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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. It argues 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 out of sample forecasting improvement over the basic macroeconomic and random walk specifications.

JEL classification: D82; E41; F31; F47
Keywords: Exchange rates; Monetary model; Order flow; Microstructure; Forecasting performance

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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

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[1] See an extended analysis on bilateral exchange rates using this framework in Alquist and Chinn (2008).

exchange rate movements. In a series of papers Evans and Lyons[2] (2002, 2005, 2008), have shown that order flow contemporaneously explains a significant proportion of the high-frequency variation in exchange rates. Though their theoretical framework is also very convincing, it has been difficult to evaluate its merit at standard macroeconomic frequencies because of the proprietary nature of the data. This paper fills this gap as it presents results on almost 100 monthly observations of order flow nested within a conventional framework[3].

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 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 central assertion of the paper is that at least one of the parameters of the utility function is privately known and can only be revealed through trading. To fix ideas, consider the following variation on the standard monetary model: Let the utility function be the following special case of a CES function:

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[2] These are just examples of their work. For a fuller account, see http://www9.georgetown.edu/faculty/evansm1/Home%20page.htm

[3] Berger et al. (2008) 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.

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

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 β_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:

$$\beta_t^j = \beta_{t-1}^j + \varepsilon_t^j \tag{2}$$

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 (2002, 2005, 2008, 2009) as well as Verdelhan (2008).

Equation (1)~~(1)(1)~~ is maximised subject to the budget constraint:

$$W_t^j = P_t^j C_t^j + M_t^j + \frac{B_t^j}{1 + i_t^j} \tag{3}$$

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:

$$W_{t+1}^j = P_{t+1}^j Y_{t+1}^j + B_t^j + M_t^j \tag{4}$$

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[4]:

$$m_t^j - p_t^j = \beta_t^j + c_t^j - \theta r_t^j \tag{5}$$

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

$$s_t = \left[\left(m_t^H - m_t^F\right) - \left(c_t^H - c_t^F\right) + \theta\left(r_t^H - r_t^F\right)\right] - \left\{\beta_t^H - \beta_t^F\right\} \tag{6}$$

The terms in the square brackets on the right hand side of equation (6)~~(6)(6)~~ 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 β_t^j. The 'exchange rate disconnect' puzzle is here explained by instability in the demand for money itself. Since the parameters β_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. 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 rate 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 (2)~~(2)(2)~~, are captured by cumulative foreign exchange order flow. Bjonnes and Rime (2005) and Killeen, Lyons and Moore (2006) provide evidence that exchange rate levels and cumulative

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[4] In equations (5)~~(5)(5)~~ and (6)~~(6)(6)~~, $r_t^j = Log\left(\frac{i_t^j}{1+i_t^j}\right)$.

order flow are cointegrated in high frequency data. If equation (6) 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.[5]

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.

The most novel aspect of the data is the long span of order flow data. That data was obtained from Electronic Broking Services (EBS). This is 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.[6] In some of the robustness checks, the order flow variables are

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[5] In the subsequent analysis, we allow for sticky prices, so that inflation enters in separately from interest rates. This specification is sometimes termed the "sticky price monetary model" or "real interest differential model".

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

normalized by volume (also adjusted into dollar terms). The untransformed order flow and order flow volume data are depicted in Figures 1 and 2.

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), income is industrial production, inflation is 1 month log-differenced CPI, annualized.[7]

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

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[7] As noted in Section 6, we also check to see if the results are robust to use of M1 as a money variable, different inflation rates (3 month or twelve month differences of log-CPI), or real GDP (at the quarterly frequency). M1 and real GDP are also drawn from *IFS*.

graphs, the exchange rates are defined (dollar/euro and dollar/yen) and order flow transformed so that the implied coefficient is positive[8].

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 (7).

$$\Delta s_t = \beta_0 + \beta_1 (i_t - i_t^*) + \beta_2 (of_t) + \beta_3 (\Delta of_t) + u_t \tag{7}$$

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[9]) when the order flow variables are omitted, and then only in the dollar/euro case. Inclusion of the order flow variables reduce 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.

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[8] 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.

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

a) The Johansen Procedure is applied to test for cointegration between the exchange rates, cumulative order flow and conventional monetary model fundamentals (here taken to be the sticky-price model determinants – money, income, interest and inflation rates).
b) The implied error correction model is estimated.
c) Out of sample forecasts for different models are compared.

