The Intraday Effects of Central Bank Intervention on Exchange Rate Spreads

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Abstract: We investigate the intraday effects of intra-marginal intervention in a horizontal band on the exchange rate spread. Official intraday data on Danish intervention transactions in the ERM II, the Exchange Rate Mechanism of the European Union, facilitates our analysis. We show that intervention purchases and sales both exert a significant influence on the exchange rate spread, but in opposite directions. Intervention purchases of the small currency, on average, narrow the spread while intervention sales of the small currency, on average, widen the spread. This is a novel finding that differs from those of existing studies that find intervention always widens the exchange rate spread and increases market uncertainty.

Key words: Foreign Exchange Intervention; ERM II; Exchange Rate Spreads; Intraday Data

JEL Classifications: E58; F31; G15

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1. Introduction

Many studies have investigated the intraday effects of foreign exchange intervention.[1] Few studies have examined the intraday effects of intervention using accurate, official intraday intervention data.[2] Even fewer studies have analyzed the intraday effects of intervention on exchange rate spreads. These studies examine the spread effects of intervention in a crawling peg (Melvin, Menkhoff and Schmeling 2009) and the spread effects of intervention in floating exchange rates (Chari 2007 and Pasquariello 2007).[3] All of these studies find that foreign exchange intervention is associated with an intraday increase in the bid-ask exchange rate spread.

In this paper we investigate how unannounced intra-marginal intervention in a horizontal band such as the ERM II, the Exchange Rate Mechanism of the European Union, influences the bid-ask exchange rate spread. Official intraday data on intervention transactions in the Danish Krone-Euro (DKK/EUR) market provided by Danmarks Nationalbank (DN), the Danish central bank, facilitates our analysis.

It is interesting to investigate how the exchange rate spread is influenced by intervention since doing so can reveal if intervention increases or reduces foreign

[1] See Humpage (2003), Menkhoff (2010), Neely (2005) and Sarno and Taylor (2001) for surveys of the intervention literature. See Dominguez (2003) for a study of the intraday effects of intervention on the level and the volatility of the exchange rate. See Dominguez, Fatum and Vacek (2010) for a study of the intraday effects of reserve sales not intended to influence the exchange rate.

[2] The Bank of Canada, Danmarks Nationalbank, and the Swiss National Bank are the only central banks to provide access to lengthy records of time-stamped intervention data. Records of time-stamped interventions (spanning 1986 to 1995) by the Swiss National Bank are the only publicly available intraday intervention data. See Fischer and Zurlinden (1999) for an early contribution that uses official Swiss intraday intervention data to analyze the effects of announced intervention on the level of the exchange rate. See Fatum and King (2005) for a study of the intraday effects of Canadian interventions.

[3] Melvin, Menkhoff and Schmeling (2009) present a case study of 5 days of intervention by the Russian Central Bank. Chari (2007) uses newswire reports in lieu of actual Bank of Japan intraday intervention data and analyzes a period of roughly one year. Pasquariello (2007) analyzes 9 years of official Swiss intraday intervention data.

exchange market uncertainty regarding whether a currency is seen as properly priced.[4] It is particularly interesting to analyze the effects of intervention on exchange rate spreads using the Danish intervention data for three reasons. First, the Danish intervention data presents a very rare opportunity for learning about the influence of intervention on exchange rate spreads using official, time-stamped data provided by a currently intervening central bank.[5] Second, no previous study has analyzed the effects of intervention in a horizontal band, such as the ERM II band, on exchange rate spreads. Third, analyzing the Danish experience of intra-marginal interventions in the horizontal ERM II band can bring insights of relevance to Denmark and to other EU member states currently participating in the ERM II as well as to the EU member states that are not in the Euro-zone and are not participating in the ERM II, but are expected to participate in ERM II at a later date in order to fulfill the exchange rate criterion necessary for adopting the EUR.[6]

In our context of unannounced intervention by a small central bank aimed at maintaining a small currency in a horizontal band around a major currency, such as maintaining the DKK against the EUR in the ERM II, we cannot assume that the effects of intervention purchases and sales are necessarily symmetric and that foreign exchange intervention is always associated with an intraday increase in the bid-ask exchange rate spread.[7] First, it

[4] Empirical evidence shows that bid-ask spreads widen when uncertainty increases. See, for example, Bollerslev and Melvin (1994). See Chari (2007) for a useful discussion of intervention and exchange rate spreads in a microstructure context.

[5] Hitherto Danish intraday intervention data has only been analyzed by Fatum and Pedersen (2009) who study the intraday effects of intervention on the exchange rate level; they do not consider the influence of intervention on the exchange rate spread.

[6] 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.

