 and 5). Table 2 also provides the serial correlation coefficients for the two key variables of the empirical analysis, return and order flow.[23] Serial correlation is absent in the case of order flow, while the log rate change displays significant mean-reversion, equal to –0.15.[24]

2.4 News

The construction of the public news variable that may in principle affect the CZK/EUR is not straightforward. I made three simplifying assumptions. First, I took into consideration the news items 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 CZK/EUR, but rather on the USD/EUR or JPY/EUR. Second, in analogy with previous studies of intraday market behaviour, I decided to focus on intraday news releases, without considering daily news sources like the press. Third, on account of the relevance of offshore koruna transactions, I took into consideration a news source in English. The natural candidate is the on-line Czech Reuters News Service, issuing articles in English from Prague and providing a broad coverage of local news compared with the Reuters Service in the Czech language. I thus use a source that is visible to most counterparts in the CZK/EUR, even outside the Czech Republic.

I therefore collected all Reuters Czech news in the sample period. For each working hour I considered all macroeconomic news[25] (macro data releases, decisions of the monetary authorities, surveys of macroeconomic conditions, etc.), all major political news (e.g.

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[23] In the serial correlation statistics, I take care to construct regularly spaced, same-day-only lags. In other words, when computing first (second) order serial correlation I 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.

[24] 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.

[25] The regular macroeconomic news releases are the monthly state budget, T-bill yields at the auction, CPI, PPI, retail sales, new car sales, industrial output, basic grain harvest, trade balance, consumer confidence, PMI, GDP (quarterly), CNB foreign currency reserves, and CNB press release (weekly).

reported public comments of leading government members) and all microeconomic news (those regarding specific companies or industries).[26]

I constructed two hourly news variables: the indicator variable A_h, taking the value 1 if one or more news items are observed in hour h, and the news count variable N_h, equal to the number of news releases in hour h. The two variables will be alternatively used in the empirical section for comparative purposes. The frequency distributions of A_h and N_h are highly concentrated: 77 per cent of total hourly intervals have no news, 19 per cent have 1 news item, 3.5 per cent have 2 items, 0.5 per cent have 3 items.

3. Empirical model

The analytical framework for my empirical investigation is provided by the EL micro portfolio-balance model, which describes the joint behaviour of order flow and returns within a trading day. The model makes the hypothesis that the arrival of news prompts an adjustment in agents' expectations, which is in turn conveyed to the market by order flow.

I view the news of intervention as a distinct item compared with the broad set of "public news" that may potentially affect the fundamental value of the exchange rate. When the central bank intervenes discreetly in the market, it constitutes initially a private information event for the counterparts of the intervention. I hypothesize that those possessing this information will gradually reveal it not only through their trades but also directly and confidentially to their own customers, 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 in view of the ability of the central bank to affect directly one of the fundamentals, namely the domestic interest rate. Hence, that type of news should have a larger impact on the exchange rate, through the order flow variable, than public news. I 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.

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[26] I filtered out the articles that did not reflect a genuine real-time news event, such as summaries of

The trading day is divided into 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 ΔR_t. The latter can be thought of as interest rate movements, although it can be seen as representing macro fundamentals more generally. In an hourly setting, the solution to the dealer's optimization problem yields two estimable equations: one for the change in the log exchange rate, Δp_h, and one for order flow, Δx_h, as follows:

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

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

where:

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

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

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

From equation (1), hourly return Δp_h is a positive function of contemporaneous order flow Δx_h and a negative function of its own lag.[27] A news event in the previous hour ($A_{h-1} = 1$) increases the contemporaneous exchange rate impact of order flow by a coefficient β_2, reflecting the incremental information about ΔR_h in the private order flow C_{1h} received from customers, which is not measurable. The incremental effect of order flow is larger in the case of the news of intervention in the previous hour, with $\gamma > \beta_2$. The mean-reversion of the exchange rate captures the transitory intraday risk premia that arise in the

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press articles, statistical boxes, market reports, research alerts, etc.

