Order Flow and the Monetary Model of Exchange Rates: Evidence from a Novel Data Set

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Abstract

We propose an exchange rate model which is a hybrid of the conventional specification with monetary fundamentals and the Evans-Lyons microstructure approach. We argue that the failure of the monetary model is principally due to private preference shocks which render the demand for money unstable. These shocks to liquidity preference are revealed through order flow. We estimate a model augmented with order flow variables, using a unique data set: almost 100 monthly observations on inter-dealer order flow on dollar/euro and dollar/yen. The augmented macroeconomic, or "hybrid", model exhibits greater in-sample stability and out of sample forecasting improvement vis a vis the basic macroeconomic and random walk specifications.

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1. Introduction

One of the most enduring problems in international economics is the 'exchange rate disconnect' puzzle. Numerous structural or arbitrage approaches have been tried. Prominent among them are:

a) the sticky price monetary model

b) the Balassa-Samuelson model

c) the portfolio balance model

d) purchasing power parity

e) uncovered interest parity.

The in-sample and forecasting goodness of fit of these models were evaluated by Cheung, Chinn and Garcia Pascual (2005 (a) and (b)). Their conclusions are not unfamiliar:

> "the results do not point to any given model/specification combination as being very successful. On the other hand, some models seem to do well at certain horizons, for certain criteria. And indeed, it may be that one model will do well for one exchange rate, and not for another."

Recently, Gourinchas and Rey (2007) have used the external budget constraint to devise a sophisticated measure of external imbalance which has forecasting power for exchange rate changes over some horizons.[1] However, the framework seems to be limited to some of the institutional features of the US dollar and is ex-ante silent on the timing and the composition of external adjustment between price and quantity. The most theoretically and empirically startling innovation in the literature has been the introduction of a finance microstructure concept – order flow – to explain exchange rate movements. In a series of papers Evans and Lyons[2] (2002, 2005, 2008), have shown that order flow contemporaneously explains a significant

[1] See an extended analysis on bilateral exchange rates using this framework in Alquist and Chinn (2008).
[2] These are just examples of their work. For a fuller account, see http://www9.georgetown.edu/faculty/evansm1/Home%20page.htm

proportion of the high-frequency variation in exchange rates. Though their theoretical framework is also very convincing, it was difficult for them to evaluate its merit at standard macroeconomic frequencies because they were working with a daily data set over four month period. Our data set is monthly over eight years. The variables in the monetary model – money stocks, prices, measures of output are only available at monthly or lower frequencies. The span and frequency of our data set enables us to nest both the Evans Lyons model and the monetary within a hybrid general specification. Other writers, most notably Berger et al. (2008), have also obtained access to a long run of EBS order flow data – 6 years from 1999 to 2004 – but they do not integrate this into the conventional monetary analysis.

In Section 2 we discuss the theoretical motivation for the hybrid monetary fundamentals-order flow model we adopt. In Section 3 we outline the characteristics of the data we employ in this study. Section 4 replicates the Evans and Lyons (2002) results at the monthly frequency, confirming the fact that the order flow data we use (and the sample period examined) are representative. Our empirical methodology and basic in-sample results are discussed in Section 5. The next section reports some of the robustness tests implemented. Section 7 reports the preliminary results of our in-sample and out-of-sample validation exercises that demonstrate the predictive power of the hybrid model. The final section makes some concluding remarks.

2. Theoretical Background

The Evans-Lyons model (Evans and Lyons, 2002) introduces the portfolio shifts model which argues that changes in exchange rates are determined by a combination of innovations in public and private information. The latter is revealed through order flow which is measured as the net of buyer over seller initiated trades in the foreign exchange market. In their paper, new public information is empirically implemented as innovations in the international interest differential though Evans and Lyons are at pains to emphasise that, in principle, they are referring to all public information relevant to exchange rate determination. They imply that this includes international money, output and inflation differentials and all of the variables that might be considered in the standard monetary model. The only reason that they this is not reflected in their empirical work is that their data is daily and the only type of public information that is available at that frequency is interest differentials. Their model is fully solved out in Killeen, Lyons and Moore (2006) which expresses the level of exchange rates in that paper's equation (5):

$$P_t = \lambda_1 \sum_{\tau=1}^{t} \Delta R_\tau + \lambda_2 \sum_{\tau=1}^{t} X_\tau \qquad (1)$$

In their notation (which we do not use in the rest of this paper), P_t is the *level* of the exchange rate, ΔR_τ is the public information innovation at time τ, X_τ is order flow at time τ and the λ_i, $i = 1,2$ are parameters which are explicitly solved for in that paper. A key feature of equation (1) to which we appeal in this paper is that order flow and public information innovations are cumulated over time. In other words, λ_1 governs the *level* of public information while λ_2 is the sensitivity to *cumulative* order flow. In short equation (1) is a cointegrating relationship.

The discussion in the Introduction summarises the consistent lack of success of the monetary model in explaining exchange rates. Nevertheless the economics profession persists in believing that it must hold in some form at least in the long-run. In the theoretical appendix, a model is sketched which suggests how this might be achieved.

In essence, it argues that one of the parameters of the utility function is privately known and can only be revealed through trading. In the appendix example, the parameter which governs the individual demand for money is stochastic and indeed follows a unit root process. Because of its non-stationarity, this effect does not wash out in the aggregate. Because it is idiosyncratic, its impact can only be observed through trading i.e. through order flow. This is a simplified way of thinking about the role in exchange rate determination of portfolio balance shocks as put forward by Flood and Rose (1999). More specifically, the existence of shocks to liquidity demands is one of the motivations offered for the link between order flow and exchange rates in the seminal paper by Evans and Lyons (2002). The contention of this paper is that cumulative shocks to liquidity demand, as specified by equation (5) in the theoretical appendix, are captured by cumulative foreign exchange order flow. Bjønnes and Rime (2005) and Killeen, Lyons and Moore (2006) provide evidence that exchange rate levels and cumulative order flow are cointegrated in high frequency data. If equation (9) in the theoretical appendix were correct, exchange rate levels should be cointegrated with *both* cumulative order flow *and* the traditional vector of 'fundamentals' of the monetary model at *all* frequencies. It has been impossible to test this up to this point because of lack of data.

The model is merely illustrative. Any latent variable or preference shift could conceivably perform the same function. In addition, the model must be incomplete because it does not specify a Bayesian updating process about private information. What it does achieve is to show that equation (1) and the monetary model are not incompatible.

3. Data

The data is monthly from January 1999 to January 2007 (see the Data Appendix for greater detail, and summary statistics). Two currency pairs are considered: dollar/euro and dollar/yen.

An attractive feature of the data is its long span of inter dealer order flow. It is by no means the first paper to have a long span of order flow type data – see Bjønnes, Rime, and Solheim (2005) and its citations – but to the best of our knowledge, it is the longest span of inter dealer order flow to be used in an academic setting. The data was obtained from Electronic Broking Services (EBS), one of the two major global inter-dealer foreign exchange trading platforms. It dominates spot brokered inter dealer trading in dollar/yen and is responsible for an estimated 90% of dollar/euro business in the same category. The two series are:

- Order Flow: Monthly buyer initiated trades net of seller initiated trades, in millions of base currency (OFEURUSD, OFUSDJPY)
- Order Flow Volume: Monthly sum of buyer-initiated trades and seller-initiated trades, in millions of base currency.

For dollar/euro, the base currency is the euro while the dollar is the base currency for dollar/yen. In the empirical exercise, we standardize the data by converting OFEURUSD into dollar terms so that the order flow variable enters into each equation analogously.[3] In some of the robustness checks, the order flow variables are normalized by volume (also adjusted into dollar terms). The untransformed order flow and order flow volume data are depicted in Figures 1 and 2.

[3] OFUSDJPY is multiplied by a negative sign to generate the corresponding yen variable.

A note of caution about the definition of order flow is worth entering at this point. We follow the convention of signing a trade using the direction of the market order rather than the limit order. For the current data set, this is carried out electronically by EBS and we do not need to rely on approximate algorithms such as that proposed by Lee and Ready (1991). The reason why the market order is privileged as the source of information is that the trader foregoes the spread in favor of immediacy when she hits the bid or takes the offer in a limit order book. Nevertheless, an informed trader can optimally choose to enter a limit order rather than a market order though she is less likely to do so. For a fuller discussion of this issue, see Hollifield, Miller and Sandas (2004) and Parlour (1998).

