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Testing the Effectiveness of the Czech National Bank's Foreign-Exchange Interventions

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1. Introduction

During 2001 and 2002, the Czech koruna experienced a strong appreciation trend against the euro in both nominal and real terms. This appreciation was regarded by both the central bank officials and other economists as being mainly driven by market expectations of the conversion of some one-off privatization revenues in euros into the domestic currency in the foreign-exchange market. The central bank (Czech National Bank, CNB) decided to intervene in the market to stop the appreciation and eventually to reverse the trend, and it finally succeeded in bringing the exchange rate back to a more fundamental-based level.

However, as discussed in (Geršl, 2004), it remains a question whether it was the foreign-exchange intervention that caused the appreciation bubble to burst, or whether other factors might have had more impact, such as a change in the government's privatization strategy, a significant decrease in the interest-rate differential, external environment or government having followed the *Strategy* (CNB, 2002), converting the euro revenues out of the market. In other words, we are interested in whether the foreign-exchange intervention was in fact effective. In this article, several econometric approaches to testing the effectiveness of foreign-exchange intervention are reviewed and subsequently some of them applied to the Czech data. By effectiveness, we mean a significant impact of interventions on exchange-rate movements in the desired direction.

The article is organized as follows: Section 2 reviews some relevant literature on the econometrics of foreign-exchange intervention. In Section 3 the CNB's interventions are discussed and the reaction function estimated. Section 4 estimates the effect of FX interventions on the exchange-rate level, while Section 5 investigates the effect on volatility. Section 6 presents the effect of intervention strategy on their successfulness within the event-study approach. Section 7 concludes the paper.

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2. Review of the Literature

The econometrics of foreign-exchange intervention usually focus on two issues: estimating the reaction function of the central bank, i.e. trying to find factors that cause the central bank to intervene in the foreign-exchange market, and testing the impact of intervention on the exchange rate (i.e. effectiveness of intervention), sometimes with reference to a particular transmission channel such as the portfolio-balance channel, signaling channel, microstructure (order-flow) channel, noise-trading channel or coordination channel.[1]

Since the end of the 1970s, a number of studies has emerged that tried to determine whether the central bank's interventions are predictable, estimating the central bank's intervention reaction function. The change of the exchange rate, the distance of the exchange rate from a targeted level, exchange-rate volatility, interventions of other central banks, as well as past interventions are usually included as explanatory variables, reflecting possible motives for intervention and the first order autocorrelation that is usually found in the intervention data (Dominguez – Frankel, 1993a), (Ramaswamy – Samiei, 2000), (Ito, 2003).[2] Given the possible simultaneity in determination of the exchange rate and intervention, as a change in the exchange rate may trigger intervention and intervention in turn influences the exchange rate, some studies apply instrumental-variables techniques.[3]

Edison (1993) and Almekinders (1995) survey the literature on reaction functions until 1992. In general, most of the studies have found a significant relationship and strong evidence for the "lean-against-the-wind" motive, i.e. to prevent the exchange rate from moving in one direction through operations with the opposite effect, although the degree of significance and the size of estimated coefficients differed across periods and countries, depending on the data used (frequency of the data and proxies for the intervention variable as most central banks do not publish official intervention data), the way of deriving the level of the targeted exchange rate (moving average, PPP equilibrium level) and the estimation method.

More recently, also because of more frequent data (such as daily data) on intervention becoming available from central banks, binary choice models such as the probit or the logit model have been used to estimate the probability of intervention rather than the precise amount (Baillie – Osterberg, 1997), (Dominguez, 1998), (Ramaswamy – Samiei, 2000), (Kim – Sheen, 2002), (Ito – Yabu, 2004), (Akinci et al., 2005). As interventions are characterized by a large number of zero-value observations when using daily data, an OLS estimation of the reaction-function coefficients would be biased given that the dependent variable is obviously truncated (Humpage, 1999),

[1] For channels of influence, see (Geršl, 2004) or (Sarno – Taylor, 2001).

[2] The reaction function is usually derived ad hoc, without any theoretical background. For an example of the reaction function derived from a model based on a loss function of the central bank, see (Almekinders, 1995, p. 63).

[3] For exchange rates, lagged variables are usually used as instruments, especially when using daily data (Dominguez – Frankel, 1993a). Humpage (1999) uses early morning quotes for the exchange rate on the right hand side, as this appears to reflect to a large extent the actual behavior of monetary authorities.

(Ito – Yabu, 2004). Thus, some studies estimate the central bank's intervention reaction function in two steps: first, the probability of intervention through discrete choice models for the decision to intervene is estimated, and second, the amount of intervention is estimated via the standard reaction function. The predicted amount of intervention is then constructed from the two estimates, using different techniques (Almekinders – Eijffinger, 1996), (Humpage, 1999), (Kearns – Rigobon, 2005).

