Do Futures Lead Price Discovery in Electronic Foreign Exchange Markets?

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ABSTRACT

Using intra-day data, this paper investigates the contribution to the price discovery of Euro and Japanese Yen exchange rates in three foreign exchange markets based on electronic trading systems: the CME GLOBEX regular futures, E-mini futures, and the EBS interdealer spot market. Contrary to evidence in equity markets and more recent evidence in foreign exchange markets, the spot market is found to consistently lead the price discovery process for both currencies during the sample period. Furthermore, E-mini futures do not contribute more to the price discovery than the electronically traded regular futures.

JEL Classifications: C32, F31, G13, G14

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INTRODUCTION

Price discovery is the process through which closely related markets attempt to reach the equilibrium price. While price discovery may be considered to be immediate in frictionless Walrasian models of trading behavior which typically assume perfect competition and free entry, such assumption is deemed far from realistic in the market microstructure literature. In fact, it has been one of the most critical questions in market microstructure to investigate how prices are actually determined inside the "black box" of a security market and the process by which prices come to impound new information. In particular, the roles of spot and futures (and other derivative financial instruments) in the price discovery process have received much attention.

In the currency market, the size of the currency futures market is relatively small compared with the over-the-counter spot market. According to the 2007 BIS Triennial survey, average daily volume in exchange-traded currency products totaled 72 billion compared with 2,319 billion in over-the-counter products. Thus, "In FX, however, the futures market is much smaller than the spot market; it is unlikely that a significant share of price determination occurs there." (Lyons, 2001)

Recent evidence, however, suggests that the currency futures market might play a big role in price discovery compared with the spot market. Using interdealer direct spot transactions market data from the Reuters Dealing 2000-1 system and the futures data from the regular floors trading on the CME for three months in 1996, Rosenberg and Traub (2007) found the currency futures market can have information shares averaging between 80 and 90 percent based on the methodology in Hasbrouck (1995) and Gonzalo and Granger (1995). The currencies they examined are the Deutsche Mark, the British Pound, the Japanese Yen and the Swiss Franc.[1] On the other hand, Tse, Xiang, and Fung (2006), using both the

GLOBEX electronic and floor-trading futures data at the CME, and the CMC foreign exchange retail-trading data for three months in 2004, reported that the GLOBEX electronic futures provide the most price discovery in the Euro, and the on-line retail-trading spot market provides the most price discovery in the Japanese Yen. Therefore, the results from Tse, Xiang, and Fung (2006) confirm that of Rosenberg and Traub (2007) in the case of the Euro but not for the Yen. This unsettled issue is particularly important, given the recent dramatic changes in the structure of the foreign exchange market as a whole (Rime 2003).

This paper provides a comprehensive analysis of the dynamic price discovery process in the electronic foreign exchange markets for two currency pairs, the Euro/US$ and the Yen/US$. We differ from the existing literature in the following aspects. Firstly, different from previous studies, this study uses the interdealer spot market data from the electronic brokering services (EBS) from April to July of 2005. In the spot market, most of the foreign exchange trading is concentrated in the interdealer market. This EBS dataset has several important advantages. Specifically, the EBS dataset consists of transactable quotes, as opposed to transaction prices from Reuters D2000-1 system used in previous studies (e.g., Evans, 2002; Rosenberg and Traub, 2007). Furthermore, EBS has become the major trading platform for the two most traded currency pairs, the Yen and the Euro, making the results based on this dataset a true representation of the behavior of global interdealer foreign exchange markets.[2] If the comparison between spot and futures needs to be made, the EBS data should provide the best representation for the spot market with regard to the Euro and the Yen.

Secondly, this paper examines the price discovery role of electronic-traded foreign exchange spot and futures markets. The allowance for the confounding effect of electronic trading is important as electronic trading has become a major factor in affecting the relative rate of price discovery across different markets. There is substantial empirical evidence showing that the use of electronic trading platforms facilitate price discovery more efficiently than floor trading in equity markets (e.g. Hasbrouck, 2003; Kurov and Lasser, 2004). Recently, Ates and Wang (2006) and Tse, Xiang, and Fung (2006) have demonstrated the informational dominance of the electronically traded regular futures markets over the floor traded regular futures. Nevertheless, no study has compared electronically traded foreign exchange spot and futures markets, with the noticeable exception of Tse, Xiang, and Fung (2006).