The other data are standard. Monthly data were downloaded from the IMF's *International Financial Statistics*. The exchange rate data used for prediction are end-of-month. The exchange rate data used to convert order flow, as well as the interest rate data, are period average, which is most appropriate given the order flow data are in flow terms. In our basic formulation, money is M2 (the ECB-defined M3 for Euro area), and income is industrial production.[4]

The key variables, the exchange rates and transformed order flow series are displayed in Figures 3 and 4 for the dollar/euro and dollar/yen, respectively. Note that in these graphs, the exchange rates are defined (dollar/euro and dollar/yen) and order flow transformed so that the implied coefficient is positive[5].

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[4] As noted in Section 6, we also check to see if the results are robust to use of M1 as a money variable, or real GDP (at the quarterly frequency) as an activity variable. M1 and real GDP are also drawn from *IFS*.

[5] Note that we have also run the regressions with the raw order flow and cumulative demeaned raw order flow data. The qualitative aspects of the regression results do not change – order flow remains important in both a statistical and economic sense.

4. Replicating the Evans-Lyons Results

In order to verify that the results we obtain are not driven by any particular idiosyncratic aspects of our data set, we first replicate the results obtained by Evans and Lyons (2002). They estimate regressions of the form

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$$\Delta s_t = \beta_0 + \beta_1(i_t - i_t^*) + \beta_2(of_t) + \beta_3\Delta(i_t - i_t^*) + u_t \quad (2)$$

Where *i* are short term nominal interest rates and *of* is order flow. The estimates we obtain are reported in Table 1. Several observations are noteworthy. First, the proportion of variation explained goes up substantially when order flow in levels is included. Second, the interest differential coefficient is only statistically significant (with the anticipated sign[6]) when the order flow variables are omitted, and then only in the dollar/euro case. Inclusion of the order flow variables reduces the economic and statistical significance of the interest rate differential in this case. In short, any suspicion that the Evans-Lyons result is an artefact of high-frequency data is firmly dispelled. The results are, however, consistent with those of Berger et al. (2008) who argue that the Evans Lyons result is relatively weaker at lower frequencies.

5. Empirics

We implement the rest of the portion of the paper in the following manner.

a) The Johansen Procedure is applied to test for cointegration between the exchange rates, cumulative order flow and conventional monetary model

[6] The negative slope is consistent with a sticky price monetary model story, though not, of course with uncovered interest parity.

fundamentals (here taken to be the flexible-price model determinants – money, income and interest rates).

b) Weak exogeneity of order flow is tested for.

c) The implied single equation error correction model is estimated.

d) Out of sample forecasts for different models are compared.

5.1 Testing for Cointegration

All the monetary fundamentals – money, industrial production and interest rate differentials – and cumulative order flow, appear to be integrated of order one (see the Data Appendix).[7] The first step in the cointegration test procedure is to determine the optimal lag length. We evaluated the VAR specifications implied by the monetary model and the monetary model augmented by the order flow variable (in this case cumulated). We term this latter version the "hybrid" model.

The Akaike Information Criterion (AIC) typically selects a fairly short lag length of one or two lags in the VAR specification. However, these specifications also typically exhibit substantial serial correlation in the residuals, according to inspection of the autocorrelograms up to lag 6. In contrast, the residuals appear serially uncorrelated when three lags are included in the VARs. Hence, we fix on the three lag specification.

Using this lag length, we applied the Johansen (1988) maximum likelihood procedure to confirm that the presence of cointegration, and to account for the possibility of

[7] We use the Elliott-Rothenberg-Stock DF-GLS test (Elliott, Rothenberg and Stock, 1996), allowing for constant and trend. The ERS unit root test is more powerful than the standard ADF test. In no case is the unit root null rejected for the levels data. In all cases – save the US-euro area interest differential – the unit root null is rejected for the first differenced data. Even in the case of the interest differential, the non-rejection is borderline.

multiple cointegrating vectors. Table 2 reports the results of these tests. The first three columns of Table 2 pertain to specifications including only flexible price monetary fundamentals. Columns 4-6 pertain to the monetary model augmented with cumulative order flow. Columns [1] and [4] pertain to model specifications allowing a constant in the cointegrating equation, columns [2] and [5] to ones allowing a constant in both the cointegrating equation, and in the VAR, and columns [3] and [6] allowing intercept and trend in the cointegrating equation, and a constant in the VAR (in all but columns [1] and [4], deterministic time trends are allowed in the data).

The numbers pertain to the implied number of cointegrating vectors using the trace and maximal eigenvalue statistics (e.g., “3,1” indicates the trace and maximal eigenvalue statistics indicate 3 and 1 cointegrating vectors, respectively). Since the number of observations is not altogether large relative to the number of coefficients estimated in the VARs, we also report the results obtained when using the adjustment to obtain finite sample critical values suggested by Cheung and Lai (1993). Hence, “Asy” entries denote results pertaining to asymptotic critical values, and “fs”, to finite sample critical values.

Inspection of Table 2 indicates that it is not easy to find evidence of cointegration, using only monetary fundamentals (money, income and interest rate differentials). The specification selected by the AIC for the monetary model is one that includes a constant in the cointegrating equation and the VAR equation for the dollar/euro, and one including a constant and trend in the cointegrating vector and a constant in the VAR, for the dollar/yen. In both instances, there is no evidence of cointegration detected.

In contrast, for the hybrid model, the AIC indicate the presence of a constant in both the cointegrating relation for the dollar/euro, and a constant in both the cointegrating relation and VAR for the dollar/yen. Using the finite sample critical values does not change the conclusions. The evidence for cointegration is relatively strong for the dollar/euro, and limited for the dollar/yen.

The resulting conclusions are suggestive that there is one cointegrating vector in almost all cases, at least insofar as the hybrid model is concerned. Hence, we proceed in our analysis assuming only one cointegrating vector.[8] This conclusion points to an important role for cumulative order flow in determining long term exchange rates but only in combination with monetary fundamentals.

5.2 Estimating the Error Correction Models

We estimate the short run and long run coefficients in an error correction model framework, focusing on the exchange rate equation.

$$\Delta s_t = \Delta X_{t-1}\Gamma + \rho_1 \Delta s_{t-1} + \rho_2 \Delta s_{t-1} + \phi(s_{t-1} - X_{t-1}B) + v_t \qquad (2)$$

Where X is a vector of monetary fundamentals and cumulative order flow, and φ should take on a negative value significantly different from zero, if the exchange rate responds to disequilibria in the fundamentals. B is the vector of cointegrating coefficients.

[8] Note that while we could rely upon the Johansen procedure to obtain estimates of the long run and short run coefficients, we decided to rely upon estimation of the single equation error correction specification, in large part because the estimates we obtained via the Johansen procedure were so implausibly large, and sensitive to specification.

Equation (2) invokes the Granger representation Theorem (Engle and Granger, 1987). This enables us to assert that a cointegrating regression of the kind discussed in section 5.1 has an error correction representation. Note that equation (2) does not provide for contemporaneous order flow nor indeed any contemporaneous first differenced variable to enter the ECM. However, this specification *is* implied if order flow is weakly exogenous for the cointegrating vector (Johansen, 1992). We can test for this condition using a likelihood ratio test on the restriction that order flow does not respond to deviations from equilibrium (Johansen and Juselius, 1990).

The test results are reported in Table 2.2. Using asymptotic critical values, the weak exogeneity assumption is rejected in a couple of cases, using the 5% significance level. However, Bruggeman (2002) notes that in small samples, the likelihood ratio test is mis-sized; using the suggested adjustment to the Chi-squared statistic[9], we obtain the test statistics reported in Table 2.3. Now, we fail to reject weak exogeneity in all cases.

Using the theorem of Johansen (1992), we implement equation (2) by adding the current value of order flow as a right hand side variable. Conveniently, the Johansen result also enables us to estimate using OLS without instrumenting the current value of a weakly exogenous variable.

We estimate (3) using nonlinear least squares, with two lags of first differenced monetary fundamentals. When the order flow fundamentals are introduced, they are incorporated first contemporaneously, then as a contemporaneous variable and a

[9] Bruggeman (2002) suggests adjusting the likelihood ratio test statistic by $(T\text{-}k)/T$, where T is sample size, and $k = r+r+K(p\text{-}1)+1$; r is the rank, p is the number of lags in the model, K is the number of variables.

lagged cumulative variable, and then finally with both these variables, as well as two lags of the order flow variable.

One could adopt a general-to-specific methodology with the objective of identifying a parsimonious specification. Typically, such an approach leads to error correction models with short lags (a lag or at most two of first differenced terms), with perhaps income variables omitted. In order to maintain consistency of specifications across models, we present the results of models incorporating two lags of the differenced monetary fundamentals.

