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Order Flow and the Polish Zloty: An Empirical Investigation

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Abstract

This paper analyses price variations in the euro-zloty and dollar-zloty exchange rates. Drawing from market microstructure, we use order flow—signed buy and sell orders—to model price variations. Our work adds support to the thesis that order flow is important in understanding exchange rate fluctuations. We look at two subsamples: pre and post May 2004, when Poland joined the European Union. Poland kept its own currency, the zloty, which experienced a structural shift in trading—from the dollar to the euro as main trading currency. At the most, order flow explains 29 percent of the variation in the zloty price of the euro. Moreover, we find that euro-zloty order flow is a better proxy for price-relevant information than the dollar-zloty order flow. Coefficient analysis shows that our model provides more statistically significant results in the post May 2004 sample for the euro-zloty equation. Variations in order flow explain variations in exchange rates, both over time and across different currencies. Our findings are important for understanding currencies that experience similar structural shifts as the zloty experienced when the euro became its main vehicle currency.

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1 Introduction

The market for foreign exchange is the backbone of international trade and global investments. It is the most liquid market in the world, with an average daily turnover of USD 5.1 trillion.[1] Exchange rates affect output and employment through changes in competitiveness; inflation through the cost of imports and commodity prices; and international capital flows through the risks and returns of different assets (King, Osler, & Rime, 2013). Indeed, exchange rates affect practically everything, which justifies the amount of attention exchange rates get from importers and exporters, institutional investors and financial institutions, the media, as well as academia.

Despite all the attention exchange rates get from all parties mentioned above, do we really understand how the market for foreign exchange works? Probably far less than we would prefer. The lack of understanding is an issue for everyone concerned with exchange rates. For example, for central banks the exchange rates can be an instrument for achieving their monetary policy goal, or the goal itself. Measuring the effects of their policy actions is difficult when exchange rate movements are hard to explain. For importers and exporters, the exchange rate affects their bottom line, and for investors the exchange rate affects returns on overseas holdings.

Exchange rate research in 1994: "*A number of authors have found that structural models appear to dominate the random walk's forecasting ability at relatively long prediction horizons [...] However, the Meese and Rogoff analysis at short horizons has never been convincingly overturned or explained. It continues to exert a pessimistic effect on the field of empirical exchange rate modelling in particular and international finance in general.*" (Frankel & Rose, 1995)

Exchange rate research in 2009: "*One of the most stunning empirical puzzles in international macroeconomics is the incredible difficulty economists have in explaining exchange rate movements in the modern floating era.*" (Rogoff, 2009)

Exchange rate research has developed, and many clever papers have been published since the 1970s—the beginning of the floating era. However, as the two quotes above illustrate, economists are far from satisfied with how

[1]In April 2016, according to Bank for International Settlements: Monetary and Economic Department, 2016.

far they have come in explaining exchange rate movements. Exchange rate research comes in two main approaches. One focuses on the macroeconomic fundamentals, such as interest rates and trade balances. The other one is a micro-based approach focusing on trading activity.

This paper draws on the microeconomics of asset pricing, using trading data to explain price changes for the Polish zloty. The data set we use is particularly interesting because of a structural shift in the market for the Polish zloty observed in 2004. Poland joined the European Union, but kept its own currency. A structural shift followed: Trading in dollar-zloty gradually decreased and trading in euro-zloty gradually increased. However, there is still significant trading in dollar-zloty. In addition to explaining the impact of transactions on prices, the observed structural shift in the market allows us to analyze microeconomic data's ability to explain price changes over time in the two zloty exchange rates—euro-zloty and dollar-zloty.

The rest of the thesis is structured as follows: Section 2 presents and discusses previous literature and motivates the microstructure approach. Section 3 provides the theoretical background for the models we use. Section 4 describes the methodology. Section 5 describes the data. Section 6 presents and discusses the results, and section 7 concludes.

2 Literature review

2.1 Macroeconomic models

After the breakdown of the Bretton Woods system in the early 1970s, the most common way to explain exchange rate movements was parity conditions and no-arbitrage arguments. That is, modeling price movements by using macroeconomic fundamentals as inputs, such as interest rates, output, inflation, and trade balances. Some of the classical macroeconomic models include those based on purchasing power parity and uncovered interest rate parity, models based on productivity differentials, and portfolio balance models. The early empirical works on exchange rate determination have assumed that there is homogeneity among agents; that information on fundamentals relevant for exchange rates is public; and that information about these variables should help to forecast future exchange rates.

Purchasing Power Parity

A well-established theory within international economics is that different currencies, when translated into one common currency, should have the same purchasing power. If the price level in the US increases, and the price level in Poland remains unchanged, or increases less than in the US, the dollar should depreciate against the zloty. The flexible-price model of Frenkel-Bilson assumes purchasing power parity, a model that includes other fundamentals such as relative money supply, relative real income, and relative short-term interest rates.

Uncovered Interest Rate Parity

News about higher deposit rates in the US will lead to an immediate appreciation of the dollar against the zloty, given that Poland's interest rates remain unchanged or increases less than the dollar rate. As higher interest rates in the US makes it more attractive to invest in the US, investors demand more US dollars, hence an appreciation of the dollar takes place which makes room for the necessary depreciation needed for the uncovered interest rate parity to hold. Well-known macroeconomic models associated with the uncovered interest rate parity includes the sticky-price monetary model of Dornbusch (1976), referred to as an "overshooting" model. (His model allows for deviations from purchasing power parity.)

Exchange-rate disconnect puzzle

Although the theories on macroeconomic fundamentals' relation to exchange rates are well-established and receive most of the attention in course literature, they have been easy to refute. Are exchange rates disconnected from macroeconomic fundamentals? This is a view Obstfeld and Rogoff (2000) call the exchange rate disconnect puzzle. Meese and Rogoff published a paper in 1983 showing that, when tested empirically, a simple random walk model performed no worse than the three competitive models they included in their analysis. This study compared the out-of-sample forecasting ability of the flexible-price and sticky-price monetary models of Frenkel-Bilson and Dornbusch-Frankel, and Hooper-Morton's sticky-price model incorporating current account. In their analysis based on root mean squared errors they found that the simple random walk model performed no worse than the structural models, even though actual realized values of future macroeconomic fundamentals were used as input in the structural models.

Several subsequent studies unsuccessfully attempted to over-turn the Meese and Rogoff analysis at short horizons (Frankel & Rose, 1995), leaving the field of exchange rate research in a crisis (Evans & Lyons, 2002a). Subsequent papers have done the same systematic evaluation of the theoretical models, such as Cheung, Chinn, and Pascual (2005), with the same conclusions: Neither of the models seem to be very successful. However, there are variations across horizons and some models explain more in some currencies than others.

At longer horizons, however, interest rate parity has gained some support (Alexius, 2001; Meredith & Chinn, 1998). MacDonald and Nagayasu (2000) found evidence that long-run interest rates had predictive power to exchange rate levels.

The lack of empirical support for the theories, especially the monetary model, has not led the economics profession to abandon the theory. Rather, it has led researchers to alter the assumption about public information and expectation homogeneity; important information may be private and revealed via trading. This has been part of the motivation for researchers to explore a relatively new area of research—*foreign exchange market microstructure*.

2.2 Market microstructure

The number of different models and variables explored within the field of exchange rate research made it difficult for researchers *"... to think of variables that have escaped consideration in an exchange rate equation"* (Meese, 1990). The field of microstructure has long been part of explaining the equity markets. Market microstructure is concerned with "the process by which investors' latent demands are ultimately translated into transactions", a field that eventually became part of foreign exchange research in the 1990s (Madhavan, 2000).

One variable that has shown to significantly increase the explanatory power of exchange rate models is order flow. Order flow is defined as the net of buyer initiated orders and seller initiated orders. Thus, it is a measure of buying or selling pressure. According to market microstructure, it is information about the 'aggressor' of the trade that moves exchange rates (King et al., 2013).

The first estimates of how order flow influences exchange rates can be found in Lyons (1995), where he found that the dealer he studied raised his quote by 0.0001 Deutsche mark for a $10 million incoming order. Results that are more reliable are presented in Evans and Lyons (2002a), who studied interdealer order flow at a daily frequency on the Deutsche mark and yen price of the US dollar. Their hybrid model, consisting of both a macroeconomic component (interest-rate differential) and a microeconomic component (order flow) accounted for about 60 percent of the variation in the DM/USD spot exchange rate. This was quite an increase from the pure macroeconomic models rarely explaining more than 10 percent.

These results have been confirmed by several subsequent studies. Studies that focused on major currencies include, among others, Danielsson and Love (2006), who studied order flow's price impact in the spot USD/EUR currency market; Payne (2003), who studied the USD/DM spot market; and Chinn and Moore (2011) who studied the USD/EUR and USD/YEN markets. Evans and Lyons (2002b) found that order flow conveyed information also for minor currencies, results that have been further verified in later studies by Smyth (2009) and Scalia (2008).

Menkhoff and Schmeling (2008) showed similar results for the Russian ruble, an emerging market currency. Moreover, their paper suggests that order flows from certain regions (Moscow and St. Petersburg) have more price impact than do order flows from other regions, supporting what is referred to as local information hypothesis: If there are agents or regions which are better informed, trades from these should have high permanent price impact, while trades from less informed ones should have low and only temporary price impact.

