

Are the Intraday Effects of Central Bank Intervention on Exchange Rate Spreads Asymmetric and State Dependent?*

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Abstract

This paper investigates the intraday effects of unannounced foreign exchange intervention on bid-ask exchange rate spreads using official intraday intervention data provided by the Danish central bank. Our starting point is a simple theoretical model of the bid-ask spread which we use to formulate testable hypotheses regarding how unannounced intervention purchases and intervention sales influence the market asymmetrically. To test these hypotheses we estimate weighted least squares (WLS) time-series models of the intraday bid-ask spread. Our main result is that intervention purchases and sales both exert a significant influence on the exchange rate spread, but in opposite directions: intervention purchases of the smaller currency, on average, reduce the spread while intervention sales, on average, increase the spread. We also show that intervention only affects the exchange rate spread when the state of the market is not abnormally volatile. Our results are consistent with the notion that illiquidity arises when traders fear speculative pressure against the smaller currency and confirms the asymmetry hypothesis of our theoretical model.

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1. Introduction

The majority of the vast literature on foreign exchange intervention investigates whether intervention influences the exchange rate market with little attention paid to explaining why intervention might be influential. Exceptions include two categories of studies, the first of which focuses on the traditional transmission channels, such as the portfolio balance and the signaling channel, for understanding how intervention works.¹ The second category of studies, to which this paper seeks to contribute, goes beyond the traditional transmission channels and offers microstructure based analyses of the interaction between intervention and exchange rates.²

The context of this paper is that of unannounced intervention aimed at maintaining a smaller currency pegged to a major currency. Our starting point is a simple theoretical model of the bid-ask exchange rate spread which we use to formulate testable hypotheses regarding how intervention may influence market perceptions of whether a currency is properly priced. In the model, foreign exchange dealers quickly pass on a central bank trade to their customers, and the bid-ask spread is determined by the slope of the aggregate customer demand curve. This slope, in turn, is directly related to customer uncertainty about market fundamentals. Within this modeling framework, a wider spread arises when the central bank's intervention induces customer uncertainty. This is the case following an intervention purchase of the major currency on normal days, i.e. days

¹ See Kumhof (2010) and Fatum (2010) for recent studies that focus on traditional transmission channels of intervention. See Humpage (2003) and Neely (2005) for broad surveys of the intervention literature.

² Microstructure based contributions include Naranjo and Nimalendran (2000), Dominguez (2003), and Chari (2007). The first study analyses the effects of intervention on exchange rate spreads using official daily intervention data, the two more recent studies use time-stamped newswire reports of intervention to analyze the effects of intervention on the first two moments of the exchange rate and the exchange rate spread, respectively. See Fischer (2006) for a discussion of the accuracy of newswire reports, and Hasbrouck (2007) for a survey of the large literature on the bid-ask spread in financial markets in general.

without abnormal exchange rate volatility, because the customers are unable to distinguish such an intervention trade from speculative pressure on the fixed exchange rate mechanism. By contrast, an intervention purchase of the smaller currency is unlikely to be interpreted by the customers as an indication of speculative pressure against the major currency. This fundamental asymmetry translates into the testable hypothesis that intervention sales of the smaller currency leads to an increase in the bid-ask spread while intervention purchases of the smaller currency do not. Interestingly, the prediction of our theory differs from the signaling channel hypothesis which suggests that a central bank intervention is influential only if it reduces uncertainty about fundamentals.

To test the predictions of our theoretical framework we employ proprietary data on official intraday intervention transactions in the Danish Krone-Euro (DKK/EUR) market provided by the Danish central bank, Danmarks Nationalbank (DN), along with indicative 5-minute spot bid and ask DKK/EUR prices.³ Our data covers the 1 August 2002 to 31 December 2004 time-period and a total of 162 intervention transactions. Importantly, all DN interventions are unannounced and, furthermore, rarely reported in the newswire services.⁴

We estimate time-series models of the DKK/EUR bid-ask spread with intervention purchases and sales entering as separate explanatory variables. Our baseline

³ The DN interventions are carried out under the provisions of the Exchange Rate Mechanism (ERM II). Denmark has participated in ERM II since 1 January 1999. In ERM II, a bilateral central rate and a deviation band is set for the currency of the participating country vis-à-vis the EUR, but not against the currency of the other member states. The official DKK/EUR central rate is 7.46038 DKK/EUR and the official deviation band is set to +/- 2.25 percent. The DKK has traded within an even narrower range of +/- 0.50 percent around the Danish ERM II central rate. For additional details on the institutional aspects of ERM II and DN intervention see Fatum and Pedersen (2009).

⁴ A comprehensive Factiva search for both English and Danish language newswire reports of DN interventions, using various search word combinations such as “Danish intervention”, “Danmarks Nationalbank”, and “Danish Crown” etc., found only four intervention reports in total (three English language reports from Reuters News and one Danish language report from a Danish daily newspaper), none of which mentions neither amount nor timing of the reported interventions.

estimations use the weighted least squares (WLS) procedure developed by Andersen and Bollerslev (1998). As a methodological robustness test we also estimate OLS models with heteroskedasticity and autocorrelation consistent (HAC) standard errors and covariances. Our study is the first to investigate the intraday effects of unannounced intervention on exchange rate spreads using accurate official intervention transactions data.⁵

Our results show that both intervention purchases and sales significantly influence the exchange rate spread, but the effects are asymmetric: Intervention purchases of the smaller currency, on average, reduce the spread while intervention purchases of the large currency, on average, increase the spread. This key result holds up against an array of robustness checks, including controlling for endogeneity, coincidental arrival of macro news, testing for break-points, and allowing for the possibility of delayed as well as lead effects. We also show that the significant and asymmetric effects of intervention purchases and sales are state dependent in the sense that interventions carried out on “normal” days in terms of exchange rate volatility are influential while interventions have no effect on the bid-ask spread when the market is abnormally volatile.

