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Do Sales of Foreign Exchange Reserves Lead to Currency Appreciation?

We employ novel time-stamped reserve sales data, provided by the Czech National Bank (CNB), to carry out a time-series analysis of the exchange rate implications of Czech reserve sales aimed at mitigating valuation losses on Euro-denominated assets. The sales were explicitly not intended to influence the value of the koruna relative to the euro. The period under study includes a well-defined regime change in the CNB's approach to reserves sales, allowing us to address whether the manner in which the sales are carried out matters for their influence on the relative value of the domestic currency. We find little evidence that reserve sales influence the exchange rate when sales are carried out on a discretionary and relatively infrequent basis. However, when the sales are carried out daily, we find a statistically and economically significant appreciation of the domestic currency follows.

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FOREIGN EXCHANGE RESERVES HAVE risen dramatically for many emerging market countries in recent years. A number of studies have attempted to

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understand the motives for reserve accumulation, the optimal level of reserves, as well as the costs and benefits of holding large reserve stocks.[1] A negative consequence of holding reserves denominated in foreign currency is the risk of valuation losses in the event of a domestic currency appreciation.[2] A straightforward way for countries with substantial reserve stocks to reduce this risk is to limit further reserve accumulation by selling reserves. Doing so, however, may prove counterproductive if the reserve sales themselves cause the domestic currency to appreciate, thereby increasing rather than mitigating valuation losses. This raises the question of whether it is possible to reduce the growth rate of foreign reserve accumulation by selling reserves without appreciating the domestic currency. Put differently, whereas reserve growth in some countries is thought to be the byproduct of a government strategy to keep the international value of the domestic currency low to boost export growth, does it follow that reserve *sales* necessarily lead to domestic currency appreciation?

In this paper, we examine whether reserve sales aimed at mitigating valuation losses on foreign currency denominated assets cause the domestic currency to appreciate. We employ novel intraday data on recent sales of euro (EUR)-denominated reserves, carried out by the Czech National Bank (CNB), to empirically address this topical question. The question that is normally asked in the foreign exchange intervention literature is whether reserve changes effectively influence exchange rates. The question we ask in this paper is whether it is possible to sell reserves and *avoid* influencing the exchange rate.[3]

It is interesting to investigate the effects of reserve sales on exchange rates in light of the dramatic accumulations of reserves in several emerging market countries. It is particularly interesting to do so using the CNB reserve sales data for two reasons. First, the CNB reserve sales data present a unique opportunity to study the intraday exchange rate effects of reserve sales that are not carried out for the purpose of influencing the exchange rate. Second, the CNB reserve sales data encompass a well-defined regime change in the approach to sales, allowing us to address whether the manner in which the sales are carried out matter for their price impact.

In April 2004, as the Czech koruna (CZK) began to appreciate against the EUR, the CNB announced that it would begin to sell some its EUR-denominated reserves.[4] At that time, the value of its foreign reserve holdings was EUR 21.9 billion (or US$26.3 billion at the then prevailing rate). The stated objective of the sales was to reduce the valuation losses that followed from the fact that Czech reserves are largely

1. See Jeanne (2007), Jeanne and Rancière (2011), and Dominguez (2010) for discussions of optimal reserve levels. Rodrik (2006) discusses the social costs of holding reserves.

2. Another way to reduce valuation risk is through diversification of the currency denomination of reserve assets (see Beck and Weber 2011).

3. See Dominguez (2003, 2006), Dominguez and Panthaki (2007), Fatum and Pedersen (2009), Fischer and Zurlinden (1999), and Melvin, Menkhoff, and Schmeling (2009) for intraday studies of the effects of intervention.

4. The announcement, at http://www.cnb.cz/en/public/media_service/press_releases_cnb/2004/543.html, emphasizes that sales of reserves "will be carried out gradually, in small volumes and if the market conditions (including liquidity, depth, and trend changes) are considered appropriate." See Osler (2009) for a general discussion of the influence of market conditions on the price impact of trades.

denominated in EUR, the value of which was falling relative to the CZK.[5] Importantly, the goal was not to induce a sizable adjustment of the foreign reserve stock. Instead, as stated in IMF Country Report No. 04/266 (p. 12), the objective was to limit further accumulation of reserves. Moreover, the CNB was explicit in not wanting to influence, and in particular further appreciate, the CZK relative to the EUR.[6,7] During the first reserve sales regime, spanning April 2004 to mid-June 2007, the CNB sold reserves in a discretionary and relatively infrequent manner. This allowed the CNB traders responsible for carrying out the sales to sell reserves when market conditions were perceived to be conducive for sales to have minimal price impact. The second reserve sales regime is markedly different. In June 2007, the CNB changed its approach to reserve sales from irregular sales to selling EUR on a daily basis, and continued to do so throughout the end of our sample period. During this second regime, the CNB sold EUR every business day in three separate transactions (the intraday timing of which remained irregular). The daily reserve sales are relatively small with each transaction accounting for roughly 0.2% of average daily turnover in the CZK/EUR spot market and roughly 0.1% of average daily total CZK spot turnover.[8,9] No official announcement of this change in the approach to reserve sales was made. According to sources at the CNB, the rationale for switching to daily sales was to make the reserve sales policy more consistent with the transparency of the CNB's inflation targeting policy.[10] Furthermore, the hope was that by effectively removing the discretionary

5. Beck and Rahbari (2011) and Dellas and Yoo (1991) and others also use the domestic currency as the reference currency for central bank foreign exchange reserves. Beck and Rahbari note that although the choice of reference currency is not obvious, using the domestic currency as the reference currency is appealing if we assume that the central bank is maximizing domestic consumption, which is generally measured in (real) domestic currency units.

6. See IMF Country Report No. 04/266 (http://imf.org/external/pubs/ft/scr/2004/cr04266.pdf), which states that the recent decision of the CNB to begin selling reserves was aimed solely at limiting further accumulation of reserves and "was not intended to influence the level of the exchange rate" (p. 12).

7. Sources at the CNB indicate that the decision to sell EUR-denominated reserves starting in 2004 was well understood by market participants, even though the details of the implementation of the policy regarding the daily frequency, intraday timing, and size of sales were not reported. Monthly CNB EUR sales data, however, can be inferred from data on unsettled foreign exchange transactions. These data are available at http://www.cnb.cz/en/financial_markets/foreign_exchange_market/DEVOP_EUR_ENG.HTML.

8. Average daily turnover in the CZK/EUR spot market was US$678 million in 2007, or roughly EUR 468 million when converted at the USD/EUR rate of 1.45 prevailing in the fall of that year, according to CNB data at http://www.cnb.cz/en/financial_markets/foreign_exchange_market/turnover/A_FT_obraty_07.html. Average daily CZK spot turnover against all currencies was US$1,630 million in 2007, or roughly EUR 1,124 million, according to the BIS Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity in 2007 at http://www.bis.org/publ/rpfxf07t.htm Statistical Annex Table E.1, p. 59.

9. As a comparison point, we note that the daily Bank of Israel intervention purchases of US$100 million carried out between July 10, 2008 and August 10, 2009 account for roughly 5% of average daily total NIS spot ("conversion") turnover, according to 2009 NIS market turnover data available at http://www.bankisrael.gov.il/deptdata/mth/exchange.htm. For a study of the recent Bank of Israel interventions see Sorezcky (2010).

10. The CNB has followed an inflation-targeting monetary regime since 1998. Actual Czech inflation generally kept well within its target range over our sample period (the CNB inflation target band was 3–5% in 2004, 2–4% in 2005, 3% in 2006, and 2% in March 2007). It is generally the case that countries that effectively target inflation sterilize their foreign currency operations. In the CNB case, sales of foreign reserves, if not sterilized with a matching increase in domestic assets, would result in a decrease in the monetary base. We address this possibility in our Robustness section.

aspect of the policy, reserve sales would be less likely to be mistaken for currency interventions.[11] Importantly, the regime change was not implemented in response to exchange rate developments or exchange market reactions to the discretionary reserves sales.