While a standard assumption in macroeconomic models has been homogeneous expectations and that information on macroeconomic fundamentals affects exchange rates directly and no trading is necessary to move prices, the microstructure vein has focused on the importance of accounting for heterogeneity: The order flow works as a transmission mechanism where heterogeneous interpretation of news (on fundamentals) is aggregated and moves prices indirectly (Rime, Sarno, & Sojli, 2010). Heterogeneity among agents has been shown in several studies such as Bacchetta and Van Wincoop (2006) and Bjønnes, Rime, and Solheim (2005). Models that consider heterogeneous expectations can therefore give better explanations of exchange rate changes.

Order flow's high explanatory power relative to that of macroeconomic variables in explaining exchange rate changes lends some support to the importance of heterogeneous expectations, but it does not necessarily imply that order flow is the underlying determinant of exchange rates (Rime et al., 2010). Consensus is still that expectations about macroeconomic fundamentals are in fact important determinants for exchange rates, but that the disappointing empirical support stems from these expectations being hard to measure. Economists are asked about their expectations regarding fundamentals, such as interest rates, trade balances, output and employment figures. However, compared to these kinds of survey measures, order flow might be a better proxy for expectations as order flow reveal expectations backed with real money (Lyons, 2001).

Different frameworks for modeling exchange rates in microstructure

Many microstructure studies on exchange rates have used the Portfolio Shifts framework of Evans and Lyons (2002a). Some of the papers mentioned above (e.g., Menkhoff & Schmeling, 2008; Payne, 2003) used the structural vector autoregression approach of Hasbrouck (1991). The Hasbrouck method has the advantage that the researcher does not have to assume that order flow is exogenous; modeling exchange rates and order flow in a vector autoregressive (VAR) system opens up for analyzing direction of causality as well as the mapping of information into the variables.

Cointegration has also been used as a framework in several studies (e.g., Chinn & Moore, 2011; Killeen, Lyons, & Moore, 2006). The cointegrating relationship between price and order flow shows how private information is important in foreign exchange markets, and that order flow has permanent effect on prices (Bjønnes & Rime, 2005). Although order flow is a proxy for macroeconomic fundamentals, finding a cointegrating relationship between exchange rates and fundamentals has not been easy. Rime et al. (2010) points out that this may be due to structural breaks.

3 Theoretical background

This section explains the theoretical assumptions of how prices move in response to information. The first subsection explains the main differences between macroeconomic approaches and microeconomic approaches to exchange rate modeling. The second subsection explains the theoretical framework upon which Evans and Lyons (2002a) based their model on.

3.1 Macro versus micro view on exchange rates

In standard macroeconomic models for exchange rates it is assumed that agents have homogeneous expectations and that all agents have the same information. In microeconomic models, however, these assumptions are relaxed; asymmetric information and heterogeneous expectations play a big role in analyzing exchange rate behavior. Agents have different beliefs both when interpreting current news as well as having heterogeneous expectations about the future. In microstructure analysis, order flow is viewed as an aggregator of these differences in beliefs. We can express the exchange rate as discounted expected payoffs:

$$P_t = \frac{\mathbb{E}\left[P_{t+1}(M_{t+1}) \mid \psi_t\right]}{1 + r_t + \tau_t} \tag{1}$$

where the numerator is expected nominal exchange rate, P_{t+1} (e.g., zloty per dollar), as a function of future macroeconomic fundamentals, M_{t+1}, conditioned upon current information, ψ_t. The denominator is the discount factor, consisting of the interest rate, r_t, and a risk premium, τ_t (Rime & Sojli, 2006).

One issue for modeling exchange rates in practice is that variables included in M, the relevant fundamentals, are likely to be many. Therefore, a proxy for these variables is often used.[2]

Broadly speaking, there are three approaches to model how information is impounded into prices. First, in standard macroeconomic models, all price-relevant information will be known for all agents and contained in τ_t. Similarly, the expectations function will take the same form—agents interpret informa-

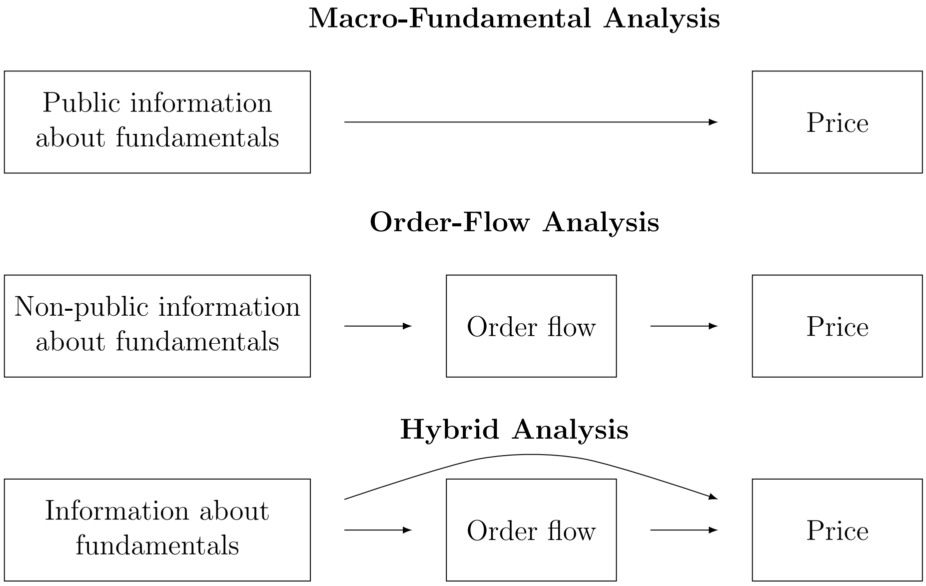
[2]For example, UIP can then be expressed as a version of equation (1): $P_t = \frac{\mathbb{E}[P_{t+1}|\psi_t](1+r^*)}{1+r+\tau}$, where r^* is the dollar interest rate and r the zloty interest rate, and τ excess return required in Poland not to invest in the US.

tion the same way and the mapping from information to price is known to all. In this approach, information is impounded directly into prices.

Second, in microstructure models one opens for heterogeneity among agents and the expectations function takes different forms. Information is dispersed and agents believe in different mappings from fundamentals to price, as suggested already in Frankel and Froot (1990).

A third approach, which is the one applied in our analysis, is a hybrid of the two above. In this approach, both channels affect price. The three approaches to exchange rate modeling are illustrated in Figure 1.

Figure 1: Three approaches to exchange rate modeling



Notes: The figure shows three approaches to exchange rate modeling as shown by Lyons (2001). In the first approach information about fundamentals is impounded directly into prices, and no trading is necessary to move prices. In the second, the pure microstructure approach, non-public information about fundamentals is observed via order flow, and then prices are adjusted. In the third, both channels affect prices.

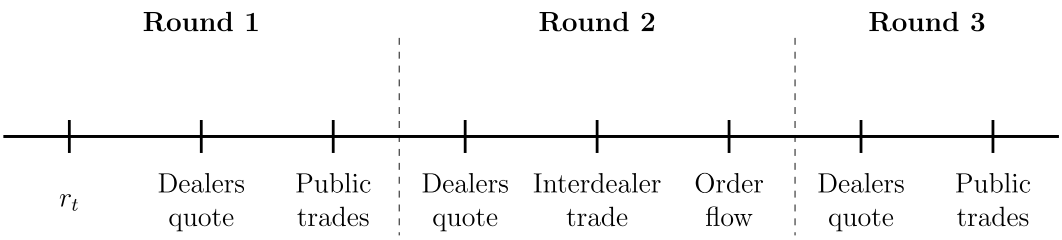
3.2 Portfolio shifts model

The theoretical framework in this part relies on Evans and Lyons (2002a), where they explain exchange rate variation using a portfolio shifts model. The model can be described in short as follows: The trading day is divided into three rounds of trading and explains how the spot price moves as a result from trading activity in these rounds. In round 1 all market participants observe innovations in payoffs, r_t, on which dealers base their quotes to buy or sell any amount from or to the public. In round 2 dealers trade with each other, and in round 3 dealers trade with the public again to share overnight risk. Se Figure 2 for an illustration of the timing in the model. The pricing relation is written as follows:

$$\Delta P_t = r_t + \lambda \Delta x_t \tag{2}$$

That is, the change in price from the end of period $t-1$ to the end of period t depends on innovations in payoffs r_t and price adjustment required to induce re-absorption of the public's portfolio shift from round 1 reflected in $\lambda \Delta x_t$.

Figure 2: Daily timing



Notes: The figure shows the timing within each round of trading. First, dealers trade with the public. Second, dealers trade with each other to share inventory risk. Third, dealers trade with the public again to share inventory risk more broadly.

4 Methodology

The methodology part outlines and describes the two models we use to analyze the Polish zloty. First, we describe the portfolio shifts model. This model is used to see if order flows in dollar-zloty and euro-zloty are informative. Second, we describe a vector autoregressive model. This model is used to see *how* informative the order flows are and to study the interdependency between the series.

4.1 Portfolio shifts model

Following Evans and Lyons' methodology, we regress price changes on a control variable and the order flow variable. The assumption as outlined in the previous section is that order flow is a proxy for price-relevant information, therein information about how changes in macroeconomic variables will affect the exchange rate. We use two different specifications for the macroeconomic control variables: One with the short-term interest rate, and the other with the term spread which captures both long and short-term interest rates. We then evaluate how the model fits the data, and pay special attention to how the relationships differ before and after Poland joined the European Union in May 2004.

We estimate the following model

$$\Delta p = \beta_0 + \beta_1 \Delta r + \beta_2 \Delta x \tag{3}$$

where r is innovations in a macroeconomic variable and x is order flow.