These empirical findings are consistent with the asymmetry hypothesis of our theoretical model and give credibility to the theoretical interpretation that the uncertainty of the market regarding the exchange rate decreases when interventions are carried out to strengthen the smaller currency, while the uncertainty of the market increases when

⁵ The Bank of Canada, the Swiss National Bank, and now DN are the only central banks that have made intraday intervention data available for research. Only the Swiss National Bank makes their intraday intervention data instantly publicly available. See Fischer and Zurlinden (1999) and Pasquariello (2007) for analyses of the intraday effects of the announced Swiss interventions on the exchange rate level and exchange rate spread, respectively. See Fatum and King (2005) for a study of the intraday exchange rate level and volatility effects of Canadian interventions.

interventions indicate that the smaller currency is overvalued. Moreover, our results illustrate the importance of distinguishing between intervention purchases and intervention sales when assessing the influence of intervention on exchange rate spreads in the context of intervention aimed at maintaining a smaller currency in a narrow band around a major currency.

The rest of the paper is organized as follows. Section 2 presents a theoretical model of the bid-ask spread. Sections 3 and 4 detail the data and the econometric methodology, respectively. Section 5 discusses the results. Section 6 presents several robustness checks. Section 7 concludes.

2. Theoretical Background

The central bank's intervention is carried out in the dealer market. Our theory starts from the observation that as direct counterparties to the central bank's intervention trade, dealers are eager to off-load this deviation from an optimal currency position to their customer traders.⁶ The price impact as well as the ensuing currency market illiquidity is therefore determined by the properties of the customers' aggregate short-run demand curve.

Although focusing on customers rather than dealers, our theory of liquidity is closely related to the inventory theory of the bid ask spread, see Stoll (1978) and Ho and Stoll (1981). In our version, customers require a liquidity premium for deviating from their ideal position. Basing our theory on this component of the bid-ask spread, we do not explicitly take into account the pure transactions costs and adverse selection costs often

⁶ Individual dealers generally eliminate inventory positions quickly. In the first instance dealers may share positions in the interdealer market, but there is pressure on all dealers to off-load positions before the end of the day. See Osler (2008) for a discussion.

investigated by the financial market microstructure literature. This is because, first, the transactions cost component is unlikely to capture any spread asymmetry, as transactions in both directions tend to be equally costly. Second, the theory of adverse selection due to counterparty information is well captured by our later assumption that the bid-ask spread widens when customer uncertainty increases.⁷

Given that the uncertainty on behalf of currency market traders determines the market's degree of liquidity, the central question becomes how central bank interventions affect this uncertainty. The central bank follows a policy of opacity, and hence does not announce its intervention. It is therefore reasonable to assume that as the intervention occurs, the customers observe only a large order flow, but they cannot discern the origin of the order flow.

The key assumptions of our model are that customer uncertainty in the market is related to the possibility that the exchange rate regime is subject to speculative pressure and that the customers in the market interpret and react to the intervention order flow as follows. If speculative pressure is based on the premise that the smaller currency is overvalued in the peg, the natural conduct of the speculators is to sell the smaller currency and purchase the large currency. As a result, when market conditions indicate a large sale of the smaller currency, customers become more uncertain about fundamentals, and the spread widens. By contrast, if the large currency is considered overvalued, there are plenty of currencies other than this particular smaller currency against which pressure on the large currency can be levied. A large sale of the large currency against the smaller currency, therefore, should not lead to a particular run for the smaller currency. Instead, a

⁷ Empirical evidence suggests that bid-ask spreads widen when uncertainty increases. See, for example, Bollerslev and Melvin (1994).

large sale of the large currency against the smaller currency can be interpreted as a sign that the peg is credible, thereby reducing uncertainty and narrowing the spread.

We also assume that the marginal effect of the central bank's intervention on the customer uncertainty is greater in a normal market than when volatility is high, simply because, in a volatile market, the central bank's intervention is less likely to be sufficiently remarkable to significantly affect customer uncertainty over fundamentals.

We will derive these implications in a formal model. After presenting the model, we discuss the incentives of the central bank and the dealers not to pass on all their information about the true market conditions to the customer market.

2.1 The Model

We model the short-run aggregate demand curve for the smaller currency from a population of many small customers. From the point of view of this customer population, the smaller currency is a risky asset. It trades at rate p , but has random value θ over the relevant holding period. We assume that the customers hold the common belief that θ is normally distributed with variance $\sigma^2 > 0$.

There is a continuum of competitive customers, maximizing expected utility of end-of-period wealth. The utility function exhibits constant absolute risk aversion (CARA) and, following Wilson (1968), there exists a representative customer with CARA utility as a function of aggregate customer wealth, $U(w) = -\exp(-\rho w)$, with risk aversion parameter $\rho > 0$.

It is well known that the CARA utility function with normally distributed asset returns gives rise to the following simple asset demand function:

$$(1) \quad x(p) = \frac{E(\theta) - p}{\rho V(\theta)},$$

where x denotes the quantity demanded, $E(\theta)$ and $V(\theta) = \sigma^2$ are the customer market's representative expectation and variance for the random variable θ , respectively. Essentially, customers are willing to purchase the asset when it trades at a price below expected value, and they are willing to take larger positions for a given expected gain the smaller is σ^2 . Thus, the aversion to risk reduces the slope of the demand curve.

The main assumptions of our analysis are the following. First, if there is an unusually large sale of the small currency asset, then the customer uncertainty parameter σ^2 rises. Second, if there is an unusually large purchase of the asset, the customer uncertainty falls. Third, in a more volatile market, a central bank intervention is less likely to be remarkable, and hence has less impact on customer uncertainty.