5.1 Testing for Cointegration

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 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 opt to 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 multiple cointegrating vectors. Table 2 reports the results of these tests.

The first three columns of Table 2 pertain to specifications including only sticky 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., "2,1" indicates the trace and maximal eigenvalue statistics indicate 2 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 confirms that that it is easy to find evidence of cointegration, even using the 1% marginal significance level.[10] The specification selected by the AIC for the monetary model is one that omits a constant in the VAR equation for the dollar/euro, and one including a constant in both the cointegrating vector and the VAR for the dollar/yen. In the case of the hybrid model, the AIC indicate the presence

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[10] Using the 5% significance level implies one cointegrating vector for the monetary model, but potentially multiple cointegrating vectors for the euro/dollar rate, and asymptotic critical values. Using the finite sample critical values, the evidence is in favour of a single cointegrating vector, with the exception of the euro/dollar rate, wherein the trace statistic indicates 3, and the maximal eigenvalue 1.

of a constant in both the cointegrating relation and the VAR. Using the finite sample critical values does not change the results appreciably.

The resulting conclusions are highly suggestive that there is one cointegrating vector in almost all cases. Hence, we proceed in our analysis assuming only one cointegrating vector.[11] 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.

$$\Delta s_t = \Delta X_{t-1}\Gamma + \rho_1 \Delta s_{t-1} + \rho_2 \Delta s_{t-1} + \varphi(s_{t-1} - X_{t-1}B) + v_t \tag{8}$$

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.

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

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[11] 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.

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 and inflation variables omitted. In order to maintain consistency of specifications across models, we opt to 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.[12] Note that the error correction term is in all cases negative and statistically significant. This implies that the exchange rate reverts to some sort of mean, confirming some form of long run linear relationship.

Turning first to Table 3, columns [1]-[4], 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 points in the wrong direction, and significantly so. 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 0.33.

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[12] 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, especially when inflation is measured as the three month change.

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, the monetary fundamentals are all now non-significant, while lagged cumulative order flow is significant.

That 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 (34%). Finally, allowing the inclusion of two lags of order flow further raises the proportion of variation explained further (37%), although the first lag is not significant.

Turning to the dollar/yen results in Table 4, one finds that in column one, many significant coefficients, although the money variable is again wrong-signed. The equation does not explain a large proportion of variation, though. It is only by the inclusion of the contemporaneous order flow variable does the fit improve substantially (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 test statistics for the hybrid model, it is interesting that cumulative order flow fails to exhibit statistical significance (the point estimate is of the same magnitude of that in the dollar/euro equation).

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 enters 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
- 3 month vs. 1 month 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

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[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 cumulated order flow.

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.

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 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. Out-of-sample Forecasting

As is well known, 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, estimates are applied 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.[14] 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.

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[14] 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.

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.

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 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.[15]

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 2.9, 2.8 and 4.0 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: 1.2, 0.9, and 0.9. The relative performance of these forecasts (random walk, monetary, hybrid) are shown in Figures 5 and 6 for the dollar/euro exchange rate.

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 an improvement vis à vis the random walk benchmark. Inspection of the Clark-West statistic indicates that the hybrid model never outperforms the random walk at conventional significance levels (although it is significant at the 17% level at the 3 and 6 month horizons). The Evans-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 the 1

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[15] The particular specification we use conforms to columns [3] and [7] in Table 1.

month horizon, and ties at the 3 month horizon.[16] However, the Evans-Lyons specification in this case does best, with the lowest Theil statistic at horizons at all horizons. Interestingly, all the structural models outperform the random walk benchmark – at least after accounting for estimation error – except for the monetary model at 6 month horizon. 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 provides 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 (1)~~(1)(1)~~

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[16] Although the monetary model consistently underperforms, in the sense that it consistently underpredicts the USD/JPY exchange rate.

to (4)~~(4)(4)~~ is that consumption in country j also depends on the unit root parameter β_t^j. This means that the international consumption differential depends on $\beta_t^H - \beta_t^F$ 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, while inflation is 1 month log-differenced CPI in the basic regressions. Specifications were also estimated using 3 month and 12 month log-differenced CPI as a measure of inflation. Money, industrial production and CPIs 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.