If order flow is a proxy for price-relevant information, we would expect this information to be carried out in the most liquid market. Before Poland joined the European Union in 2004, most trading with the zloty was concentrated in the dollar market. Following 2004, there has been a shift towards euro as the main trading currency. Order flow's explanatory power is expected to be greater in the dollar-zloty equation pre May 2004, and in the euro-zloty equation post May 2004.

The market for foreign exchange is complex and the themes change from time to time. Variations in performance of a pure macroeconomic model over time can be due to changes in how important the explanatory variables in that model is at different times. For example, commodity currencies are more sensitive to commodity prices when they are particularly high or low because the country is more dependent on the income (e.g., Akram, 2004). The assumption for order flow, however, is that it carries different kinds of relevant information. Changes in how well order flow explains price variations might therefore be attributed to a change in where the information is revealed.

Structural break

The volume and order flow series in euro-zloty and dollar-zloty shows that trading in zloty, which used to be concentrated in the dollar market, quickly shifted to the euro market when Poland joined the European Union in May 2004. Therefore it is in our interest to formally test whether this structural shift in the market also affects the parameters in our model. By splitting our sample into two subsamples, one before and one after the assumed structural break in May 2004, we estimate three regressions (pre, post, and entire sample) and compare residual sum of squares in these three.

More specifically, we calculate a test statistic

$$test\ statistic = \frac{RSS - (RSS_1 + RSS_2)}{RSS_1 + RSS_2} \times \frac{T - 2k}{k} \tag{4}$$

where

RSS = residual sum of squares for whole sample

RSS_1 = residual sum of squares for subsample 1

RSS_2 = residual sum of squares for subsample 2

k = number of regressors

T = number of observations

The null hypothesis is that parameters are stable over time, which is also the restriction in the F-test. Therefore, the null hypothesis is rejected if the test statistic is greater than the critical value from the F-distribution with $(k, T-2k)$ degrees of freedom. The results in Table 1 supports our presumption of a structural break in May 2004.

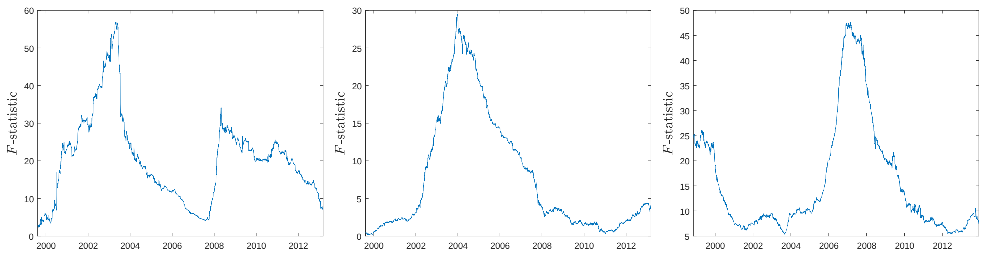
Table 1: Chow test for break date May 5, 2004

	Euro-Zloty	**Dollar-Zloty**
F-statistic	56.476	19.196
	[0.000]	[0.000]
Log-likelihood ratio	166.120	57.256
	[0.000]	[0.000]

Notes: Table shows test results from a Chow test with exogenous break date on May 5, 2004, the first observation in the month when Poland joined the EU. Numbers in brackets represent p-values for the F-statistic and χ^2-statistic. Null of no structural break on May 5, 2004, is rejected.

The market for foreign exchange is complex and our model could be subject to several structural breaks in addition to that experienced when Poland joined the EU. In this thesis we are not looking into those other sources of structural shifts in the market, but we want to verify that possible other breaks are of less importance (or without the same magnitude as the break in May 2004). This can be done by performing the Chow test repeatedly for different break dates, and analyzing the F-statistics. The plots in Figure 3 show results from a Quandt-Andrews test for unknown break points, where the maximum F-statistic appears around our presumed break date, May 2004.

Figure 3: F-statistic for break dates in the three pairs



(a) Euro-Zloty (b) Dollar-Zloty (c) Euro-Dollar

Notes: The figure shows plots of the F-statistics from a Quandt-Andrews unknown breakpoint test. As shown, there are several dates where the F-statistic is rather high, for example the peak in 2008 for the euro-zloty and euro-dollar. However, the maximum F-statistic is approximately at our presumed break date. The euro-dollar equation is included for comparison, where there is no break in 2004.

The Quandt-Andrews test for unknown break date suggests that the break date for the euro-zloty equation was on May 20, 2004, and on December 27, 2004 for the dollar-zloty equation. We associate both to be due to Poland joining the EU. Further in our analysis we will split our sample on the first observation in May 2004 for both models.

Table 2: Quandt-Andrews unknown break test results

	Euro-Zloty	**Dollar-Zloty**	**Euro-Dollar**
Max. LR F-statistic	56.91	29.47	47.66
Break date	05-20-2004	12-27-2004	02-26-2008

Notes: The table shows test results from a Quandt-Andrews unknown break date test. Sample is trimmed 5 percent on each side to avoid breaks too close to the end points of the sample. The break dates found in this test for the two zloty equations are in the same neighborhood as the exogenous break date used in the Chow test, May 5, 2004.

Testing for unit root

To make statistical inferences from our models it is in our interest to know more about the properties and behavior of the series we use. Stationarity in the series is desired; non-stationarity may lead to regression results that look good but are really valueless, so-called spurious regressions. It can also be shown that standard assumptions for asymptotic analysis will be invalid. That is, t-ratios will not follow the t-distribution, and F-statistics will not follow the F-distribution (Brooks, 2014).

We estimate the following equation for all the series

$$\Delta y_t = \psi y_{t-1} + \sum_{i=1}^{P} \alpha_i \Delta y_{t-i} + u_t \tag{5}$$

where the unit root test (Augmented Dickey-Fuller) will be on ψ.

Table 3: Augmented Dickey-Fuller test for unit root

	Level		1st-difference		Conclusion
	T-stat	P-value	T-stat	P-value	$I(p)$
Euro-Zloty					
Order flow	-21.579	<0.001	-	-	$I(0)$
Interest diff	-1.552	0.507	-25.653	<0.001	$I(1)$
Term spread diff	-4.593	<0.001	-	-	$I(0)$
Exchange rate	-2.801	0.058	-65.317	<0.001	$I(1)$
Dollar-Zloty					
Order flow	-19.153	<0.001	-	-	$I(0)$
Interest diff	-1.638	0.463	-23.307	<0.001	$I(1)$
Term spread diff	-4.859	<0.001	-	-	$I(0)$
Exchange rate	-2.100	0.245	-61.969	<0.001	$I(1)$
Euro-Dollar					
Order flow	-12.199	<0.001	-	-	$I(0)$
Interest diff	-1.786	0.388	-25.615	<0.001	$I(1)$
Term spread diff	-6.489	<0.001	-	-	$I(0)$
Exchange rate	-1.327	0.619	-67.539	<0.001	$I(1)$

Notes: The table shows results from an augmented Dickey-Fuller test on the order flow, interest differential, term spread differential (the one-year rate less the overnight rate) and exchange rate for the three pairs. Lag-length was chosen automatically using Schwarz Information Criterion, and was approximately 5 days for order flow series, 20 days for exchange rate series, and between 5-10 for interest rate and term spread series. Note that the order flow variable we use is daily order flow, i.e., first difference of cumulative order flow. Since the exchange rate series will be transformed to first difference log, the results in the 1st-difference column is on the log series. The conclusion is that variables are $I(1)$ processes and must be differenced once.

Table 3 shows test results from an Augmented Dickey-Fuller test. We find that interest rate differential and exchange rate for all three pairs are $I(1)$ processes, and that order flows and term spreads are $I(0)$ processes. Our order flow series is stationary in 'level', but is in its construction actually a differenced variable (daily order flow).

The unit root test is oversized in presence of structural breaks, and may reject the null hypothesis even when it is correct (Leybourne, Mills, & Newbold, 1998). However, in accordance with previous literature we continue with the series in first difference, but keep in mind the shortcoming of the ADF test when drawing inferences from the estimations.

4.2 Vector auto regression

The portfolio shifts model assumes that exchange rate changes are endogenous and a result of changes in the interest rate differential and order flow. However, this need not be the case. Moreover, with the quite significant structural shifts in the series, the direction of causality could have changed. In particular, the shift from dollar to euro as main trading currency may imply that information concentration also has shifted from the dollar to the euro market as well.

We will analyze this by performing Granger causality tests between returns and order flows in the dollar-zloty and euro-zloty markets. To analyze possible shifts in (direction of) causality we use the two subsamples covering the periods before and after Poland joined the European Union in May 2004.

We define a quad-variate vector autoregressive system, where each variable in the system is dependent on own lags and lags of the three other variables. A quad-variate VAR(1) could be written as

$$\begin{bmatrix} y_{1t} \\ y_{2t} \\ y_{3t} \\ y_{4t} \end{bmatrix} = \begin{bmatrix} \alpha_{10} \\ \alpha_{20} \\ \alpha_{30} \\ \alpha_{40} \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} \\ \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} \\ \beta_{31} & \beta_{32} & \beta_{33} & \beta_{34} \\ \beta_{41} & \beta_{42} & \beta_{43} & \beta_{44} \end{bmatrix} \times \begin{bmatrix} y_{1t-1} \\ y_{2t-1} \\ y_{3t-1} \\ y_{4t-1} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \\ u_{4t} \end{bmatrix} \tag{6}$$

The number of lags to include in the VAR will be chosen using information criteria. More specifically, we chose the model that minimizes the Schwarz Information Criteria[3]

$$SBIC_{\ell} = -2\ell/T + \frac{k}{T}(lnT) \tag{7}$$

The VAR system can be estimated using ordinary least squares, and by imposing restrictions on the coefficients we can conduct joint hypothesis tests on all of the lags of each variable. The test statistic will be the usual F-statistic.