The fact that our data span two distinct reserve sales regimes, and that the regime change was not a response to implications of the reserve sales in the first regime, allows us to address whether the manner in which the sales are carried out matter for their price impact. Particularly, it makes it possible to evaluate if discretionary or daily reserve sales are preferable if the objective is to avoid influencing the foreign exchange market.

To assess whether the intraday effects of reserve sales had unintended exchange rate consequences, and to address whether the manner in which reserve sales are carried out matters, we estimate time-series models of the CZK/EUR exchange rate return, calculated from indicative 15-minute spot CZK/EUR quotes. We do so over the full April 2004 to November 2007 sample as well as separately across the two distinct reserve sales regimes. We carry out our baseline estimations using the weighted least squares (WLS) procedure developed by Andersen and Bollerslev (1998).

During the first regime we find little evidence that reserve sales influenced the CZK. By contrast, the reserves sales carried out during the second regime, when the CNB sold reserves every business day, are associated with a statistically and economically significant appreciation of the CZK relative to the EUR. Our results hold up against an array of robustness checks, including employing a different econometric procedure and controlling for endogeneity as well as coincidental arrival of macro news.

The rest of the paper is organized as follows. Section 1 describes the institutional context in which the Czech authorities sold their foreign reserves. Sections 2 and 3 detail our data and econometric methodology, respectively. Section 4 presents our results. Section 5 provides robustness checks, and Section 6 concludes.

1. INSTITUTIONAL ASPECTS

The Czech Republic became an independent state in January 1993 following the break-up of the Soviet Union. A decade later, in May 2004, the Czech Republic joined the European Union and thus committed to adopt the EUR at some point.[12] Although the Czech Republic has yet to join the European Exchange Rate Mechanism

11. It is unclear why the CNB did not make its reserve sale policy change transparent. It is, however, common for central banks not to publicize details regarding reserve policies or foreign exchange market operations. Bhattacharya and Weller (1997), Ghosh (2002), and others discuss the advantages of secrecy in the context of foreign exchange operations aimed at influencing relative currency values. It is noteworthy that the switch to daily reserve sales was met with internal resistance by CNB dealers who felt that more discretion in the timing of sales would better allow them to avoid influencing the foreign exchange market.

12. The Czech koruna (or crown) has been the currency of the Czech Republic since February 8, 1993, when it replaced the Czechoslovak koruna at par. The Czech Republic planned to adopt the EUR in 2012, but its government suspended that plan in 2007. Denmark and the United Kingdom are the only EU member states with a formal exemption clause ("opt-out") according to which adoption of the EUR is not obliged.

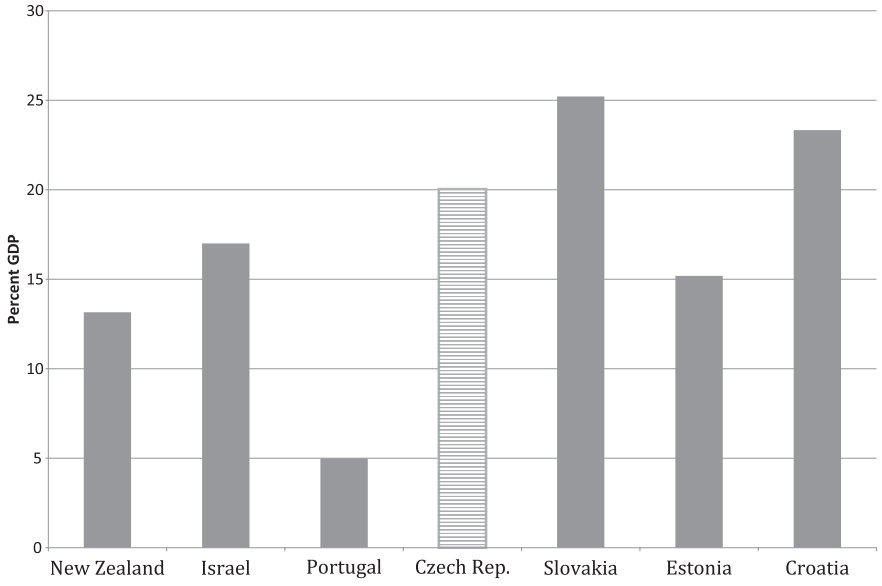

FIG. 1. Official Reserve Assets as a Percentage of GDP (December 2007), Held by Countries with similar GDP per capita as the Czech Republic.

SOURCE: IMF, IFS Statistics.

(ERM II), a precondition for joining the euro zone, the CNB intervened frequently in the CZK/EUR market through September 2002.[13,14] Throughout this period, the CNB was largely engaged in leaning-against-the-wind operations to slow down the steady appreciation of the CZK relative to the EUR (over the period 1999 to September 2002 the CZK appreciated more than 25% against the EUR). The CZK abruptly reversed direction in the fall of 2002 and depreciated relative to the EUR through early 2004 (during which time the CNB ceased intervening).

Figures 1 and 2 show that Czech reserve holdings as a percentage of GDP in December 2007 were close to the median relative to other emerging market countries with similar per capita GDP and close to the median relative to other Eastern European countries and Russia. At the end of 2007, foreign exchange reserves represented approximately 83% of the CNB's assets, of which 57.4% were denominated in EUR, and the return on these reserves was the CNB's most significant revenue item.[15]

13. Denmark, Latvia, and Lithuania are currently in ERM II. Bulgaria, the Czech Republic, Hungary, Poland, Romania, Sweden, and the United Kingdom have not adopted the EUR and do not participate in ERM II.

14. The CNB intervened on 1,247 occasions over the period 1997 to September 2002. See Disyatat and Galati (2007), Egert and Komarek (2006), Gersl and Holub (2006), and Scalia (2008) for analyses of these operations. See Derviz (2003) for details on the market for CZK.

15. See the Annual Report of the CNB (2004, 2005, 2006, 2007) for additional details. The reports are available at http://www.cnb.cz/en/about_cnb/performance/annual_reports/index.html.

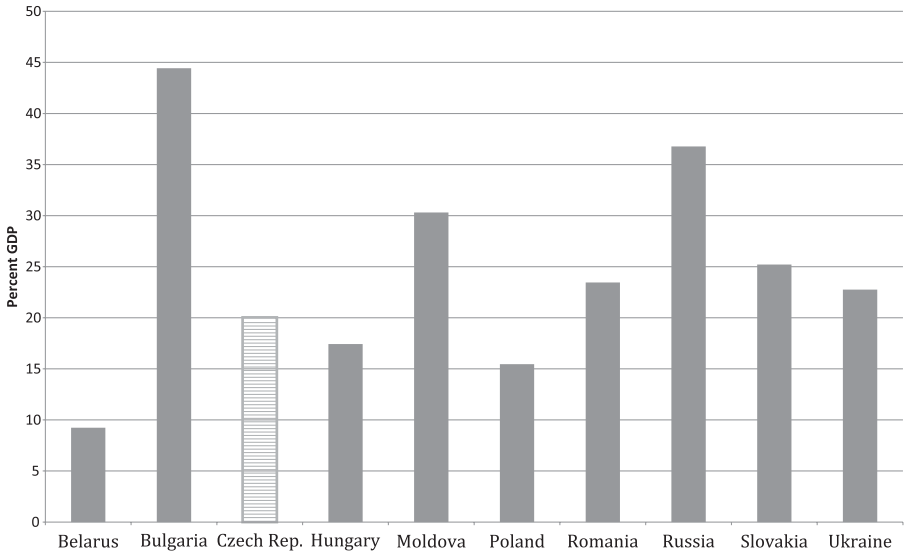

FIG. 2. Official Reserve Assets as a Percentage of GDP (December 2007), Held by Eastern European Countries and Russia.

SOURCE: IMF, IFS Statistics.