[7] The empirical intervention literature in general pays limited attention to the possibility that the effects of intervention might be asymmetric across intervention purchases and intervention sales. Oftentimes estimated models implicitly and a priori impose symmetry across purchases and sales, by simply not

is reasonable to assume that as the intervention occurs, foreign exchange market customers observe only a large order flow but cannot discern the origin of the trade.[8] Therefore, an unannounced intervention by the small central bank, whether a sale or a purchase, is initially understood by customers only as a large trade and, accordingly, interpreted as informative regarding pressure, either upwards or downwards, on the small currency. An unannounced intervention by the small central bank, however, is unlikely to be interpreted as informative regarding pressure on the large currency.[9]

Second, downward pressure on a currency in a horizontal band is potentially more concerning than upward pressure, especially if the downward pressure adversely affects the credibility of the currency and its exchange rate regime.[10] This concern is particularly relevant for the DKK, which has a relatively recent history of instability and frequent devaluations prior to participation in the ERM I, the predecessor of the ERM II. The fact that the DKK is continuously maintained at an appreciated rate relative to the central rate corroborates that downward pressure is viewed as more concerning than upward pressure. Reduced credibility will manifest itself in the form of increased uncertainty and thus a

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distinguishing between the two, or by analyzing data sets encompassing only interventions in one direction. For example, of the aforementioned three existing studies of the intraday effects of intervention on the exchange rate spread, only Pasquariello (2007) analyzes intervention data encompassing both intervention purchases and intervention sales.

[8] The dealers, i.e. the commercial bank counterparts to the DN, are explicitly requested not to disseminate information regarding the origin of the DN initiated intervention trades to their customers. See Bhattacharya and Weller (1997), Ghosh (2002), and others for the advantages of unannounced interventions.

[9] A large sale of the small currency by the small central bank against the large currency might indicate that the small currency is overvalued and subject to downward pressure, possibly leading to uncertainty regarding the sustainability of the exchange rate regime. By contrast, a large purchase of the large currency by the small central bank against the small currency would not necessarily imply that there is upward pressure on the large currency since there are plenty of currencies other than this particular small currency against which pressure on the large currency can be levied.

[10] Intervention purchases of the domestic currency are, in principle, restricted by the amount of finite foreign exchange reserves at the disposal of the small country, whereas intervention sales are, in principle, unrestricted as the monetary authority of the small country has the capability to print money to sell against the large currency.

widening of the exchange rate spread. By contrast, a large purchase of the small currency may be interpreted as a confirmation of the credibility of the small currency and the exchange rate regime, thereby leading to reduced uncertainty and thus a narrowing of the exchange rate spread. In other words, the effects of unannounced intervention in a horizontal band could be asymmetric across purchases and sales.

To assess the intraday effects of intervention on the exchange rate spread in the horizontal ERM II band, and to formally test whether intervention purchases and intervention sales influence the spread asymmetrically, we estimate time-series models of the DKK/EUR exchange rate bid-ask spread, calculated from indicative 5-minute spot bid and ask DKK/EUR prices purchased from Olsen and Associates, with intervention purchases and sales entering as separate explanatory variables. Our sample covers the 1 August 2002 to 31 December 2004 period. We carry out our baseline estimations using OLS with heteroskedasticity and autocorrelation consistent (HAC) standard errors and covariances. As a methodological robustness test we also estimate models using the weighted least squares (WLS) procedure developed by Andersen and Bollerslev (1998).

Consistent with the existing studies of the intraday effects of intervention on the exchange rate spread in the context of a crawling peg or floating exchange rates, our results confirm that intervention significantly influences the spread. However, in contrast with these studies, we show that interventions in a horizontal band do not necessarily increase the spread. Instead, we show that intervention purchases of the small currency, on average, reduce the spread, while only intervention sales, on average, increase the spread. This finding conforms to the suggestion that uncertainty in the market regarding the exchange rate decreases when interventions can be interpreted as upward pressure on

the small currency, while uncertainty in the market increases when interventions can be interpreted as downward pressure on the small currency. 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 2 discusses institutional aspects or ERM II and the Danish interventions. Sections 3 and 4 present the data and the empirical model, respectively. Section 5 discusses the results. Section 6 presents several robustness checks. Section 7 concludes.

2. Institutional Aspects

The ERM II replaced the exchange rate mechanism (ERM I) of the European Monetary System (EMS) when the EUR became legal tender on 1 January 1999. The EU Accession Treaty stipulates that two years of successful participation in ERM II is a requirement for joining the European Monetary Union (EMU) and thus for adoption of the EUR. Currently 8 of the 10 EU member states that are not in the Euro-area are legally required to, at some point, participate in the ERM II in order to obtain EMU membership and Euro-area entry.[11] The currencies of Denmark, Latvia, and Lithuania, are currently maintained in the ERM II. The currencies of Bulgaria, The Czech Republic, Hungary, Poland, Romania, Sweden, and the United Kingdom, are not within the ERM II.