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.

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

	LXEU	M2_EU	Y_EU	I_EU	PI1_EU	Z1EU	CUMZ1EU
Mean	0.077	-0.018	-0.015	0.005	0.006	0.011	0.622
Median	0.086	-0.007	-0.017	0.005	0.005	0.011	0.633
Maximum	0.309	0.016	0.019	0.028	0.143	0.033	1.079
Minimum	-0.172	-0.102	-0.053	-0.020	-0.102	-0.018	0.008
Std. Dev.	0.143	0.029	0.018	0.016	0.043	0.009	0.344
Skewness	-0.196	-1.370	-0.018	-0.042	0.351	-0.461	-0.208
Kurtosis	1.647	3.869	1.956	1.328	4.612	3.426	1.684
Observations	97	97	97	97	97	97	97

Note: Order flow variables here expressed in trillions of USD per month.

Table A2: Summary Statistics for Dollar/Yen

Sample: 1999M01 2007M01

	LXJP	M2_JP	Y_JP	I_JP	PI1_JP	Z1JP	CUMZ1JP
Mean	-4.743	-4.774	0.015	0.034	0.030	-0.013	-0.701
Median	-4.755	-4.759	0.013	0.036	0.035	-0.013	-0.697
Maximum	-4.627	-4.623	0.065	0.065	0.128	0.006	-0.020
Minimum	-4.897	-4.933	-0.027	0.010	-0.062	-0.033	-1.283
Std. Dev.	0.063	0.093	0.020	0.018	0.045	0.008	0.362
Skewness	-0.189	-0.217	0.464	0.068	-0.257	-0.028	0.027
Kurtosis	2.473	1.756	2.972	1.512	2.457	2.744	1.839
Observations	97	97	97	97	97	97	97

Note: 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, PI1_## is the relative one month annualized inflation rate, Z1## is order flow, and CUMZ1## is cumulated order flow.

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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**	0.003	0.005	**0.023**	**0.030**	0.005
	0.003	0.005	0.005	0.003	0.006	0.004	0.007	0.006
Int. diff.	**-0.410**		-0.270	**-0.405**	-0.172		-0.186	-0.170
	0.169		0.182	0.171	0.147		0.145	0.140
OF		**1.179**	**1.080**			**1.799**	**1.807**	
		0.333	0.333			0.301	0.312	
Δ OF				0.392				**1.114**
				0.258				0.156
adj.R sq.	0.05	0.16	0.17	0.06	0.01	0.34	0.35	0.24
N	96	96	96	96	96	96	96	96

Notes: Top entry is the OLS regression coefficient while the bottom entry is the Newey-West robust standard error. **Bold face** denotes coefficients significant at the 10% marginal significance level. Int. Diff. is the money market interest differential, OF is order flow in trillions of USD.

Table 2: Johansen Cointegration Test Results, 1999M04-2007M01

		[1]	[2]	[3]	[4]	[5]	[6]
		Monetary Fundamentals			Hybrid		
USD/EUR	asy	***1,1***	1,1	1,1	2,2	***2,1***	2,1
	fs	***1,1***	1,1	1,1	2,2	***1,1***	1,1
USD/JPY	asy	2,2	1,1	***1,1***	2,2	***1,1***	1,1
	fs	2,2	1,1	***0,1***	1,1	***0,1***	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. ***Bold italics*** denotes the trend specification with the lowest AIC for single cointegrating vector case. All results pertain to specifications allowing for 3 lags in the levels-VAR specification.

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

coefficient	[1]	[2]	[3]	[4]
Error correction term	**-0.0652**	**-0.0522**	**-0.0875**	**-0.0859**
	(0.0385)	(0.0299)	(0.0341)	(0.0363)
lag money	**-4.4418**	**-9.8273**	-3.5667	**-6.4155**
	(1.9166)	(4.3574)	(2.5037)	(3.4498)
lag income	0.2010	-9.1941	-3.0104	-7.4858
	(6.8814)	(11.2760)	(5.7884)	(8.1076)
lag int rate	-9.5746	-1.9370	0.1355	2.1832
	(7.4101)	(7.7748)	(5.0111)	(6.1952)
lag infl rate	1.0621	1.4740	0.5515	0.7311
	(2.0818)	(1.7263)	(1.0373)	(1.0612)
OF		**1.8578**	**1.8222**	**1.7748**
		(0.3604)	(0.3519)	(0.3358)
lag OF				0.6498
				(0.4285)
2nd lag OF				0.5241
				(0.2946)
lag cumulative OF			**0.3124**	0.2539
			(0.1690)	(0.1854)
adj.R sq.	0.015	0.331	0.339	0.367
N	94	94	94	94