[3]This is the formulation EViews uses, derived from the log-likelihood function value from a maximum likelihood estimation.

Causality

The joint hypothesis tests mentioned above can be used to draw inferences on causality[4] between the variables, and which direction the causality goes. Alternatively put: whether variables are exogenous. If β_{12} is significant it is said that y_2 Granger causes y_1, and vice versa. If β_{12} is significant and β_{21} is insignificant, then it is said that y_2 is strongly exogenous. In the case where both are significant, the test suggests that there is bi-directional causality between the variables.

Impulse response functions

The causality tests imply which variables that have significant impacts on other variables in the system. However, they do not explain the sign nor the longitude of these effects. To analyze this we calculate the impulse response functions to see how long it takes for a unit shock in one variable to work through the system.

Consider the VAR(1) in equation (6), which one can rewrite as

$$y_t = A_1 y_{t-1} + u_t \tag{8}$$

In case of a unit shock to y_{1t} at time $t = 0$, that is

$$y_0 = \begin{bmatrix} u_{10} \\ u_{20} \\ u_{30} \\ u_{40} \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

one can trace how the shock works through the system during the following periods $t = 1, 2, \ldots$ if no further shocks occur

$$y_1 = A_1 y_0 = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} \\ \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} \\ \beta_{31} & \beta_{32} & \beta_{33} & \beta_{34} \\ \beta_{41} & \beta_{42} & \beta_{43} & \beta_{44} \end{bmatrix} \times \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \beta_{11} \\ \beta_{21} \\ \beta_{31} \\ \beta_{41} \end{bmatrix}$$

[4]The word causality means only a correlation between the *current* value of one variable and the *past* values of others; it does not mean that movements of one variable cause movements of another (Brooks, 2014).

$$y_2 = A_1 y_1 = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} \\ \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} \\ \beta_{31} & \beta_{32} & \beta_{33} & \beta_{34} \\ \beta_{41} & \beta_{42} & \beta_{43} & \beta_{44} \end{bmatrix} \times \begin{bmatrix} \beta_{11} \\ \beta_{21} \\ \beta_{31} \\ \beta_{41} \end{bmatrix} = \begin{bmatrix} \beta_{11}\beta_{11} + \beta_{12}\beta_{21} + \beta_{13}\beta_{31} + \beta_{14}\beta_{41} \\ \beta_{21}\beta_{11} + \beta_{22}\beta_{21} + \beta_{23}\beta_{31} + \beta_{24}\beta_{41} \\ \beta_{31}\beta_{11} + \beta_{32}\beta_{21} + \beta_{33}\beta_{31} + \beta_{34}\beta_{41} \\ \beta_{41}\beta_{11} + \beta_{42}\beta_{21} + \beta_{43}\beta_{31} + \beta_{44}\beta_{41} \end{bmatrix}$$

and so on for the later periods. Plotting the second element in y for t periods will show how the second variable responds to a unit shock in the first variable, and trace how that shock persists over time. Since the variables we analyze have different scales, however, we will look at the response of a shock of one standard deviation rather than a unit.

5 Data

5.1 Trading data

The data from Reuters D2000-2 contains several variables on trading activity. Table 4 shows an example of how the trading data appears and how the variables are created.

Table 4: Trading data example

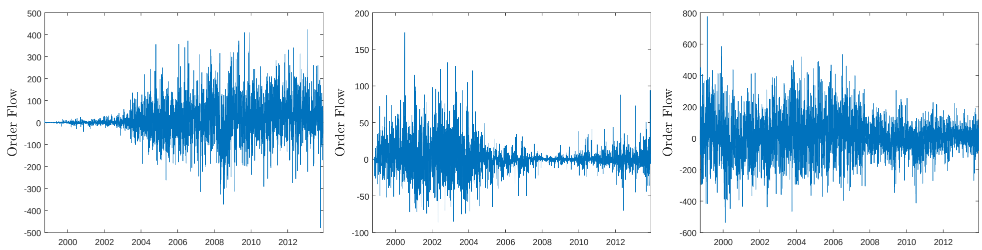
Time	Bid	Ask	Trade
08:00:00	3.52	3.58	
08:00:30	3.51		
08:00:35			3.51
08:01:40	3.53	3.57	
08:02:00			3.57

Notes: The table shows an example of trading activity during two minutes. During these two minutes there are three bid quotes, two ask quotes, one sell order and one buy order. Order flow during this period will be $+1 - 1 = 0$; the relative spread in the first row will be $\frac{3.52-3.58}{(3.52+3.58)/2} = 1.7\%$.

Order flow

Order flow is a variable constructed to reflect net buying pressure. Our order flow variable is the daily net of all buy orders (+1) and sell orders (−1). In Table 4 the order flow during the two minutes is 0. A positive order flow during one day means that there has been more buy orders than sell orders. This is the variable we pay most attention to. Order flows are viewed as information aggregators.

Figure 4: Order flows



(a) Euro-Zloty (b) Dollar-Zloty (c) Euro-Dollar

Notes: The figure shows daily order flows. The order flow variable presented here is already differenced in the sense that it is not cumulative order flow. The structural shift is easy to spot around 2004 in both zloty pairs, while the same cannot be seen for the euro-dollar order flow.

Table 5: Descriptive statistics order flow

	PLN/EUR	PLN/USD	USD/EUR
Mean	14.545	2.354	10.446
Median	1.000	0.000	4.000
Maximum	424.000	173.000	776.000
Minimum	-479.000	-86.000	-537.000
Std. Dev.	80.175	19.900	128.790
Skewness	0.420	1.103	0.301
Kurtosis	6.353	9.779	4.657
Jarque-Bera	1971.940	8390.756	512.935
Probability	0.000	0.000	0.000
Observations	3,962	3,962	3,962

Notes: The table shows descriprive statistics for order flows in the common sample. Order flows are measured in the base currency—the denominator. That is, it has been a net purchase of euro and dollar against the zloty, and a net purchase of euro against the dollar.

Table 6: Serial Correlation in Order Flows

	Order Flow Euro-Zloty				Order Flow Dollar-Zloty			
	Pre May 2004				Pre May 2004			
Lag	**AC**	**PAC**	**Q-Stat**	**Prob**	**AC**	**PAC**	**Q-Stat**	**Prob**
1	0.046	0.046	2.530	0.112	0.062	0.062	4.636	0.031
2	-0.023	-0.025	3.155	0.206	0.011	0.007	4.784	0.091
3	-0.025	-0.023	3.926	0.270	0.030	0.029	5.874	0.118
4	0.044	0.046	6.246	0.181	0.032	0.028	7.081	0.132
5	0.121	0.116	23.733	0.000	-0.006	-0.011	7.129	0.211
6	-0.061	-0.071	28.170	0.000	0.006	0.005	7.167	0.306
7	-0.012	0.001	28.356	0.000	0.083	0.082	15.537	0.030
8	0.019	0.022	28.812	0.000	0.012	0.001	15.698	0.047
9	0.053	0.038	32.148	0.000	-0.020	-0.022	16.195	0.063
10	-0.016	-0.030	32.469	0.000	-0.010	-0.012	16.312	0.091
	Post May 2004				Post May 2004			
Lag	**AC**	**PAC**	**Q-Stat**	**Prob**	**AC**	**PAC**	**Q-Stat**	**Prob**
1	0.153	0.153	65.126	0.000	0.021	0.021	1.269	0.260
2	0.154	0.134	131.250	0.000	0.102	0.102	30.350	0.000
3	0.085	0.046	151.300	0.000	0.042	0.038	35.271	0.000
4	0.088	0.053	172.700	0.000	0.025	0.013	36.953	0.000
5	0.093	0.061	196.780	0.000	0.016	0.007	37.651	0.000
6	0.068	0.029	209.770	0.000	0.025	0.019	39.356	0.000
7	0.017	-0.023	210.540	0.000	-0.029	-0.034	41.717	0.000
8	0.072	0.051	224.800	0.000	0.022	0.018	43.068	0.000
9	0.052	0.026	232.260	0.000	-0.027	-0.024	45.069	0.000
10	0.055	0.022	240.700	0.000	0.042	0.041	49.872	0.000

Notes: The table shows autocorrelation and partial autocorrelation up to ten lags for the two order flows before and after Poland joined the European Union in May 2004. The pattern in the euro-zloty in the subsample pre May 2004 was mixed, while the dollar-zloty showed slightly more evidence toward a positive autocorrelation up to four days. In the subsample post May 2004, the data suggests a more significant positive autocorrelation for the euro-zloty, and somewhat less for the dollar-zloty.

Relative spreads

Relative bid-ask spread is the bid-ask spread divided by the mid quote. In the example in Table 4, the relative spread in the first row is 1.7%. The spread reflects liquidity; in very liquid markets spreads are tight. Assessing the development in bid-ask spreads during our sample can say something about whether liquidity in the zloty market improved after the euro became main trading currency.

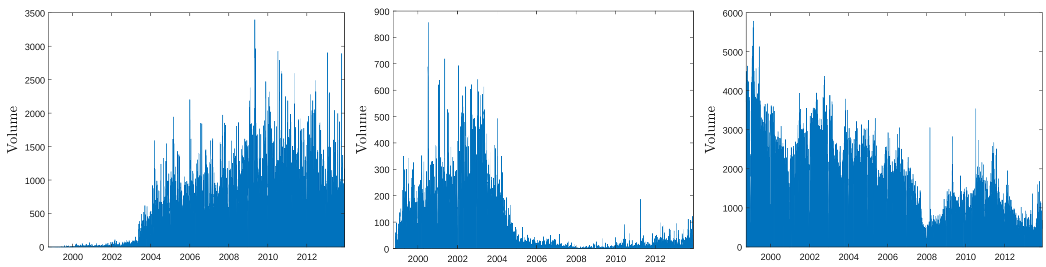
Number of bid and ask quotes

During the trading day, market makers usually make thousands of quotes both for bid and ask. In the example there are three bid quotes and two ask quotes. Market makers usually quote approximately the same number of bid and ask quotes. If there is significantly more ask quotes it must be that they are willing to sell but not buy the currency.