In their annual reports over the 2004–07 period, the CNB describes that it attempts to manage foreign exchange rate and interest rate risk on foreign reserves based on the requirement that the EUR portfolio should not record a loss (in absolute terms and relative to an unspecified benchmark portfolio) in any moving 12-month period (for comparison, the USD portfolio criteria is that it not record a loss in any moving 36-month period). Figure 3 shows the evolution of the CZK/EUR rate from 1999 to the end of 2008. Over most of this period, the CZK steadily appreciated against the EUR. It is in this context that the CNB decided to sell EUR-denominated reserve assets beginning in 2004.

Although the CNB decision to sell EUR-denominated reserves is documented in its annual reports starting in 2004 as well as in the IMF Article IV consultation reports, to the best of our knowledge no publicly released details regarding the implementation of this policy, in terms of the amount of reserves to be sold or the timing of the sales, exist. The transactions data we obtained from the CNB indicate no discernible patterns of sales in terms of days of the week, time of day, or amounts in the first 3 years of our sample. Starting in mid-2007 and throughout the remainder of our sample period, three reserve sales in equal-sized transactions occur on every business day. The unpredictable aspect of sales in this period is the intraday timing of the transactions as well as the continuity of the regime (the CNB never announced the new reserve sales strategy nor provided any information on how long it would last).

The CZK appreciating trend briefly reversed in the first half of 2007. The use of the CZK as a funding currency for carry trade operations can explain most of this

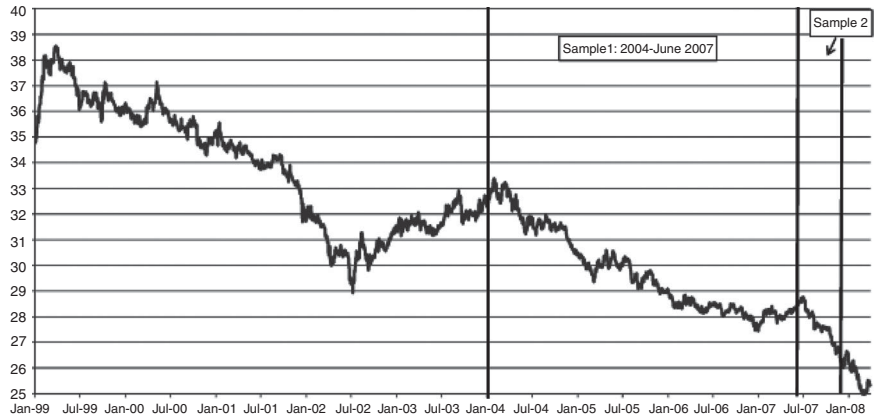

FIG. 3. CZK-EUR Rate (1999–2008).

DATA SOURCE: GenesisFT.

turnaround. The ECB started tightening monetary policy in 2006 and relatively low interest rates in the Czech Republic led investors to borrow in CZK to finance the purchase of debt instruments in higher-yielding currencies (such as the Icelandic krona). In mid-2007, the CNB responded by tightening monetary policy, resulting in an unwinding of the CZK carry trade by mid-August. It is worth noting that the CNB continued to sell EUR-denominated reserves during this brief period of CZK depreciation.

2. DATA

The reserve sales data used in this study cover all CNB transactions over the January 1, 2004 to November 23, 2007 period. The data are proprietary, provided by the CNB, and the sample period is determined by data availability. The data include transaction-specific information on the EUR value of each sale and the time-stamp to the nearest minute. During our sample period, all CNB reserve transactions are sales of EUR-denominated assets. All reserve sales are carried out in the spot market either by phone or by electronic trading platform.[16]

Table 1 provides descriptive statistics of the CNB reserve sales data. Our sample includes 498 days with reserve sales and 1,048 intraday reserve sale transactions. The maximum intraday transaction is EUR 7 million in 2004 and the minimum intraday transaction amount is EUR 1 million. The yearly cumulated amount of reserve sales ranges from EUR 208 million in 2006 to EUR 707 million in 2007. In percentage terms, relative to the total reserve stock, the CNB sales are quite small. For example,

16. According to CNB dealers, no pattern or rule describes whether a sale is carried out by phone or electronic trading. We do not have information regarding how an individual sales transaction is carried out.

TABLE 1

CNB Euro Reserve Sales

	2004	2005	2006	2007
Total number of days with reserve sales	105	114	72	207
Total number of intraday reserve sales transactions	193	231	104	520
Maximum transaction amount (intraday)	€7	€2	€2	€2
Minimum transaction amount (intraday)	€1	€1	€2	€1
Cumulated EUR value of reserve sales	€439	€461	€208	€707

Notes: (i) Data source: Czech National Bank.
(ii) Reserve transaction amounts in millions of EUR.
(iii) Sample ends November 23, 2007.

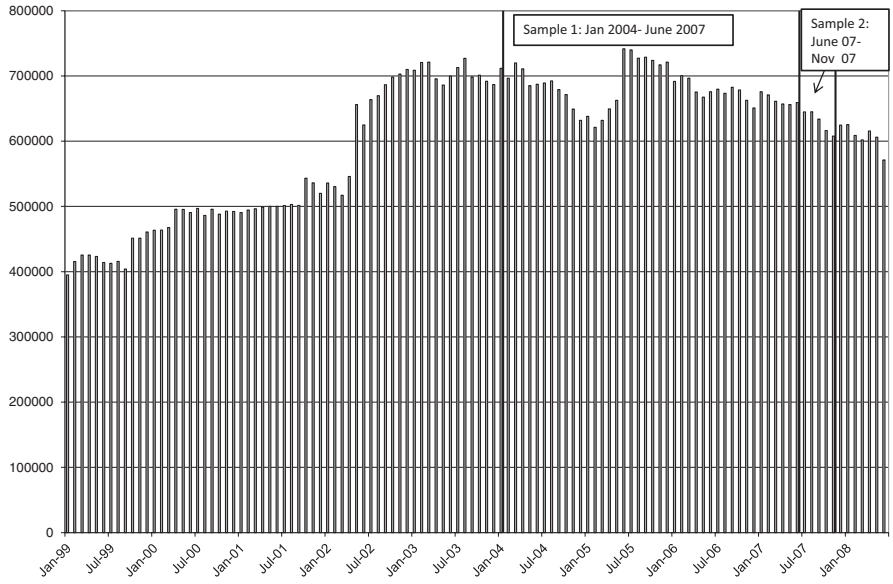

Fig. 4. CNB Foreign Reserve Stock (Monthly, in Millions of Koruna).

Data Source: Czech National Bank.

in 2007 the EUR value of CNB reserves was EUR 23.7 billion, so total 2007 reserve sales of EUR 707 million amounts to 3.5% of the total stock. Figure 4 shows that the CZK value of CNB reserve stocks fell by around 13% over this 4-year period. This decline in value is due both to the appreciation of the CZK and sales of reserves.[17]

The high-frequency CZK/EUR exchange rate data are from GenesisFT and cover the full 2004–07 sample period. The data consist of quotes for the CZK/EUR spot

17. Figure 5 shows the EUR value of CNB reserve stocks.

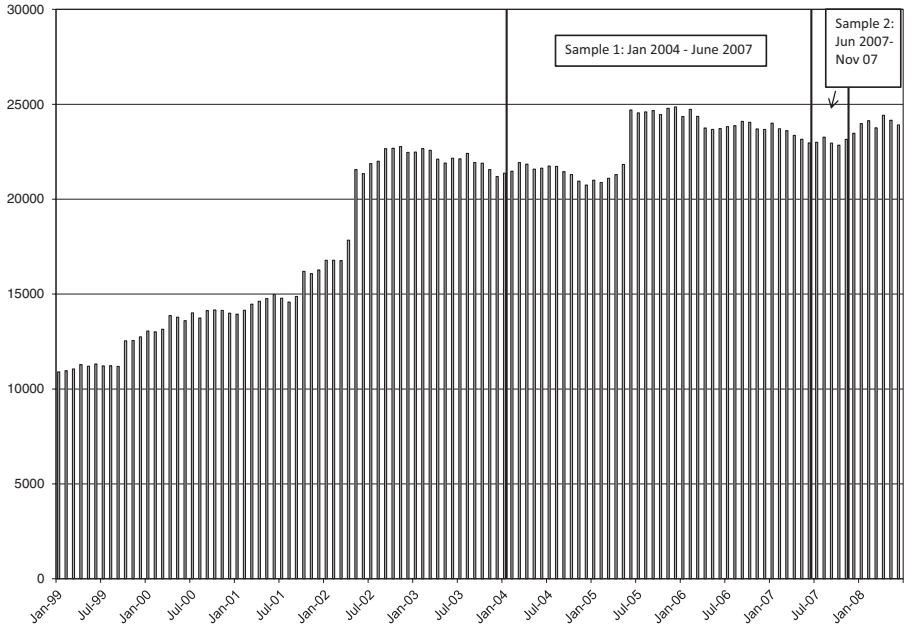

FIG. 5. CNB Foreign Reserve Stock (Monthly, in Millions of Euro).