[27] 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 Δx 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.

model. The residual term η_h^P in the return equation is linked to the arrival of news in the form of ΔR_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 η_h^x captures the flow of unmeasured, contemporaneous customer orders.

In the empirical implementation of the next section I will first estimate equations (1)-(2) of the base model. From there I will move on to a more general specification, which includes an equation for the conditional volatility of exchange rate returns. In the extended model, which is admittedly ad hoc, I follow a general-to-simple estimation approach. In the remainder of this section I present the extended model.

I generalize the base equations in two ways. First, I allow for the possibility that additional lags of the exchange rate return Δp exert an influence on its current value, implying that mean reversion would last longer than one hour. Second, I 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 USD/EUR. In the latter hypothesis, I 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 explained in the light of information aggregation in a 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, I will allow for the possibility that intraday order flow in CZK/EUR is positively affected by contemporaneous order flow in USD/EUR.

The extended equations for the exchange rate and, respectively, order flow are as follows:

$$(3) \qquad \Delta p_h = \left(\beta_{11} + \delta \, A_{h-1} + \gamma \, INT_{h-1} \right) \Delta x_h + \beta_{12} \, \Delta p_{h-1} + \beta_{13} \, \Delta p_{h-2} + \beta_{14} \, \Delta x_h^{US} + \eta_h^P$$

$$(4) \qquad \Delta x_h = \beta_{21} \Delta x_{h-1} + \beta_{22} \Delta p_{h-1} + \beta_{23} \Delta x_h^{US} + \eta_h^x .$$

For simplicity of notation I limit the lag length of Δp to 2 because I empirically find that longer lags are never statistically significant (see below).[28] I would expect $\gamma > \delta > 0$. Besides, Δx_h^{US} is contemporaneous (same hour) order flow in the USD/EUR contract on the Reuters Spot Matching market, with a plus indicating net euro purchases and vice versa. Other things being equal, I would expect a net purchase (sale) of euros with US dollars to be associated with a net purchase (sale) of euros with korunas, which implies $\beta_{23} > 0$; this order flow should directly affect the nominal CZK/EUR 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, 2004; Dominguez, 2003, 2005; Pasquariello, 2002b).

This has led me to introduce the third extension of the base model, namely a parsimonious GARCH effect alongside equation (3). 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, is such that my time series are not continuous. Indeed, they display overnight breaks plus weekend breaks; together, these breaks make the estimation of a GARCH model infeasible. I try to circumvent this limitation through a pseudo-GARCH specification as follows. I 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). I compute the hourly series of the unconditional variance (i.e. the square) of exchange rate returns for the regular intervals only

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[28] The lag structure of equation (3), spanning two hours, requires me to "sacrifice" the first two intervals every day to prevent discontinuities in the hourly time series (see footnote 23).

(excluding the overnight and weekend intervals, see footnote 23). I 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. Consistently with the hypothesis that volatility persists during the day, I expect a positive coefficient in my pseudo-GARCH model.

To test for the presence of an intervention effect on exchange rate volatility I include the first lag of the intervention variable *INT* in the conditional variance equation. This is motivated by the nature of the residual term η_h^P, linked to the arrival of news.

Lastly, I will allow for the possibility that time-varying trading intensity affects the conditional variance of the exchange rate equation. I hypothesize that trading intensity *I*, which I 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 Δp_h equation. Hence I would expect a negative impact on the variance of residuals.

The resulting conditional variance equation is:

$$(5) \qquad Var\left(\eta_h^p\right) = \alpha_0 + \alpha_1\left(\Delta p_{h-1}\right)^2 + \alpha_2\ INT_{h-1} + \alpha_3\ I_{h-1}$$

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 CZK/EUR exchange rate during our sample period, I conjecture that a break in the model has occurred in the middle of the period (see Section 2.2). This is motivated by the circumstance that in July-September 2002 market dealers had widespread expectations that the central bank might intervene in the foreign exchange market, whereas such expectations faded during October-December. Now I 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 equations (3)-(5). In particular, I would expect, other things being equal, a high probability of intervention to cause an increase in the ordinary responsiveness of the

exchange rate to order flow, β_{11}, and an increase in the conditional mean reversion coefficient β_{12}, the latter motivated by a higher intraday risk premium.