In the late 1980s and early 1990s, the literature on the effectiveness of foreign-exchange intervention concentrated on testing the relevance of the portfolio-balance channel and signaling channel (Humpage – Osterberg, 1992), (Dominguez, 1992), (Ghosh, 1992), (Edison, 1993), (Dominguez – Frankel, 1993a, 1993b), (Kaminsky – Lewis, 1996), (Baillie – Osterberg, 1997).[4] The evidence is mixed for the portfolio-balance channel, while for the signaling channel most studies found some significant impact of intervention.

Since the mid-1990s, the focus has moved to analysis of channels based on the microstructure and functioning of the foreign-exchange market such as the noise-trading channel (Hung, 1997), order-flow channel (Lyons, 2001) or coordination channel (Reitz – Taylor, 2006).[5] Empirical studies based on these channels usually use daily or even high-frequency (i.e. intraday) data, finding support for functioning of the channels (Dominguez, 2003), (Scalia, 2004a, 2004b).

The recent literature adopts a direct approach to testing the effectiveness of intervention, regressing changes in exchange-rate level and volatility on the intervention variable and other variables of influence, taking into account particular econometric difficulties associated with such a direct approach. These studies do not relate the results to a particular channel of influence, although indirectly they usually refer to the market microstructure or signaling effect of intervention. Two main approaches are usually applied: a structural approach and event-study approach (Neely, 2005).

The structural approach takes into account the simultaneous determination of the exchange rate and intervention that would lead to inconsistent estimates of coefficients within the simple OLS estimation.[6] Thus, a system

[4] The portfolio-balance channel assumes that domestic and foreign assets are imperfect substitutes and investors thus diversify their holdings among both types of assets based on expected returns and variance in returns. An intervention operation leads investors to rebalance their portfolios and, as a result, to a change in the exchange rate. In the signaling channel, intervention serves as a means to convey inside information from the central bank to markets, either about the "correct" fundamental level of the exchange rate, which may be assessed differently by the central bank than by the rest of the FX market, or about future monetary policy, thereby influencing exchange-rate expectations (Sarno – Taylor, 2001), (Geršl, 2004).

[5] The noise-trading channel assumes that if the majority of FX traders are chartists (noise traders), i.e. relying on the most recent market developments, volatility-enhancing intervention may reverse their trading strategies and stop, for example, an exchange-rate misalignment. The order-flow model of exchange-rate determination subscribes the main driving force of the exchange-rate movements to the way private information is transmitted throughout the market via order flows, i.e. signed buyer-initiated versus seller-initiated transactions. The coordination channel assumes that central-bank intervention may act as a coordinating signal in a situation of strong and persistent exchange-rate misalignment caused by non-fundamental factors (Geršl, 2004).

[6] Simple OLS was used for the example by Dominguez and Frankel (1993a).

of simultaneous equations is formed and estimated via the instrumental-variables approach. Some studies use lagged interventions as an instrument for current interventions (Ramaswamy – Samiei, 2000), (Égert – Komárek, 2005), while other studies apply the two-stage least squares approach, estimating first the reaction function with lagged exchange rate as an instrument for the current exchange rate and subsequently using the fitted values of interventions from the reaction function as an instrument for current interventions in the exchange-rate equation (Almekinders, 1995), (Galati et al, 2005), (Disyatat – Galati, 2005), (Kearns – Rigobon, 2005).

Within the event-study approach, a success criterion is specified that enables differentiation between "successful events" of intervention and unsuccessful events (Humpage, 1999). For example, successful events may be defined as those days of intervention in which intervention sales (purchases) of foreign currency were associated either with domestic currency appreciation (depreciation) on that day, or smaller depreciation (appreciation) when compared to the previous day. All other intervention days are defined as unsuccessful. The proportion of successful interventions reveals whether intervention has been effective.

By concentrating only on the days of intervention (events), the event-study approach allows tackling the usual difficulty with time-series econometrics of interventions, namely the high number of periods of no intervention that may cause the time-series approach to find no relationship between interventions and the exchange rate. However, an analysis of the effectiveness of interventions based on the intra-event exchange-rate change (in this case the change within a day) may be subject to the "endogeneity" problem: as the central bank's decision to intervene may be dependent on the exchange-rate development in the period of intervention, the reason to intervene would also label the intervention successful or not, thus biasing the results towards ineffectiveness.