DATA SOURCE: Czech National Bank.

rate at the end of every 15-minute interval over every 24-hour period. These rates are not transactions prices but indicative quotes posted by traders.[18] Transactions prices would be preferable because indicative quotes are not necessarily traded quotes, and therefore, indicative quotes are not binding commitments to trade. Moreover, indicative quotes may reflect dealer-specific inventories or beliefs. Despite these potential shortcomings, the statistical properties of exchange rate return series derived from transactions prices and indicative quotes at lower sampling frequencies (e.g., lower than 5 minutes) are extremely similar (see Danielsson and Payne 2002).[19] We follow Dacorogna et al. (1993) and filter the data for anomalies and bad quotes. This filtering procedure is purposely "weak" or unrestrictive to not reject a substantial part of the real information along with the outliers. It does not overcome the aforementioned potential shortcomings associated with indicative quotes, it only ensures that outliers are removed from the analysis.

18. Intraday transaction prices are, to the best of our knowledge, not available for the CZK/EUR exchange rate market.

19. Danielsson and Payne (2002) also show that this is not the case for indicative quotes at very high sampling frequencies (e.g., every minute), because indicative quotes tend to be more volatile than transaction prices at higher than 5-minute frequencies. Their results thus suggest that using higher frequency indicative quotes would be counterproductive.

TABLE 2
SUMMARY STATISTICS

	Maximum	Minimum	Nonzero observations
CZK/EUR spot rate	33.555	26.516	96,480
	Mean	SD	–
	29.51555	1.640642	–
	Maximum	Minimum	Nonzero observations
CZ monetary policy rate	0.25	− 0.25	11
CZ CPI MoM	1.1	− 0.5	37
CZ 3-month PRIBOR	0.22	− 0.25	427
CZ CPI YoY	1.1	− 0.5	34
CZ PPI MoM	0.8	− 0.8	40
CZ industrial production	7.40	− 6.7	47
CZ unemployment	0.2	− 0.2	26
CZ trade balance	11,212	−5,776	44
EUR monetary policy rate	0.25	0	12
EUR CPI YoY	0.1	− 0.1	17
EUR PPI YoY	0.5	− 0.2	26
EUR PPI MoM	0.4	− 0.2	22
EUR GDP YoY	0.3	− 0.3	20
EUR unemployment	0.4	− 0.2	22

NOTES: (i) All data series run from January 1, 2004 to November 23, 2007.
(ii) The exchange rate series contain a quote every 15 minutes; the macro surprises are measured as the difference between the time-stamped announcement and preceding median survey value. The Czech 3-month PRIBOR rate as well as the Czech and euro area monetary policy rate series measure actual changes.
(iii) The intraday exchange rate data are from GenesisFT. The reserve sales and PRIBOR data are provided by the Czech National Bank. The macro news is obtained from Bloomberg.

Consistent with other intraday studies focusing on currency pairs with limited trading outside of local business hours (see Fatum and Pedersen 2009), we define a trading day in the Czech currency market to start at 8 a.m. (7.00 GMT+1) and finish at 6 p.m. (17.00 GMT+1).[20] As a result, our analysis spans 1,005 trading days and a total of 41,205 15-minute observations. All CNB reserve sales transactions under study are carried out during Prague business hours; thus, they are consistent with our trading day definition. Although the exchange rate is quoted every 15 minutes, reserve transaction times are provided to the minute. We thus cumulate reserve transactions in each 15-minute interval.

Czech and euro area interest rates are obtained from the websites of the CNB (www.cnb.cn/en) and the ECB (www.ecb.int), respectively. Time-stamped Czech and euro area macro announcements and preceding survey expectations are obtained from Bloomberg. The inclusion of macro news surprise variables is constrained by data availability, particularly the availability of survey expectations. Table 2 provides summary statistics for the CZK/EUR intraday exchange rate, the interest rates, and the macro news control variables.

20. This definition of a trading day carries over naturally to a definition of a weekend; that is, we define a weekend to start at 17.15 GMT+1 Friday and finish at 7.00 GMT+1 Monday.

3. ECONOMETRIC METHODOLOGY

To take into account the possibility of long memory and intraday seasonality in our context of high-frequency exchange rate determination, our baseline estimates of the response of the CZK/EUR exchange rate to CNB reserve sales follow the WLS procedure developed by Andersen and Bollerslev (1998). Specifically, we model the CZK/EUR exchange rate as a linear function of J-lagged values of the exchange rate itself and the contemporaneous and K lags of the reserve sales variable, R_t:

$$s_t = \beta_0 + \sum_{j=1}^{J} \beta_j s_{t-j} + \sum_{k=0}^{K} \gamma_k R_{t-k} + \varepsilon_t, t = 1, \ldots, T, \tag{1}$$

where s_t is the first difference in logs of the CZK/EUR spot exchange rate. As noted earlier, $T = 1\,41{,}205$. We include three lags (45 minutes) of CZK/EUR returns ($J = 3$) based on the Schwartz and Akaike information criteria and we include prior reserves sales in the previous 75 minutes ($K = 5$).[21] We vary the number of lags of reserve sales in the robustness section.

The estimation procedure is as follows: first, we estimate equation (1) by ordinary least squares (OLS) and obtain the estimated residuals, $\hat{\varepsilon}_t$; next, we model the volatility pattern using the estimated residuals. We follow Andersen et al. (2003) in using the following parameterization:

$$|\hat{\varepsilon}_t| = c + \alpha \frac{\hat{\sigma}_t}{\sqrt{n}} + \sum_{k=0}^{K} \beta_k R_{t-k} + \left(\sum_{q=1}^{Q} \delta_q \cos\left(\frac{q 2\pi t}{40}\right) + \phi_q \sin\left(\frac{q 2\pi t}{40}\right) \right) + u_t, \tag{2}$$

where the absolute value of the residuals in equation (1) proxies for volatility in the 15-minute interval t, c is a constant, n is the number of intervals in a day (in our case 40), $\hat{\sigma}_t$ is the 1-day-ahead volatility forecast for day t (i.e., the day that contains interval t), q is a specific intraday calendar effect, Q is the total number of calendar effects accounted for ($Q = 5$, based on the Schwartz and the Akaike information criteria), and u_t denotes the residuals (assumed to be standard normal). We model the lower frequency intraday pattern (the first term after the constant) using realized volatility, and we model the higher frequency periodicity by inclusion of the Fourier flexible form (the terms in the parenthesis of equation (2)). To take into account the possibility that volatility is influenced by reserve sales, we include the reserve sales variable in the volatility equation.

21. Additional details regarding the information criteria and lag structures are available from the authors upon request.