In ERM II, a bilateral central rate and a horizontal deviation band is set for the currency of the participating country vis-à-vis the EUR, but not against the currency of other member states. The standard ERM II deviation band is set to +/- 15%. The ERM II

[11] 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.

member state manages its currency inside the deviation band by adjusting short term interest rates or by carrying out foreign exchange market intervention. Only if the currency reaches either the upper or the lower limit of the deviation band is the European Central Bank obligated to intervene. So far this has not happened in the case of any ERM II currency, thus so far all ERM II interventions have been intra-marginal and carried out unilaterally by the ERM II member state.

Denmark has participated in ERM II since 1 January 1999, thus all DN interventions in the DKK/EUR exchange rate market under study are carried out under the provisions of the ERM II. The official deviation band for the DKK is set to +/- 2.25 percent around the DKK/EUR central rate of 7.46038 DKK/EUR. The DKK has traded within an even narrower range of +/- 0.50 percent around the Danish ERM II central rate.[12]

As discussed in Fatum and Pedersen (2009), the Danish exchange rate and intervention policy is motivated by the recent history of the DKK.[13] It is also motivated by the intent to keep open the possibility of adopting the EUR at any future point in time, and by the desire to show the financial markets that, regardless of the Danish unwillingness to adopt the EUR, the commitment to maintaining the DKK in a narrow horizontal band is credible. The DN interventions, therefore, are not carried out to "calm disorderly markets" but "serve the purpose of reminding the financial markets of the Danish commitment to keeping the DKK/EUR rate virtually fixed" (Fatum and Pedersen 2009, p. 13).

[12] Similar to Denmark, the ERM II member state Latvia unilaterally maintains a 1% deviation band around the central rate of the LVL.

[13] The recent history of the DKK includes exchange rate instability and frequent devaluations prior to participating in the ERM I. The recent history also includes two referendums on EUR participation, in 1992 and 2000, in both of which Danish adoption of the EUR was rejected.

See DN (2003), ECB (2004), and Fatum and Pedersen (2009) for additional details on ERM II and the Danish exchange rate policy.

3. Data

The intervention data covers all DN interventions in the DKK/EUR market over the 1 August 2002 to 31 December 2004 period.[14] The data includes the exact amount and time-stamp to the nearest minute obtained directly from the trade-sheet of each intervention transaction. Intervention amounts are quoted in EUR and a positive amount denotes a purchase of EUR against a sale of DKK.[15]

Table 1A displays descriptive statistics of the intervention data, and Figure 1 shows the interventions juxtaposed against the DKK/EUR exchange rate. 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.[16]

Despite the motivation and purpose of the Danish intervention policy, as discussed in the previous section, the DN follows standard central bank practice in not announcing its interventions. Furthermore, the DN interventions are rarely reported in the

[14] The sample period is determined by data availability.

[15] 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.

[16] Average daily turnover in the DKK/EUR market was USD 2,236 million in 2004, or roughly EUR 3,200 million when converted at the prevailing USD/EUR rate of 1.44. See BIS Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity in 2004, http://www.bis.org/publ/rpfxf07t.htm Statistical Annex Table E.6, pp 61, for statistics on average daily turnover in the DKK/EUR market.

newswire services and none of the reports mentions amount or timing of the interventions.[17]

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.[18] Table 1B summarizes key statistical properties of our 5-minute bid-ask exchange rate spreads (defined as ask minus bid). Figure 2 shows the average intraday spread across the intervals of the day.

There is 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.[19] Consequently, our analysis considers a total of 603 trading days consisting of a total of 64383 5-minute DKK/EUR exchange rate bid-ask spreads.[20] Importantly, our trading day definition encompasses all intervention transactions during the period under study.

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

[17] A Factiva search for both English and Danish language newswire reports of DN interventions over the August 2002 to December 2004 period, using various search word combinations such as "Danish intervention", "Danmarks Nationalbank", and "Danish Crown" etc., finds only four intervention reports in total (three English language reports from Reuters News and one Danish language report from a Danish daily newspaper). The reports are available upon request. See Fischer (2006) for a discussion of the accuracy of newswire reports.

[18] Superior transactions bid and ask prices are not available for the DKK/EUR exchange rate market for the period under study. For this reason we refrain from assessing the economic significance implied by the coefficient estimates when discussing the estimation results in Section 5. See Danielsson and Payne (2002) for a detailed comparison of indicative quotes to transactions data.

[19] 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.

[20] We also deleted the following 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).