The "event window", i.e. the number of periods forming one event, varies across studies. Fatum and Hutchison (1999), Fatum (2000), Fatum and Hutchison (2003), Edison et al. (2003), Fratzscher (2005) and Égert and Komárek (2005) define the event window according to the number of consecutive days of no intervention between days of intervention. Fatum (2000) considers, for example, a maximum of 15 days of intervention inactivity between consecutive days of intervention, i.e. an event is identified as a series of consecutive days starting and ending with an intervention day and with a maximum of 15 consecutive days of no intervention allowed within the event. Moreover, as the criterion of successfulness the change in the exchange rate, either after the event (in the post-event window) or between the levels prevailing before and after the event (i.e. between pre-event and post-event windows), is used in order to eliminate the endogeneity problem. Again, the length of pre-event and post-event windows may reach from one to more days, but are usually symmetric and the same across the whole analysis.

The event-study approach also allows inferring what makes intervention successful. The events are labeled successful or unsuccessful and denoted 1 for successful and 0 for unsuccessful. Subsequently, a discrete-choice model is applied (probit or logit). Among the explanatory variables, the amount of intervention, a dummy for coordination among the central banks concerned, changes in interest rates and other relevant (factors that could have impact on the effectiveness of intervention can be found in the literature (Humpage, 1999), (Fatum, 2000), (Fratscher, 2005).

The impact of interventions on volatility has also attracted a lot of attention in the literature on intervention. Most studies analyze the effectiveness of interventions within a GARCH framework, estimating both the effect of interventions on levels in the mean equation and on conditional volatility in the variance equation (Almekinders, 1995), (Almekinders – Eijffinger, 1996), (Baillie – Osterberg, 1997), (Dominguez, 1998), (Domac – Mendoza, 2002), (Ito, 2003), (Nagayasu, 2004), (Guimaraes – Karacadag, 2004), (Akinci et al., 2005), (Égert – Komárek, 2005), (Geršl – Holub, 2006).[7] Other studies use data on implied volatility derived from option prices (Bonser-Neal – Tanner, 1996), (Dominguez, 1998), (Galati et al., 2005), (Disyatat – Galati, 2005). Most studies found a significant effect on exchange-rate volatility, but in some studies interventions were found to enhance volatility, while in others to decrease volatility.

Some authors argue that the effectiveness of intervention may by greater in emerging markets compared with developed economies. Based on a survey among central banks, Canales-Kriljenko (2003) identifies four reasons why central-bank intervention in emerging markets may have more of an impact on the exchange rate: lack of full sterilization, the large amount of intervention relative to market turnover, informational advantage of the central bank over market participants and moral suasion. However, empirical evidence on emerging markets is mixed, as most studies found a greater effect of intervention on volatility than on the level of the exchange rate, especially when analyzing Mexico and Turkey (Domac – Mendoza, 2002), (Guimaraes – Karacadag, 2004), (Akinci et al., 2005), (Ishii et al., 2006).

Available studies on the interventions of the CNB also provide mixed evidence as to the effectiveness of interventions. While some studies found no or small and short-term impact on the exchange-rate level and significant impact on increased volatility (Holub, 2004), (Disyatat – Galati, 2005), (Geršl – Holub, 2006), other studies came to more positive results with regard to the effect on the exchange-rate level, using either the event-study approach (Égert – Komárek, 2005) or intra-day data on order flows (Scalia, 2004a, 2004b).

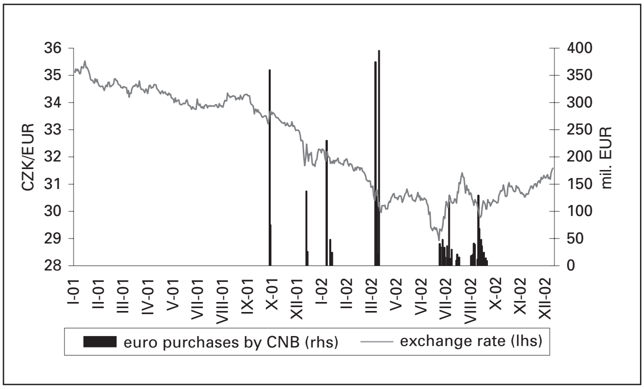
3. The Czech National Bank's Interventions and the Reaction Function

During 2001 and 2002, the Czech National Bank intervened in the FX market, purchasing euros in order to reduce the value of the Czech koruna that began to appreciate sharply against the euro in mid-2001.[8]

[7] Some studies extend the GARCH framework by allowing the volatility to be regime-dependent (Markov-switching models), see (Reitz, 2002) or (Beine et al., 2003).

[8] For discussion of the Czech interventions and other policy measures that accompanied the interventions, see (Geršl, 2004), (Holub, 2004), (Scalia, 2004a, 2004b), (Égert – Komárek, 2005), (Disyatat – Galati, 2005) and (Geršl – Holub, 2006).