Finally, this is the first attempt to investigate the role of E-mini futures in price discovery for the Euro/US$ and the Yen/US$. The CME introduced E-mini Euro and Yen futures in October 1999. The evidence of the dominant role of E-mini futures in price discovery has been recorded from equity markets (Hasbrouck, 2003; Kurov and Lasser, 2004; Ates and Wang, 2005). However, to the best of our knowledge, no other study has explored the price discovery role of E-mini futures on foreign exchange markets.

The rest of the paper is organized as follows. Section 2 presents the data. Section 3 describes the estimation procedure and presents the results. A brief summary concludes the paper in Section 4.

DATA DESCRIPTION

The dataset consists of intraday tick by tick observations (later converted to 5-second intervals in the analysis) covering a four-month period from April 4th, 2005 until July 29th, 2005. [3] Prices are log-transformed and multiplied by a constant number ($p_t^* = \log(p_t) * 10,000$). Data were obtained for three major financial instruments (regular futures, E-mini futures and the interdealer spot market) in two currency markets (Euro/$ and yen/$). Both E-mini futures and the spot market are electronically traded while regular futures have both floor trading and electronic trading at the same time from 7:20 a.m. to 2:00

p.m., but only electronic trading in other times. In this study, however, only data from electronic trading are used.[4]

Futures Market Data

The regular and E-mini futures data are the time and sale data from the Chicago Mercantile Exchange (CME). These futures are the most actively traded FX futures in the CME. Table I provides the summary statistics for the futures contracts used in this paper. Specifically, for the regular futures contracts, they are not only traded at the CME Globex electronic market but also are traded side-by side with the floor trading using the open outcry system during the regular hours. CME E-mini Japanese Yen futures and E-mini Euro futures began trading in 1999 exclusively on CME Globex. E-mini futures contracts are sized at one-half of the regular futures contracts to make E-mini trading affordable to traders with small margin accounts.

While CME offers a forum for trading the Yen and the Euro in its FX futures markets on both its Globex electronic trading platform as well as on the trading floor, the trading hours differ across these two trading venues (see Table I). This study will only include intraday data for the period of the day when all markets are open (7:20 am to 2:00 pm). These daily samples will make it possible to analyze the price dynamics during information-intensive periods, as the data will also (at least partially) capture any information generated in the floor trading during this period.

For the futures contracts, the nearby contract is the most active contract. Therefore, only the last three full months of the life of nearby contracts are used, and they are rolled over to the next nearby contract the last day of the month prior to the expiration month. Hence, the sample period for the regular futures contracts is constructed using transaction prices from two months (April and May) of the June 2005 contract and two months (June and July) of the September 2005 contract.

The futures volume statistics in Table I show that the most frequently traded is the Euro/US$ regular futures contract. On the other hand, the Yen/US$ E-mini futures contract is far less traded than any of the other instruments. Day trading on Globex seems to be the most active of all. Night and overnight trading accounts for roughly 25% of the daily volume in all markets. Furthermore, floor trading accounts for a very small percentage of the total daily volume in these derivative markets. The information clearly suggests the attractiveness of the sample data which covers day trading in the electronic markets (GLOBEX).

Spot Market Data

The spot foreign exchange market is much less centralized than the FX futures markets. This market is best described as a decentralized multiple-dealer market. There is no physical location or exchange where dealers meet other traders, nor there is a screen that consolidates all executable quotes in the market. In this way, the spot FX market is very different from most futures markets. Dominated by interbank trading, spot currency transactions occur in the over-the-counter (OTC) markets. Cash currency trading takes place in a number of interconnected markets. On the other hand, private vendors offer electronic trading platforms and market data available for a fee. These retail markets are very accessible to small traders; however, these retail markets are different from the inter-dealer market where large traders account for most of the daily trading volumes in the currency markets. The spot currency market participants are banks, commercial companies, central banks, investments companies, and retail FX brokers. There are 3 main features that distinguish spot FX markets from other markets: a very high trading volume, interdealer trading accounts for most of the volume, and transparency is low.