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

We follow Melvin, Menkhoff and Schmeling (2009) and use OLS with heteroskedasticity- and serial-correlation consistent (HAC) errors to model the exchange rate spread, SP_t, as a linear function of (absolute) intervention, I_t, and lagged values of the spread itself:

(1) $$SP_t = \beta_0 + \sum_{j=1}^{J} \beta_j SP_{t-j} + \gamma_0 |I_t| + \varepsilon_t, t = 1...T$$

As noted earlier, T=64383. We choose J=6 based on the Schwartz and Akaike information criteria. We test for delayed effects of intervention and control for macro news in the robustness section.

This preliminary specification ignores the possibility of asymmetric effects across (absolute) intervention purchases, (I^P_t), and (absolute) intervention sales, (I^S_t). To allow for the possibility of asymmetries we estimate the following model:

(2) $$SP_t = \beta_0 + \sum_{j=1}^{J} \beta_j SP_{t-j} + \gamma^P{}_0 |I^P{}_t| + \gamma^S{}_0 |I^S{}_t| + \varepsilon_t, t = 1...T$$

We include 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, the EUR-DKK interest rate differential, as well as lags (two and six, respectively) of the 5-minute exchange rate volatility. We use the absolute value of the residual of the

conditional mean model of the exchange rate return, as estimated in Fatum and Pedersen (2009), as a proxy for the 5-minute exchange rate volatility.[21]

The distance from parity and the interest rate differential variables are insignificant. The inclusion of lags of volatility improves the overall fit of the model, but the significance level and size of the coefficient estimates of the lags of the spread are affected by this inclusion (due to multicollinearity between spread and volatility). The results with respect to significance of the intervention variables are unchanged regardless of whether or not lags of volatility are included in the estimations. As a result, we exclude these additional explanatory variables from the rest of the analysis. Results with the additional variables included are available from the authors upon request.

5. Results

The first column of Table 2 displays the results of the OLS-HAC estimation of Equation 1. As the table shows, the coefficient estimate associated with intervention is insignificant, i.e. we find no evidence that intervention, on average, has an intraday influence on the exchange rate spread. Clearly, this seems at odds with the existing intraday studies of intervention and spreads who all find that foreign exchange intervention is associated with an intraday increase in the bid-ask exchange rate spread (see Chari 2007; Melvin, Menkhoff and Schmeling, 2007; and Pasquariello 2007).[22] We

[21] The results of the daily data analysis of intervention in ERM I by Brandner, Grech and Stix (2006) show that the distance from parity significantly influences the level of the DKK/DEM exchange rate. In the context of intraday data and intervention in ERM II, Fatum and Pedersen (2009) find no significant effects of either distance from parity or the EUR-DKK interest rate differential on the level of the DKK/DEM exchange rate. The intraday analysis of intervention and spreads by Melvin, Menkhoff and Schmeling (2009) includes two lags of both spread and volatility in some of their estimations. Their results in regards to intervention are not affected regardless of whether lags of spreads and volatility are included.

[22] The lack of significance of intervention, on average, is also at odds with Naranjo and Nimalendran (2000) who, in the context of intervention in the DEM/USD market over the 1976 to 1994 period, find that

discuss our findings and why they might differ from those of the existing literature after presenting the results of the analysis that allows for the possibility asymmetric effects across intervention purchases and sales.

To test for such intervention asymmetries we estimate the baseline model with intervention purchases and sales entering as separate variables (as described in Equation 2). The results, displayed in the second column of Table 2, show that contemporaneous intervention purchases of DKK as well as contemporaneous intervention sales of DKK are significant (at 95% and 90%, respectively) but influence the exchange rate spread in opposite directions. Specifically, intervention purchases of the small currency decrease the exchange rate spread while intervention sales of the small currency 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, at least in our context of unannounced intervention in a horizontal band. Moreover, the results corroborate the idea that unannounced interventions, of which the foreign exchange market customers cannot know the origin and, therefore, observe only as large order flows, affect the perception of the market regarding whether there is pressure on a currency and in which direction. The interpretation of a large sale of the small currency as an indication of the relatively more concerning downward pressure within the horizontal band increases market uncertainty and widens the spread. By contrast, the interpretation of a large purchase of the small

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intervention, on average, increases the spread. Their analysis, however, pertains to daily data on intervention in a floating exchange rate over an 18 year period during which intervention occurs on almost a third of the trading days in their sample (intervention occurs on 1512 of their 4723 trading days under study). Therefore, their data and context are substantially different from ours thus it does not seem meaningful to further compare our findings to theirs.

currency as an indication of upward pressure is a confirmation of the exchange rate regime in the sense that the lower bound is less likely to be tested and, as a result, market uncertainty decreases and the spread narrows.