Trading volume and number of trades

This variable is the number of trades executed during the day. In the example in Table 4, there are one buy transaction and one sell transaction, resulting in a trading volume of 2.

Figure 5: Trading volume in 10,000 of base currency



(a) Euro-Zloty (b) Dollar-Zloty (c) Euro-Dollar

Notes: The figure shows daily trading volume in 10,000 of the base currency (euro, dollar, and euro respectively). Similar to the order flow plots, we observe the structural shift from dollar to euro as main trading currency for the zloty after 2004.

5.2 Exchange rates and macroeconomic data

Data on exchange rates and interest rates is downloaded from Thomson Reuters Datastream. The series are daily and matches our trading data, and spans the entire sample from 1999 to 2014.

Exchange rates

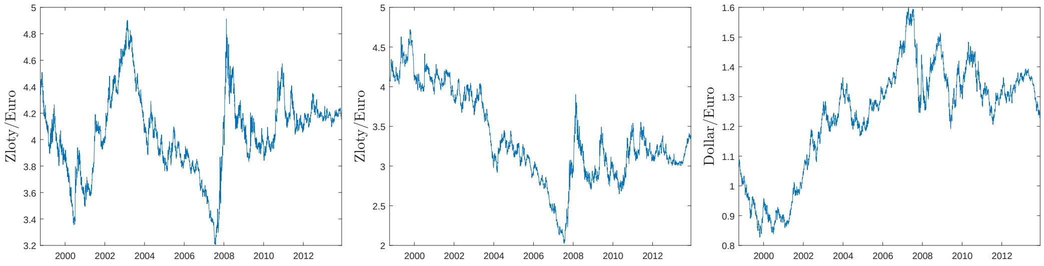
Daily exchange rate series with the same timespan as the trading data are downloaded from Thomson Reuters Datastream, and are closing spot rates. The exchange rates are measured in zloty per dollar and euro, and dollar per euro. Consequently, an increase in the zloty exchange rate is a depreciation of the zloty, and an increase in the dollar-euro rate is a depreciation of the dollar. Plots of the exchange rates are presented in Figure 6.

Table 7: Serial Correlation in Returns

	Return Euro-Zloty				**Return Dollar-Zloty**			
	Pre May 2004				Pre May 2004			
Lag	**AC**	**PAC**	**Q-Stat**	**Prob**	**AC**	**PAC**	**Q-Stat**	**Prob**
1	-0.107	-0.107	13.280	0.000	0.052	0.052	3.083	0.079
2	-0.023	-0.035	13.901	0.001	0.023	0.020	3.673	0.159
3	-0.067	-0.074	19.167	0.000	-0.027	-0.029	4.526	0.210
4	-0.067	-0.085	24.448	0.000	-0.008	-0.006	4.609	0.330
5	0.073	0.052	30.673	0.000	-0.017	-0.015	4.953	0.422
6	-0.007	-0.003	30.728	0.000	-0.069	-0.068	10.531	0.104
7	-0.007	-0.015	30.785	0.000	-0.032	-0.025	11.688	0.111
8	-0.021	-0.020	31.277	0.000	0.004	0.009	11.710	0.165
9	0.001	0.004	31.278	0.000	-0.036	-0.040	13.210	0.153
10	0.018	0.011	31.637	0.000	0.032	0.033	14.415	0.155
	Post May 2004				Post May 2004			
Lag	**AC**	**PAC**	**Q-Stat**	**Prob**	**AC**	**PAC**	**Q-Stat**	**Prob**
1	-0.002	-0.002	0.007	0.936	0.003	0.003	0.033	0.855
2	-0.019	-0.019	1.028	0.598	-0.002	-0.002	0.045	0.978
3	-0.037	-0.038	4.919	0.178	-0.041	-0.041	4.687	0.196
4	-0.023	-0.024	6.448	0.168	-0.003	-0.003	4.718	0.317
5	-0.078	-0.080	23.374	0.000	-0.046	-0.046	10.571	0.061
6	-0.031	-0.034	25.997	0.000	-0.028	-0.030	12.778	0.047
7	0.005	-0.001	26.067	0.000	0.028	0.028	14.972	0.036
8	0.023	0.015	27.494	0.001	0.046	0.043	20.932	0.007
9	-0.020	-0.026	28.588	0.001	-0.040	-0.043	25.384	0.003
10	0.028	0.021	30.784	0.001	-0.007	-0.006	25.514	0.004

Notes: The table shows autocorrelation and partial autocorrelation for the two return series before and after Poland joined the European Union in 2004. The euro-zloty rate shows negative autocorrelation in both subsamples, however with more significant Q-stats in the sample pre May 2004. The dollar-zloty rate shows mixed signs and generally less significant Q-stats.

Figure 6: Exchange rates in zloty per euro and dollar, and dollar per euro



(a) Euro-Zloty (b) Dollar-Zloty (c) Euro-Dollar

Notes: The figure shows evolution of the three exchange rates during our sample period. The zloty has appreciated against both the dollar and the euro, and the dollar has depreciated against the euro.

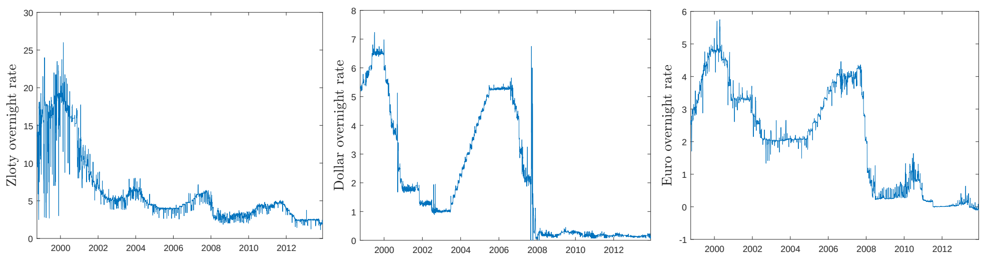
Interest rates

The relative level of interest rates in two countries affects the exchange rate, at least according to theory. A relatively higher interest rate in euro compared to zloty makes the euro more attractive, and hence a buying pressure on the euro should lead to an immediate appreciation against the zloty to give room for the necessary depreciation over time to eliminate arbitrage.

We use the interest rate as the macroeconomic variable in addition to order flow to model behavior of the exchange rate. The short-term interest rates are much more volatile than the longer-term interest rates, and the volatility in the exchange rate itself suggests that the overnight rate would be able to capture more of this volatility. Figure 7 presents plots of overnight rates and one-year rates.

Figure 7: Long and short interest rates

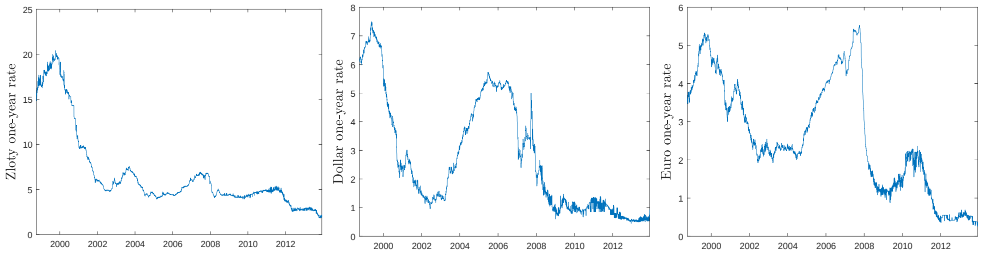
Overnight rate



(a) Zloty (b) Dollar (c) Euro

Figure 7 *continued*

One-year rate

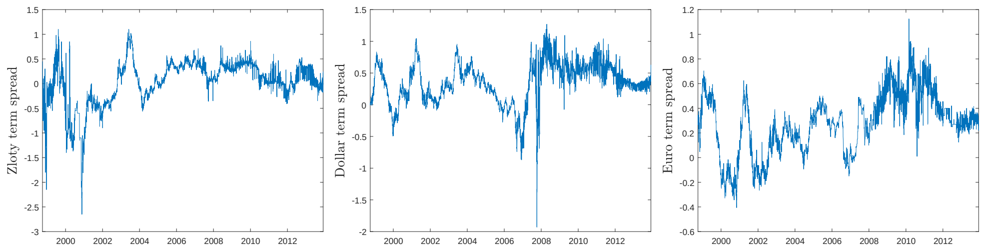


(d) Zloty (e) Dollar (f) Euro

Notes: The figure shows overnight and one-year interest rates for the three currencies. The overnight rate is more volatile than the one-year rate for all currencies. The zloty rate is also up to fivefold of the two other rates, reflecting different economic conditions.

Although the volatile behavior of the exchange rate may be better captured by short-term interest rates, information about the long-term rates is also relevant for the exchange rate. The long-term rates carry expectations of future short-term rates. Hence, an alternative that would capture both is the term spread. The term spread is presented in Figure 8 and shows the spread between the one-year rate and the three-month rate. Compared to the interest rates individually, the term spreads look more stationary (based on graphical inspection).