TABLE 3

EXCHANGE RATE RESPONSES TO RESERVE SALES: CONDITIONAL MEAN EQUATION

	Full sample	Subsample 1	Subsample 2
Constant	1.84	2.10	2.96
	(1.45)	1.61	(4.15)
DLNCZKEUR(−1)	− 0.27***	− 0.29***	− 0.17***
	(0.00)	(0.00)	(0.01)
DLNCZKEUR(−2)	− 0.07***	− 0.08***	− 0.05***
	(0.00)	(0.00)	(0.01)
DLNCZKEUR(−3)	− 0.04***	− 0.05***	0.01
	(0.00)	(0.00)	(0.01)
RESSALE	3.57	5.72	− 13.24
	(4.07)	(4.46)	(10.49)
RESSALE(−1)	− 10.45**	− 9.83**	− 10.90
	(4.39)	(4.84)	(10.20)
RESSALE(−2)	5.06	6.27	− 0.77
	(4.19)	(4.69)	(9.78)
RESSALE(−3)	− 6.67*	− 7.81*	5.29
	(3.99)	(4.49)	(8.94)
RESSALE(−4)	− 10.57**	− 7.70	− 33.58***
	(4.85)	(5.43)	(10.49)
RESSALE(−5)	0.16	4.48	− 19.22
	(4.86)	(5.29)	(12.56)
Sum of RESSALES	− 18.90	− 8.87	− 72.42
Wald statistic	3.30*	0.59	7.84***
Observations	41,180	36,547	4,633

NOTES: (i) *denotes significance at 90%; **denotes significance at 95%; ***denotes significance at 99%.
(ii) Standard errors are in parentheses below the point estimates.
(iii) Estimations are defined in equation (1) in the text, and carried out using 2WLS.
(iv) The dependent variable, DLNCZKEUR, is the first difference of the log of the 15-minute CZK/EUR spot exchange rate.
(v) RESSALE denotes reserve sales of EUR carried out by the CNB. RESSALE is measured in millions of EUR.
(vi) Point estimates and standard errors associated with Constant, RESSALE, and Sum of RESSALES are multiplied by 10(E6) for readability.
(vii) Sum of RESSALES refers to the cumulative effect of contemporaneous and five lags of reserve sales.
(viii) Subsample 1 runs from January 1, 2004 to June 18, 2007; subsample 2 runs from June 19, 2007 to November 23, 2007.
(ix) R^2 is not applicable to the WLS estimation procedure.

4. RESULTS

We estimate the baseline model over the full sample period, January 1, 2004 to November 23, 2007, as well as separately across the two sales regimes. The second regime begins on June 19, 2007, the first day of equal-sized everyday sales. A positive reserve transaction indicates a sale of EUR against CZK; the exchange rate is measured in terms of CZK per EUR. Therefore, a negative reserve sale coefficient estimate or a negative cumulative effect of reserve sales would imply that sales of reserves are associated with an appreciation of the CZK vis-à-vis the EUR.

Tables 3 and 4 display the results of the WLS estimations of equations (1) and (2), respectively. The first column of Table 3 shows that for the full sample the coefficient estimates associated with the first, third, and fourth lags of reserve sales are significant at either 95% or 90% significance levels, and these coefficients are of the expected negative sign (sales of EUR-denominated reserves are associated with a CZK appreciation). The Wald test of the hypothesis that the (negative) sum of the estimated reserve sales coefficients is equal to 0 is marginally rejected at 90% significance.

TABLE 4

EXCHANGE RATE RESPONSES TO RESERVE SALES: VOLATILITY EQUATION

	Full sample	Subsample 1	Subsample 2
Constant	4.4681***	4.4259***	5.5213***
	(0.48202)	(0.52754)	(1.3573)
Realized volatility	0.57415***	0.57426***	0.55597***
	(0.008069)	(0.0085997)	(0.031715)
RESSALE	− 1.601**	− 1.4058*	− 2.927*
	(.70367)	(0.76247)	(1.6435)
RESSALE(−1)	− .83874	− 0.61256	− 3.1001*
	(0.7041)	(0.76285)	(1.6447)
RESSALE(−2)	− 1.3077*	− 0.93504	− 3.6178**
	(0.70409)	(0.76271)	(1.6466)
RESSALE(−3)	− 1.7565**	− 1.3378*	− 5.2815***
	(0.70409)	(0.76271)	(1.6466)
RESSALE(−4)	0.26497	0.63672	− 2.6724
	(0.70437)	(0.76285)	(1.6509)
RESSALE(−5)	0.22122	0.28121	− 0.026462
	(0.70557)	(0.76387)	(1.6604)
$\delta(1)$	2.4858	2.8846	− 1.0071
	(2.9144)	(3.1796)	(6.3943)
$\delta(2)$	− 1.4757	− 0.33122	− 8.9307
	(2.9144)	(3.1791)	(6.3988)
$\delta(3)$	3.9579	4.3334	5.8841
	(2.9142)	(3.1789)	(6.3926)
$\delta(4)$	0.75642	0.77641	0.029398
	(2.9142)	(3.1789)	(6.3985)
$\delta(5)$	− 0.94428	− 0.083674	3.428
	(2.9143)	(3.1789)	(6.3957)
$\varphi(1)$	− 0.1573	− 0.5494	2.4482
	(2.9143)	(3.1788)	(6.3931)
$\varphi(2)$	− 0.73456	− 1.7634	− 10.258
	(2.9146)	(3.1793)	(6.4027)
$\varphi(3)$	3.4246	4.7982	5.2266
	(2.9141)	(3.1789)	(6.3934)
$\varphi(4)$	− 3.8461	− 3.9839	4.3773
	(2.9141)	(3.1789)	(6.4003)
$\varphi(5)$	2.0185	3.8104	12.329*
	(2.9142)	(3.1789)	(6.3951)
R^2	0.11029	0.10925	0.069477

NOTES: (i) *denotes significance at 90%; **denotes significance at 95%; ***denotes significance at 99%.
(ii) Standard errors are in parentheses below the point estimates.
(iii) Estimations are defined in equation (2) in the text.
(iv) The dependent variable is the absolute residual from the auxiliary regression defined in equation (1).
(v) The independent variables are the constant, a realized volatility measure, reserve sales (RESSALE), and trigonometric terms (cosine terms denoted by δ, sine terms denoted by φ). RESSALE is measured in millions of EUR.
(vi) Constant and reserve sales point estimates and standard errors are multiplied by 10(E5); point estimates and standard errors associated with trigonometric terms are multiplied by 10(E6).
(vii) Subsample 1 runs from January 1, 2004 to June 18, 2007; subsample 2 runs from June 19, 2007 to November 23, 2007.

As expected, given that we are using indicative exchange rate quotes, some serial correlation of the intraday exchange rate is detected (see Danielsson and Payne 2002).

The results pertaining to the first reserve sales regime (subsample 1) are shown in column 2. As the table shows, we find that the cumulative (negative) effect of reserve sales is insignificant. This result indicates that during the first more than 3 years of discretionary reserve sales, the CNB was able reduce its EUR-denominated reserve holdings without adversely affecting the value, in domestic currency terms, of its remaining EUR-denominated reserves.

By contrast, column 3 shows that this result is reversed in the second sales regime (subsample 2). The results show that reserve sales significantly impact the CZK rate (at the 99% significance level) during the second regime. Furthermore, the Wald test strongly rejects (again at the 99% significance level) that the (negative) sum of the estimated reserve sales coefficients is equal to 0. These estimates suggest that during this second regime the CNB reserve sales influenced the CZK rate in the theoretically consistent but, from a policy perspective, undesired direction.

The economic significance of the appreciation during the second regime is not negligible. The coefficient associated with the cumulative effect of reserve sales for subsample 2 is −72.42(10E6), implying that a EUR 100 million reserve sale corresponds, on average, to a 0.7% appreciation of the CZK. In other words, our estimates suggest that the cumulative effect on the CZK of a year's worth of daily CNB reserve sales (220 days times EUR 3 million thus EUR 660 million) would lead to a 4.6% appreciation of the CZK relative to the EUR.[22] It is interesting to note that our estimates of the effects of the daily CNB reserve sales are similar to estimates in the literature on the effects of interventions in currency markets, even though the CNB explicitly did not intend to influence the value of the CZK and switched to daily sales partially to avoid the perception that reserve sales are currency interventions.[23]

Table 4 displays the results of the estimation of the volatility model described in equation (2). Whether we estimate the volatility model across the full sample (column 1), subsample 1 (column 2), or subsample 2 (column 3), our results suggest that reserve sales are associated with reduced exchange rate volatility. Although the realized volatility term associated with lower frequency periodicity is highly significant, the trigonometric terms are largely insignificant, implying an absence of intraday calendar effects. The absence of intraday seasonality is not surprising considering that we are analyzing indicative quotes (see Danielsson and Payne 2002).