Proposition 1 *The spread is directly proportional to the customer uncertainty parameter σ^2 . The first assumption implies that the spread increases when the central bank intervenes with a sale of the smaller currency. The second assumption implies that the spread falls when the central bank purchases the smaller currency. The third assumption implies that both effects are smaller in a more volatile market.*

Proof Suppose that the central bank intervenes with the net trade z while other exogenous market net trades of amount u arrive at the market. Short-run market clearing implies that $x(p) = z + u$. The resulting short-run equilibrium rate becomes $p = E(\theta) - \rho \sigma^2 (z + u)$. As is common in the literature on market microstructure, at least since Kyle (1985), we can interpret $dp/du = \rho \sigma^2$ as a natural measure of market illiquidity. The round-trade spread, defined as the cost of first buying then selling one unit, becomes

$2\rho\sigma^2$. The three results follow from translating each assumption about σ^2 into implications for the spread. □

The proof reveals that the spread is also proportional to the risk aversion parameter ρ . This deep preference parameter is unlikely to be affected by the direction of the central bank's intervention. The central bank's intervention is not announced to the entire market. This suggests that the central bank is hoping to obtain a larger immediate price impact in the market through secrecy than through an openly announced intervention.⁸ To the extent that this lack of openness is responsible for the widening bid-ask spread following a sale of the smaller currency, the central bank is willing to obtain a greater price impact at the cost of greater illiquidity.⁹

Similarly, we assume that dealers do not pass on information about interventions to the customers. A committed strategy of concealment may help dealers to continue profitable market operations in the event of speculative pressure. Moreover, it seems natural that speculators want to secretly build up positions against the currency with minimal price impact before revealing any intentions to speculate against the currency.

3. Data

The intervention data covers all DN interventions in the DKK/EUR market over the 1 August 2002 to 31 December 2004 period.¹⁰ The data includes the exact amount and time-stamp to the nearest minute obtained directly from the trade-sheet of each

⁸ Bhattacharya and Weller (1997) and Vitale (1999) discuss advantages of secret interventions.

⁹ Similar concerns affect other market manipulators such as investment banks seeking to stabilize IPO after-market prices, or firms trading in their own stock.

¹⁰ The sample period is determined by data availability and coincides with the period studied by Fatum and Pedersen (2009) in which they show that DN intervention is, on average, effective in influencing the level of the DKK/EUR exchange rate.

intervention transaction. Intervention amounts are quoted in EUR and a positive amount denotes a purchase of EUR against a sale of DKK.¹¹

Table 1A displays descriptive statistics of the intervention data. Our sample consists of a total of 73 intervention days, encompassing a total of 162 intervention transactions. On intervention days, the average daily intervention amount is EUR 155 million, which is roughly 5.5% of the average daily turnover in the DKK/EUR market.¹²

The high-frequency DKK/EUR exchange rate data is provided by Olsen and Associates. The data consists of the bid and the offer spot exchange rate at the end of every 5-minute interval over every 24-hour period. The quotes are indicative quotes, i.e. not necessarily traded quotes. We follow Dacorogna, Müller, Nagler, Olsen and Pictet (1993) and filter the data for anomalies and bad quotes.¹³

There is very virtually no trading of the Danish currency outside of standard Danish business hours (see DN 2003 and ECB 2004), thus we define a trading day in the Danish currency market to start at 8.00 GMT+1 and finish at 17.00 GMT+1.¹⁴ Consequently, our analysis considers a total of 603 trading days consisting of a total of

¹¹ In accordance with the ERM II provisions, the DN trader conducting an intervention operation is required to write the amount and the exact time of the operation on the trade-sheet immediately after the completion of each individual intervention transaction. This information is forwarded to the ECB by the end of the trading day, at the latest. Our intraday intervention data consists of this extremely reliable information.

¹² Average daily turnover in the DKK/EUR market was USD 2,236 million in 2004, or roughly EUR 2,800 million when converted at the prevailing USD/EUR rate of 1.25. See BIS Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity in 2004, <http://www.bis.org/publ/rpfx07t.htm> Statistical Annex Table E.6, pp 61, for statistics on average daily turnover in the DKK/EUR market.

¹³ Transactions bid and ask prices are not available for the DKK/EUR exchange rate market.

¹⁴ This definition of a trading day carries over naturally to a definition of a weekend, i.e. we define a weekend to start at 17.05 GMT+1 Friday and finish at 8.00 GMT+1 Monday.

64383 5-minute DKK/EUR exchange rate bid-ask spreads.¹⁵ Importantly, our trading day definition encompasses all intervention transactions in the period under study.

Table 1B summarizes key statistical properties of our 5-minute bid-ask exchange rate spreads (defined as ask minus bid). Figure 1 shows the interventions juxtaposed against the DKK/EUR exchange rate.

Danish and Euro-Area interest rates are obtained from the websites of DN (www.nationalbanken.dk) and the ECB (www.ecb.int), respectively. Time-stamped Danish, German, and Euro-area macro announcements and preceding survey expectations are obtained from Bloomberg. Summary statistics regarding interest rates and macro news are available from the authors upon request.

4. The Empirical Model

In order to obtain consistent and asymptotically efficient estimates of the response of the bid-ask spread series to an intervention we employ the WLS procedure developed by Andersen and Bollerslev (1998).

First, we model the response of the exchange rate spread, SP_t , as a linear function of J lagged values of the spread itself, K lags of (the absolute value of) intervention purchases (I^P_t), and H lags of (the absolute value of) intervention sales (I^S_t):

$$(2) \quad SP_t = \beta_0 + \sum_{j=1}^J \beta_j SP_{t-j} + \sum_{k=0}^K \gamma_k |I^P_{t-k}| + \sum_{h=0}^H \gamma_h |I^S_{t-h}| + \varepsilon_t, t = 1 \dots T$$

As noted earlier, $T=64383$. We choose $J=6$ based on the Schwartz and Akaike information criteria and we set $K=H=0$ in our baseline estimations (we control for

¹⁵ We also deleted the following fixed holidays from the analysis: 1 January, Easter (three holidays), Christmas (24/25/26 December), 31 December as well as four Denmark-specific holidays (Store Bededag, Kristi Himmelfartsdag, Anden Pinsedag, and Grundlovsdag).

delayed effects in our robustness checks). We estimate the conditional mean expression using OLS and obtain the estimated residuals, $\hat{\varepsilon}_t$.¹⁶ Next, we model the volatility pattern using the estimated residuals of Equation (2) and the following parameterization:

(3)

$$|\hat{\varepsilon}_t| = c + \alpha \frac{\hat{\sigma}_t}{\sqrt{n}} + \sum_{v=0}^V \beta_v |I^P_{t-v}| + \sum_w^W \beta_w |I^S_{t-w}| + \left(\sum_{q=1}^Q \delta_q \cos\left(\frac{q2\pi t}{108}\right) + \varphi_q \sin\left(\frac{q2\pi t}{108}\right) \right) + \Delta_m + u_t$$

where the absolute value of $\hat{\varepsilon}_t$ proxies for the volatility in the 5-minute interval t, M is the number of normalizing constants (in our case 3), n is the number of intervals in a day (in our case 108), $\hat{\sigma}_t$ is the one-day ahead volatility forecast for day t (i.e. the day that contains interval t), V and W are the number of lags of interventions included (V=W=1 based on the Schwartz and the Akaike criteria), q is a specific intraday calendar effect, Q is the total number of calendar effects accounted for (Q=8, based on the Schwartz and the Akaike criteria), and u_t denotes the residuals (assumed to be standard normal).