Notes: Estimates from error correction model, estimated using nonlinear least squares, with two lags of first differences, not all of which are reported. Top entry is coefficient; HAC robust standard error in parentheses. **Bold face** denotes significance at 10% msl. Coefficients on lagged first difference terms not reported.

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

coefficient	[1]	[2]	[3]	[4]
Error correction term	**-0.201**	**-0.154**	**-0.154**	**-0.155**
	(0.057)	(0.045)	(0.046)	(0.047)
lag money	**-0.452**	**-0.772**	0.096	0.399
	(0.173)	(0.191)	(2.180)	(2.292)
lag income	**-1.127**	**-2.104**	**-2.022**	**-1.963**
	(0.675)	(0.541)	(0.572)	(0.568)
lag int rate	**-1.914**	**-3.469**	**-2.982**	-2.644
	(0.867)	(1.159)	(1.522)	(1.873)
lag infl rate	-0.448	0.102	0.117	0.135
	(0.450)	(0.364)	(0.386)	(0.373)
OF		**2.099**	**2.090**	**2.107**
		(0.269)	(0.271)	(0.275)
lag OF				-0.047
				(0.324)
2nd lag OF				-0.136
				(0.428)
lag cumulative OF			0.216	0.279
			(0.543)	(0.563)
adj.R sq.	0.167	0.570	0.565	0.554
N	94	94	94	94

Notes: Estimates from error correction model, estimated using nonlinear least squares, with two lags of first differences, not all of which are reported. Top entry is coefficient; HAC robust standard error in parentheses. **Bold face** denotes significance at 10% msl. Coefficients on lagged first difference terms not reported.

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	-0.0160***	-0.0421***	-0.0886***
	std error	0.0067	0.0151	0.0281
	Theil	2.8973	2.7908	3.9940
	Clark-West	-0.9595	0.1346	-0.0295
hybrid	mean error	0.0013	0.0035	0.0021
	std error	0.0048	0.0107	0.0180
	Theil	1.2113	0.8723	0.8542
	Clark-West	0.8236	0.9815	0.9974
Evans-Lyons	mean error	-0.0101	-0.0243*	-0.0616***
	std error	0.0073	0.0145	0.0212
	Theil	1.9581	1.7861	2.2006
	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***	0.0316***	0.0509***
	std error	0.0044	0.0083	0.0144
	Theil	1.4629	1.6501	1.7189
	Clark-West	1.1803	0.3997	-0.0428
hybrid	mean error	-0.0014	0.0001	0.0067
	std error	0.0066	0.0139	0.0269
	Theil	1.1779	1.6961	2.4177
	Clark-West	0.4594	0.6407	0.6229
Evans-Lyons	mean error	0.0011	0.0037	0.0054
	std error	0.0041	0.0086	0.0151
	Theil	0.6226	0.6495	0.7701
	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.