5.3 Long- and Short-Run Coefficients

The results of estimating these equations for the dollar/euro and dollar/yen are reported in Tables 3 and 4, respectively.[10,11] Note that the error correction term is in all cases negative and statistically significant. This implies that the exchange rate reverts to a conditional mean, confirming some form of long run linear relationship.

Since the estimation procedure does not necessarily lead to consistent estimates of the standard errors for the long run coefficients, we report the coefficient estimates obtained by implementing dynamic OLS, or DOLS (Stock and Watson, 1993).[12]

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[10] We rely upon a single equation estimation methodology focused on the exchange rate as the dependent variable, which is appropriate if the "fundamentals" are weakly exogenous. We tested for this condition, and this is typically the case.

[11] In all cases, the specifications pass diagnostics for serial correlation, as indicated by the Q-statistics and Breusch-Godfrey LM test.

[12] We use two leads and two lags of the right hand side variables in the DOLS regressions. The long run covariance estimate incorporates a Bartlett kernel, with Newey-West bandwidth set to 4). Point estimates and standard error estimates obtained using the Phillips-Hansen FMOLS procedure are similar to these DOLS estimates.

Turning first to Table 3, columns [1]-[2], one finds little evidence that the exchange rate reacts to the long run monetary fundamentals, at least in the manner indicated by the simple monetary model (note that while order flow is included in columns [2] , it is not in the cointegrating relation). The money stock variable coefficient points in the wrong direction. All the other coefficients are not statistically significant.

In column [2], order flow is included contemporaneously. It enters into the determination of the exchange rate in an important manner; the proportion of variation explained rises dramatically, from 0.02 to 0.34. The estimated short run effect is 1.889, indicating that a $1 billion dollar increase in order flow leads to a dollar appreciation of approximately 0.2 percent, or 20 basis points. This is somewhat lower than Evans and Lyons' (2002) estimate.

The cointegration tests suggest that cumulative order flow does enter into the cointegrating relationship. The specification in column [3] conforms to that specification. In this case, money is now non-significant, while income is wrong-signed.

The error correction specification, allowing the cumulative order flow to enter into the long run relationship, explains an even larger proportion of variation in the exchange rate change (37%). Finally, allowing the inclusion of two lags of order flow slightly raises the proportion of variation explained (38%), although the lagged order flow and lagged cumulative order flow coefficients are not significant.

Turning to the dollar/yen results in Table 4, one finds in column [1] a significant error correction term, although the money coefficient is again wrong-signed. However, the equation does not explain a large proportion of variation. Only when the contemporaneous order flow variable is included (column [2]) does the fit improve substantially, to 57%. Interestingly, in the case of dollar/yen rate, the inclusion of the cumulative order flow in the long run relationship (columns [3]-[4]) does not have a substantial impact on the equation's explanatory power. While the specification in column [4] is consistent with the cointegration test results for the hybrid model, it is interesting that cumulative order flow fails to exhibit statistical significance.

To sum up the results from this section, there does appear to be significant evidence of a long run relationship between exchange rates and monetary fundamentals augmented by cumulative order flow. Even when cumulative order flow might be argued to not enter into the long run relationship (i.e., in the case of the dollar/yen), it is clear that order flow does enter into the short run relation.

6. Robustness Tests

We have investigated a number of variations to the basic specifications, to check whether the empirical results are robust.

- Order flow vs. normalized order flow
- M1 vs M2
- Inclusion of inflation
- Quarterly vs. monthly data

We deal with each of these issues in turn.

Order flow issues. The order flow variables are included in dollar terms. It is reasonable to scale net order flow variable by the *volume* of order flow. The results in the Evans and Lyons regressions are basically unchanged. Using this normalized order flow variable in the hybrid model specifications (conforming to columns [2]-[3] in Tables 3 and 4) does not result in any appreciable change in the results.[13]

Money measures. While the substitution of narrow money for M2 results in slightly different results, particularly with respect to the short- and long-run coefficients on the money variable, the impact on the general pattern of estimates is not significant. In particular, the coefficient on the cumulative order flow variable remains significant.

Inclusion of inflation. Inclusion of an inflation measure would be consistent with a sticky-price monetary model. Over the given sample period, the inflation differential appears to be stationary, so inclusion in the long run cointegrating relationship would not be justified. However, as a practical matter, re-estimating the cointegrating relationships with inflation leads to slightly greater evidence of cointegration, but no substantive changes in the findings regarding the importance of order flow variables.[14]

Quarterly data. At the cost of considerable reduction in the number of observations, one can switch to quarterly data. The benefit is that one can then use real GDP as a measure of economic activity, rather than the more narrow industrial production

[13] Another point related to order flow is that net order flow is positive in the raw data. This could be ascribed to a data recording error. As long as the *level* of order flow enters in the level in the error correction specification, then only the constant is affected. However, when the cumulated order flow enters into the long run relationship, a deterministic trend is introduced. We can address this by allowing a deterministic trend in the data. A direct way to address this issue is by demeaning the raw order flow data. Using demeaned order flow has no impact on the order flow coefficient, but changes substantially the long run coefficient on cumulative order flow.

[14] A previous version of this paper incorporated sticky-price monetary fundamentals, with inflation measured as annualized month-to-month CPI growth rates. Using 3 month growth rates yielded similar results.

variable. As a check, we re-estimated the error correction models (both in a constrained version, using nonlinear least squares, and in an unconstrained version using OLS). What we find is that we recover the same general results as that obtained using the monthly data. While money coefficients remain wrong-signed (as do income variables for the yen), the order flow and cumulative order flow variables show up as economically and statistically significant.

7. Model Validation

We approach model validation in two ways. First, is to examine the in-sample stability of the monetary versus hybrid models. The second is a comparison of out-of-sample forecasting performance.

One way to assess in sample stability is to conduct tests on recursive one-step-ahead residuals. In recursive least squares the equation is estimated repeatedly, incrementing the sample observation by observation, with the parameter estimates updated with each additional observation. The recursive residual for period t is the actual minus predicted based on the parameter estimates obtained on the sample up to t-1. This process of recursive estimation is repeated until all the sample points have been used. If the estimated model is valid, then the resulting errors should be i.i.d., and normally distributed. The one-step ahead forecast error resulting from these sequential predictions can then be tested, after scaling by the standard deviation, to see if they conform to the posited distribution. Rejection of the null hypothesis of independence and normality indicate parameter instability (Kianifard and Swallow, 1996).

In Figures 5-8, the recursive residuals and ±2 standard error bands are illustrated for the error correction models.[15] We compare the monetary against hybrid models (respectively, specifications in columns [1] and [4] of Tables 3 and 4), for the dollar/euro and dollar/yen. In Figure 5, the dollar/euro monetary model exhibits substantial instability, with nine structural breaks indicated by the one-step ahead recursive residuals, using the 10% msl. In contrast, the hybrid model residuals, shown in Figure 6, indicate only five breaks (only two, using the 5% msl). For the dollar/yen, the differences are not as striking. Nonetheless, using the 15% msl, the hybrid model (in Figure 8) exhibits fewer breaks than the monetary model (Figure 7). Furthermore, the n-step ahead recursive residuals test (essentially a sequence of Chow tests) indicates instability at the beginning and end of the samples for the monetary model. No such instability is indicated for the hybrid model.

As is well known in the exchange rate literature, findings of good in-sample fit do not often prove durable. Hence, we adopt the convention in the empirical exchange rate modeling literature of implementing "rolling regressions." That is, the error correction models are estimated over an initial data sample up to 2003(12) , out-of-sample forecasts produced, then the sample is moved up, or "rolled" forward one observation before the procedure is repeated. This process continues until all the out-of-sample observations are exhausted. Note that this is sometimes referred to as a historical simulation, as the ex post realizations – as opposed to ex ante values – of the right hand side variables are used. In this sense, our exercise works as a model validation exercise, rather than a true forecasting exercise.

[15] These tests are applied to the unconstrained error correction models estimated by ordinary least squares, rather than the constrained equations estimated by nonlinear least squares.

To standardise the results, we generate our forecasts for the monetary model from the simple specifications of column (1) in both Tables 3 and 4. For the hybrid model, we use column (4) from both Tables[16].

Forecasts are recorded for horizons of 1, 3, and 6 months ahead. We could evaluate forecasts of greater length, but we are mindful of the fact that the sample we have reserved for the out of sample forecasting constitutes only three years worth of observations. Forecasts at the 3 month horizon for the random walk, monetary and hybrid models are presented in Figures 9 and 10.