We model the lower frequency intraday pattern (the first term after the vector of constants) using the concept of realized volatility (RV), calculated on 30 minute returns.¹⁷ Since the RV forecast cannot capture the observed cyclical intraday patterns (the slow decay in the autocorrelations), we model the higher frequency periodicity by inclusion of a Fourier flexible form (see Gallant, 1981).¹⁸ Consistent with Andersen and Bollerslev

¹⁶ We also include in the conditional mean model as additional explanatory variables the distance from parity, i.e. a measure of the distance between the DKK/EUR exchange rate and the central rate, as well as the EUR-DKK interest rate differential. Both variables proved insignificant in all estimations and were thus excluded from the conditional mean model for the remainder of the analysis.

¹⁷ RV is defined as the daily sum of squared returns and constitutes an unbiased, efficient and asymptotically consistent estimate of the true daily quadratic variation. A key advantage of using RV is that this semi-parametric approach does not require additional model estimation.

¹⁸ A Fourier flexible form consists of a number of sine- and cosine terms with varying degrees of periodicity (the terms in the parenthesis of Equation 3). It allows for a model specification as flexible as possible, thereby enabling us to fit the intraday pattern of the residuals from Equation (2).

(1998) and Andersen, Bollerslev, Diebold and Vega (2003), who include their macro news variables in the volatility equation, we include the intervention variable (i.e. our main “news” variable) in the volatility model.

5. Results

Table 2 displays the results of the WLS estimation of the conditional mean model (Equation 2). The first column shows the results of a preliminary regression that does not distinguish between intervention purchases and sales, i.e. as a preliminary exercise Equations 1 and 2 are simplified such that absolute intervention purchases, I_t^P , and absolute intervention sales, I_t^S , are replaced by a variable containing (the absolute value of) all interventions, I_t (thus $I_t^P + I_t^S = I_t$). As the table shows, the coefficient estimate associated with intervention is insignificant, suggesting that intervention, on average, has no intraday influence on the exchange rate spread.

To allow for the possibility of non-uniform effects on the exchange rate spread across intervention purchases and sales, and to test the first two predictions of Proposition 1, we estimate the baseline model with intervention purchases and sales entering as separate variables (as described in Equations 1 and 2). The results, displayed in the second column of Table 2, show that contemporaneous intervention purchases as well as contemporaneous intervention sales are significant (both at 95%) and do in fact influence the exchange rate spread in opposite directions. Consistent with the first two predictions of Proposition 1, intervention sales of EUR decrease the exchange rate spread while intervention purchases of EUR increase the spread.

Certainly, these results make clear the necessity of distinguishing between intervention purchases and intervention sales when assessing the influence of intervention on exchange rate spreads when intervention is aimed at maintaining a smaller currency in a narrow band around a major currency. Moreover, the results provide evidence that unannounced interventions of which the foreign exchange market customers cannot know the origin and, therefore, observe only as large order flows, significantly affect the market's perception of whether a currency is under- or overvalued, and they do so in an asymmetric manner. Intervention aimed at appreciating the smaller currency is interpreted by the market to indicate that speculative pressure against this currency is less likely, thereby reducing the price risk associated with holding said currency. This reduced risk is manifested in the narrowing of the exchange rate spread. By contrast, intervention aimed at depreciating the smaller currency is interpreted to indicate that speculative pressure against this currency might be increasing and, as a result, the spread widens.¹⁹

It is interesting to relate our findings to Fatum and Pedersen (2009). They use the same intervention data as ours to show that intervention sales of DKK (the smaller currency) significantly influence the level of the exchange rate in the intended direction whereas intervention purchases have no detectable level effect. Our results, therefore, are perfectly consistent with theirs, suggesting that in the case of unannounced intervention sales of the smaller currency it is the fear of speculative pressure and associated increased uncertainty regarding whether the currency is properly priced that causes the market to

¹⁹ Table 3 displays the results of the estimation of the volatility model described in Equation (3). The RV is highly significant, as are most of the trigonometric terms, thus suggesting that the model captures the intraday periodicity well. Interestingly, all the intervention variables, regardless of whether the model specification distinguishes between purchases and sales, and regardless of the direction of the interventions, are negative and significant at either 90 or 95%, thereby indicating that regardless of whether intervention increases or decreases market uncertainty, the variation of this uncertainty declines.

depreciate the currency; by contrast, unannounced intervention purchases of the smaller currency are interpreted by traders as a confirmation of the peg, thereby decreasing the uncertainty surrounding the currency with no detectable adjustment of the price.

5.1 State Dependence

In order to test the third and final part of Proposition 1, that the effects of intervention on the exchange rate spread are state dependent with respect to the volatility of the foreign exchange market, we distinguish between interventions that occur on “high-volatility” days and interventions that occur on “normal” days. We define a “high-volatility” day as a day with either a significant intraday volatility jump, i.e. a “jump-day” as defined in Andersen, Bollerslev, and Diebold (2007), or with a daily realized volatility that is at least the average realized volatility of the sample plus two times its standard deviation. A “normal” day is defined as all other days.

Table 4 displays the results of re-estimating the conditional mean model (Equation 1) with intervention on “high-volatility” days and intervention on “normal” days entering as separate variables. As before, we first carry out a preliminary estimation that does not distinguish between intervention purchases and sales. The results are displayed in the first column of Table 4 and show a complete absence of significant effects of intervention on the exchange rate spread regardless of the state of the market.