Figure 8: Term spreads – 1-year less 3-month



(a) Zloty (b) Dollar (c) Euro

Notes: The figure shows the term spread for the three currencies, calculated as the spread between the one-year and the three-month interest rate. The term spread captures both the short-term volatility as well as the long-term economic outlooks.

Table 8: Descriptive statistics macroeconomic data – Entire sample

	Mean	Median	Std. Dev.	Skewness	Kurtosis
Depreciation rate					
PLN/EUR	-0.001	-0.025	0.676	0.422	8.357
USD/EUR	0.005	0.007	0.639	0.028	4.498
PLN/USD	-0.007	-0.028	0.915	0.294	7.193
Interest diff.					
PLN/EUR	-4.072	-2.934	3.702	-1.848	5.641
USD/EUR	-0.040	0.017	1.238	-0.307	2.467
PLN/USD	-4.032	-3.440	3.782	-1.138	4.193
Term spread diff.					
PLN/EUR	0.234	0.231	0.397	0.574	5.348
USD/EUR	-0.077	-0.090	0.275	0.493	4.688
PLN/USD	0.312	0.340	0.522	0.129	4.582

Notes: The table presents descriptive statistics for interest differentials, term spread differentials, and depreciation rates. All are reported in percentage, and covers the series' common sample (3885 observations).

Table 9: Descriptive statistics macroeconomic data – Excluding year of 2008

	Mean	Median	Std. Dev.	Skewness	Kurtosis
Depreciation rate					
PLN/EUR	-0.005	-0.029	0.659	0.413	7.822
USD/EUR	0.006	0.008	0.617	-0.037	4.156
PLN/USD	-0.013	-0.029	0.869	0.327	5.928
Interest diff.					
PLN/EUR	-4.236	-3.024	3.776	-1.755	5.254
USD/EUR	-0.161	-0.018	1.171	-0.427	2.341
PLN/USD	-4.075	-3.345	3.898	-1.086	3.930
Term spread diff.					
PLN/EUR	0.254	0.254	0.396	0.579	5.480
USD/EUR	-0.086	-0.090	0.261	0.094	2.763
PLN/USD	0.340	0.360	0.509	0.241	4.666

Notes: The table presents descriptive statistics for interest differentials, term spread differentials, and depreciation rates. All are reported in percentage, and covers the series' common sample excluding the year of the financial crisis, 2008 (3625 observations).

6 Results

This part will go through the results and relate inferences to the original objective of this thesis—has the pricing mechanism of the Polish zloty changed during the sample period spanning from 1999 to 2014? The first section presents results from the portfolio shifts model, focusing on the changes in informativeness before and after the structural break. The second section presents the portfolio shifts model with a rolling regression analysis. Finally, the third section presents results from the vector autoregressive model, focusing on how causality and impulse responses have changed before and after the structural break that was found to be in May 2004.

6.1 Portfolio shifts model

If order flow is a proxy for price-relevant information, we would expect this information to be carried out in the most liquid market. Before Poland joined the European Union in May 2004, most trading with the zloty was concentrated in the dollar-zloty market. After 2004, however, there has been a shift towards euro as main trading currency.

Estimation results are presented in Table 10 and Table 11. The euro-zloty order flow explained less than the dollar-zloty order flow in our sample before May 2004, while the opposite was the case in our sample after May 2004. In addition, the explanatory power of the euro-zloty equation post May 2004 is higher than that of the dollar-zloty equation before 2004. The order flow coefficients are correctly signed and significant for all specifications in both equations, both before and after the structural break.

In the euro-zloty equation, the order flow coefficient was 2.844 before May 2004 and 0.361 after May 2004. In the dollar-zloty equation, the order flow coefficient was 1.013 before May 2004 and 2.021 after May 2004. This means that a net buy order of 10 million euro would induce a depreciation in the zloty versus the euro of 2.844 basis points before 2004, and 0.361 basis points after 2004. If the spot rate was 4.0000 zloty per euro, the new spot rate would be 4.0011 before 2004, and 4.0001 after 2004. Against the dollar the zloty would depreciate 1.013 basis points before 2004 and 2.021 after 2004. That is, a buy order of 10 million dollar would move the price from, say, 3.5000 zloty per dollar to 3.5005 and 3.5007, before and after 2004, respectively. Coefficients

Table 10: Estimation output euro-zloty equation

	Pre May 2004		Post May 2004	
	(1)	(2)	(1)	(2)
Constant	-1.514	-1.523	-7.917	-7.906
	[1.665]	[2.102]	[1.039]**	[1.040]**
Interest diff.	-1.008		-1.133	
	[1.070]		[3.023]	
Term spread diff.		-4.755		-10.261
		[9.346]		[9.236]
Order flow	2.844	2.844	0.361	0.361
	[0.247]**	[0.240]**	[0.018]**	[0.018]**
Adj. R-squared	0.108	0.107	0.288	0.289

Notes: Table shows regression results for the euro-zloty equation before and after Poland joined the European Union in May 2004. Specification (1), with the overnight interest differential as macroeconomic control variable, is reported with HAC standard errors in both samples, while specification (2) with the term spread as macroeconomic control variable, is reported with HAC standard errors only in the sample post May 2004. Coefficients are presented in basis points (10^4). Order flow coefficients are correctly signed and significant, while coefficients on interest rates are incorrectly signed and not significant. We observe that explanatory power in the period post May 2004 is almost threefold of the explanatory power pre May 2004.

on interest rates and term spreads are insignificant in all equations—there is no evidence supporting the uncovered interest rate parity in our sample.

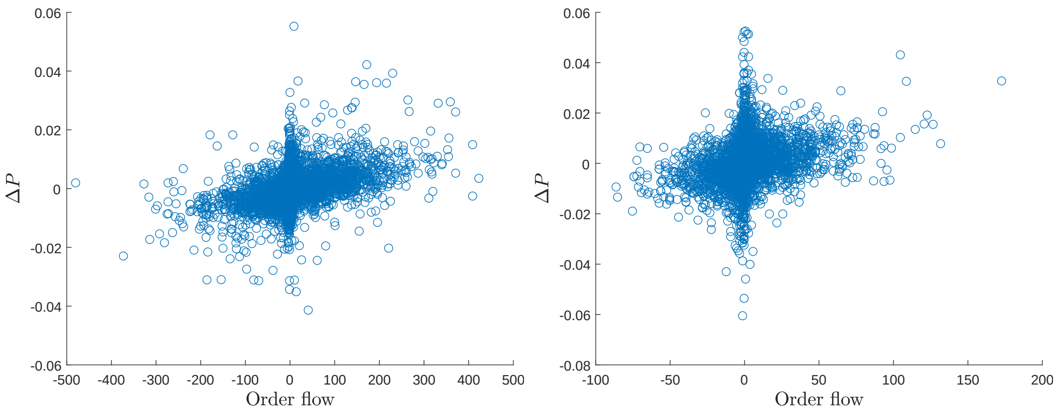
The positive relationship between order flow and exchange rate changes can be seen in the two-dimensional plot in Figure 9. The coefficients on interest rate differentials are negative in all instances except pre May 2004 for the dollar-zloty equation. As mentioned above, however, interest rates do not have significant impact in our sample. A three-dimensional plot is presented in Figure 10, where the most apparent relationship is between order flow and exchange rate changes, while any relationship with interest rates is hard to spot.

Table 11: Estimation output dollar-zloty equation

	Pre May 2004		**Post May 2004**	
	(1)	(2)	(1)	(2)
Constant	-8.910	-8.903	-0.558	-0.556
	[1.843]**	[1.806]**	[1.831]	[1.692]
Interest diff.	0.729		-3.417	
	[0.893]		[5.024]	
Term spread diff.		-0.976		-22.747
		[7.833]		[13.065]
Order flow	1.013	1.013	2.021	2.021
	[0.060]**	[0.080]**	[0.137]**	[0.146]**
Adj. R-squared	0.199	0.198	0.073	0.074

Notes: The table shows regression results in the dollar market before and after Poland joined the European Union in May 2004. Specification (2), with the term spread as macroeconomic control variable, is reported with HAC standard errors in both samples. Coefficients are presented in basis points (10^4). Two stars denote significance on the 1%-level. Order flow coefficients are correctly signed and significant, while coefficients on interest rates are incorrectly signed in three of four cases, however, none are significant. We observe that explanatory power in the period pre May 2004 was almost threefold of the explanatory power post May 2004.

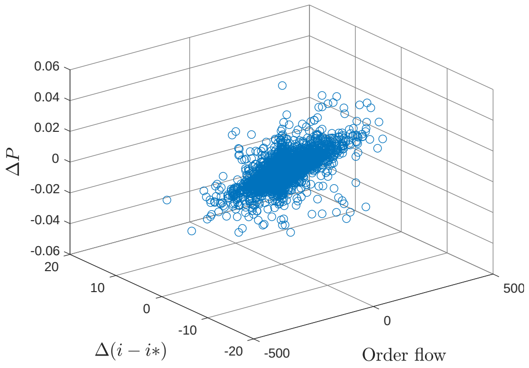
Figure 9: In-sample fit 2D – Log change in price and order flow



(a) Euro-Zloty (b) Dollar-Zloty

Notes: The figure shows two-dimensional plots of daily order flow against change in the log spot price. We observe a positive relationship between order flow and log change in zloty price of the euro and dollar.

Figure 10: In-sample fit 3D – Log change in price, order flow and interest rate differential



(a) Euro-Zloty (b) Dollar-Zloty

Notes: The figure shows three-dimensional plots of daily order flow and change in interest rate differential against change in the log spot price. The positive relationship between order flow and log price change is observable, but it is difficult to fit interest rates into any relation.