FIGURE 1 Interventions and Exchange-Rate Development



Source: CNB; Bloomberg

Figure 1 shows that there were actually two different periods of intervention activity: in the first period, from October 2001 to April 2002, the CNB intervened only on a few days, disclosed its intervention activity to the public, and purchased huge amounts of euros, reaching almost 400 million euros in a single day of intervention. In the second period – from July until September 2002 – the CNB intervened in a more discrete manner, purchasing euros much more frequently, but only in small amounts.

In the first period the CNB intervened on 13 days within seven months and the average amount of intervention was 150 million euros a day, while in the second period it intervened on 28 days within three months and the average amount was only 35 million euros a day.

Following Ito (2003), we estimate an intervention reaction function of the following form, using daily data:

$$INT_t = b_0 + b_1 \Delta s_{t-1} + b_2(s_{t-1} - \hat{s}_{t-1}) + b_3\, VOL_{t-1} + b_4 INT_{t-1} + \eta_t \qquad (1)$$

As the CNB intervened over the period of interest only against appreciated currency, i.e. purchasing euros, the intervention variable *INT* is defined as the amount of euro purchases. We expect the central bank to intervene if the change in the spot rate is large, or if the spot exchange-rate deviates from a "target" exchange rate $\hat{s}_{t-1}$ (that is allowed to be time-dependent and was set to a 10-day backward-moving average), or if the volatility of the exchange rate *VOL*, as measured by standard deviation of changes in the exchange rate over the last five days, is high. Moreover, interventions usually come in clusters, so that yesterday's intervention makes today's intervention more likely, a reason to include lagged intervention.

In order to address the simultaneity bias when estimating the reaction function, we follow the common practice and use only lagged values of the exchange rate. *Table 1* shows the estimation results for the reaction function given by (1).

Table 1 indicates that the central bank systematically intervened to correct the deviation of the exchange rate from the "target" value. As the tar-

TABLE 1 Estimated Reaction Function

	Coefficient	Standard error	Significance level
b_0	–3.30	5.56	0.55
b_1	–18.76	22.20	0.39
b_2	–22.43	13.38	0.09
b_3	81.25	36.22	0.03
b_4	0.13	0.07	0.04

get value is moving, this might be interpreted as the CNB having intervened when the exchange rate appreciated too much compared with the average value of the last five days. The coefficient for the reaction on the short-term change in the spot exchange rate has the right sign, but is not statistically significant. The central bank's interventions were also triggered by higher volatility.

The results are in line with Geršl and Holub (2006), who estimate a similar reaction function, but do not include volatility as an explanatory variable and estimate the function over a longer period. Similarly, Disyatat and Galati (2005) found that the CNB tended to intervene mainly when the speed at which the koruna appreciated against the euro tended to accelerate.

4. Effectiveness of the CNB's Interventions within the Structural Approach

Due to possible endogeneity bias, we apply the instrumental variables approach and estimate the impact of interventions on the exchange rate level using the two-stage least squares method.[9] We estimate the following exchange-rate equation:

$$\Delta s_t = d_0 + \sum_{i=0}^{4} a_i INT_{t-i} + \sum_{i=1}^{n} c_i X_{it} + \varepsilon_t \tag{2}$$

The change in closing exchange rate s between the day t–1 and t is expected to be dependent on the volume of interventions (purchases of foreign currency) INT conducted by the central bank during the day t and possibly also on previous days, and on other control variables X. If intervention is effective, we expect a positive a_i (i.e. purchases of foreign currency are associated with the depreciation of the domestic currency).

As an instrument for interventions we use the predicted values from reaction function (1). However, low adjusted R^2 in Table 1 suggests that we are able to explain only a small part of the variance in the intervention variable. This is caused mainly by the fact that the intervention variable INT is characterized by a number of zeros, as out of the 262 business days in

[9] The system of simultaneous equations is made by equations (1) and (2). Related econometric estimation problems of such a system are discussed in (Neely, 2005) and (Disyatat – Galati, 2005). Here, we follow the common practice and use lagged variables and fitted variables within the two-stage least squares approach as instruments. Ideally, one should select the instruments from the list of predetermined exogenous and lagged endogenous variables.