One key difference between our implementation of the error correction specification and that undertaken in some other studies involves the treatment of the cointegrating vector. In some other prominent studies, the cointegrating relationship is estimated over the entire sample, and then out of sample forecasting undertaken, where the short run dynamics are treated as time varying *but the long-run relationship is not.* This approach follows the spirit of the Cheung, Chinn and Garcia Pascual (2005b) exercise in which the cointegrating vector is recursively updated.

The results for the dollar/euro are reported in Table 5.1. Mean error, standard errors, Theil U statistic, and the Clark-West statistic (2007) are reported. The Theil U statistic is the ratio of the model RMSE to the benchmark model (in this case random walk) RMSE. Ratios greater than unity indicate the model is outpredicted by the benchmark model. The Clark-West statistic is a test statistic that takes into account

[16] All of these regressions contain the lagged interest differential as regressors. Consequently a forecasting model based on carry trade returns is nested within the exercise.

estimation error, and is normally distributed at 0 under the null that the forecasts from the model and benchmark model are of equal predictive capability.

The first two rows pertain to the no-drift random walk forecast. The next two blocks of cells pertain to the monetary model, and the hybrid model. The final block is the Evans-Lyons model, which we include for purposes of comparison. Note that the Evans-Lyons model does not incorporate a long run relationship incorporating cumulated order flow.[17]

Turning first to the dollar/euro exchange rate, notice that monetary model does very badly relative to the random walk at all horizons. The ratio of the monetary model to the random walk RMSE (the Theil U-statistic) is 1.6, 1.6 and 2.0 at the 1, 3 and 6 month horizons. In contrast, the mean error is smaller for the hybrid model at all horizons, and Theil statistic (vis a vis the random walk) is much smaller: 1.1, 0.9, and 1.0. The relative performance of the 3-month-ahead forecasts (random walk, monetary, hybrid) are shown in Figures 9 and 10.

Perhaps more remarkable, the RMSE for the hybrid model is smaller than the random walk at the 3 and 6 month horizons. The upward bias in the model-based RMSE versus the random walk RMSE (see Clark and West, 2007) suggests that the hybrid models exhibit noticeable improvement vis à vis the random walk benchmark. Unfortunately, inspection of the Clark-West statistic indicates that the hybrid model never outperforms the random walk at conventional significance levels.[18] The Evans-

[17] The particular specification we use conforms to columns [3] and [7] in Table 1.
[18] An order flow augmented sticky-price hybrid model does outperform a random walk at the 17% significance level, at the 3 and 6 month horizons.

Lyons model does particularly badly at all horizons, but the performance is only statistically worse than that of the random walk at the 6 month horizon.

The results are somewhat different in the case of the dollar/yen. There, by the RMSE criterion, the hybrid model substantially outperforms the monetary model at all horizons. However, the Evans-Lyons specification in this case does best, with the lowest Theil statistic at horizons at all horizons. The specification in column [4] can be beaten in certain cases. For the dollar/yen, a specification conforming to column [2] outperforms a random walk, according to the Clark-West statistic, at the 5% msl.

Interestingly, all the structural models outperform the random walk benchmark – after accounting for estimation error. That being said, only the monetary model at the one month horizon comes close to significantly outperforming a random walk. A noticeable feature is that the hybrid model is the only one that that returns a positive Clark-West statistic at all horizons for both currency pairs.

8. Conclusion

We have laid out a simple and transparent framework in which non-stationary private liquidity preference shocks give rise to instability in the demand for money and the apparent failure of the monetary model of exchange rates. Cumulative order flow tracks these shocks and is a candidate for the 'missing link' to augmenting the explanatory power of conventional monetary models. We show that the hybrid model beats both the monetary model *and* a random walk in a simple forecasting exercise. Berger et al. (2008) concluded that while order flow plays a crucial role in high-frequency exchange rate movements, its role in driving long-term fluctuations is much more limited. We contend that this conclusion is premature.

In summary, we find substantial evidence to support our proposition that order flow is an important variable in exchange rate determination, whose role can be rationalized on the basis of a straightforward macroeconomic model. One of the appealing implications of the household optimizing problem as specified in equations (4) to (7) is that consumption in country j also depends on the unit root parameter ξ_t^j. This means that the international consumption differential depends on $\xi_t^H - \xi_t^F$ and therefore on order flow from our interpretation. This may go some distance to explain the international consumption correlations puzzle. However, we leave this to later work.

Data Appendix

For the conventional macroeconomic variables, monthly frequency data were downloaded from *International Financial Statistics* (accessed November 4, 2007).

End of month data used for exchange rates when used as a dependent variable. Interest rates are monthly averages of daily data, and are overnight rates (Fed Funds for the US, interbank rates for the euro area, and call money rate for Japan). In the basic regressions, money is M2 (the ECB-defined M3 for Euro area), although specifications using M1 were also estimated. Income is proxied by industrial production. Money and industrial production are seasonally adjusted.

Order flow was obtained from Electronic Broking Services (EBS). In order to make the specifications consistent across currencies, the order flow data is converted to dollar terms by dividing by the period-average exchange rate (for OFEURUSD) and by putting a negative in front (for OFUSDJPY). Hence, the exchange rates are defined (USD/EUR, USD/JPY) and order flow transformed so that the implied coefficient is positive[19]. In the regression results (Tables 1, 3 and 4), the order flow variable is divided by 1,000,000.

In some unreported regressions, the order flows are normalized by volume. Order flow volume was also converted to dollar terms, in the same manner that order flow was converted.

[19] Any differences in results caused by the choice of numeraire would arise from Jensen's inequality. This is, of course, second order.

For the quarterly regressions (not reported), we use end-of-period exchange rates, and the last month of each quarter for interest rates and inflation rates. The income variable is US GDP (2000$), and for Euro area and Japan, GDP volume (1995 ref.).

Table A1: Summary Statistics for Dollar/Euro

Sample: 1999M01 2007M01	DLXEU	DM2_EU	DY_EU	DI_EU	Z1EU
Mean	0.00134	-0.00087	-0.00014	2.02E-05	10925.54
Median	-0.00131	-0.00089	0.000887	0.000155	10871.6
Maximum	0.069179	0.010421	0.018158	0.00308	33243.27
Minimum	-0.05029	-0.01655	-0.02321	-0.00793	-18058.8
Std. Dev.	0.027138	0.006239	0.008525	0.001907	9391.482
Skewness	0.413441	-0.3023	-0.31197	-1.55544	-0.46969
Kurtosis	2.695157	2.526386	2.634583	7.260148	3.405607
Observations	96	96	96	96	96

Note: D denotes first difference; LXEU is log dollar/euro exchange rate; M2_EU is US-euro area M2 log difference; Y_EU is US-euro area industrial production log difference; I_EU is US-euro area overnight interest differential, in decimal form. Z1EU is order flow; Order flow variables here expressed in trillions of USD per month.

Table A2: Summary Statistics for Dollar/Yen

Sample: 1999M01 2007M01	DLXJP	DM2_JP	DY_JP	DI_JP	Z1JP
Mean	-0.00053	0.003197	1.66E-05	5.71E-05	-13227.2
Median	-0.00215	0.002828	0.000868	9.00E-05	-13359
Maximum	0.051271	0.017703	0.045435	0.00266	5844
Minimum	-0.06808	-0.00706	-0.03498	-0.00589	-32780
Std. Dev.	0.02504	0.004129	0.012944	0.0019	8208.162
Skewness	-0.06316	0.513087	0.238788	-1.33065	-0.02836
Kurtosis	2.865523	4.148955	4.003145	4.863387	2.744249
Observations	97	97	97	97	97

Note: D denotes first difference; LXJP is log dollar/yen exchange rate; M2_JP is US-Japan area M2 log difference; Y_JP is US-Japan industrial production log difference; I_JP is US-Japan overnight interest differential, in decimal form. Z1JP is order flow; Order flow variables here expressed in trillions of USD per month.

For each variable EU, denotes Euro Area, and JP denotes Japan, relative to the United States variable. LX## is the log exchange rate, M2_## is the relative log M2 money stock, Y_## is the relative log industrial production, I_## is the relative short term interest rate, Z1## is order flow, and CUMZ1## is cumulated order flow.

Tables A3 and A4 report unit root tests for the variables and their first differences.