5. ROBUSTNESS

To test the robustness of our results, we carry out the analysis using a different econometric procedure, take into account the possibility that the reserve sales variable contains an expected component, control for macro news surprises, control for the possibility that the reserve sales are unsterilized, change the reserve sales lag-structure, employ a different subsample demarcation point, test for evidence of a learning process, use a different trading day definition, investigate if the reserve sales are anticipated by testing for lead effects, and take into account a proxy for trading volume.[24]

22. As usual, these calculations assume that the effects of reserve sales on the exchange rate are linear, the average daily turnover in the CZK/EUR spot market is largely constant, the intraday effects are permanent, and no delayed effects at lower frequencies occur.

23. For example, Dominguez and Frankel (1993) find that a US$100 million intervention purchase by the Fed leads to a 1.6% appreciation of the U.S. dollar.

24. Estimation results regarding endogeneity and macro news are displayed in Tables 5–7. All other robustness estimation results are available from the authors upon request.

First, the gain in efficiency from the WLS procedure is potentially costly in terms of inconsistent estimates if the residuals from the initial estimation of equation (1) are improperly fitted in the volatility model described by equation (2). To address this potential concern, we also estimate the baseline model using heteroskedasticity- and serial-correlation-consistent (HAC) standard errors (i.e., we reestimate equation (1) using HAC errors). The HAC results are qualitatively identical to the conditional mean results based on the two-step WLS procedure.

Second, it is possible that the specific timing of reserve sales transactions is influenced by contemporaneous and recent (lagged) exchange rate movements. Furthermore, current reserve sales may be correlated with recent (lagged) reserve sales. As a result, our reserve sales variable may contain an expected component that, if unaccounted for, could lead to an underestimation of the true exchange rate effect of the reserve sales. To control for this potential endogeneity, we follow a similar strategy as the daily data study by Humpage (1999) and the intraday study by Fatum and Pedersen (2009). We first estimate a CNB reserve sales reaction function to capture the expected component of reserve sales. We then use the residuals from the reserve sales reaction function estimation (i.e., we subtract the expected component of reserve sales from the actual reserve sales when are carried out) as a measure of unexpected reserve sales. In this way we can obtain an estimate of the influence of unexpected CNB reserve sales on the CZK/EUR exchange rate that is free of simultaneity bias. The results of the reaction function estimation are provided in Table 5.[25]

The results of the reestimation of the conditional mean model described in equation (1) using unexpected reserve sales in place of actual reserve sales are shown in Table 6. As the table shows, the cumulative sum of reserve sales is insignificant for subsample 1 and significant for subsample 2; thus, the results are qualitatively similar to the baseline estimation results that are carried out without controlling for endogeneity.[26]

Third, to ensure that the estimated effects of reserve sales are not tainted by the coincidental arrival of macro news, we extend our analysis to include time-stamped Czech and euro area macro news. Specifically, we include official macroeconomic announcements pertaining to changes in the Czech monetary policy rate (CZMONPOL) and surprises in Czech CPI (CZCPIYOY and CZCPIMOM), PPI (CZPPIMOM), industrial production (CZINDPROD), unemployment (CZUNEMP), and trade balance (CZTB), as well as changes in the euro area monetary policy rate (EURMONPOL)

25. It is interesting to notice that for subsample 2, none of the exchange rate lags helps explain the reserve sales, thereby confirming that reserve sales are not carried out with an eye to timing of the market during the regime of daily sales. It is also interesting to notice that although the R^2 is low across all reserve sales reaction function estimations, as expected in our context of intraday data, it is nevertheless higher for subsample 2 during which reserve sales are carried out with regularity.

26. For completeness, we also control for endogeneity by subtracting the expected component of reserve sales from the actual reserve sales variable even when no reserve sales are carried out, thereby allowing for the possibility that expectations of reserve sales when no sales occur can influence the exchange rate (see Fatum and Scholnick 2006 for details in the context of the effects on exchange rates of changes in expectations of future monetary policy). As it turns out, the results are not affected by this theoretically more consistent way of controlling for endogeneity.

TABLE 5
RESERVE SALE REACTION FUNCTION

	Subsample 1		Subsample 2	
	All lags	Selected lags	All lags	Selected lags
Constant	0.04***	0.04***	0.08***	0.08***
	(0.00)	(1591.02)	(0.00)	(0.00)
DLNCZKEUR(−1)	2.15	–	−2.25	–
	(2.07)		(8.86)	
DLNCZKEUR(−2)	2.48	–	−13.88	–
	(2.14)		(8.94)	
DLNCZKEUR(−3)	−1.58	–	11.57	–
	(2.45)		(8.94)	
DLNCZKEUR(−4)	7.58***	7.62***	−1.68	–
	(2.93)	(2.71)	(8.21)	
DLNCZKEUR(−5)	1.00	–	−4.39	–
	(2.86)		(8.83)	
DLNCZKEUR(−6)	−0.38	–	−12.92	–
	(2.51)		(8.94)	
DLNCZKEUR(−7)	3.09	–	5.04	–
	(2.57)		(9.44)	
DLNCZKEUR(−8)	0.71	–	−3.50	–
	(2.52)		(9.12)	
RESSALE(−1)	0.035***	0.035***	0.045**	0.044**
	(0.012)	(0.012)	(0.018)	(0.018)
RESSALE(−2)	0.003	–	−0.008	–
	(0.06)		(0.014)	
RESSALE(−3)	0.013**	0.014**	−0.010	–
	(0.006)	(0.006)	(0.012)	
RESSALE(−4)	0.019***	0.019***	−0.012	–
	(0.007)	(0.007)	(0.012)	
RESSALE(−5)	0.014**	0.015**	−0.022**	−0.023**
	(0.007)	(0.007)	(0.011)	(0.011)
RESSALE(−6)	0.006	–	−0.025**	−0.023**
	(0.006)		(0.010)	(0.010)
RESSALE(−7)	0.006	–	−0.030***	−0.030***
	(0.006)		(0.010)	(0.010)
RESSALE(−8)	0.012*	–	−0.012	–
	(0.012)		(0.013)	
Observations	36547	36547	4633	4633
R^2	0.003	0.002	0.006	0.004
SE of regression	0.29	0.29	0.28	0.28
F-statistic	6.13***	17.22***	1.75**	4.78***

NOTES: (i) *denotes significance at 90%; **denotes significance at 95%; ***denotes significance at 99%.
(ii) Standard errors are in parentheses below the point estimates.
(iii) Estimations are carried out using OLS with heteroskedasticity- and autocorrelation-consistent (HAC) standard errors and covariances.
(iv) The dependent variable, RESSALE, denotes reserve sales of EUR carried out by the CNB and is measured in millions of EUR. The variable DLNCZKEUR is the first difference of the log of the 15-minute CZK/EUR spot exchange rate.
(v) Subsample 1 runs from January 1, 2004 to June 18, 2007; subsample 2 runs from June 19, 2007 to November 23, 2007.

and surprises in euro area CPI (EURCPIYOY), PPI (EURPPIYOY and EURPPIMOM), GDP (EURGDP), and unemployment (EURUNEMP).[27]

We measure macro surprises as the difference between the macro announcement and the preceding survey expectation obtained from Bloomberg, and we standardize

27. We only consider macro control variables that contain a sufficient number of nonzero observations for inclusion to be meaningful. As a result, different Czech and euro area macro variables are included (e.g., euro area GDP is included, whereas Czech GDP is not).