TABLE 2 Effectiveness of Intervention

Variable		Regression I	Regression II	Regression III	Regression IV	Regression V
		Δs_t	Δs_t	$s_t - s_{t-2}$	$s_t - s_{t-3}$	$s_t - s_{t-4}$
Intercept	d_0	0.01	–0.01			
Int_t	a_0	0.002**	0.003***	0.002	0.000	–0.001
Int_{t-1}	a_1		–0.002*	–0.000	0.001	0.000
Int_{t-2}	a_2		–0.003**		–0.001	–0.002
Int_{t-3}	a_3		0.003**			0.002
Int_{t-4}	a_4		0.000			
3M money market spread	c_1	–0.009	–0.009	–0.033***	–0.044***	–0.056***
ΔHUF/EUR	c_2	0.019**	0.020**	0.015	0.014	0.010
ΔSKK/EUR	c_3	0.377***	0.339***	0.362***	0.302***	0.281***
Δ Dow Jones Euro Stoxx Broad Index	c_4	–0.004**	–0.005***	–0.005**	–0.005***	–0.005**
adjusted R^2		0.16	0.19	0.17	0.15	0.13

Notes: Estimated via instrumental variables (TSLS); sample: October 1, 2001 to October 1, 2002; 262 observations
* = significance at 10% level; ** = significance at 5% level; *** = significance at 1% level

Source of data: Bloomberg; Reuters; ECB; CNB

the sample the CNB intervened on only 41 days. This particular feature of interventions may cause any further inference based on the predicted values from the reaction function to be invalid (correlation between such an instrument and the actual variable *INT* is only around 25 %). Thus, following Humpage (1999), we replace the predicted values with zeros on the days of no intervention (via this correction the correlation increases to around 50 %).[10]

Table 2 shows the estimation results for the exchange rate equation (2). As control variables we have used the three-month money market interest rate spread between CZK and EUR, changes in the exchange rates of some of the "peer" currencies (SKK/EUR and HUF/EUR), as investors may treat eastern European currencies as substitutes, contributing to common movements, and changes in the Dow Jones Euro Stoxx Broad Index to control for external developments.[11]

Regression I aims at capturing the short-term (one-day) impact of interventions. For a possible medium-term impact, i.e. lasting more than one

[10] Of course, as the decision to conduct interventions might also be dependent on the development of the exchange rate, we might partly bring back the simultaneity bias. However, as the simultaneity problem is much more serious in the intervention days, for which correction is done, the resulting bias is probably negligible. Other methods discussed in the literature to make the reaction function better predict the zero values are the binary choice model (Ito – Yabu, 2004), the "friction" model (Almekinders – Eijffinger, 1996), and the model of shadow interventions (Kearns – Rigobon, 2005).

[11] We report only those control variables that appeared to be significant. We have also tried other daily variables from financial markets, such as stock market indices, oil prices, other currencies and long-term interest rate spreads.

day, we show the results for the impact of lagged interventions on the current change in the spot exchange rate (II), and for the impact of past interventions on the change of the level of the exchange rate over a period of two (III), three (IV) and four (V) days.

Table 2 indicates that interventions had immediate impact on the spot exchange rate in regression I, suggesting that a purchase of 100 million euros by the CNB led to depreciation of the Czech koruna by 0.2 CZK. However, as regards the medium-term impact, regressions II–V suggest that the impact was insignificant or with wrong signs.

These results are similar to those of Geršl and Holub (2006) who, using a longer period, found some short-term effect in some specifications but no cumulative effect of subsequent interventions. However, the results differ from Disyatat and Galati (2005) who found no statistically significant contemporaneous effect, but some (weakly) statistically significant cumulative effect over one week.

5. Impact of Interventions on Exchange Rate Volatility

Two contrasting views exist on the impact of interventions on volatility of the exchange rate. According to the traditional view, interventions are used to calm "disorderly" markets, i.e. to decrease volatility. On the other hand, following Hung (1997), interventions could be used to increase volatility, thereby raising the two-sided risk in the market and causing market participants to alter their expectations away from the certain appreciation trend towards a more balanced development, correcting previous trading strategies.

Following Almekinders and Eijffinger (1996), we apply a GARCH model of the exchange rate, allowing both the change in the exchange rate and the conditional volatility to be dependent on the volume of intervention. A GARCH model specified in (3a–c) is estimated.

$$\Delta s_t = \gamma_0 + \gamma_1 I_t + \sum_{i=2}^{n} \gamma_i X_{it} + \varepsilon_t \tag{3a}$$

$$\varepsilon_t \mid \Omega_{t-1} \sim N(0, \sigma^2) \tag{3b}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 + \alpha_3 I_t + \sum_{i=4}^{n} \alpha_i X_{it} + u_t \tag{3c}$$

As interventions react to volatility and changes in exchange-rate levels, we control for simultaneity bias by (1) including only lagged values of interventions (regressions I and II) and by instrumental variables, using the fitted values from the reaction function for the days of interventions (regression III).[12]

[12] When applying GARCH models, most authors do not control for simultaneity, but they subsequently test the degree of endogeneity of interventions, for example by estimating a Probit model of the reaction function (Guimaraes – Karacadag, 2004) or by the Granger causality test (Égert – Komárek, 2005). If the degree of endogeneity is found to be rather small, the possibility of a simultaneity bias is downplayed.