4. Results

4.1 Exchange rate

In the first place I ran regression (1) with robust estimators for the standard errors. The results are shown in Table 3a, line *a*. I assume that the intervention news variable *INT* turns on from 10:00 onwards on intervention days, which implies that the impact of intervention on the exchange rate, if any, is felt from 11:00 onwards on those days. I obtain an ordinary price impact estimate equal to 0.766 and highly significant. The incremental effect related to public news announcements is equal to 0.144; it has the correct sign and a plausible size, but it is not significant. The intervention effect γ is equal to 0.308 and significant. It shows that the ordinary price impact of order flow on the CZK/EUR is augmented by 40 per cent at times of intervention, consistently with the notion of effectiveness. Lastly, the mean reversion coefficient is equal to –0.176. The Breusch-Pagan test on the distribution of residuals reveals the presence of heteroskedasticity.

Next I turned to the estimation of the extended model of equations (3) and (5). Lines *b-c* give the results for the base version, which covers the entire sample period. From line *b* I 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 *c* gives the results obtained by dropping the public news variable A_{h-1}. The ordinary exchange rate impact of order flow, measured by β_{11}, is equal to 0.761 and highly significant. This figure is virtually unchanged compared with the estimate of the original model, from line *a*. This implies that a net purchase of euros with koruna of €10 million brings about a 7.6 basis points rise on CZK/EUR.[29] 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

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[29] In view of the overall market size and the CNB intervention size, taking €10 million as a yardstick for the measurement of hourly price impact seems the most reasonable choice. In particular, I 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 reasons, I observe that the issue of possible non-linearity in the response of the exchange rate to order flow has little practical relevance.

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,[30] and therefore my estimate is over twelve times as large as the EL estimate. Froot and Ramadorai (2005) provide projections of order flow[31] 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. Based on the estimates of Domaç and Mendoza (2004), the price impact corresponding to a $10 million intervention would be 0.8 basis points for the Mexican peso and 2 basis points for the Turkish lira, respectively. The difference between my estimates and those from previous studies seems clearly related to the different degree of liquidity of the CZK/EUR contract compared with the major currency pairs.

I estimate a highly significant effect for the intervention variable, with a value of γ equal to 0.387. With a one-hour delay from the start of intervention, the additional impact of order flow normalized by €10 million is thus equal to 3.9 basis points. Summing the ordinary effect β_{11} to γ, at times of intervention a net purchase of euros with koruna of €10 million causes a within-hour nominal change in the CZK/EUR of +35 pips, e.g. from 30.540 to 30.575. I observe that, by construction, this 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 β_{12} and β_{13} is slightly larger than the cumulative unconditional mean reversion effect (equal to -0.20, from Table 2). Additional lags of Δp proved to be insignificant. The cross effect of order flow on the USD/EUR is equal to 0.020 with the expected sign. In view of the much bigger size of the USD/EUR 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

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

[31] 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.

CZK/EUR exchange rate by 2.0 basis points in the same hourly interval, equivalent to 6 pips. It is not possible to compare directly my 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 raw measure of the degree of international integration of the local currency market. In my case this ratio is equal to (0.020/0.761=) 0.03, whereas from the study cited we generally obtain much larger figures, such as 0.2 for the British pound, 0.5 for the Swiss franc and 4 for the Swedish krona.[32]

I show the results for conditional variance on the right-hand side of each line, after the results for equation (3). From line c we notice that the lag of volatility is positive and significant as expected.[33] The effect of intervention is positive, with α_2 equal to 0.031. The hypothesis that trading intensity dampens the variance of residuals is also confirmed, with α_3 equal to –0.007.