Since no previous study has investigated the influence of intervention on exchange rate spreads in the context of the horizontal ERM II band, we compare our findings to existing studies of intervention and spreads with caution. That said, it is nevertheless interesting to note that our results are, upon closer inspection, consistent with the findings of both Chari (2007) and Melvin, Menkhoff and Schmeling (2009). Their samples consist of only intervention sales (intervention sales of JPY and RUB, respectively, against USD), thus by nature of their intervention data they do not consider the influence of intervention purchases. They find that intervention sales of the smaller currency increase the spread, as do we. This could suggest that the downward pressure concern manifests itself not only in our context of the horizontal ERM II band, but also in other exchange rate systems such as floating rates. More research, such as analyzing the intraday effects of intervention purchases of JPY, is warranted in order to answer whether intervention asymmetries are present in, say, floating rates.

Unlike the intervention data studied by Chari (2007) and Melvin, Menkhoff and Schmeling (2009), the Swiss intraday intervention data investigated by Pasquariello (2007) contains both purchases and sales. Contrary to the insignificant intervention coefficient of our preliminary analysis that does not distinguish between purchases and sales, he finds that intervention, on average, increases the intraday spread. However, Pasquariello (2007) also shows that intervention sales of the CHF exert a stronger influence on the CHF/USD spread than intervention purchases of the CHF. Our results,

therefore, are consistent with his in terms of intervention sales of the smaller currency increasing the spread and in terms of showing that the effects on the spread of intervention purchases and sales are asymmetric. By contrast, our results differ in regards to whether intervention purchases of the small currency decrease the spread, as in our data, or whether intervention purchases merely increase the spread less than intervention sales, as in Pasquariello (2007). We conjecture that this difference is due to the fact that our context is that of unannounced intervention in a horizontal band while the Swiss interventions are announced and carried out in a floating exchange rate regime. Only in our context can a purchase of the small currency be interpreted by the market as a confirmation of the credibility of the band which, as we suggest, is the reason why intervention purchases reduce market uncertainty and narrow the spread.[23]

Lastly, it is also interesting to relate our findings to Fatum and Pedersen (2009), who analyze the same data and sample period as ours. They show that intervention sales of DKK significantly depreciate the DKK while intervention purchases of DKK have no detectable effect on the level of the DKK/EUR rate. Consistent with Osler (2008), who points out that the price effect of a trade is larger when spreads are wide, our findings in conjunction with those of Fatum and Pedersen (2009) suggest that interventions that cause the spread to widen also induce a significant adjustment of the DKK/EUR exchange rate, whereas interventions that cause the spread to narrow do not.[24]

[23] The CHF is a widely traded safe-haven currency while the DKK is not. We therefore compare the details of our findings to those of Pasquariello (2007) with particular caution.

[24] While it is beyond the scope of our study to consider the longer-term (e.g. daily) effects of intervention on exchange rate spreads, it is interesting to notice that the case study by Melvin, Menkhoff and Schmeling (2009) shows that intervention increases the spread only temporarily, i.e. at the intraday level, but decreases the spread at the daily level. By contrast, the daily data analysis of Naranjo and Nimalendran (2000) finds that intervention increases the spread at the daily level. Further research on the longer-term effects of intervention on spreads seems warranted.

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

First, we re-estimate the models described in Equations (1) and (2) using the weighted least squares (WLS) procedure developed by Andersen and Bollerslev (1998). The results of the conditional mean estimations, displayed in Table 3 (the first column shows the results of the preliminary estimation that does not allow for asymmetries and the second column shows the results using separate intervention purchases and sales variables), are virtually identical to those of the OLS-HAC estimations. The intervention variable described in Equation (1) is, again, insignificant while both intervention variables (purchases and sales) described in Equation (2) are, again, significant and of opposite signs. The only difference is that the WLS estimation results are marginally stronger in the sense that both intervention sales and intervention purchases are now significant at the 95% level compared to the OLS-HAC estimations (Table 2) where intervention sales are significant at 95% and intervention purchases are significant at only 90%.

Second, while there is no reason to believe that intervention is triggered by the contemporaneous exchange rate spread (i.e. the change in the 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.[25] 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 Humpage (1999) 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. The results of estimating the effects of unexpected intervention on exchange rate spreads are displayed in Table 4 (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.[26]

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 unexpected macro news. To address this concern we include macro

[25] See Neely (2001, 2008) for useful insights on what prompts central bank intervention.
[26] This is not surprising considering that R^2 in the intraday intervention reaction function is below 1%. See Fatum and Pedersen (2009) for additional details.