TABLE 3 GARCH Model

		Regression I	Regression II	Regression III
Mean equation				
Int$_{t-1}$	γ_1	–0.0002		
Int$_t$ (instrumented)	γ_1			0.005***
Intercept	γ_0			
3-month money market rate spread	γ_2	–0.012	–0.013	–0.017**
ΔHUF/EUR	γ_{-3}	0.012	0.012	0.013
ΔSKK/EUR	γ_{-4}	0.346***	0.055***	0.374***
ΔDow Jones Euro Stoxx Broad Index	γ_{-5}	–0.005***	–0.005***	–0.003
Variance equation				
Intercept	α_0	0.002**	0.002**	0.007***
Arch(1)	α_1	0.142**	0.143**	0.113
Garch(1)	α_2	0.776***	0.758***	0.356**
Int$_{t-1}$	α_3	0.000	0.000	
Int$_t$ (instrumented)	α_3			0.002***
adjusted R^2		0.14	0.14	0.10

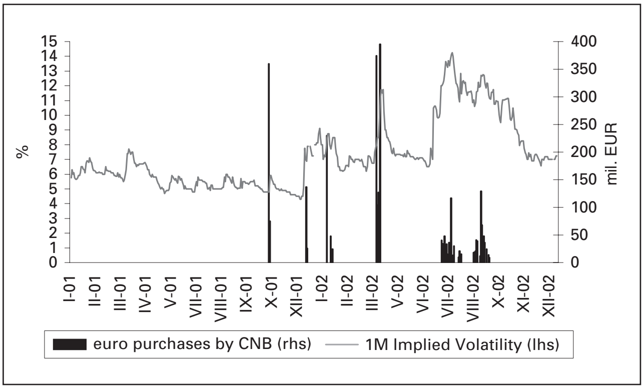
Notes: Estimated via maximum likelihood; sample: October 1, 2001 to October 1, 2002; 262 observations
* = significance at 10% level; ** = significance at 5% level; *** = significance at 1% level

As *Table 3* shows, (lagged) interventions did not have any significant impact on the level of the exchange rate. Using the instrumented interventions, there might have been some effect on the level, a result that is in line with the preceding section. Results of regression III also suggest that interventions may have contributed to an increased (conditional) volatility of the exchange rate. This might indicate that the CNB indeed wanted to raise volatility in the markets to make market participants aware of the two--sided risk.

These results confirm the findings by Égert and Komárek (2005). They apply a variety of GARCH models in order to test the impact of interventions conducted by the CNB on the CZK/EUR exchange-rate level and conditional volatility over the period 1997–2002. Using a slightly different set of control variables, they find a statistically significant, but wrong-signed effect of CZK purchases on the level. For CZK sales, the intervention strategy in 2001–2002, they find a statistically significant impact on the level only when using current interventions. For lagged interventions, only large koruna sales seem to have worked. They also find that the CNB's interventions tend to be associated with increased volatility of the exchange rate. Geršl and Holub (2006) also find some, but a very small effect of interventions on conditional volatility.

The volatility-enhancing strategy of the CNB may be further confirmed by analyzing the impact of interventions on market expectations of volatility, namely on implied volatility derived from currency option prices. In the option pricing terminology, implied volatility is the expected volatility of the return of the underlying asset prevailing at the time when the option matures. It measures the degree of uncertainty that the market at-

FIGURE 2 Interventions and One-Month Implied Volatility



Source: CNB; Citibank

taches to the future return. As the only unobserved variable in the Black and Scholes pricing formula for options is the implied volatility, it is possible to derive it from the option price for a given strike price of the option.

For our analysis we use one-week, one-month and three-month implied volatilities derived from prices of at-the-money call options on the CZK/EUR exchange rate. As Bonser-Neal and Tanner (1996, p. 859) argue, at-the-money options are the most sensitive to changes in volatility, and thus the most informative about the expected volatility of an exchange rate. *Figure 2* shows the one-month implied volatility together with the conducted interventions.

Figure 2 suggests that interventions may have raised implied volatility, especially in the second period of interventions, as days of intervention seem to be correlated with higher implied volatility. However, as discussed in previous sections, the link can run both ways, as interventions can be triggered by increased (implied) volatility. Regressing changes in implied volatility on current interventions could thus cause the estimated coefficients to be biased.

However, in contrast to regressions on changes in the level of the spot exchange rate, the simultaneity problem is probably less severe here. First, data on implied volatility were not directly observable in the market due to their OTC character. Second, the Granger causality test suggests that there is indeed a statistically significant link between interventions and implied volatility, but the link runs only one way (from interventions to volatility) at higher lags.[13] To reflect possible simultaneity at low lags, we follow Bonser-Neal and Tanner (1996) and include also lagged implied volatility among explanatory variables. If intervention is correlated with lagged implied volatility, the intervention coefficients measure the effect of intervention conditional on the level of recent volatility.[14] Thus, we estimate the equation (4) where *imvol* stands for implied volatility:

[13] The results of the Granger causality test are available from the author on request.