An interesting issue is whether "expected" interventions have a different impact on market conditions compared with "unexpected" interventions. In empirical tests this question can 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 my empirical model, as well as the limitations in the available data, suggested to me a different approach. As I argued, the nominal level of the CZK/EUR in July-September and the policy reaction of the CNB were such that all the intervention episodes in that period could be safely deemed to be "likely" ex ante. I do not attempt to measure how likely they were. Rather, I 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. I simply assume that the market's expectation of intervention switched from high to low at the beginning of October and remained such until December. Therefore I set out to check whether this change in the state of the foreign exchange market affected its micro-structural behaviour, by running equations (3) and (5) in

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[32] These figures are purely indicative. I 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.

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

the two sub-samples. As I argued in Section 2, I would expect that when the probability of intervention is high β_{11}, the exchange rate impact coefficient, and β_{12}, the mean reversion coefficient, should both increase compared with the low probability state.

I report the estimates of the base equations (3) and (5) in the first sub-period in lines *d-e* of Table 3a. Line *d* shows the results for the full specification. The δ coefficient is again not statistically different from 0. A number of coefficients are also not significant at the usual confidence levels: the intervention coefficient γ (equal to 0.230) and the USD/EUR order flow effect β_{14}, in the exchange rate equation; the intervention effect α_2 and the coefficient of trading intensity α_3, in the variance equation. A specification search led to a simpler regression equation, where I retained the intervention effect in the exchange rate equation and dropped the remaining terms which were previously insignificant. The results are given in line *e*. I find that the ordinary price impact effect is equal to 0.931, i.e. over 20 per cent larger than for the entire sample period (from line *c*). The differential impact of actual intervention, given by γ, is equal to 0.293. The sum of the two effects is 1.224, as against 1.148 during July-December. I also find that mean reversion is substantially larger compared with the entire period: the sum of β_{12} and β_{13} is now equal to –0.345, against –0.253. Turning to the variance equation, the GARCH effect is lower, with α_1 equal to 2.896, against 4.308 in the entire period.

The results for the second sub-period are given in lines *f-g*. In the full regression of line *f* a number of coefficients are not significant, so I provide a streamlined version in line *g*. Ordinary price impact is equal to 0.660, corresponding to 70 per cent of the estimate for July-September (from line *e*). Based on a χ^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, I fail to detect a significant incremental effect of public news arrival on exchange rate impact. This might be attributed in part to the nature of the public news variable which, in spite of my efforts, is rather difficult to measure. Second, I 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 per cent, of the within-hour effect.

Third, based on the assumption that a break took place in the micro working of the market, the evidence accords fully with the predictions of the model. I have empirically estimated the parameters of a rather tense market in the first sub-period. Dealers' behaviour appears smoother in the second sub-period, where I 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 USD/EUR order flow, displays a bigger effect on the CZK/EUR, by over 50 per cent, consistently with the notion that domestic conditions matter less.

Fourth, from a policy perspective, regressions e and g provide a quantitative estimate of the effectiveness of intervention under three possible states of the market. The period-2 estimate of β_{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 effect that central bank intervention would have if it were kept 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. I note that this type of measure has a symmetric property, because it would apply to central bank operations on either side of the market. It has also a different and more meaningful interpretation because it gives the price impact of transactions unrelated to exchange rate policy that the central bank may want to carry out on the forex market, e.g. acting as agent for the government or to rebalance its foreign reserve assets.[34] In the latter type of transaction the central bank tries to avoid sending unintended signals to the forex market. Thus, although the concern here is to *minimize*, rather than maximize, the impact on the

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[34] These operations would typically be conducted discreetly and in an orderly market. Although interventions may have the same technical form as 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 sub-group 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).

exchange rate of the domestic currency, the central bank is still interested in having a quantitative assessment of such impact.

The second layer for the effectiveness of central bank interventions is related to the mere likelihood of their occurrence. I 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 β_{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, β_{11} in period 1 tells the central bank how effective its intervention would have been *if* it had been kept 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 γ value in period 1. The following chart summarizes my estimates of the effect on the CZK/EUR that a €10 million net sale of koruna would have had based on regressions *e* and *g*.