The spot market data for this study were collected from one of the two leading electronic brokers of interdealer spot foreign exchange market, EBS. Although retail electronic trading in the FX spot markets has been exploding, most of the trading is concentrated in the interbank market. Currently, two electronic brokering systems are used globally for interbank spot trading, one offered by Electronic Broker System (EBS) and one offered by Reuters (Dealing 3000). The Euro/US$ and the Yen/US$ are traded primarily on EBS. Therefore, our data were collected from the leading electronic brokering system in the Euro/US$ and the Yen/US$ interbank markets, which comprise most global transactions in these two FX markets. This data provider offers a screen-based anonymous dealing service, operating during global trading hours, which supports trading in all major currencies. Each day 2,000 traders on more than 700 floors globally use this trading platform to trade an average of USD145 billion a day in spot foreign exchange transactions. The data obtained for the spot rates are the bid/ask midpoint. As mentioned in the introduction, the EBS has become the major trading platform for the two most traded currency pairs, the Yen and the Euro.

Table II reports the summary statistics of all currency markets for both exchange rates. During the 4-month period covered in the sample, trading activity in terms of price quote is significantly higher in the regular futures and spot markets. For the Euro market, the number of transactions is higher in regular futures than the number of midpoint quotes in the spot market; while for the Yen market, the number of midpoint quotes is higher in the spot market. At the first look, this result on the Euro is surprising given the general notion that the spot market is much larger than the futures market. The result is also consistent with Rosenberg and Traub (2007) who found that there are more futures trades during regular futures trading hours than that in the spot market. Moreover, we only consider regular futures trading hours on the CME Globex (8:20 a.m. to 3:00 p.m. Eastern time), and this time period does not fully overlap with some of the times of heavy volume in the spot market. On the other hand, in our data, the EBS mid-quotes between bid and ask points are used for the spot market, but actual transaction prices are used for both futures markets. Given that multiple transactions can occur at the same quote, the use of midpoint quote would imply that there are far more actual transactions in the spot markets than indicated by the number of observations on Table 2.

The higher number of daily average trades in the regular futures market does not extend to the E-mini futures market. Trading activity in the E-mini futures markets is significantly lower than either of the other two markets considered here. In particular, the Yen/US$ E-mini futures contract has a relative extreme low trading frequency with 42 trade per day on average over the sample period. Hence, the E-mini Yen futures time series is dropped from the present analysis because of the very low number of observations within a day. This low trading frequency prevents the convergence of our estimation method resulting in considerably unreliable parameter estimates and price discovery measures."

As the correlation coefficient matrix shows, the series are highly correlated. An exception is the correlation between the E-mini contract and the other two instruments in the Yen/US$ market. This correlation is particularly low, due to infrequent trading in the E-mini Yen futures market.

EMPIRICAL RESULTS

Based on the standard Augmented Dickey-Fuller unit root test, the null hypothesis of a unit root cannot be rejected for any price series under study. The Johansen (1991) cointegration test results show that the spot exchange rate, the regular futures, and the E-mini futures in the Euro/US$ markets are cointegrated with two cointegration relationships. Similarly, there is one cointegrating vector between regular futures and spot markets for the Yen/US$ series. Hence, the results confirm that prices in the two or three foreign exchange markets share one common stochastic trend or "efficient price." [5] Given these statistical results, it is appropriate to proceed with the price discovery analysis.

Two standard approaches are used to examine the relative rates of price discovery: (1) Information shares and (2) Gonzalo-Granger common factor weights. Both approaches assume that an underlying security trading in multiple markets has a common implicit efficient price. We also further supplement the analysis with the error correction adjustment approach as used in Eun and Sabherwal (2003). Also note that the paper's results reported below remain significant when other time intervals (1 second, 10 seconds, 30 seconds and 1 minute) are considered in the estimation of the model. All the estimations are conducted on daily basis and closely follow that of Hasbrouck (2003).

Information Share (IS) approach

The information share approach proposed by Hasbrouck (1995) decomposes the price series into a random walk component and a stationary component. The random-walk component represents the security's efficient price which is common to all markets, while the stationary term captures market-specific characteristics. Studying the properties of this common component is the goal of this measure. In particular, Hasbrouck (1995) decomposes the variance of the common efficient price (random walk) innovations. The portion of the variance explained by each market is called the information share of market j. The information share measures the portion of a subset of the market's information that is impounded into prices by different markets trading the same underlying security. The market with the largest information shares "leads" the other markets by reacting to new information first. If the innovations in a market drive the reaction of the other markets, then this market is informationally dominant.