The second column of Table 4 shows the results of the conditional mean model when distinguishing between “high-volatility” and “normal” days across separate intervention purchases and intervention sales variables, i.e. intervention is divided into four separate intervention variables (intervention purchases when the market is volatile,

intervention purchases when the market is normal, intervention sales when the market is volatile, and intervention sales when the market is normal). Consistent with the baseline estimations, the results show that intervention purchases of the smaller currency decrease the exchange rate spread while intervention sales increase the spread, but only for interventions carried out on days when the market conditions are not considered volatile.

While these results further confirm the necessity of taking into account that intervention purchases and sales impact the exchange rate spread in opposite directions, they also show that the significant and asymmetric effects of intervention purchases and sales are not uniform across intervention days but stem solely from the effects of interventions that are carried out on days when the state of the market is normal rather than volatile. This is consistent with the third prediction of Proposition 1.

6. Robustness

In order to test the robustness of our results, we re-estimate the baseline model using a different econometric procedure, take into account the possibility that the intervention variables contain expected components, control for macro news surprises, include lags and leads of the intervention variables, and test for structural breaks to ensure that our parameter estimates are stable across the sample period.²⁰

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 (2) are improperly fitted in the volatility model described by Equation (3). In order to address this potential concern we re-estimate the baseline model using heteroskedasticity- and

²⁰ Results pertaining to HAC estimations, delayed effects, lead effects, and break point test are not shown for brevity but available from the authors upon request.

serial-correlation consistent (HAC) standard errors (i.e. we re-estimate Equation 2 using HAC errors). The HAC results are qualitatively identical to the conditional mean results based on the WLS procedure.

Second, while there is no reason to believe that intervention is triggered by the contemporaneous exchange rate spread (i.e. the change in exchange rate spread that occurs over the 5-minute interval within which intervention is carried out), intervention is nevertheless correlated with recent (lagged) exchange rate movements and with recent (lagged) intervention, even at the intraday frequency. Therefore, our intervention variables are likely comprised of unexpected as well as expected components. To ensure that failure to disentangle the latter from the former does not lead to an underestimation of the true impact of intervention on exchange rate spreads, we follow Naranjo and Nimalendran (2000) and others by estimating a central bank reaction function to capture the expected component of the (in our context) intraday intervention variable. In turn, we subtract the expected component of intervention from the actual intervention variables in intervals where the latter are non-zero. The resulting series constitute proxies for unexpected interventions.²¹ The results of estimating the effects of unexpected intervention on exchange rate spreads are displayed in Table 5 (the first column shows the results when all interventions are contained in one variable while the second column shows the results using separate intervention sales and purchases variables). As the table shows, the results are qualitatively identical to the comparable estimation results from estimations that do not distinguish between actual intervention and unexpected intervention. This is unsurprising considering that the reaction function estimations explain only a minor part of the interventions.

²¹ For additional details see Fatum and Pedersen (2009).

Third, to ensure that our estimated effects of intervention are not tainted by the coincidental arrival of macro news, we extend our analysis to include time-stamped Danish, German, and Euro-area macro surprises. This is important because macro surprises can change the perception of the market in regards to whether a currency is properly aligned with fundamentals, i.e. we need to make sure that what we label the reaction of the market to unannounced interventions is not in actuality a matter of the market adjusting to macro news. To address this concern we include macro surprises regarding Danish Unemployment (DKUNEMP), Trade Balance (DKTB), Current Account (DKCA), CPI (DKCPI), GDP (DKGDP) and Consumer Confidence (DKCC); German IFO Index (DEIFO), GDP (DEGDP), and Industrial Production (DEIP); Euro-Area CPI (EACPI), Industrial Production (EAIP), and Business Climate Index (EABC). Macro surprises are measured as the difference between macro announcement and preceding survey expectation. The macro news as well as the intervention variables are standardized (i.e. we divide each variable by its sample standard deviation). The results of the estimations with macro surprises included, displayed in Table 6, show that a few of the macro surprises influence the spread. More importantly, the results regarding the asymmetric effects of intervention purchases and sales remain.

Fourth, in order to test for delayed effects of intervention, we re-estimate our baseline models with 12 lags (60 minutes) of both intervention purchases and intervention sales included (i.e. we set $K=H=12$ in Equation 2). The results show no systematic pattern of delayed effects and, moreover, the previously discussed asymmetric contemporaneous effects of intervention purchases and sales, respectively, are unchanged.

Fifth, we address the possibility that the market anticipates and, therefore, reacts in advance of the interventions by testing for the presence of lead effects. Specifically, we add two (10 minutes) and, subsequently, six leads (30 minutes) of intervention purchases and intervention sales to the baseline conditional mean model (Equation 2). None of the leads is individually significant and, moreover, the respective sums of leads (two or six leads) are not significantly different from zero.

Sixth, to ensure that our parameter estimates are valid across the entire sample period we employ the Andrews (1993) test for unknown break point. The test does not detect any evidence of a break point and, therefore, we accept the hypothesis of parameter stability across our sample.²²

In sum, all our robustness checks confirm that intervention aimed at strengthening the smaller currency (i.e. sales of EUR against purchases of DKK) decreases the exchange rate spread while intervention aimed at depreciating the smaller currency (i.e. purchases of EUR against sales of DKK) increases the spread.

7. Conclusion

The context of the paper is that of unannounced intervention aimed at maintaining a smaller currency pegged to a major currency. Our theoretical framework suggests that unannounced interventions of which the foreign exchange market customers cannot know the origin and, therefore, observe simply as large order flows, significantly affect the market's perception of whether a currency is under- or overvalued in an asymmetric manner. We hypothesize that the traders who determine market liquidity become

²² Fatum and Pedersen (2009) also reject the hypothesis of parameter instability over the August 2002 to December 2004 period in their study of the intraday exchange rate level effects of DN intervention.

uncertain regarding whether the price of the smaller currency is properly aligned with fundamentals when the central bank intervenes with an opaque sale of said currency, a sale that due to its unknown origin can be falsely attributed to speculative pressure. This increased uncertainty is then manifested in an increase in the exchange rate bid-ask spread. By contrast, a large purchase of a smaller currency is unlikely to indicate speculative pressure against the large currency but might instead be interpreted to indicate credibility of the peg of the smaller currency and, as a result, lead to reduced uncertainty about the price of the smaller currency vis-à-vis the large currency. This reduced uncertainty will then materialize itself in a narrowing of the spread.