	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 per cent*
2) The central bank intervenes secretly, the likelihood of intervention is high	*9.31 basis points (28 pips)*	*74 per cent*
3) The central bank intervenes discreetly, the likelihood of intervention is high ex ante and the market learns that intervention is occurring	*(9.31+2.93=) 12.24 basis points (37 pips)*	*74 per cent*

To check for the robustness of my results, I performed alternative regression estimates covering the full sample period with modifications of the explanatory variables. I report

these alternative estimates in Table 3b.[35] The first check aims to test whether the assumption that the news of intervention spreads from 10:00 onwards on intervention days has any effect on the results. Lines h and i provide the estimates under the alternative assumption that the switching time is 9:00 and 11:00 respectively (I rule out additional switching times for the reasons given in the previous section). In the first case, from line h I notice that the intervention effect γ declines slightly, to 0.340, compared with the base case (Table 3a, line c), while the remaining coefficients of both the mean equation and the variance equation are virtually unchanged. In the second case, it is noteworthy that γ almost vanishes, to 0.059, and becomes statistically insignificant. Correspondingly, we observe an increase in the ordinary price impact, to 0.872, and in α_2, the intervention effect on the variance equation, which doubles to 0.063 (compared with 0.031, see line c). I recall that, according to the lag structure of the model, the last case rests on the assumption that the intervention news hits the market from 11:00 and its effect on mean and volatility is felt 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 at 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, I have found that choosing 9:00, as opposed to 10:00, for the initial spreading of the news does not alter substantially the results. I 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 my 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 variation for the public news variable, partly motivated by the poor performance of the 0/1 indicator variable employed so far. In line j I show the estimates of equations (3) and (5) using the news count variable N_h. Even in this case the public news variable remains insignificant. I also tried alternative specifications of the news

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[35] In additional checks, not reported for simplicity, I 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. None of the sub-categories improved our results.

variable. In particular, I tried separately three distinct *A* variables built respectively on macroeconomic announcements, political news and microeconomic news. None of the alternatives improved the statistical significance of the news variable and I do not report the results for simplicity.

An additional 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 from what I have done so far. Owing, among other things, 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. I 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. I 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 hypothesis that interdealer trading is largely visible to all dealers.

The estimates are shown in line *k*. All in all, I 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 with the base case of line *c*, from roughly 50 to 68 per cent. 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.

Finally, it might be argued that variations in trading intensity I_h could affect not only the conditional variance of the exchange rate but also, and more intrinsically, the relationship between prices and order flow. Therefore my last robustness check seeks to test whether trading intensity matters in the parameter estimates. To this end I partitioned all hourly

intervals into two quantiles based on trading intensity I, obtaining a low intensity quantile and a high intensity quantile, and ran two separate regressions of equations (3) and (5). The results are shown in lines *l-m*. I observe from line *m* that under high trading intensity the price impact estimates of β_{11} and γ, respectively equal to 0.778 and 0.380, are virtually unchanged compared with the baseline case of line *c*. In the low intensity intervals I estimate a smaller β_{11}, equal to 0.592, and a larger γ, equal to 0.464, and the statistical significance of both coefficients declines; I also note that under low trading intensity the conditional variance is virtually constant. The results from lines *l-m* enable us to further qualify the conclusions drawn from the general case. An increase in trading intensity makes the signal contained in order flow more precise; however, in a thin market the news of intervention appears to prompt a larger reaction of price to order flow.

4.2 Order flow

In Table 4 I report consistent estimates of the order flow equation. Line *a* shows the results for the original specification, namely equation (2). The lagged order flow coefficient is indistinguishable from 0. The lagged currency return coefficient, although positive as expected, is not significant.