TABLE 4 Interventions and Implied Volatility

Dependent variable *(change in)*		1-week implied volatility	1-month implied volatility	3-month implied volatility
Intercept	b_0	0.292**	0.173*	0.137***
Int_t	b_1	0.003***	0.002***	0.001***
Int_{t-1}	b_2	0.002*	0.002***	0.001***
Lagged implied volatility	b_3	–0.040***	–0.024**	–0.021*
adjusted R^2		0.06	0.08	0.06

Notes: Estimated via OLS; sample: October 1, 2001 to October 1, 2002; 262 observations
* = significance at 10% level; ** = significance at 5% level; *** = significance at 1% level

$$\Delta imvol_t = b_0 + b_1 INT_t + b_2 INT_{t-1} + b_3 imvol_t + \varepsilon_t \tag{4}$$

Table 4 shows the results of regression of changes in implied volatilities of different maturities on current and lagged interventions.[15]

Table 4 indicates that interventions, both current and lagged, led to higher implied volatility. This result is also in line with the previous section. In addition, the effect is not negligible: a purchase of EUR 100 million raises 1W implied volatility by 40 basis points today and 20 basis points tomorrow. The results differ from findings by Disyatat and Galati (2005), who have not detected any significant effect of intervention on implied volatility.

The existence of implied volatilities from options of three different maturities – one week, one month and three months – allows us to analyze whether interventions have had both short-term and medium-term effects on volatility as expected by market participants. The results in Table 4 suggest that interventions have indeed raised the uncertainty about possible developments of the exchange rate at least on a three-month horizon. However, the effect of intervention on expected volatility decreases with longer horizons.

6. What Makes Intervention Successful? Evidence from the Event Study

The last issue we want to explore econometrically is what makes an intervention effective, i.e. successful. To answer this question, we apply the event-study approach: we first define an intervention event, and then we specify a criterion under which an intervention event can be viewed as successful. Finally, using a logit model, we look for factors that can explain the success of intervention.

[14] Another possibility would be to use instrumental variables: either the fitted values from the reaction function for days of interventions, or lagged interventions. However, the results do not change substantially, as the sign and significance of intervention coefficients remain the same.

[15] In principle, one could form an "umbrella' (nested) model of the impact of interventions on implied volatility and treat the models with different maturities as special cases.

TABLE 5 Successfulness of Interventions

	Interventions			Control sample
	Total	Successes		Successes
	#	#	%	%
1st intervention period (October 2001–April 2002)	13	8	61.5	45.6
2nd intervention period (July 2002–September 2003)	28	11	39.3	45.6
Intervention period total	41	19	46.3	45.6

Following Humpage (1999), we define an intervention event as a single day of intervention. The event is labeled as successful if the intra-day change of the exchange rate – i.e. the change between the opening and closing levels of the exchange rate – goes in the right direction. Thus, in our case where the CNB intervened against appreciation of the Czech koruna, the successful events are those intervention days where the exchange rate depreciated over the day.

The event-study literature also considers other criteria of success, such as the "smoothing" criterion (purchase of the foreign currency leads to smaller appreciation than in a period preceding the event). However, our choice of the event window length and the specific "direction" criterion of success (Fatum, 2000) reflects three considerations: first, larger event windows would substantially decrease the number of events, as we had in 2001–2002 only 41 days of interventions. Second, comparing the exchange-rate development between predefined pre-event and post-event windows would bring additional difficulties as the interventions are clustered over several subsequent days, so that the windows would overlap. Third, we presume that the appreciation pace of the CZK/EUR rate was so fast and the Czech koruna was in the intervention periods of 2001 and 2002 so strong that the real aim of interventions was to depreciate the domestic currency, not to smooth its appreciation path. Moreover, with successful intervention the monetary authority sends, in terms of reversing the trend, probably a much clearer signal towards markets than when it succeeds in only smoothing.

Table 5 gives an overview of the successfulness of interventions in 2001–2002 and in both intervention periods separately.

Table 5 shows that in the first period of intervention activity only 8 out of 13 events were successful, just slightly over 60 %. For the second period of "undisclosed" interventions, the results were even worse: just 11 out of 28 interventions, i.e. slightly less than 40 %, were successful in depreciating the currency. Overall, the share of successful interventions amounts to 46 %, so less than half of interventions were successful.