We test the predictions of our theoretical framework on proprietary time-stamped intraday intervention data provided by the Danish central bank along with indicative 5-minute spot bid and ask DKK/EUR exchange rate quotes over the 1 August 2002 to 31 December 2004 period. The Danish interventions are unannounced and generally not reported on the newswire. No previous study has analyzed the intraday effects of unannounced interventions on exchange rate spreads using official intraday data.

Consistent with our hypothesis the results of our time-series estimations show that intervention purchases of DKK (the smaller currency) decrease the spread while intervention sales of DKK increase the spread. This key result holds up against an array of robustness checks, including controlling for endogeneity, coincidental arrival of macro news, testing for break-points, and allowing for the possibility of delayed as well as lead effects. We also show that the significant asymmetric effects of intervention purchases and sales stem solely from days when the market is normal rather than volatile. This

finding confirms our priors regarding the importance of the state of the market and that intervention does not affect the bid-ask spread when the market is volatile.

The existing microstructure based literature on intervention focuses on flexible exchange rates of major currencies where an asymmetry arising from traders' fear of speculative pressure building against one currency, and as a result opaque intervention sales triggering a different market reaction than opaque intervention purchases, is unlikely to be as important as in our context of a smaller currency pegged to a major currency. It is, therefore, difficult to compare our findings to other studies. Nevertheless, it is noteworthy that our results show that the intraday effects of intervention on spreads are asymmetric, thereby contrasting the results of studies by Chari (2007) and Naranjo and Nimalendran (2000) that, in the context of intervention in the JPY/USD and the DEM/USD markets, respectively, show that intervention, on average, increases the spread. Our finding that the influence of interventions is state dependent is, however, consistent with the results of Dominguez (2003).

In conclusion, our study illustrates the market power of central banks and their ability to influence foreign exchange trader's perception of uncertainty in regards to whether a currency is priced correctly or not. Ironically, this ability seems contingent on traders being unaware that what they are influenced by is in fact the action of the central bank rather than a privately initiated trade. As such, our study, therefore, provides some rationale for carrying out opaque rather than announced interventions. Finally, our study shows that a necessary condition for central bank interventions to influence the exchange rate spread is that the market is not abnormally volatile, thereby illustrating that the market power of central banks is also contingent on the state of the market.

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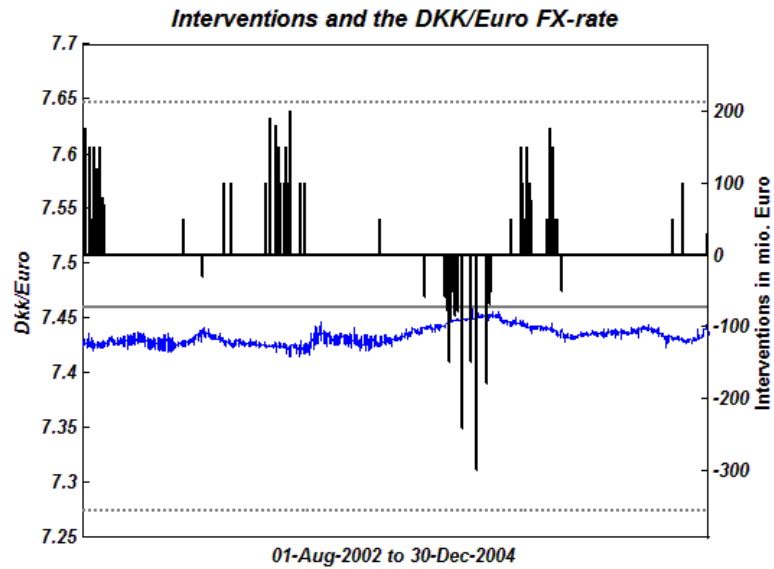
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Figure 1



Notes:

- a) Data Source: Danmarks Nationalbank (interventions) and Olsen and Associates (exchange rates).
- b) A positive intervention is a purchase of EUR against a sale of DKK; a negative intervention is a sales of EUR against a purchase of DKK.
- c) The upper and lower lines are the ERM II deviation bands. Interventions are plotted against the central parity exchange rate of 7.46038.

TABLE 1A Intervention Summary Statistics		
	Number of Interventions	Average amount (mill. EUR)
<i>Daily interventions</i>		
All	73	155
Purchases of EUR/Sales of DKK	52	144
Sales of EUR/Purchases of DKK	21	182
<i>Intraday interventions</i>		
All	162	70
Purchases of EUR/Sales of DKK	99	76
Sales of EUR/Purchases of DKK	63	61
NOTES: Data source: Danmarks Nationalbank Sample period: 1 August 2002 to 31 December 2004		

TABLE 1B Summary Statistics for 5 Minute DKK/EUR Exchange Rate Spreads			
Mean	Std. Dev.	Skewness	Kurtosis
0.021 (-0.001)	0.0342 (-)	2.7586 (0.0097)	10.4709** (0.0193)
Minimum	Maximum	BJ-test for normality	LB Q-test (5-day lag)
0	0.3420	231372*** [5.9915]	138172*** [3.8415]
NOTES: Data source: Olsen and Associates Sample period: 1 August 2002 to 31 December 2004 The data consists of 64383 observations of DKK/EUR exchange rate bid- and ask prices The exchange rate spreads are calculated as ask minus bid prices * Denotes significance at 90%, ** denotes significance at 95%, *** denotes significance at 99% Standard Errors in () below the point estimates; critical values in []			