Table A3: Unit Root Tests for Dollar/Euro Variables

	LXEU	M2_EU	Y_EU	I_EU	CUMZ1EU
	Levels				
ERS	-1.1623	-0.6522	-1.5631	-1.6081	0.2052
Lag	0	0	3	3	1
	First Differences				
ERS	**-7.6123**	**-6.9473**	**-4.4548**	-2.5583	**-6.9923**
Lag	0	0	2	2	0

Notes: Elliot-Rothenberg-Stock DF-GLS test statistics, allowing for constant, trend. Lag length selected using Schwartz Bayesian Criterion, allowing up to maximum 11 lags. **Bold face** denotes significant at 10% msl. Critical values are *(**)[***] for -2.752, (-3.043) [-3.595].

Table A4: Unit Root Tests for Dollar/Yen Variables

	LXJP	M2_JP	Y_JP	I_JP	CUMZ1JP
	Levels				
ERS	-1.8134	-1.8644	-1.9935	-0.94	-1.1361
Lag	0	0	1	1	0
	First Differences				
ERS	**-6.0799**	**-5.2745**	**-14.2133**	**-4.2849**	**-8.8864**
Lag	0	1	0	0	0

Notes: Elliot-Rothenberg-Stock DF-GLS test statistics, allowing for constant, trend. Lag length selected using Schwartz Bayesian Criterion, allowing up to maximum 11 lags. **Bold face** denotes significant at 10% msl. Critical values are *(**)[***] for -2.752, (-3.043) [-3.595].

Theoretical Appendix

Let the utility function be the following special case of a CES function:

$$E_0 \sum_{t=0}^{\infty} \delta^t \frac{\left[\left(C_t^j\right)^{\frac{\theta-1}{\theta}} + e^{\frac{\xi_t^j}{\theta}} \left(\frac{M_t^j}{P_t^j} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}}{\frac{\theta}{\theta-1}} \tag{3}$$

Where $j = H, F$ for home and foreign respectively; C_t^j is consumption at time t; M_t^j is nominal money balances and P_t^j is the price of C_t^j. θ, δ and ξ_t^j are parameters. The CES parameter, θ, and the discount rate, δ, are common knowledge but the parameter governing the demand for money is idiosyncratic and follows a unit root process as follows:

$$\xi_t^j = \xi_{t-1}^j + \varepsilon_t^j \tag{4}$$

Where ε_t^j is an i.i.d. random error with the property that $Cov\left(\varepsilon_r^H, \varepsilon_s^F\right) = 0 \quad \forall r, s$.

The idea that preference shocks can used to explain asset pricing is not eccentric. This is the main concept behind Campbell and Cochrane (1999) which has already been applied to an exchange rate setting by Moore and Roche (2010) as well as Verdelhan (2010).

Equation (3) is maximised subject to the budget constraint:

$$W_t^j = P_t^j C_t^j + M_t^j + \frac{B_t^j}{1 + i_t^j} \tag{5}$$

Where i_t^j is the nominal return on one period riskless bonds and B_t^j is the number of bonds held. W_t^j is wealth, the only state variable and the control variables are C_t^j, M_t^j and B_t^j ., The equation of motion for W_t^j is:

$$W_{t+1}^{j} = P_{t+1}^{j} Y_{t+1}^{j} + B_t^j + M_t^j \tag{6}$$

Where Y_t^j is labor income.

The solution to this is straightforward and the demand for money (using lowercase symbols to represent the natural log of a variable) is[20]:

$$m_t^j - p_t^j = \xi_t^j + c_t^j - \theta r_t^j \tag{7}$$

Denoting the home price of foreign currency as s_t and using PPP, $s_t = p_t^H - p_t^F$, we have:

$$s_t = \left[\left(m_t^H - m_t^F\right) - \left(c_t^H - c_t^F\right) + \theta\left(r_t^H - r_t^F\right)\right] - \left\{\xi_t^H - \xi_t^F\right\} \tag{8}$$

The terms in the square brackets on the right hand side of equation (8) constitute a standard way of expressing the monetary model. The novel feature is the final term in curly brackets. Assuming the substitution semi-elasticity of the demand for money, θ , is 'small', variations in velocity for each country's will be largely driven by ξ_t^j . The 'exchange rate disconnect' puzzle is here explained by instability in the demand for money itself. Since the parameters ξ_t^j (and their relation), are unknown in advance, they can only be revealed though the act of trading itself i.e. through foreign exchange order flow.

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[20] In equations (7) and (8), $r_t^j = Log\left(\dfrac{i_t^j}{1+i_t^j}\right)$.

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Table 1: Evans-Lyons specification, 1999M02-2007M01

coefficient	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	USD/EUR				USD/JPY			
constant	0.003	**-0.012**	**-0.009**	**-0.012**	0.005	**0.023**	**0.030**	**0.024**
	(0.003)	(0.005)	(0.005)	(0.005)	(0.006)	(0.004)	(0.007)	(0.004)
Int. diff.	**-0.410**		-0.270		-0.172		-0.186	
	(0.169)		(0.182)		(0.147)		(0.145)	
OF		**1.179**	**1.080**	**1.182**		**1.799**	**1.807**	**1.857**
		(0.333)	(0.333)	(0.332)		(0.301)	(0.312)	(0.296)
Δ(Int. diff.)				0.590				1.308
				(0.988)				1.099
adj.R sq.	0.05	0.16	0.17	0.15	0.01	0.34	0.35	0.34
N	96	96	96	96	96	96	96	96

Notes: Dependent variable: First log difference of exchange rate, dollars per foreign currency unit. OLS regression coefficients (Newey-West robust standard errors in parentheses). **Bold face** denotes coefficients significant at the 10% marginal significance level. “Int. diff.” is the money market interest differential, in decimal form, OF is net order flow measured in trillions of USD.

Table 2.1: Johansen Cointegration Test Results, 1999M04-2007M01

		[1]	[2]	[3]	[4]	[5]	[6]
		Monetary Fundamentals			Hybrid		
USD/EUR	asy	0,0	***0,0***	0,0	***3,1***	3,0	3,0
	fs	0,0	***0,0***	0,0	***1,0***	0,0	1,0
USD/JPY	asy	2,2	0,1	***0,0***	2,2	***0,1***	0,0
	fs	1,2	0,0	***0,0***	1,1	***0,0***	0,0

Notes: Implied number of cointegrating vectors using Trace, Maximal Eigenvalue statistics and 1% marginal significance level. "Asy" ("fs") denotes number of cointegrating vectors using asymptotic (finite sample) critical values (Cheung and Lai, 1993). Columns [1] and [4] indicate a constant is allowed in the cointegrating equation and none in the VAR; columns [2] and [5] indicate a constant is allowed in the cointegrating equation and in the VAR; columns [3] and [6] indicate an intercept and trend is allowed in the cointegrating equation and a constant in the VAR. "Monetary fundamentals" include the exchange rate, money, income, and interest differentials. "Hybrid" includes the exchange rate, money, income and interest differentials, and cumulative order flow. ***Bold italics*** denote the specification with the lowest Akaike Information Criterion for the single cointegrating vector case. All results pertain to specifications allowing for 3 lags in the levels-VAR specification.

Table 2.2: Tests for weak exogeneity of order flow

		[4]	[5]	[6]
			Hybrid	
USD/EUR	Chi-Sq	3.465	0.481	0.041
	p-val.	0.063	0.488	0.840
USD/JPY	Chi-Sq	3.857	3.879	1.260
	p-val.	0.050	0,049	0.262

Notes: For an explanation of the three specifications [4], [5] and [6], see the notes to Table 2.1. Likelihood ratio test statistic for restriction that order flow does not respond to disequilibrium, distributed Chi-squared. [p-value for restriction α=0, in brackets].

Table 2.3: Tests for weak exogeneity of order flow, adjusted statistics

		[4]	[5]	[6]
			Hybrid	
USD/EUR	Chi-Sq	2.581	0.358	0.031
	p-val.	0.108	0.5496	0.860
USD/JPY	Chi-Sq	2.873	2.900	0.939
	p-val.	0.090	0,089	0.333

Notes: For an explanation of the three specifications [4], [5] and [6], see the notes to Table 2.1. Likelihood ratio test statistic for restriction that order flow does not respond to disequilibrium, adjusted for small sample (Bruggeman, 2002), distributed Chi-squared. [p-value for restriction α=0, in brackets].