I moved on to estimate the extended specification of equation (4), which includes a cross-effect from the USD/EUR contract. The results, shown in line *b*, are still inconclusive. The lagged order flow and lagged rate change are both insignificant. The contemporaneous effect of euro/dollar 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 I made some specification checks. First, I split the sample period as I did in the case of equation (3). From lines *c* and *d* we note no significant change in the performance of equation (4) in either sub-period. I then tried the order count variable as an alternative measure for the left-hand side of the equation (see line *e*). Again, I found no improvement in the results. Finally, I estimated separately the order flow equation for the intervals with low and high trading intensity respectively. The results, shown in lines *f-g*, are inconclusive. In additional checks I included longer lags of the

predetermined variables and tried separately to interact the intervention news indicator with the explanatory variables. I had no improvement and do not report the results for simplicity.

5. Concluding remarks

I have failed to find support for the hypotheses underlying the intraday order flow equation. In particular, I do not detect the positive serial correlation in order flow that would be consistent with "hot potato" trading on the CZK/EUR.

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 in line with the predictions of the model. I 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 per cent persists over time. I also document the presence of conditional mean reversion in the exchange rate, which is linked to the existence of an intraday risk premium. The difficulty of disentangling econometrically the effect of public news does not seem to hinder my conclusions.

My 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, I note a reason why my evidence has a bearing on that issue as well. The results for the exchange rate equation 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 may have persistent price effects. In the case of the Czech koruna interventions, I believe that both sources of effectiveness identified by Canales-Kriljenko (2003) for emerging markets are at work: namely, a size effect, which supports the portfolio balance channel, and an information advantage effect, which may explain why the presence of the central bank in the market prompted a change in its micro working.

When conducting intervention central banks reportedly seek to dampen the excessive volatility of the exchange rate. Hence they are first and foremost interested in short- and medium-term market developments. From a policy viewpoint, the long-term efficacy of intervention is obviously a key concern, and it is usually accompanied 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, as the CNB did in our sample period.

I note that the relatively low liquidity and high volatility of the koruna market, like those of other Central European currencies, reveal its potential fragility to speculative attacks. This reinforces the need for sound monitoring by the monetary authorities.

I am aware that any inference from the experience of the CNB in the summer of 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, partly owing to the clinical nature of my econometric setting, I 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.

With these important qualifications, the findings of this paper provide useful indications on the effects of central banks' actions in the foreign exchange markets of Central Europe.

Tables and Graphs

Table 1

**CZK/EUR TRANSACTIONS ON THE REUTERS SPOT MATCHING MARKET
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 17:00 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 per cent level, ** denote significance at the 5 per cent level, * denotes significance at the 10 per cent level.

Table 2

CZK/EUR TRANSACTIONS ON THE REUTERS SPOT MATCHING MARKET
HOURLY DATA
(8:00-17:00 CET)

Summary statistics

	Obs.	Mean	Std. dev.	Min.	Max.
Turnover	1130	18.1	17.9	0	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 per cent level, ** denote significance at the 5 per cent level, * denotes significance at the 10 per cent level.

EXCHANGE RATE EQUATION

Conditional mean

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

Conditional variance

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

	Conditional mean						Conditional variance				ARCH p-value	Wald test p-value	Obs.
	Δx_h	A_{h-1}	INT_{h-1}	Δp_{h-1}	Δp_{h-2}	Δx_h^{US}	const.	$(\Delta p_{h-1})^2$	INT_{h-1}	I_{h-1}			
Base model, eq. (1)													
a)	0.766	0.144	0.308	-0.176							0.00		917
	(9.84)	(1.01)	(2.10)	(-3.72)									
Extended model eqs.(3)-(5)													
b)	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)			
c)	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													
d)	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)			
e)	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													
f)	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)			
g)	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 to 17:00 CET on working days. Δp_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 events occur in hour h, and 0 otherwise. INT_h is an indicator variable equal to 1 from 10:00 onwards on intervention days, and 0 otherwise. Δx_h is hourly interdealer order flow in millions of euros (negative for net seller-initiated trades). Δx_h^{US} is interdealer order flow in the USD/EUR contract on the Reuters Spot Matching system in millions of euros. I_h is turnover in interval h, measured as the number of trades.