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. To facilitate a comparison of the relative influence of macro news and interventions, all macro and 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 5, show that some of the macro surprises influence the spread. More importantly, the results regarding the asymmetric effects of intervention purchases and sales remain.[27]

Fourth, in order to test for delayed effects of intervention, we re-estimate our models described in Equations 1 and 2 with 12 lags (60 minutes) of both intervention purchases and intervention sales included. The results show no systematic pattern of delayed effects and the cumulative sums of lags are all insignificant. 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 models in Equations 1 and 2. None of the leads is

[27] Interestingly, the relative influence of intervention is generally quite small compared to the relative influence of macro news. This is, however, not surprising considering that, as previously discussed, the Danish interventions are carried out to confirm the commitment of the Danish exchange rate policy rather than to calm disorderly markets, or to bring about substantial changes in the DKK/EUR exchange rate.

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.[28]

In sum, all our robustness checks confirm that intervention purchases of the small currency decrease the exchange rate spread while intervention sales increase the spread.

7. Conclusion

The existing literature on intervention and spreads is very scarce, and it does not consider intervention in a horizontal band such as the ERM II. Our study is the first to analyze the intraday effects of intra-marginal intervention on the exchange rate spread in the context of a horizontal ERM II band. Proprietary data on official Danish intervention transactions in the DKK/EUR exchange rate market facilitates our analysis.

It is interesting to investigate how the exchange rate spread is influenced by intervention because doing so can reveal whether intervention affects foreign exchange market uncertainty. It is particularly interesting to study the Danish intervention experience in ERM II since it can provide valuable insights of relevance to not only Denmark but also to the currently 8 EU member states that have not yet adopted the EUR but are legally required to do so at some point in time. These 8 EU member states,

[28] Fatum and Pedersen (2009) also reject the hypothesis of parameter instability over the August 2002 to December 2004 period.

therefore, are either already participating in the ERM II or expected to participate in the ERM II at a later date prior to joining the Euro-area.

Our time-series estimations of the 5-minute DKK/EUR exchange rate bid-ask spread provide two insights. First, we show that failure to allow for the possibility of asymmetric affects across intervention purchases and intervention sales can lead to failure to detect the influence of intervention. This is a result of general interest as it illustrates the necessity of considering asymmetries when assessing the influence of large trades, such as intervention transactions, in foreign exchange rate markets.

Second, we show that intervention purchases and sales in a horizontal ERM II band both significantly influence the spread, but the direction of the intervention matters for the resolution, or creation, of uncertainty in the market. Specifically, we show that intervention purchases of the ERM II currency, on average, reduce the spread while intervention sales of the ERM II currency, on average, increase the spread.

This is a new and interesting result that differs from those of existing studies that find intervention to increase market uncertainty regardless of the direction of the intervention. It is also a finding of practical relevance to authorities with the mandate to carry out interventions in the context of a horizontal band. Contrary to findings of studies analyzing intervention in floating exchange rates that, regardless of the exchange rate level or volatility effects of intervention, show that intervention is costly because it increases market uncertainty, we show that this is not necessarily the case. Instead, depending on the direction of intervention, we show that intervention can, in fact, reduce market uncertainty. Lastly, our result has implications for hedge funds and other

speculators that may profit when spreads widen or narrow with intervention in a predictable manner.

The institutional framework surrounding intervention in a horizontal ERM II band is markedly different from that of intervention in other exchange rate regimes such as, for example, floating rates. Therefore, we can not infer that our results describe the intraday effects of intervention on the exchange rate spread in general, i.e. regardless of the specifics of the exchange rate system within which the interventions occur. Rather, our study encourages additional research in order to assess the extent to which our findings also describe the influence of intervention on the exchange rate spread in the context of other exchange rate systems.