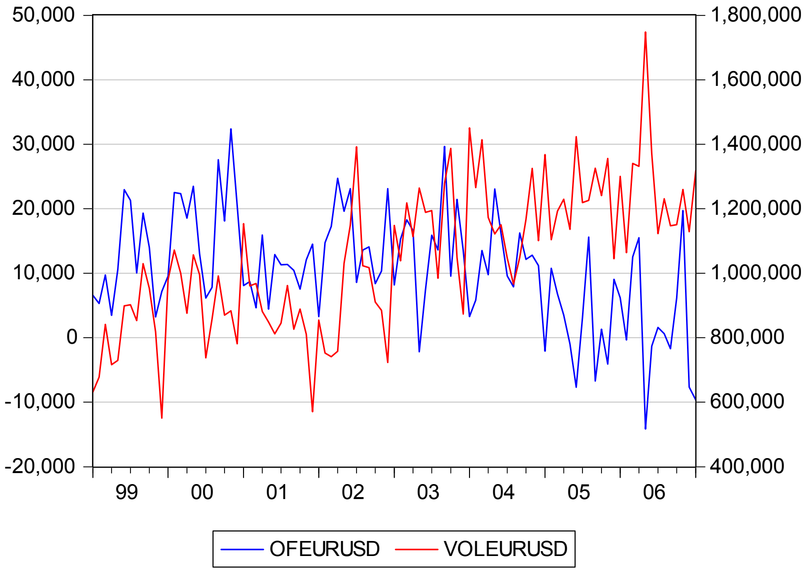

Figure 1: EUR/USD monthly order flow and order flow volume, in millions of euros.

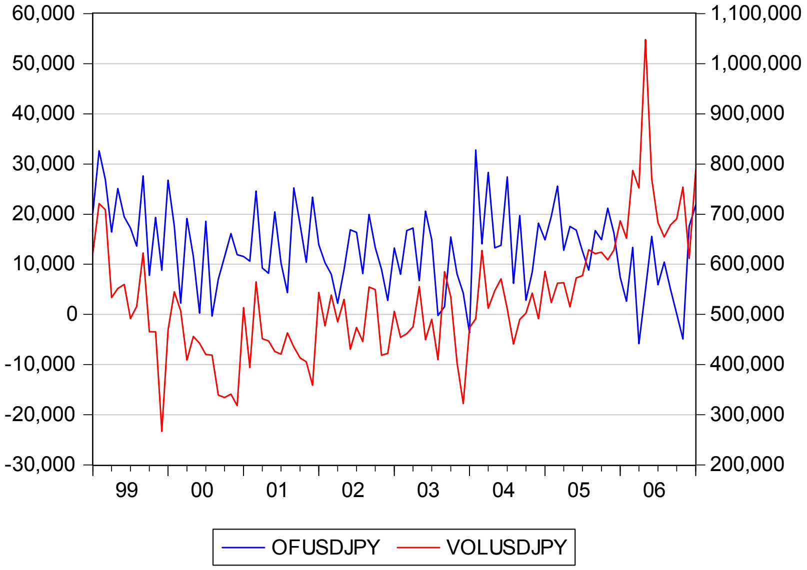

Figure 2: USD/JPY monthly order flow and order flow volume, in millions of dollars.

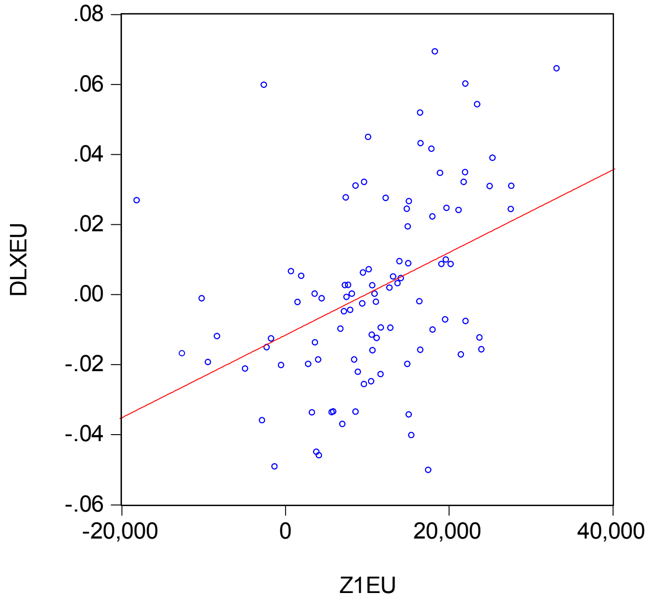

Figure 3: First difference of log USD/EUR exchange rate and monthly net order flow in millions of USD (purchases of euros)