6.2 Rolling regression

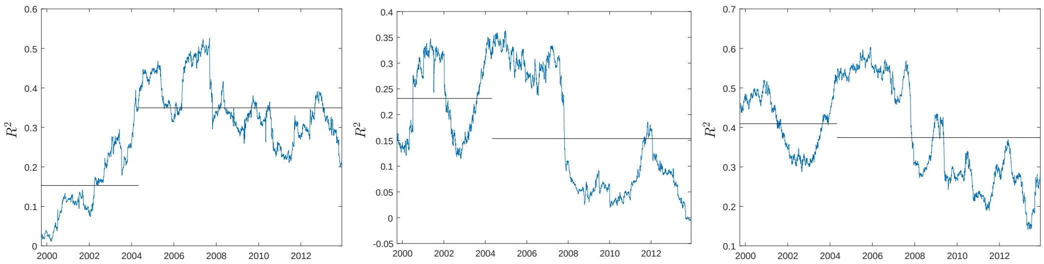
To see how the relationships have changed over time, we run the regressions using a rolling window of one year (260 trading days) and step size of one day. From this program we save the β-coefficients and R^2s to analyze how estimation results change over the course of our sample.

Residual statistics

Under the assumption that the model does explain something about the two markets, using a rolling-window analysis allows us to see how the two markets have evolved. Figure 11 presents the rolling R^2s from the two models, as well as a similar estimation on a dollar-euro equation. We see a downward trend of explanatory power in the dollar-zloty equation, and an upward trend in the euro-zloty equation. If this suggests price relevant information is first absorbed in the euro-zloty market, then another possible inference can be made: The relatively higher level of explanatory power in the euro-zloty equation after May 2004 compared to the dollar-zloty equation before May 2004 suggest that the euro-zloty market is more efficient than the dollar-zloty market. That is, euro-zloty order flow aggregates more price relevant information, and euro-zloty order flow is a better information transmission mechanism than dollar-zloty order flow.

Moreover, as can be seen from Figure 12 (c), the change in order flow's explanatory power in the two zloty markets is not due solely to Poland joining the European Union which led to a shift from dollar to euro as main trading currency. Other market conditions affects order flow's explanatory power as well.

Figure 11: Rolling R^2s



(a) Euro-Zloty (b) Dollar-Zloty (c) Euro-Dollar

Notes: The blue line shows rolling adjusted R^2s using a window of approximately one year (260 days) with rolling steps of one day. The black line shows the mean before and after Poland joined the European Union in May 2004. The euro-zloty equation shows increasing R^2s during the sample, while the opposite is true for the dollar-zloty equation. The euro-dollar equation is presented for comparison.

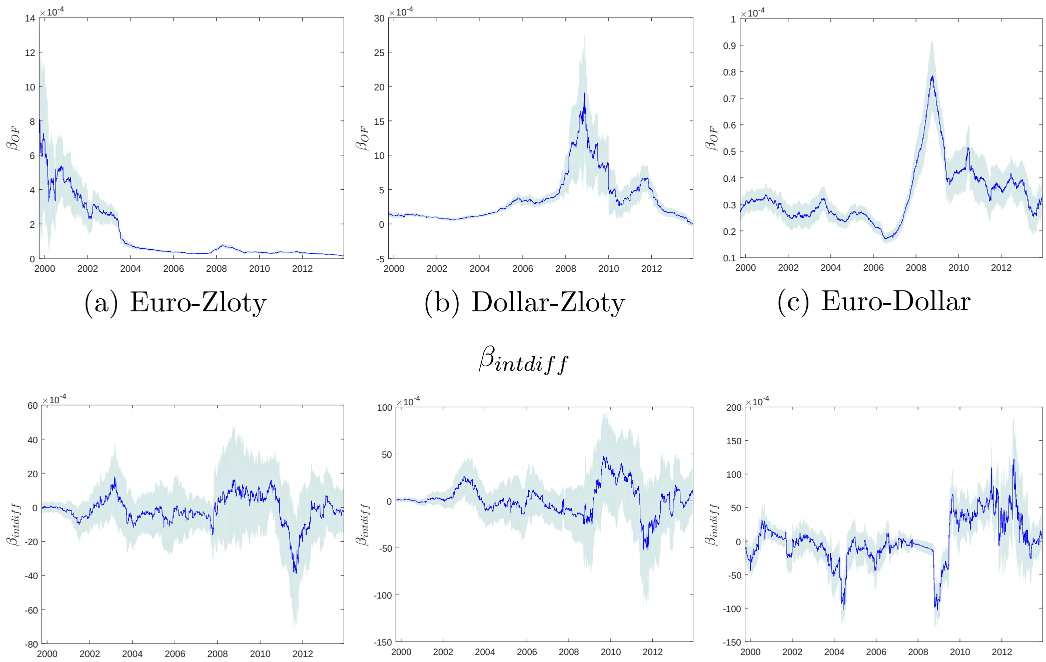
Coefficient statistics

In addition to the rolling R^2s discussed above, analyzing the coefficients over time also points in the direction that information is concentrated in the euro market. Figure 12 presents rolling coefficients for both order flow and overnight interest rates in the euro-zloty and the dollar-zloty equation. Again, a similar graph from the euro-dollar equation is presented for comparison.

Coefficients for order flow in the euro-zloty equation were more unstable before 2004, but stabilized after with narrower confidence bands. For the dollar-zloty equation the opposite can be observed. The coefficients for interest rates were more volatile during the whole period in both equations. In addition, the estimated coefficients for interest rates are in general less significant during the whole sample.

Figure 12: Rolling coefficients

β_{OF}



(a) Euro-Zloty (b) Dollar-Zloty (c) Euro-Dollar

$\beta_{intdiff}$

(d) Euro-Zloty (e) Dollar-Zloty (f) Euro-Dollar

Notes: The figure shows rolling coefficients using a window of approximately one year (260 days) with rolling step of one day. The shaded area represents 95% confidence bands. Order flow coefficients became increasingly stable and significant in the euro-zloty equation, while the opposite is observed for the dollar-zloty equation. Coefficients on interest rates are in general insignificant and less stable.

6.3 Vector autoregression

Causality

Interdependency between returns and order flows has changed during the sample. The most notable observation is that dollar-zloty order flow Granger causes euro-zloty return but not dollar-zloty return before 2004, while euro-zloty order flow Granger causes both returns after 2004. Results from pairwise Granger causality tests are presented in Table 12.

Table 12: Pairwise Granger causality tests

	Dependent variable	**Order flow** USD		EUR		**Return** USD		EUR	
		Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Order flow	USD	—		3.02 (∗)	0.52	0.68	0.46	8.69 (∗∗)	0.12
	EUR	1.49	0.33	—		1.34	4.31 (∗)	0.90	4.11 (∗)
Return	USD	0.99	2.65	3.71 (∗)	0.81	—		17.10 (∗∗)	0.33
	EUR	1.51	0.23	3.28 (∗)	4.43 (∗)	13.51 (∗∗)	1.32	—	

Notes: The table shows results form Granger causality tests performed on the two subsamples before and after Poland joined the EU. The dependent variables are in the top row, and the exogenous variable in the first column. For example, 3.02 in the top row third column is the test statistic obtained when testing if dollar-zloty order flow Granger caused euro-zloty order flow in the sample pre May 2004. The notation (∗) and (∗∗) denotes significance of the F-statistics on the 5% and 1%-level respectively. The equations included two lags, chosen by Schwarz Information Criteria.

The results reported in Table 12 suggest that dollar-zloty order flow and dollar-zloty return did not have a causal relationship neither pre nor post May 2004. Euro return preceded euro-zloty order flow before May 2004, while after May 2004 there was a bi-directional relationship. Dollar order flow was strongly exogenous in both the euro-zloty return equation and euro-zloty order flow equation before May 2004, but neither had a causal relationship after May 2004. The returns were bi-directional before May 2004, but showed no relationship after. Dollar return was strongly exogenous in the euro-zloty order flow equation before May 2004, euro-zloty order flow was strongly exogenous in the dollar-zloty return equation after May 2004.

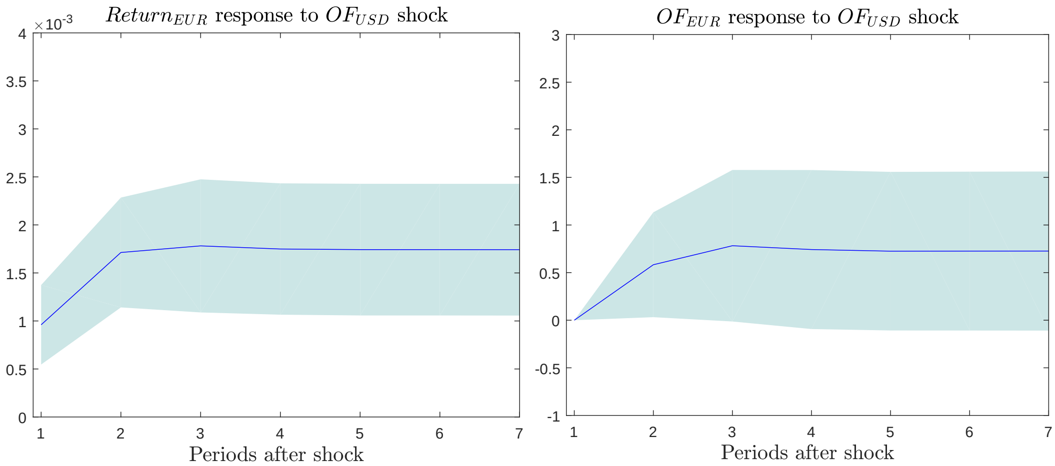
Impulse response functions

The impulse response functions for return from a standard deviation shock in order flows show the usual shape (e.g., Payne, 2003): It takes approximately three days for the shocks to die out. Consistent with causality findings in Table 12, Figure 13 and 14 present impulse response functions for variable pairs that showed causal relationships in Granger's sense before and after May 2004, respectively.