The Stock and Watson (1988) common trends representation of the model is as follows:

$$p_t = p_0 + \psi\left(\sum_{i=1}^{t} \varepsilon_i\right)\iota + \Psi(L)\varepsilon_t \qquad (1)$$

where p_0 is a constant n-vector and $\Psi(L)$ is a matrix polynomial in the lag operator. More specifically, the first term on the right-hand side of equation (1) is a vector of initial values that may reflect non-stochastic differences between the price variables. The second term is the product of a scalar random walk and a unit vector, which captures the random walk component that is common to all prices (the "efficient" price). Although this component is unobservable without further identification restrictions, its innovations have the property that they are linear in the disturbances. The third term in equation (1) is a zero-mean covariance stationary process.

Define and note that ψ represents the common row vector of $\Psi(1)$. If n = 3, then

$$\mathrm{var}(\psi\varepsilon_t) = J_1^2\sigma_{11} + J_2^2\sigma_{22} + J_3^2\sigma_{33} \qquad (2)$$

where J_i are the elements in $\Psi(1)$. Each of these terms represents the contribution to the random-walk innovation from a particular market. The proportion of this for market j (for j = 1, 2, 3) relative to the total variance is defined as the market's j information share:

$$IS_j = \frac{\psi_j^2\Omega_{jj}}{\psi\Omega\psi'} \quad \text{or} \quad IS_j = \frac{J_j^2\sigma_{jj}}{J_1^2\sigma_{11} + J_2^2\sigma_{22} + J_3^2\sigma_{33}}$$

where Ω is the covariance matrix. The measure in the above equation is too restrictive since price innovations are generally correlated across markets trading the same underlying instrument. If the price innovations are correlated (i.e. $\sigma_{ij} \neq 0$ for $i \neq j$), no unique values may be found for the information shares, and triangularization of the covariance matrix may be used to establish upper and lower bounds.[6]

Therefore, when the covariance matrix Ω is not diagonal, Hasbrouck (1995) defines the information shares of the market j prices as

$$IS_j = \frac{([\psi F]_j)^2}{\psi\Omega\psi'} \qquad (3)$$

In this equation, F is the Cholesky factorization of Ω, and a lower triangular matrix such that

$\Omega = FF'$. The variance attributed to a particular market j is $([\psi F]_j)^2$ and $[\psi F]_j$ is the jth element of the row matrix ψF. The lower triangular factorization maximizes the information shares on the first price. By permuting the order of the market prices, equation (3) will provide an upper and lower bound for the information share of each market.

Table III presents estimates relating to the information shares and the correlations of the price innovations. Due to the presence of nonzero off-diagonal correlations in the innovations, only upper and lower bounds for the information shares can be established. Care must be exercised in interpreting the lower and upper bounds since they do not provide a single measure of information share. However, following Booth et al. (2002) and many others, the midpoints of lower and upper bounds can be used as a unique measure of the price discovery contribution. The information share statistics reflect the average of all daily estimates. Panel A of Table III shows that the Euro/US$ spot market contributes the most to price discovery, accounting roughly for over 60% of the information share. The other two prices share the remainder, with the regular futures accounting for 33% and the E-mini futures accounting for comparable shares on average. In the Yen/US$ market, the spot trades lead the price discovery process with roughly 75% of the information share, while the regular futures contributes only about 25% of price discovery.

The findings confirm the recent work of Tse, Xiang and Fung (2006) on Yen as they provide evidence that the Yen spot foreign exchange market dominates the futures markets in price discovery. However, the findings contradict that of Rosenberg and Traub (2007) who find regular futures contribute more to the price discovery in 1996. Also in contrast with the evidence in the equity markets, the results show that the E-mini futures do not dominate the price discovery process in foreign exchange markets. The finding may not be surprising, given relatively low number of trades on the E-mini futures market in Table II. As further pointed out by the referee, although the E-mini currency futures market is a global market,

p_t

it's rather concentrated among a few banks. Thus, there might not be many informed traders in this market.