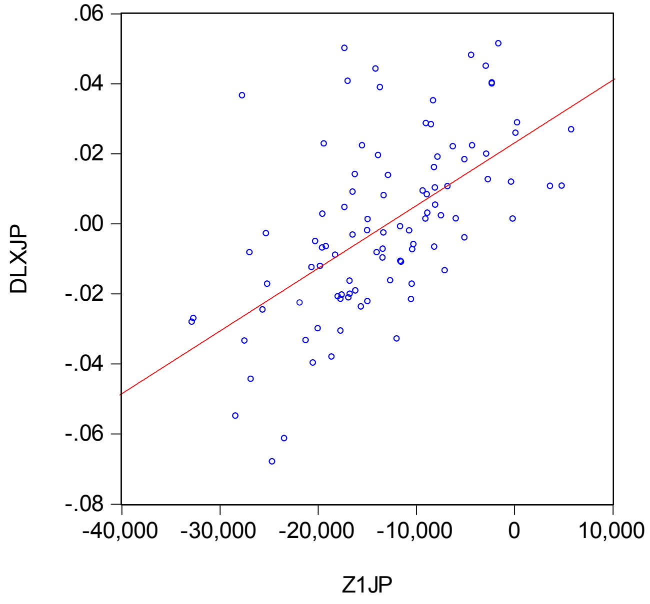

Figure 4: First difference of log USD/JPY exchange rate and monthly net order flow in millions of USD (purchases of yen)

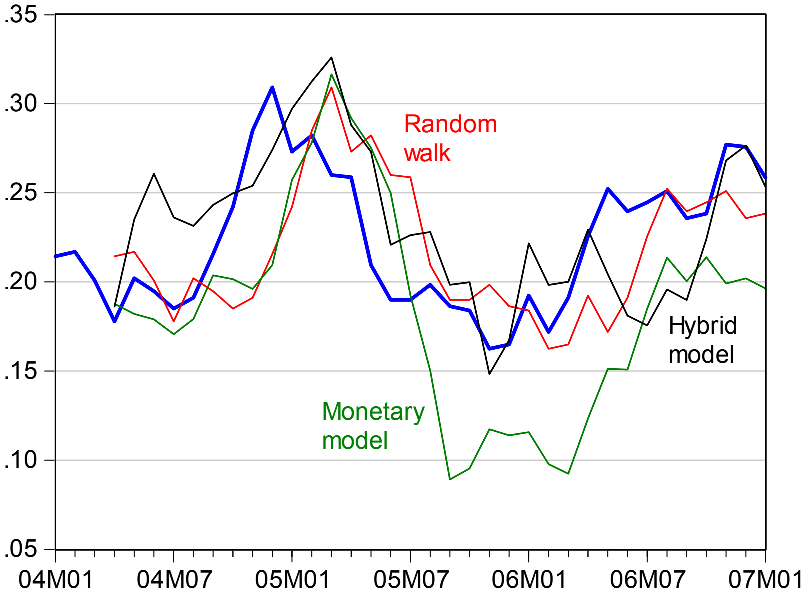

Figure 5: Out-of-sample forecasts of USD/EUR, 3 month horizon

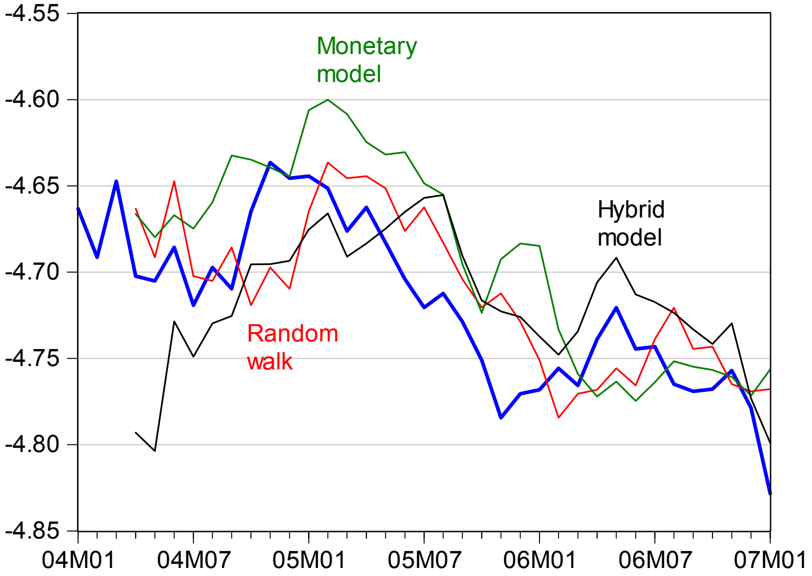

Figure 6: Out-of-sample forecasts of USD/JPY, 3 month horizon