Due to the martingale nature of the exchange rate, i.e. high frequency of changes of both directions, it is possible that some of the interventions may appear successful in terms of our criterion, but the success was not due to interventions. Thus, we also show in Table 5 the share of days that could be labeled "successful" in a control sample (in days of no intervention in

TABLE 6 Logit Model of the Successfulness of Interventions

	Regression I	Regression II
amount of intervention	0.017	0.008*
# ticks	0.006	
# morning ticks / # ticks	0.263	
3-month money market spread	–0.867	
undisclosed intervention	–1.339	–0.724*
surprise intervention	–0.374	
Monday	–1.685	
Friday	0.627	

Notes: Estimated via maximum likelihood; 41 observations
* = significance at 10% level; ** = significance at 5% level; *** = significance at 1% level

2001 and 2002). Comparison of the successfulness of interventions with the control sample indicates that the effect of intervention on reversing the trend is probably not statistically significant over the whole period, a result that is in line with Humpage (1999), but in contrast to Fatum (2000). Nevertheless, in the first intervention period the impact was much clearer.

Finally, we would like to know whether a specific intervention strategy makes intervention successful in terms of the direction criterion. We apply a logit model such as in (5), where y_i is the dummy variable that takes the value of 1 if the intervention event is successful and 0 otherwise, and x_i stands for a vector of explanatory variables that may influence the likelihood of success.

$$P(y_i = 1|x_i) = F(\beta x_i) = \frac{1}{1 + \exp(-\beta x_i)} \tag{5}$$

Among explanatory variables we include the amount of intervention, number of ticks (i.e. trades within a single day), the proportion of morning ticks, a dummy for Monday and Friday, a dummy for disclosure of interventions, a dummy for a “surprise” intervention (i.e. an intervention that does not directly follow another one), and the interest rate spread (see *Table 6*).

Table 6 suggests that no particular intervention strategy made intervention more successful in terms of moving the exchange rate towards more depreciated levels within one day. It does not seem to make any difference whether the interventions were conducted on Friday or Monday (on Friday the markets are usually quite thin), or whether the interventions follow in a row or not. Similarly, the number of trades (ticks) within one day or the proportion of trades conducted in the morning hours does not help to explain the successfulness either. Results of regression II indicate that at the 10% level of significance the amount of intervention may have contributed to the successfulness, while conducting interventions in an undisclosed manner actually made them less effective.

Égert and Komárek (2005) apply the event-study approach to the Czech intervention data as well, but because they define an event according to the number of days of no intervention that can pass within an event, their event window is longer than one single day. For defining a successful event, they compare the development of the exchange rate in the pre-event window and post-even window, and find that almost all intervention events were successful in either reversing the trend or smoothing the appreciation, regardless of how long the pre-event and post-event windows are considered to be. Nevertheless, they do not explore what has contributed to such successfulness of the interventions.

7. Conclusions

In this paper, the effectiveness of interventions conducted by the Czech National Bank in 2001 and 2002 was discussed. The traditional approaches that were discussed and applied here included the estimation of the reaction function and estimation if the impact of interventions on the exchange-rate level, as well as on conditional and expected (implied) volatility. In addition, the event-study approach was explored and used to answer the question of what can make interventions successful.

The results suggest that the CNB systematically intervened to limit or stop too-rapid appreciation and that interventions were also triggered by increased volatility. With regard to the effectiveness of intervention, the results indicate that the interventions conducted by the Czech National Bank in 2001 and 2002 against the strengthening koruna had some small short-term impact on the exchange-rate level, but almost no medium-term or even long-term impact. On the other hand, the analysis showed that interventions have contributed to increased volatility, both conditional and implied, and this holds true for longer horizons as well. Thus, the interventions might have been effective in the medium term through raising the two-sided risk in the market and thus inducing market participants to alter their expectations away from the certain appreciation trend towards a more balanced path of the exchange rate.

The event study revealed that over the whole period of interventions, just around 45 % of intervention days were crowned with success in terms of depreciating the currency within one day. However, this share of successful interventions does not significantly differ from the share of days with depreciation of the koruna from the no-intervention control sample, indicating that the interventions probably had no significant impact. Nevertheless, the results are sensitive to the definition of success and to the event size. The analysis of factors that may have contributed to successful intervention showed that no particular intervention strategy increased the likelihood of success.

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SUMMARY

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Testing the Effectiveness of the Czech National Bank's Foreign-Exchange Interventions

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This article reviews several approaches to testing the effectiveness of foreign-exchange interventions and applies some of these to data on interventions made by the Czech National Bank in 2001 and 2002. The reaction function of the CNB and the impact of interventions on exchange rates and on conditional and implied volatility are estimated, and the successfulness of interventions is discussed within the event-study approach. The results indicate that the interventions by the central bank had only a minor, short-term effect on exchange rates and, to a certain extent, contributed to increased conditional and implied volatility.