Table 3: USD/EUR Monetary/Order Flow Hybrid Exchange Rate Regression Results, 1999M04-2007M01

coefficient	[1]	[2]	[3]	[4]
Error correction term	-0.059	-0.046	**-0.085**	**-0.083**
	(0.038)	(0.029)	(0.034)	(0.036)
OF		**1.889**	**1.873**	**1.802**
		(0.351)	(0.320)	(0.324)
lag OF				**0.637**
				(0.429)
2nd lag OF				0.571†
				(0.297)
Long Run Coeffs.				
lag money	**-3.772**	**-3.772**	-0.629	-0.629
	(0.723)	(0.723)	(1.413)	(1.413)
lag income	**5.558**	**5.558**	**5.160**	**5.160**
	(2.734)	(2.734)	(2.149)	(2.149)
lag int rate	**-7.835**	**-7.835**	-3.220	-3.220
	(3.013)	(3.013)	(2.930)	(2.930)
lag cumulative OF			**0.306**	**0.306**
			(0.093)	(0.093)
adj.R sq.	0.023	0.341	0.365	0.381
SER	0.027	0.022	0.022	0.021
N	94	94	94	94
Q(6)	2.9751	3.9282	3.1184	1.5985
	[0.812]	[0.686]	[0.794]	[0.953]
Q(12)	4.9065	6.2252	7.1515	4.5493
	[0.961]	[0.904]	[0.847]	[0.971]
LM(6)	0.7687	1.4496	1.0080	0.5217
	[0.597]	[0.208]	[0.427]	[0.790]

Notes: Dependent variable: First log difference of exchange rate, dollars per foreign currency unit. Estimates from error correction model, estimated using nonlinear least squares, (Newey-West robust standard error in parentheses), except for lagged long run coefficients, which are estimated used DOLS(2,2), using Bartlett kernel, and Newey-West bandwidth set to 4. Coefficients for first difference terms for monetary fundamentals not reported. OF is order flow measured in trillions of USD. Adj-R sq., SER, and serial correlation diagnostics for error correction regression. Q(6) and Q(12) are Box Q-statistics for test of serial correlation of order 6 and 12, respectively. LM(6) is the Breusch-Godfrey LM test statistics for serial correlation of order 6. [p-values in brackets]. **Bold face** denotes significance at 10% msl.

Table 4: USD/JPY Monetary/Order Flow Hybrid Exchange Rate Regression Results, 1999M04-2007M01

coefficient	[1]	[2]	[3]	[4]
Error correction term	**-0.210**	**-0.155**	**-0.155**	**-0.154**
	(0.054)	(0.044)	(0.046)	(0.046)
OF		**2.100**	**2.104**	**2.110**
		(0.252)	(0.252)	(0.259)
lag OF				-0.129
				(0.311)
2nd lag OF				-0.140
				(0.444)
Long Run Coeffs.				
lag money	-0.110	-0.110	0.077	0.077
	(0.099)	(0.099)	(1.747)	(1.747)
lag income	**-1.864**	**-1.864**	**-1.876**	**-1.876**
	(0.523)	(0.523)	(0.550)	(0.550)
lag int rate	-0.511	-0.511	-0.230	-0.230
	(0.539)	(0.539)	(1.241)	(1.241)
lag cumulative OF			0.054	0.054
			(0.426)	(0.426)
adj.R sq.	0.169	0.570	0.561	0.556
SER	0.023	0.017	0.017	0.017
N	94	94	94	94
Q(6)	4.2276	0.9741	1.6187	1.6120
	[0.646]	[0.987]	[0.951]	[0.952]
Q(12)	8.6855	9.1572	9.9178	9.6516
	[0.730]	[0.689]	[0.623]	[0.646]
LM(6)	2.0609	0.1653	0.4016	0.4828
	[0.068]	[0.985]	[0.876]	[0.819]

Notes: Dependent variable: First log difference of exchange rate, dollars per foreign currency unit. Estimates from error correction model, estimated using nonlinear least squares, (Newey-West robust standard error in parentheses), except for lagged long run coefficients, which are estimated used DOLS(2,2), using Bartlett kernel, and Newey-West bandwidth set to 4. Coefficients for first difference terms for monetary fundamentals not reported. OF is order flow measured in trillions of USD. Adj-R sq., SER, and serial correlation diagnostics for error correction regression. Q(6) and Q(12) are Box Q-statistics for test of serial correlation of order 6 and 12, respectively. LM(6) is the Breusch-Godfrey LM test statistics for serial correlation of order 6. [p-values in brackets]. **Bold face** denotes significance at 10% msl.

Table 5.1: USD/EUR Out of Sample Forecasting Performance, 2004M02-07M01

model	statistic	1 month	3 month	6 month
random walk	mean error	-0.0012	-0.0053	-0.0106
	std error	0.0040	0.0113	0.0198
monetary	mean error	-0.0166***	-0.0431***	-0.0945***
	std error	0.0062	0.0142	0.0276
	Theil	1.6185	1.6161	2.0532
	Clark-West	-0.5006	-0.0967	-0.1369
hybrid	mean error	0.0010	0.0018	0.0027
	std error	0.0048	0.0107	0.0185
	Theil	1.0649	0.9423	0.9517
	Clark-West	0.4114	0.4244	0.1151
Evans-Lyons	mean error	-0.0101	-0.0243*	-0.0616***
	std error	0.0073	0.0145	0.0212
	Theil	1.3993	1.3365	1.4834
	Clark-West	-1.1979	-1.2973	-1.9597**

Notes: Mean error for out-of-sample forecasting. Newey-West robust standard errors. ***(**) denotes significance at 1%(5%) marginal significance level. Theil U-statistic is the ratio of the model RMSE relative to random walk RMSE. A U-statistic > 1 indicates the model performs worse than a random walk. Clark-West is the Clark-West statistic distributed Normal (0,1). CW statistic > 0 indicates the alternative model outperforms a random walk.

Table 5.2: USD/JPY Out of Sample Forecasting Performance, 2004M02-07M01

model	statistic	1 month	3 month	6 month
random walk	mean error	0.0046	0.0107	0.0184
	std error	0.0035	0.0087	0.0149
monetary	mean error	0.0138***	0.0301**	0.0474***
	std error	0.0044	0.0085	0.0157
	Theil	1.2714	1.2814	1.3380
	Clark-West	1.1803	0.5100	0.1645
hybrid	mean error	-0.0012	0.0003	0.0059
	std error	0.0065	0.0141	0.0276
	Theil	1.1191	1.3607	1.6261
	Clark-West	0.0355	0.2832	0.4513
Evans-Lyons	mean error	0.0011	0.0037	0.0054
	std error	0.0041	0.0086	0.0151
	Theil	0.7891	0.8059	0.8776
	Clark-West	0.5583	0.7010	0.6301

Notes: Mean error for out-of-sample forecasting. Newey-West robust standard errors. ***(**) denotes significance at 1%(5%) marginal significance level. Theil U-statistic is the ratio of the model RMSE relative to random walk RMSE. A U-statistic > 1 indicates the model performs worse than a random walk. Clark-West is the Clark-West statistic distributed Normal (0,1). CW statistic > 0 indicates the alternative model outperforms a random walk.

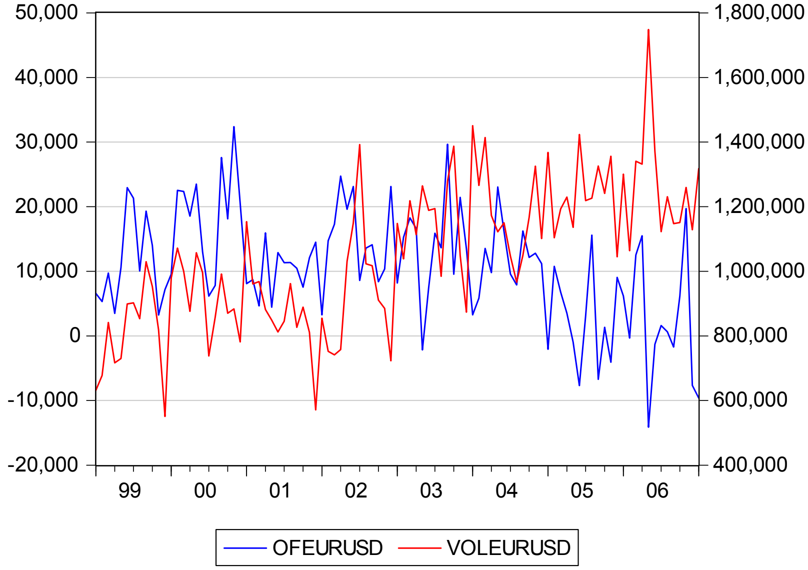

Figure 1: EUR/USD monthly order flow and order flow volume, in millions of euros. Order flow, left axis; order flow volume, right axis.