TABLE 2 Exchange Rate Spread Responses to Intervention: Conditional Mean Equation		
	All Interventions	Separate Intervention Purchases and Sales
Constant (e-5)		
$\beta(0)$	0.002*** (0.0001)	0.002*** (0.0001)
Interventions (e-5)		
$\gamma(0)_{ALL}$	0.8065 (1.2776)	-
Intervention Sales of EUR/Purchases of DKK (e-5)		
$\gamma_S(0)$	-	-2.5852** (1.2166)
Intervention Purchases of EUR/Sales of DKK (e-5)		
$\gamma_P(0)$	-	4.3464** (2.1773)
Lags of FX-spreads		
$\beta(1)$	0.33*** (0.0079)	0.34*** (0.0087)
$\beta(2)$	0.19*** (0.0072)	0.20*** (0.0082)
$\beta(3)$	0.12*** (0.0070)	0.12*** (0.0080)
$\beta(4)$	0.10*** (0.0067)	0.09*** (0.0076)
$\beta(5)$	0.07*** (0.0067)	0.06*** (0.0075)
$\beta(6)$	0.08*** (0.0063)	0.08*** (0.007)
#Interventions	162	162
NOTES: (a) * Denotes significance at 90%, ** denotes significance at 95%, *** denotes significance at 99% (b) Standard Errors in () below the point estimates; lags in () in Variable Name (c) Estimations are defined in Equation (2) in the text, and carried out using WLS (d) The dependent variable is the DKK/EUR exchange rate spread (e) The independent variables are current intervention, and lags of the dependent variable (f) R^2 is not applicable to the two-stage WLS estimation procedure.		

TABLE 3 Exchange Rate Spread Responses to Intervention: Volatility Equation		
	All Interventions	Separate Intervention Purchases and Sales
Constants		
Constant	0.1834*** (0.0677)	0.1835*** (0.0677)
Normalising constant I	-0.1310** (0.0510)	-0.1311** (0.0510)
Normalising constant II	0.0156** (0.0062)	0.0156** (0.0062)
Interday Volatility		
Realized Volatility	57.2750*** (0.9005)	57.2781*** (0.9004)
Sine Terms (e-3)		
$\delta(1)$	0.0028 (0.0022)	0.0028 (0.0022)
$\delta(2)$	0.0017** (0.0009)	0.0017** (0.0009)
$\delta(3)$	0.0012*** (0.0004)	0.0012*** (0.0004)
$\delta(4)$	0.0007*** (0.0002)	0.0007*** (0.0002)
$\delta(5)$	0.0007*** (0.0001)	0.0007*** (0.0001)
$\delta(6)$	0.0003*** (0.0001)	0.0003*** (0.0001)
Cosine Terms (e-3)		
$\varphi(1)$	-0.0081*** (0.0029)	-0.0081*** (0.0029)
$\varphi(2)$	-0.0020*** (0.0003)	-0.0020*** (0.0003)
$\varphi(3)$	-0.0004** (0.0002)	-0.0004** (0.0002)
$\varphi(4)$	-0.0000 (0.0002)	-0.0000 (0.0002)
$\varphi(5)$	0.0001 (0.0002)	0.0001 (0.0002)
$\varphi(6)$	0.0004*** (0.0001)	0.0004*** (0.0001)
Excess Volatility Dummies		
Δ_1	0.0029** (0.0014)	0.0029** (0.0014)
Δ_2	0.0051*** (0.0010)	0.0051*** (0.0010)
Δ_3	0.0032*** (0.0010)	0.0032*** (0.0010)
Intervention (e-4)		
$\gamma(0)$	-0.3951** (0.1489)	-
Intervention Sales of EUR/Purchases of DKK (e-4)		
$\gamma_S(0)$	-	-0.2361* (0.1697)
Intervention Purchases of EUR/Sales of DKK (e-4)		
$\gamma_P(0)$	-	-0.7185** (0.2308)
R^2	0.1340	0.1339

NOTES:

- (a) * Denotes significance at 90%, ** denotes significance at 95%, *** denotes significance at 99%
- (b) Standard Errors in () below the point estimates; lags in () in Variable Names
- (c) Estimations are defined in Equation (3) in the text
- (c) The dependent variable is the absolute residual from the auxiliary regression of Equation (2)
- (d) The independent variables are normalizing constants, a realized volatility measure, trigonometric terms, excess volatility dummies, current and lagged intervention sales of EUR (denoted by subscript S), current and lagged intervention purchases of EUR (denoted by subscript P), or current and lagged interventions (no subscript).

TABLE 4 Exchange Rate Spread Responses to Intervention: State Dependence		
	All Interventions	Separate Intervention Purchases and Sales
Interventions All on “High-Volatility” Days (e-5)		
$\gamma_J(0)$	-0.28 (4.2352)	-
Interventions All on “Normal” Days (e-5)		
$\gamma_{NJ}(0)$	2.83 (1.9257)	-
Intervention Sales of EUR/Purchases of DKK on “High-Volatility” Days (e-5)		
$\gamma_{SJ}(0)$	-	0.52 (0.8217)
Intervention Sales of EUR/Purchases of DKK on “Normal” Days (e-5)		
$\gamma_{SNJ}(0)$	-	-3.17*** (1.0660)
Intervention Purchases of EUR/Sales of DKK on “High-Volatility” Days (e-5)		
$\gamma_{PJ}(0)$	-	-1.22 (5.4948)
Intervention Purchases of EUR/Sales of DKK on “Normal” Days (e-5)		
$\gamma_{PNJ}(0)$	-	7.77*** (2.6954)
R ²	0.60	0.60
#Interventions on “High-Volatility” Days	62	-
#Interventions on “Normal” Days	100	-
#Intervention Sales of EUR on “High-Volatility” Days	-	19
#Intervention Sales of EUR on “Normal” Days	-	44
#Intervention Purchases of EUR on “High-Volatility” Days	-	30
#Intervention Purchases of EUR on “Normal” Days	-	69
NOTES: (a) * Denotes significance at 90%, ** denotes significance at 95%, *** denotes significance at 99% (b) Standard Errors in () below the point estimates (c) Estimations are carried out using OLS with heteroskedasticity and autocorrelation consistent (HAC) standard errors and covariances (d) The dependent variable is the DKK/EUR exchange rate spread (e) Column 1: The independent variables are current intervention on “high-volatility” days (denoted by subscript J), current intervention on “normal” days (denoted by subscript NJ), and lags of the dependent variable. Column 2: The independent variables are current intervention sales of EUR on “high-volatility” days (denoted by subscript SJ), current intervention sales of EUR on “normal” volatility days (denoted by subscript SNJ), current intervention purchases of EUR on “high-volatility” days (denoted by subscript PJ), current intervention purchases of EUR on “normal” days (denoted by subscript PNJ), and lags of the dependent variable (f) A “high-volatility day” is defined as a day with either a significant intraday volatility jump, i.e. a “jump-day” as defined in Andersen, Bollerslev, and Diebold (2007), or with a daily realized volatility that is at least the average realized volatility of the sample plus two times the standard deviation of the realized volatility of the sample; a “normal” day is defined as all other intervention days (g) The coefficient estimates associated with the constant and the lags of the dependent variable not shown for ease of exposition		