Conditional mean

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

Conditional variance

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

	Conditional mean						Conditional variance				Wald test p-value	Obs.
	Δx_h	A_{h-1}	INT_{h-1}	Δp_{h-1}	Δp_{h-2}	Δx_h^{US}	const.	$(\Delta p_{h-1})^2$	INT_{h-1}	I_{h-1}		.
h) Intervention news after 9:00	0.751 (10.71)		0.340 (2.78)	-0.167 (-4.05)	-0.083 (-2.36)	0.020 (1.89)	5.389 (34.26)	4.346 (4.27)	0.028 (1.89)	-0.007 (-1.64)	0.00	777
i) Intervention news after 11:00	0.872 (12.73)		0.059 (0.40)	-0.151 (-3.76)	-0.074 (-2.24)	0.020 (2.02)	5.374 (38.38)	4.666 (6.19)	0.063 (3.76)	-0.008 (-2.41)	0.00	777
j) News count var. N_h	0.718 (10.50)	0.191 (1.30)	0.361 (2.62)	-0.172 (-4.28)	-0.083 (-2.36)	0.020 (1.94)	5.378 (42.35)	4.286 (5.94)	0.029 (1.75)	-0.007 (-2.33)	0.00	777
k) Δx, Δx^{US} defined as order count	0.953 (12.27)		0.651 (3.92)	-0.156 (-3.47)	-0.076 (-2.11)	0.033 (1.78)	5.328 (29.03)	4.348 (2.25)	0.033 (1.98)	-0.006 (-0.93)	0.00	777
l) Intervals with low trading intensity	0.592 (4.01)		0.464 (1.77)	-0.222 (-3.96)	-0.098 (-1.64)	0.015 (0.96)	5.164 (28.39)	1.186 (0.45)	0.080 (1.36)	-0.008 (-0.58)	0.00	391
m) Intervals with high trading intensity	0.778 (11.32)		0.380 (2.72)	-0.137 (-2.42)	-0.082 (-1.85)	0.024 (1.66)	5.674 (45.21)	4.664 (5.78)	0.028 (1.68)	-0.012 (-2.53)	0.00	386

Notes: Heteroskedasticity-consistent *t*-statistics are reported in parentheses. The estimates are based on hourly data from 8:00 to 17:00 CET on working days. Δp_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 (except in lines *g* and *h*) on intervention days, and 0 otherwise. Δx_h is hourly interdealer order flow in millions of euros (negative for net seller-initiated trades). Δx_h^{US} is interdealer order flow in the USD/EUR 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

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

	Δx_{h-1}	Δp_{h-1}	Δx_h^{US}	R^2	ARCH p-value	Obs.
Base model, eq. (2)						
a)	-0.003 (-0.07)	0.032 (1.35)		0.003	0.020	904
Extended model, eq. (4)						
b)	-0.003 (-0.08)	0.032 (1.33)	0.012 (1.92)	0.007	0.028	904
c) July-September 2002	-0.024 (-0.40)	0.044 (1.47)	0.017 (2.00)	0.012	0.154	472
d) October-December 2002	0.028 (0.50)	0.011 (0.28)	0.002 (0.29)	0.002	0.123	432
e) $\Delta x, \Delta x^{US}$ *defined as order count*	-0.009 (-0.19)	0.024 (1.27)	0.018 (2.07)	0.007	0.077	903
f) Intervals with low trading intensity	-0.002 (-0.07)	0.016 (1.26)	0.001 (0.12)	0.004	0.528	451
g) Intervals with high trading intensity	-0.009 (-0.14)	0.039 (1.02)	0.021 (1.93)	0.010	0.013	453

Notes: Heteroskedasticity-consistent *t*-statistics are reported in parentheses. The estimates are based on hourly data from 8:00 to 17:00 CET on working days. Δp_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, e-f* (alternatively *b*) Δx_h is hourly interdealer order flow (count) in millions of euros (in number of trades). Δx_h^{US} is the corresponding variable for the USD/EUR 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 null hypothesis that the variance of residuals is constant. The ARCH column gives the *p*-value of the LM test on the absence of ARCH effects.

Graph 1

CZK/EUR EXCHANGE RATE

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