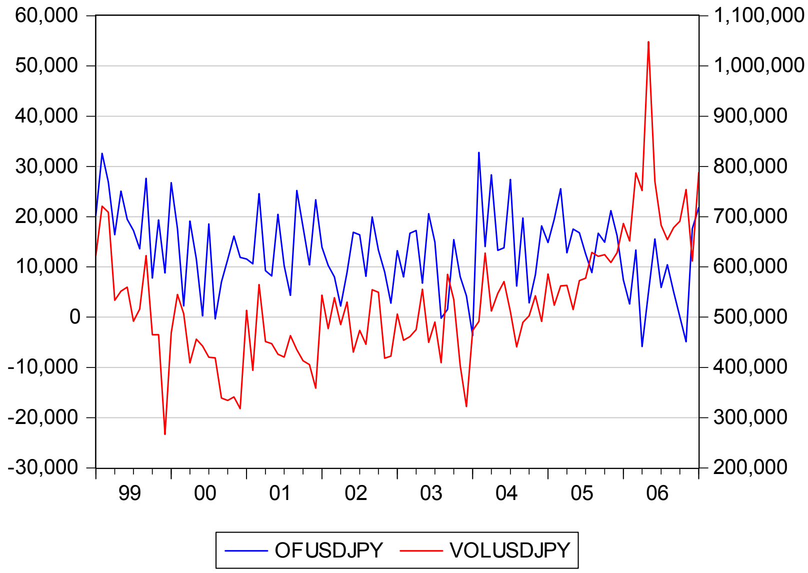

Figure 2: USD/JPY monthly order flow and order flow volume, in millions of dollars. Order flow, left axis; order flow volume, right axis.

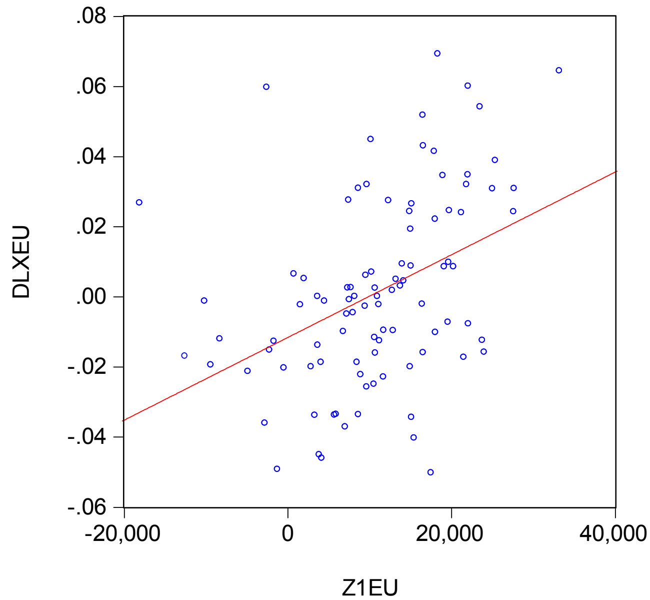

Figure 3: First difference of log USD/EUR exchange rate and monthly net order flow in millions of USD (purchases of euros)

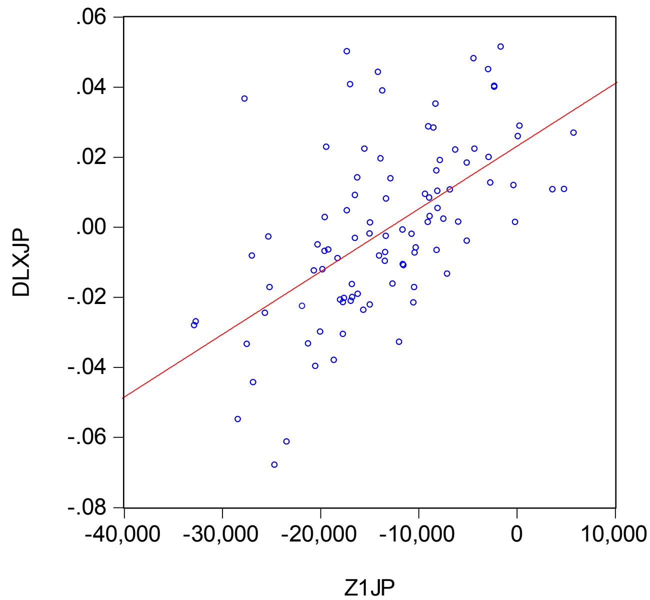

Figure 4: First difference of log USD/JPY exchange rate and monthly net order flow in millions of USD (purchases of yen)

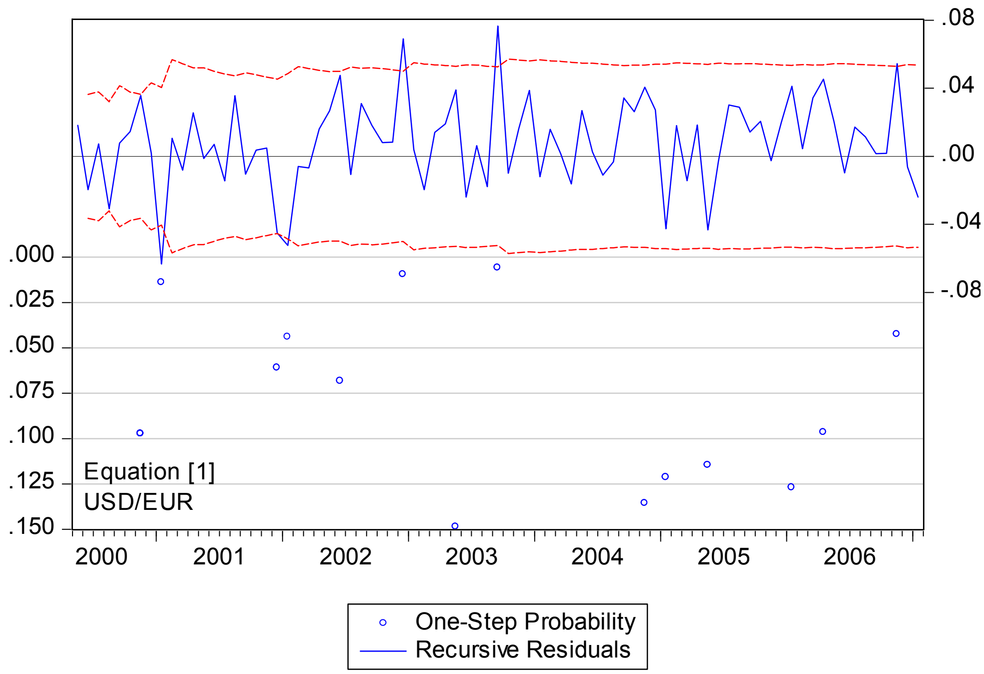

Figure 5: Recursive one step ahead recursive residuals for monetary model, USD/EUR.

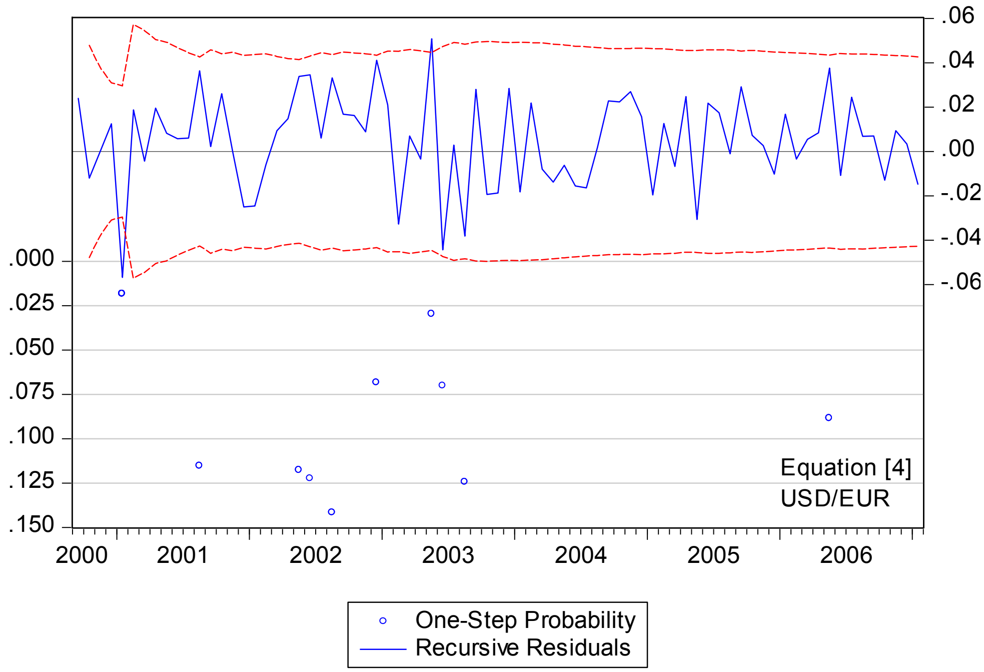

Figure 6: Recursive one step ahead recursive residuals for hybrid model, USD/EUR.