TABLE 6

EXCHANGE RATE RESPONSES TO UNEXPECTED RESERVE SALES

	Subsample 1	Subsample 2
Constant	−1.15	−3.51
	(3.18)	(7.02)
DLNCZKEUR(−1)	−0.31***	−0.16***
	(0.01)	(0.03)
DLNCZKEUR(−2)	−0.10***	−0.04*
	(0.01)	(0.03)
DLNCZKEUR(−3)	−0.05***	0.03
	(0.01)	(0.02)
UNEXRESSALE	16.02	−8.05
	(10.19)	(22.91)
UNEXRESSALE(−1)	−0.40	−28.46
	(0.94)	(20.95)
UNEXRESSALE(−2)	8.17	−9.28
	(10.11)	(20.03)
UNEXRESSALE(−3)	−9.94	10.90
	(8.84)	(16.80)
UNEXRESSALE(−4)	−10.61	−19.89
	(10.58)	(18.82)
UNEXRESSALE(−5)	2.33	−37.71*
	(9.64)	(22.56)
Sum of RESSALES	5.57	−92.49
Wald statistic	0.04	3.60*
Observations	36547	4633
R^2	0.09	0.03
SE of regression	0.00	0.00
F-statistic	332.35***	13.08***

NOTES: (i) *denotes significance at 90%; ***denotes significance at 99%.
(ii) Standard errors are in parentheses below the point estimates.
(iii) Estimations are defined in equation (1) in the text, and carried out using OLS with heteroskedasticity- and autocorrelation-consistent (HAC) standard errors and covariances.
(iv) The dependent variable, DLNCZKEUR, is the first difference of the log of the 15-minute CZK/EUR spot exchange rate.
(v) UNEXRESSALE denotes unexpected reserve sales of EUR carried out by the CNB and is measured in millions of EUR. Unexpected reserve sales are proxied by the residuals of the reserve sale reaction function.
(vi) Constant point estimates and standard errors are multiplied by 10(E6); point estimates and standard errors associated with UNEXRESSALE, as well as sum of UNEXRESSALES, are multiplied by 10(E11).
(vii) Sum of RESSALES refers to the cumulative effect of contemporaneous and five lags of reserve sales.
(viii) Subsample 1 runs from January 1, 2004 to June 18, 2007; subsample 2 runs from June 19, 2007 to November 23, 2007.

each variable by dividing by its sample standard deviation. Almeida, Goodhart, and Payne (1998) and Andersen et al. (2003) show that the conditional mean of the exchange rate generally adjusts immediately in response to macro news; thus, we only control for contemporaneous macro news.[28]

The results of rerunning equations (1) and (2) with the macro news variables included are shown in Table 7.[29] The estimated coefficients indicate that, with few exceptions, macro surprises exert no significant influence on the CZK/EUR exchange rate. Of more importance to our research question, the table also shows that the cumulative sum of reserve sales is, again, significant only across subsample 2; thus,

28. In another set of estimations, we include the first lag of macro news as well, to take into account the possibility of slower adjustment in this market, and find the results to be unchanged. These estimation results are not shown for brevity but are available from the authors upon request.

29. Due to the relatively short duration of the second subsample, only a limited number of nonzero macro news data points are included in the estimations.

TABLE 7

EXCHANGE RATE RESPONSES TO RESERVE SALES AND MACRO NEWS

	Full sample	Subsample 1	Subsample 2
Constant	−0.72	−0.86	3.81
	(2.91)	(3.11)	(7.76)
DLNCZKEUR(−1)	−0.30***	−0.31***	−0.17***
	(0.01)	(0.01)	(0.03)
DLNCZKEUR(−2)	−0.09***	−0.10***	−0.05**
	(0.01)	(0.01)	(0.02)
DLNCZKEUR(−3)	−0.04***	−0.05***	0.04*
	(0.01)	(0.02)	(0.02)
RESSALE	12.48	14.96	−11.06
	(9.19)	(9.91)	(21.59)
RESSALE(−1)	−4.12	−0.79	−29.20
	(8.59	(0.94)	(20.70)
RESSALE(−2)	6.33	8.21	−5.28
	(9.30)	(10.10)	(19.99)
RESSALE(−3)	−8.62	−10.58	11.83
	(8.13)	(8.86)	(16.56)
RESSALE(−4)	−10.61	−9.93	−18.62
	(9.77)	(10.65)	(18.58)
RESSALE(−5)	−0.53	3.34	−35.41
	(0.90)	(9.63)	(22.26)
CZMONPOL	0.56	3.54	−13.19
	(3.65)	(3.43)	(8.66)
CZCPIYOY	−7.07	−8.36	−9.06
	(6.31)	(6.48)	(8.92)
CZCPIMOM	8.46	10.46	−14.43
	(6.52)	(6.65)	(9.34)
CZPPIMOM	0.16	0.11	0.10
	(1.40)	(1.50)	(2.53)
CZINDPROD	0.02	−0.06	0.14
	(0.16)	(0.16)	(0.24)
CZUNEMP	−1.60	−3.20	19.37
	(4.58)	(4.46)	(13.09)
CZTB	0.00	−0.00	0.00*
	(0.00)	(0.00)	(0.00)
EURMONPOL	−4.87	−4.99	−2.01
	(7.23)	(7.82)	(12.11)
EURCPIYOY	1.41	1.81	−3.17***
	(8.79)	(9.34)	(0.95)
EURPPIYOY	−0.12	−6.41	15.86
	(1.19)	(11.15)	(12.21)
EURPPIMOM	2.26	12.00	−16.24
	(10.13)	(10.68)	(12.14)
EURGDP	−14.99**	−18.04**	−4.40***
	(6.01)	(7.44)	(1.11)
EURUNEMP	3.90	6.37	−2.03
	(5.48)	(7.93)	(1.98)
Sum of RESSALES	−5.07	5.21	−87.74
Wald statistic	0.07	0.06	4.22**
Observations	41,180	36,547	4,633
R^2	0.09	0.09	0.03

(Continued)

TABLE 7
Continued

	Full sample	Subsample 1	Subsample 2
SE of regression	0.0006	0.0006	0.0004
F-statistic	174.65***	164.29***	7.55***

NOTES: (i) *denotes significance at 90%; **denotes significance at 95%; ***denotes significance at 99%.
(ii) Standard errors are in parentheses below the point estimates.
(iii) Estimations are defined in equation (1) in the text, and carried out using OLS with heteroskedasticity and autocorrelation consistent (HAC) standard errors and covariances.
(iv) The dependent variable, DLNCZKEUR, is the first difference of the log of the 15-minute CZK/EUR spot exchange rate.
(v) RESSALE denotes reserve sales of EUR carried out by the CNB. RESSALE is measured in millions of EUR.
(vi) Czech macro news variables control for monetary policy rate changes (CZMONPOL) and surprises in CPI year-on-year (CZCPIYOY), CPI month-on-month (CZCPIMOM), PPI month-on-month (CZPPIMOM), industrial production (CZINDPROD), unemployment (CZUNEMP), trade balance (CZTB); euro area macro news variables control for monetary policy rate changes (EURMONPOL) and surprises in CPI year-on-year (EURCPIYOY), PPI year-on-year (EURPPIYOY), PPI month-on-month (EURPPIMOM), GDP (EURGDP), and unemployment (EURUNEMP).
(vii) Constant point estimates, RESSALE, sum of RESSALES, and associated standard errors are multiplied by 10(E6); point estimates and standard errors associated with the macro news are multiplied by 10(E4).
(viii) Sum of RESSALES refers to the cumulative effect of contemporaneous reserve sale and the five lags of reserve sales.
(ix) Subsample 1 runs from January 1, 2004 to June 18, 2007; subsample 2 runs from June 19, 2007 to November 23, 2007.

inclusion of macro news does not change the previously reported results regarding the influence of reserve sales on currency values.

Fourth, we control for the possibility that reserve sales are not sterilized by including a daily (11 a.m. CET) Czech short-term interest rate (the 3-month PRIBOR rate).[30] The daily PRIBOR rate is statistically insignificant in all specifications estimated across the full sample period as well as separately across the two subsamples, and inclusion of the interest rate does not influence any of the coefficient estimates on the other explanatory variables in the regressions. These results thus suggest that CNB reserve sales are sterilized.