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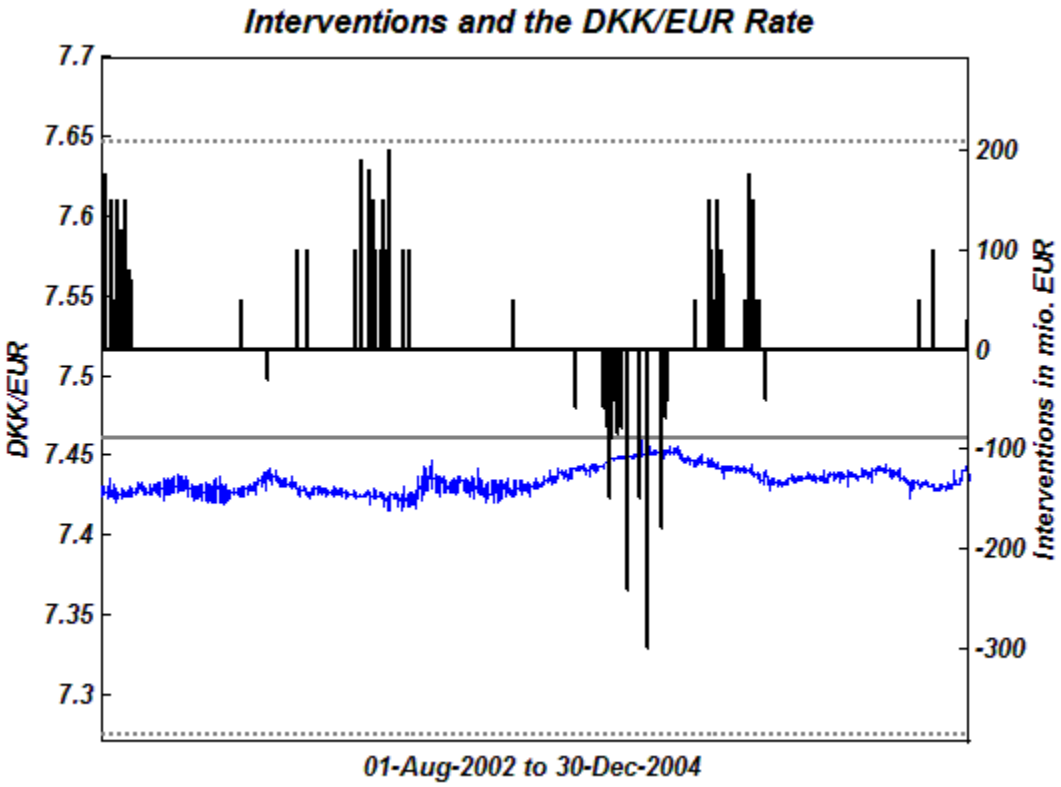
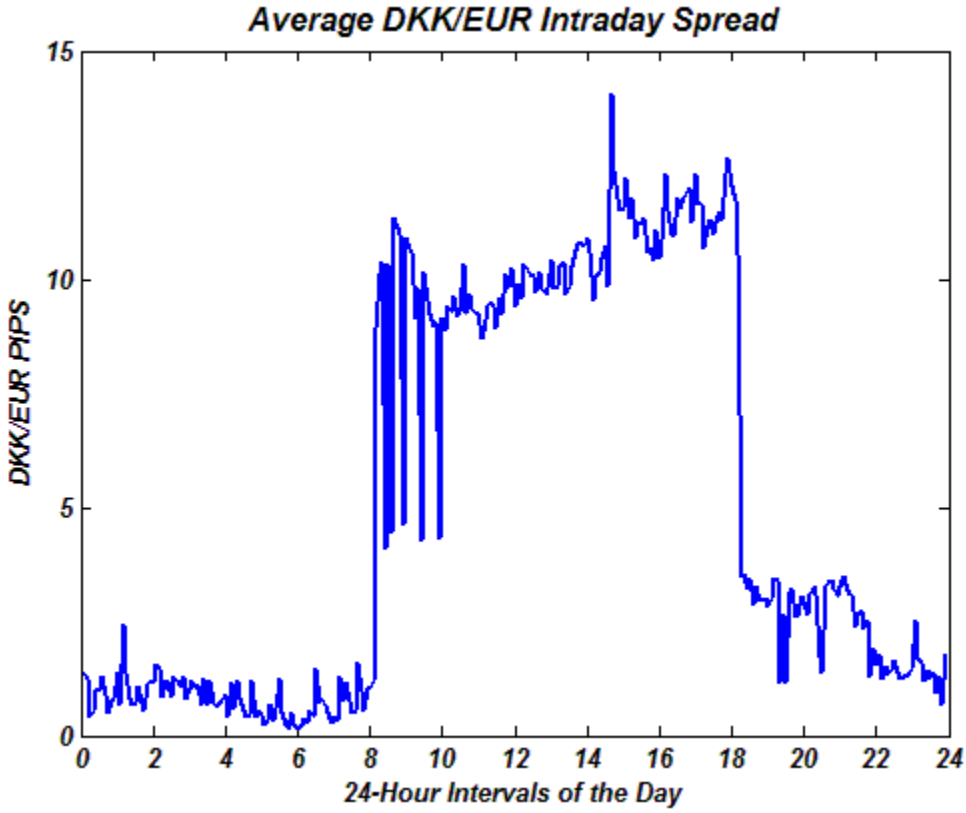
Figure 1



Notes:
a) Data Sources: 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 sale of EUR against a purchase of DKK; the interventions are plotted against the central parity of 7.46038 DKK/EUR
c) The exchange rate is the 5 min. spot exchange rate; the upper and lower lines are the ERM II deviation bands