In the subsample before May 2004, there was no significant evidence that the euro-zloty order flow Granger caused euro-zloty return. Euro-zloty return Granger caused euro-zloty order flow, but as the impulse response function in Figure 13 (c) shows, after two days it seems to correct back to its original level. There are no permanent effects.

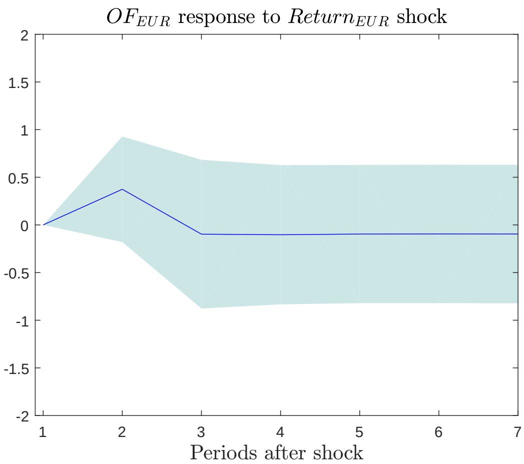
In the subsample after May 2004, there were three pairs where Granger causality was significant: euro-zloty order flow Granger caused euro-zloty return, and the shock had permanent effects and stabilized within a week (Figure 14 (a)); euro-zloty order flow Granger caused dollar-zloty return, and the response was similar to euro-zloty return (Figure 14 (b)); and euro-zloty return Granger caused euro-zloty order flow—making it a bi-directional relationship—and the negative effects stabilized within a week here as well (Figure 14 (c)).

Figure 13: Impulse response functions: Pre May 2004

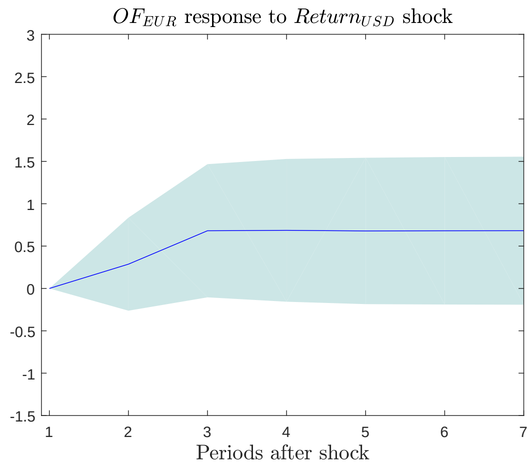


(a) (b)

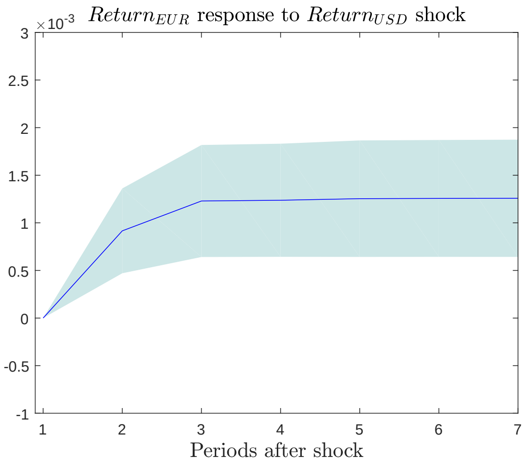
Figure 13 *continued*



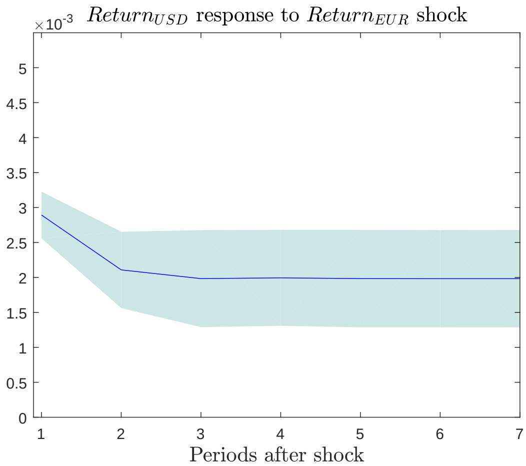
(c)



(d)



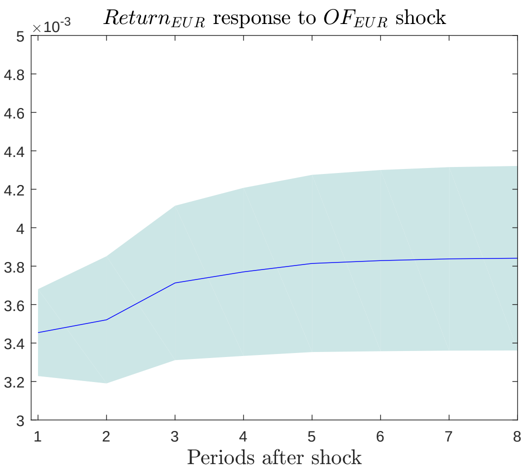
(e)



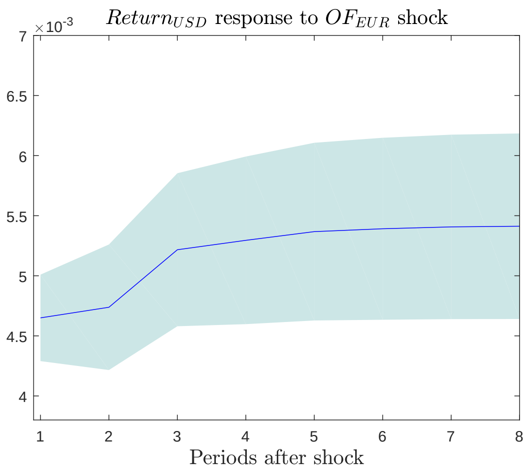
(f)

Notes: The figure shows pre May 2004 impulse response functions with ±2 standard deviation bands. There was no significant evidence that the euro-zloty order flow Granger caused euro-zloty return. However, euro-zloty return Granger caused euro-zloty order flow, but as the impulse response function in Figure (c) shows, after two days, the shock seems to correct back; i.e., there were no permanent effects.

Figure 14: Impulse response functions: Post May 2004

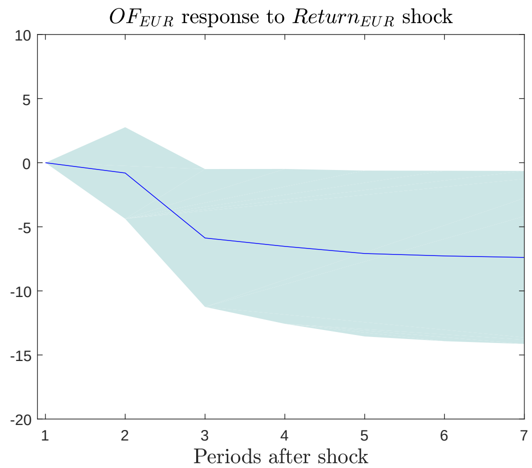


(a)



(b)

Figure 14 *continued*



(c)

Notes: The figure shows post May 2004 impulse response functions with ±2 standard deviation bands. (a) Euro-zloty order flow Granger caused euro-zloty return, and the shock had permanent effects and stabilized within a week; (b) euro-zloty order flow Granger caused dollar-zloty return, and the response was similar to euro-zloty return; and (c) euro-zloty return Granger caused euro-zloty order flow—making it a bi-directional relationship—and the negative effects stabilized within a week here as well.

7 Conclusions

This paper analyses price variations in the euro-zloty and dollar-zloty exchange rates, using a microstructure approach. Specifically, we examine changes in how well the order flow variable—signed buy and sell orders—explain price changes throughout a sample spanning from 1999 to 2014. Using the framework introduced by Evans and Lyons (2002a) we find that order flows are in fact important for explaining exchange rate changes. At the most, order flow explains 29 percent of the price variation in the Polish zloty. Moreover, we find that euro-zloty order flow is a better proxy for price-relevant information than the dollar-zloty order flow. Coefficient analysis shows that our model provides more statistically significant results in the sample post May 2004 for the euro-zloty equation.

In addition to uncovering changes in how well order flow works as a proxy for price-relevant information throughout our sample, we also find changes in direction and significance of causality between order flows and exchange rates. While it seems like dollar-zloty order flow carried out most information and caused changes in both the euro-zloty and dollar-zloty exchange rate before May 2004, euro-zloty order flow was the main information carrier in the sample post May 2004. This supports our belief that the euro is a better suited main vehicle currency for the zloty.

Our paper adds support to the thesis that order flow is important in understanding exchange rate fluctuation. The main finding is that euro trading seems more efficient in bringing information about the underlying value of the zloty to the market. Further, we find that there are variations in how well order flow explains price variations; our model's explanatory power varies over time and between the euro-zloty and dollar-zloty exchange rates. In particular, our findings are helpful for understanding currencies that experience similar structural shifts as the Polish zloty.

There are several extensions to the analyses that would add interesting insights into the microstructure of exchange rates and its importance in explaining price variations. One is to include other currencies that have experienced similar structural shifts in trading activity. Another is to add releases of macroeconomic data to the analysis to see if there are differences in how the two order flows respond to different news.

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