Fifth, to test for delayed effects of reserve sales beyond the fifth lag captured by our baseline model, we reestimate our models with an additional four lags (60 minutes) of reserve sales included. These estimates confirm that reserve sales are only significantly associated with an appreciation of the CZK in subsample 2. Furthermore, none of the additional reserve sales lags (lags 6–9) are individually significant, and a separate test of the hypothesis that the sum of the reserve sales coefficients for lags 6–9 equals 0 is not rejected.

Sixth, we change the subsample demarcation point. The hitherto employed demarcation point of June 19, 2007 is well defined because, as noted earlier, it is when the CNB switched to a regime of daily reserve sale transactions. However, because the reserve sales frequency increased gradually by the beginning of 2007 (although not to the point of daily sales), we test the robustness of our results by employing as an alternative demarcation point January 7, 2007, the first day of more frequent

30. Unsterilized reserve sales lead to intraday changes in the monetary base. These changes in the monetary base could, in turn, influence the coefficient estimates of the reserve sales given that reserve sales and monetary base changes in this case would be highly correlated. We use intraday frequency interest rates as proxies for monetary base changes because intraday data on the monetary base does not exist. We also do not have the necessary intraday data on open-market bond purchases; thus, we are unable to provide direct evidence of sterilization.

but not daily sales. Although the overall fit of the model deteriorates slightly when estimated across the alternatively defined (and thus extended) subsample 2, the results remain qualitatively unchanged. Subsample 1 reserve sales have no detectable influence on the exchange rate, whereas subsample 2 sales are, on average, systematically associated with an appreciation of the CZK vis-à-vis the EUR.

Seventh, we test for the presence of a learning process pertaining to the policy switch because, as noted earlier, the change in the reserve sales policy from relatively infrequent sales to daily sales was not announced. To address whether it took several days or weeks for the policy of daily sales to influence the exchange rate, we employ the Andrews (1993) test for unknown breakpoint. To ensure that we allow for the possibility of a short learning process of only a few days, we carry out the Andrews test using trimming levels of 5% (corresponding to roughly 6 business days) and 10% (corresponding to roughly 12 business days) along with the standard trimming level of 15% (corresponding to roughly 18 business days). We find no evidence of breakpoints regardless of whether we use trimming levels of 5%, 10%, or 15%; that is, we do not find evidence of a learning process.

Eighth, to ensure that the possibility of abnormal trading activity at either the beginning or the end of the trading day is not affecting our results, we respectively shrink and expand our trading day definition by 60 minutes; that is, we first redo the baseline estimations with a trading day defined to start at 7:30 a.m. (6.30 GMT+1) and finish at 6:30 p.m. (17.30 GMT+1) and, subsequently, a trading day defined to start at 8:30 a.m. (7.30 GMT+1) and finish at 5:30 p.m. (16.30 GMT+1).[31] As expected, considering that, as shown in the WLS estimations of the baseline model, the Fourier flexible form is insignificant and no intraday seasonality is detected, the estimation results associated with these alternative trading day definitions are qualitatively identical to the previously discussed results.

Ninth, we address the possibility that the market anticipates and, therefore, systematically prices in the effect of the reserve sales prior to their occurrence by testing for the presence of lead effects of reserve sales. Specifically, we add two (30 minutes) and, subsequently, five (75 minutes) leads of reserve sales to the baseline conditional mean model (equation (1)) and test whether the respective sums of leads (two or five leads) are significantly different from zero. Whether testing for lead effects of reserve sales across the full sample or separately across either of the two subsamples, we find no evidence of lead effects.

Tenth, and finally, we consider the influence of trading volume by comparing the average daily-realized volatility (measured as the square root of the squared intraday returns during trading hours) across the two sample periods. We are unable to control for trading volume directly in our regressions because volume data at daily or higher frequencies do not exist. However, the foreign exchange market microstructure literature suggests that trading volume and market volatility are positively correlated (Osler 2009). We thus use daily-realized volatility as a proxy for market volume at

31. When we shrink the trading day definition, two end-of-day reserve sales transactions are excluded from the analysis.

the daily frequency. Market microstructure models generally suggest that the price impact of trades will be higher during periods of low trading volume. Therefore, if we find that trading volumes differ across the two samples, this could help explain why reserve sales across the two periods are associated with different exchange rate effects. The average daily realized volatility is 0.0035 (0.0025) during the first (second) subsample. A *t*-test for equality of means indicates that the two averages are significantly different at the 99% level.[32] Although this evidence is only indicative, it nevertheless suggests that lower average daily trading volume, as proxied by lower average daily realized volatility, during the second subsample could be a contributing factor in explaining the inability of the CNB to sell reserves without influencing the exchange rate during this period.

6. CONCLUSION

In this paper, we examine the implications of systematic reserve sales, intended to mitigate valuation losses, on domestic currency movements. Novel intraday data on sales of EUR-denominated reserves, carried out by the CNB, facilitate our investigation.[33] We find no evidence that reserve sales influence the exchange rate when they are carried out irregularly. By contrast, our results show that when these sales are carried out on a daily basis, a statistically significant appreciation of the domestic currency follows.

It is interesting to compare our results with those of the foreign exchange intervention literature. It remains controversial whether intervention operations that are *intended* to influence currency values are able to do so. In our context of reserve sales that are explicitly *not* intended as interventions in currency markets, our results nonetheless show that they can indeed lead to unintended domestic currency appreciations if carried out on a daily basis.

This finding that daily reserve sales lead to an appreciation of the domestic currency is particularly interesting. On the one hand, economic theory generally suggests that "expected" policies are less likely to have an influence than "unexpected" ones.[34] Yet it is during the regime in which the CNB routinely sold reserves

32. The *t*-statistic for equality of means is 8.98 and computed as the difference in means divided by the square root of the sum of the variances adjusted for subsamples sizes. For additional details of the equality of means test when variances differ across samples, see, for example, Anderson et al. (2010).

33. It is important to note that the reserve sales we study in this project occur over a time period in which the CZK was not in crisis. Indeed, the reason the Czech monetary authority decided to sell reserves starting in 2004 was because the CZK was strong relative to the underlying currencies (particularly the EUR) denominating the Czech reserve portfolio. Our results are therefore not indicative of what might happen in reaction to reserve depletion during a currency crisis.

34. For an early example, see Sargent and Wallace (1975) who show that if expectations are formed rationally (and there are no other sources of stickiness in the price mechanism) anticipated policies should have no real effects. It should be emphasized that in our context of a reserves sales regime where the sales occur on an everyday basis, market participants have no way of knowing at what times during the day reserves will be sold or, more importantly, for how long the regime of equal-sized daily sales will continue. The reserve sales policy of the second regime, therefore, does not constitute an entirely anticipated policy.

that the sales influence the value of the domestic currency. Viewed in this light, our results are puzzling. On the other hand, the empirical literature on the microstructure of exchange rates generally shows that the price impact of trades is contingent on market conditions (such as overall trading volume and volatility). Discretionary reserve sales can be carried when market conditions are considered appropriate and thus conducive for a price effect to be less likely. By design, the daily sales during the second regime, however, occur regardless of whether market conditions are favorable or not. Consequently, consistent with the aforementioned concern of the CNB dealers regarding the reserve sales regime change, sales will be initiated even when market conditions are such that detectable price effects are likely. Viewed in this light, it is not as surprising that the reserve sales during the discretionary regime, on average, succeed in avoiding unintended domestic currency appreciations whereas the reserve sales in the second regime do not. Our results are also consistent with the possibility that relatively infrequent reserve sales do not induce a detectable exchange rate response because such sales are perceived by the market to be the outcome of a transitory policy. Infrequent sales may not persuade a forward-looking market that the reserve policy will continue. By contrast, daily sales may be interpreted by the market as a manifestation of a permanent policy, convincing the market that sales will endure.

Overall, our results show that it is possible to sell foreign exchange reserves without the sales leading to an appreciation of the domestic currency. Moreover, our results indicate that the manner in which the sales are carried out matters. Specifically, our results suggest that discretionary sales can be carried out with no detectable influence on the foreign exchange market, whereas opting instead for daily reserve sales comes at the cost of unintended exchange rate effects.

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