TABLE 5 Exchange Rate Spread Responses to Unexpected Intervention		
	All Interventions	Separate Intervention Purchases and Sales
Constant (e-5)		
$\beta(0)$	0.002*** (0.0001)	0.002*** (0.0001)
Unexpected Interventions (e-5)		
$\gamma_U(0)$	1.94 (1.7594)	-
Unexpected Intervention Sales of EUR/Purchases of DKK (e-5)		
$\gamma_{US}(0)$	-	-2.36** (1.0806)
Unexpected Intervention Purchases of EUR/Sales of DKK (e-5)		
$\gamma_{UP}(0)$	-	4.99* (2.6572)
R ²	0.60	0.60
#Interventions	162	-
#Intervention Sales of EUR	-	63
#Interventions Purchases of EUR	-	99
<p>NOTES:</p> <p>(a) * Denotes significance at 90%, ** denotes significance at 95%, *** denotes significance at 99%</p> <p>(b) Standard Errors in () below the point estimates</p> <p>(c) Estimations are carried out using OLS with heteroskedasticity and autocorrelation consistent (HAC) standard errors and covariances</p> <p>(d) The dependent variable is the DKK/EUR exchange rate spread</p> <p>(e) Column 1: The independent variables are contemporaneous unexpected intervention (denoted by subscript U) and lags of the dependent variable. Column 2: The independent variables are contemporaneous unexpected intervention sales of EUR (denoted by subscript US), current intervention purchases of EUR (denoted by subscript UP), and lags of the dependent variable</p> <p>(f) Unexpected intervention is proxied by the residual of an intervention reaction function estimation</p> <p>(g) The coefficient estimates associated with the constant and the lags of the dependent variable not shown for ease of exposition</p>		

TABLE 6 Exchange Rate Spread Responses to Intervention and Macro News		
	All Interventions	Separate Intervention Purchases and Sales
Standardized Intervention All		
$\gamma_{SDALL}(0)$	0.0017 (0.0016)	-
Standardized Intervention Sales of EUR/Purchases of DKK		
$\gamma_{SDS}(0)$	-	-0.0016** (0.0007)
Standardized Intervention Purchases of EUR/Sales of DKK		
$\gamma_{SDP}(0)$	-	0.0022* (0.0012)
Standardized Danish Macro News		
DKUNEMP(0)	0.0108* (0.0060)	0.0108 (0.0060)
DKUNEMP(1)	0.00102* (0.0044)	0.0102** (0.0044)
DKTB(0)	0.0045 (0.0041)	0.0045 (0.0041)
DKTB(1)	-0.0035** (0.0021)	-0.0035 (0.0021)
DKCA(0)	-0.0112*** (0.0035)	-0.0112*** (0.0035)
DKCA(1)	-0.0044 (0.0043)	-0.0044 (0.0043)
DKCPI(0)	0.0138 (0.0150)	0.0138 (0.0150)
DKCPI(1)	-0.0048 (0.0078)	-0.0048 (0.0078)
DKGDP(0)	-0.0085 (0.0099)	-0.0085 (0.0099)
DKGDP(1)	-0.0274*** (0.0054)	-0.0274*** (0.0054)
DKCC(0)	0.0120*** (0.0049)	0.0120** (0.0049)
DKCC(1)	-0.0065** (0.0029)	-0.0065** (0.0029)
Standardized German Macro News		
DEIFO(0)	-0.0101*** (0.0038)	-0.0101*** (0.0038)
DEIFO(1)	0.0018 (0.0045)	0.0018 (0.0045)
DEGDP(0)	-0.0155*** (0.0026)	-0.0155*** (0.0026)
DEGDP(1)	-0.0057*** (0.0020)	-0.0057*** (0.0020)
DEIP(0)	0.0035 (0.0033)	0.0035 (0.0033)
DEIP(1)	0.0070 (0.0075)	0.0070 (0.0075)
Standardized Euro-Area Macro News		
EACPI(0)	-0.0053 (0.0058)	-0.0053 (0.0058)
EACPI(1)	0.0044 (0.0033)	0.0044 (0.0033)
EAIP(0)	0.0029 (0.0031)	0.0029 (0.0031)
EAIP(1)	-0.0023 (0.0023)	-0.0023 (0.0023)
EABC(0)	-0.0355	-0.0355

	(0.0242)	(0.0243)
EABC(1)	0.0134 (0.0098)	0.0134 (0.0098)
R ²	0.60	0.60

NOTES:

(a) * Denotes significance at 90%, ** denotes significance at 95%, *** denotes significance at 99%

(b) Standard Errors in () below the point estimates; lags in () in Variable Names

(c) Estimations are carried out using OLS with heteroskedasticity and autocorrelation consistent (HAC) standard errors and covariances

(d) The dependent variable is the DKK/EUR exchange rate spread.

(e) The independent variables are contemporaneous standardized intervention sales of EUR (denoted by subscript SDS), contemporaneous standardized intervention purchases of EUR (denoted by subscript SDP), contemporaneous and lagged standardized macro news, and lags of the dependent variable

(f) Macro news variables capture news surprises as the difference between actual announcement and survey expectations extracted from Bloomberg. The estimations take into account news regarding Danish Unemployment (DKUNEMP), Trade Balance (DKTB), Current Account (DKCA), CPI (DKCPI), GDP (DKGDP), and Consumer Confidence (DKCC); German IFO Index (DEIFO), GDP (DEGDP), and Industrial Production (DEIP); Euro-Area CPI (EACPI), Industrial Production (EAIP), and Business Climate Index (EABC).

(g) All variable s are standardized by dividing each variable by its respective sample standard deviation

(h) The coefficient estimates associated with the constant and the lags of the dependent variable not shown for ease of exposition