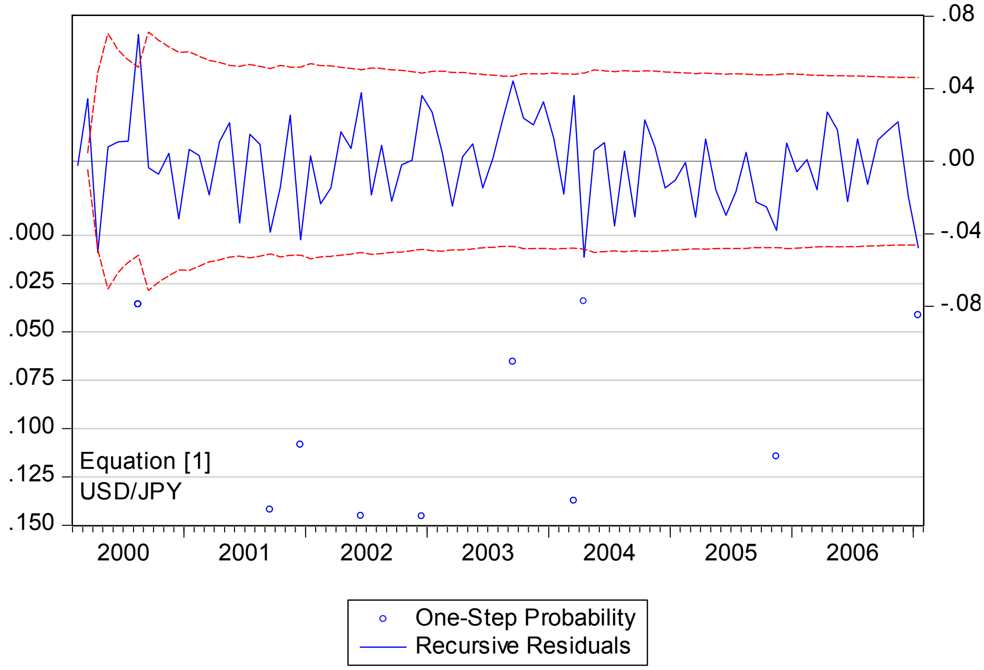

Figure 7: Recursive one step ahead recursive residuals for monetary model, USD/JPY.

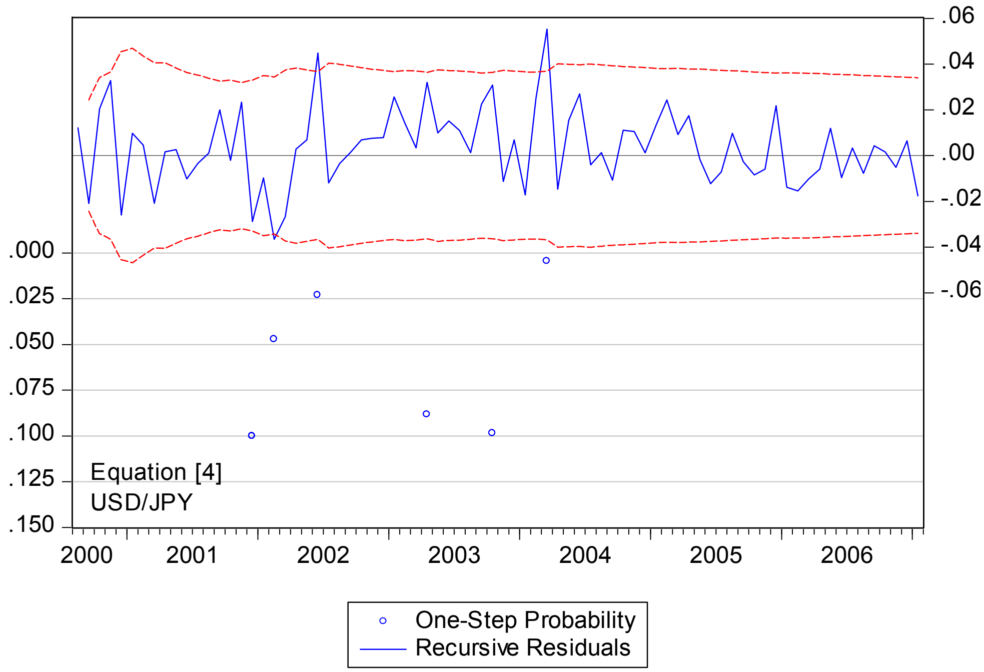

Figure 8: Recursive one step ahead recursive residuals for hybrid model, USD/JPY.

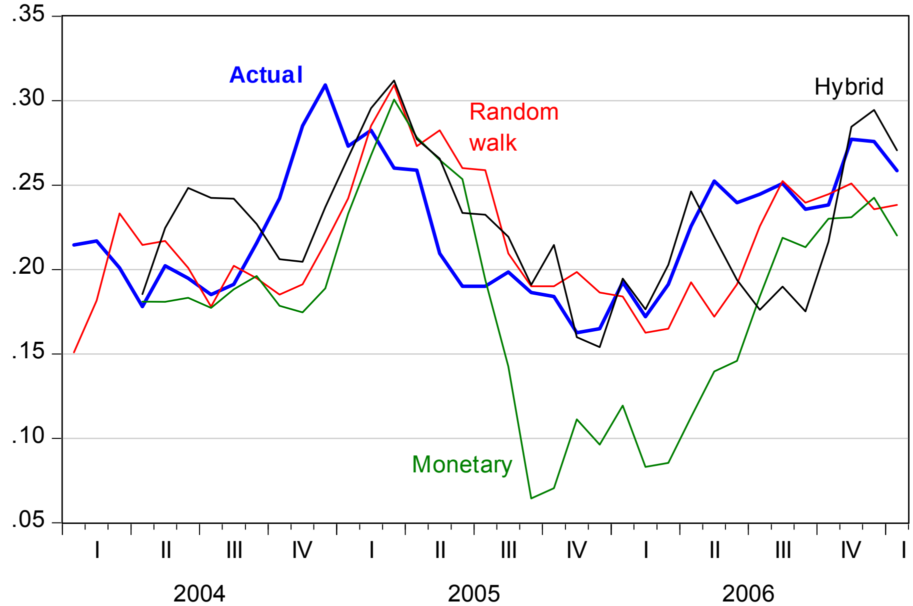

Figure 9: Out-of-sample forecasts of USD/EUR, 3 month horizon

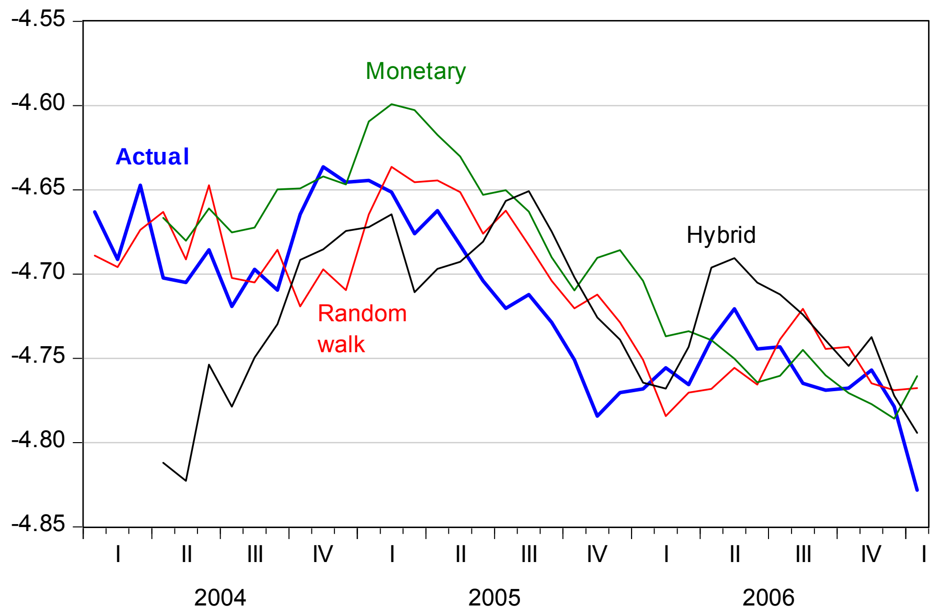

Figure 10: Out-of-sample forecasts of USD/JPY, 3 month horizon