Figure 2



Notes:
a) Data Source: Olsen and Associates and own calculations
b) The spread is defined as bid minus ask price and measured in PIPS

TABLE 1A	**Intervention Summary Statistics**	
	Number of Interventions	**Average amount (mill. EUR)**
Daily interventions		
All	73	155
Purchases of EUR/Sales of DKK	52	144
Sales of EUR/Purchases of DKK	21	182
Intraday interventions		
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**
2.1 (~0.1)	3.4 (-)	2.7586 (0.0097)	10.4709** (0.0193)
Minimum	**Maximum**	**BJ-test for normality**	**LB Q-test (5-day lag)**
0	31.0	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**

	All Interventions	**Separate Intervention Purchases and Sales**
Constant (e-5)		
$\beta(0)$	0.002*** (0.0001)	0.002*** (0.0001)
Interventions (e-5)		
$\gamma(0)$	1.93 (1.76)	-
Intervention Sales of EUR/Purchases of DKK (e-5)		
$\gamma_S(0)$	-	-2.30** (1.07)
Intervention Purchases of EUR/Sales of DKK (e-5)		
$\gamma_P(0)$	-	4.92* (2.63)
Lags of FX-spreads		
$\beta(1)$	0.34*** (0.010)	0.34*** (0.009)
$\beta(2)$	0.20*** (0.008)	0.20*** (0.008)
$\beta(3)$	0.12*** (0.008)	0.12*** (0.008)
$\beta(4)$	0.09*** (0.008)	0.09*** (0.008)
$\beta(5)$	0.07*** (0.009)	0.07*** (0.009)
$\beta(6)$	0.08*** (0.007)	0.08*** (0.007)
R^2	0.60	0.60
#Interventions	162	-
#Intervention Sales of EUR	-	63
#Interventions Purchases of EUR	-	99

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 carried out using OLS with heteroskedasticity and autocorrelation consistent (HAC) standard errors and covariances
(d) Column 1 displays the estimation results pertaining to Equation (1) in the text; column 2 displays the estimation results pertaining to Equation (2) in the text
(e) The dependent variable is the DKK/EUR exchange rate spread
(f) The independent variables are contemporaneous intervention, and lags of the dependent variable

TABLE 3 **Exchange Rate Spread Responses to Intervention: WLS 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)		
$\gamma(0)$	0.81 (1.28)	-
Intervention Sales of EUR/Purchases of DKK (e-5)		
$\gamma_S(0)$	-	-2.59** (1.22)
Intervention Purchases of EUR/Sales of DKK (e-5)		
$\gamma_P(0)$	-	4.35** (2.18)
Lags of FX-spreads		
$\beta(1)$	0.33*** (0.008)	0.34*** (0.009)
$\beta(2)$	0.19*** (0.007)	0.20*** (0.008)
$\beta(3)$	0.12*** (0.007)	0.12*** (0.008)
$\beta(4)$	0.10*** (0.007)	0.09*** (0.008)
$\beta(5)$	0.07*** (0.007)	0.06*** (0.008)
$\beta(6)$	0.08*** (0.006)	0.08*** (0.007)
#Interventions	162	-
#Intervention Sales of EUR	-	63
#Interventions Purchases of EUR	-	99

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) Column 1 displays the estimation results of the conditional mean model defined in Equation (1) in the text; column 2 displays the estimation results of the conditional mean model defined in Equation (2) in the text
(e) The dependent variable is the DKK/EUR exchange rate spread
(f) The independent variables are contemporaneous intervention, and lags of the dependent variable
(g) R^2 is not applicable to the WLS estimation procedure

TABLE 4 **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 (1.76)	-
Unexpected Intervention Sales of EUR/Purchases of DKK (e-5)		
$\gamma_{US}(0)$	-	-2.36** (1.08)
Unexpected Intervention Purchases of EUR/Sales of DKK (e-5)		
$\gamma_{UP}(0)$	-	4.99* (2.66)
R^2	0.60	0.60
#Interventions	162	-
#Intervention Sales of EUR	-	63
#Interventions Purchases of EUR	-	99

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 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), contemporaneous unexpected intervention purchases of EUR (denoted by subscript UP), and lags of the dependent variable
(f) Unexpected intervention is proxied by the residual of an auxiliary intervention reaction function estimation
(g) The coefficient estimates associated with the constant and the lags of the dependent variable are not shown for ease of exposition

TABLE 5	**Exchange Rate Spread Responses to Intervention and Macro News**	
	All Interventions	**Separate Intervention Purchases and Sales**
Standardized Intervention All		
$\gamma_{SD}(0)$	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
#Interventions	162	-
#Intervention Sales of EUR	-	63
#Interventions Purchases of EUR	-	99

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 variables 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