Panel A and B in Figure 1 present the time series of the daily information shares of the three Euro/US$ instruments and the two Yen/US$ instruments respectively. The information share midpoints are shown. Despite some time variations, it is clear that the spot markets consistently dominate the futures markets over the sample period.[7] These findings hold for both currency markets. It can also be seen that in the Euro/US$ market, there is no information dominance of the E-mini futures market over the regular futures. Overall, these results provide evidence that the spot market is the major contributor to price discovery in foreign exchange markets over time.

Common factor component weight (GG) approach

Let p_t be a (n x 1) vector of I(1) price series for the same underlying security in n markets. Even though each individual price series is non-stationary, they are cointegrated with h (h = n-1 in this study) cointegrating relations. The Granger representation theorem shows that the VAR(p) with cointegrated variables can be written in its error-correction form

$$\Delta p_t = Bz_{t-1}^* + \varsigma_1 \Delta p_{t-1} + \varsigma_2 \Delta p_{t-2} + \varsigma_3 \Delta p_{t-3} + ... + \varsigma_{p-1} \Delta p_{t-p+1} + \varepsilon_t$$

Stock and Watson (1988) shows that the price vector can be decomposed into a permanent and a transitory component. Gonzalo and Granger (1995) propose an alternative decomposition of p_t where the permanent component will be a function of the current values of p_t (which differs from the Stock and Watson (1988) representation where the common trend is a function of the current and lagged values of the disturbances and therefore of p_t).[8] The vector of prices p_t is decomposed as follows,

$$p_t = F_1 f_t + F_2 \tau_t$$

where: f_t = common long memory component (vector of common stochastic trends)

τ_t = stationary component

Two conditions are imposed:

(i) f_t is an exact linear function of the current values of p_t

(ii) The transitory component, τ_t, has no permanent effect on p_t

These assumptions or conditions make it possible to identify the common factor and also make the common efficient price f_t observable (a function of the current values of the price vector). In other words, the Gonzalo-Granger approach defines the permanent component of the vector of prices p_t as a linear combination of the current values of the price vector itself, where the linear combination is given by the structure of the A_*. A_* is a matrix orthogonal to the matrix of cointegrating vectors A , and can be estimated as a matrix of (*n* - *h*) eigenvectors using the Johansen (1991) procedure. Given the nature of the Gonzalo-Granger decomposition and the following result:

$$f_t = A_*^{'} p_t$$

the A_* matrix (after normalization) becomes a natural measure of the contribution to price discovery of market *i*. The higher the weight, the larger the contribution of the market to the information impounding process is. There is no restriction in the decomposition procedure which prevents the factor weights from being negative. Since the size (not the sign) of the weights provide a measure of the market's role in the price discovery process, the weights are normalized so that they come out to be positive and the sum of these weights is equal to one,

$$\omega^{'} = (abs(A_*^{'})\iota)^{-1} abs(A_*^{'})$$

where *abs*(.) denotes the absolute value of each element in the matrix and ι is (nx1) vector of ones.

Table IV provides the summary statistics of the common factor weights for each market price in the model. The first half of each panel presents the common-factor coefficients obtained by the Gonzalo and Granger (1995) method, and the second half presents the normalized coefficients or weights.[9] In panel A for the Euro, the daily average of the normalized common-factor weights is evidence of a predominant price discovery role of the spot markets. On average, the spot price contributes 60% of the formation of the common-factor component or "efficient price". The other two prices share the remainder, with the regular futures contributing 23% and the E-mini futures markets contributing 17%. Another interesting observation is that the table under "Min", both the regular and the E-mini futures prices show no contribution to price discovery in some of the sample days. Panel B shows similar results for the Yen/US$ markets. The common factor weight for the regular futures markets (28%) is much smaller than that of the spot market. Furthermore, compared with the case of the Euro, leaving out the E-mini from the analysis for the Japanese Yen has increased the spot weight by a much larger percentage than the increase in the regular futures weight. This could imply that the spot prices may better capture the price information revealed in the E-mini market than the regular futures market does.

Panel A and B in Figure 2 present the time series behavior of the daily estimated Gonzalo-Granger common factor weights over the sample period. The estimate for the spot series is mean reverting around a point higher than 50% in both currency markets. These results are obviously consistent with the results in Table IV. In summary, in line with the information share results, the results here support the findings of the dominance of spot market over both the regular and E-mini futures markets and almost equal performance of the regular futures and E-mini futures in the foreign exchange market price discovery.

Error-correction adjustment approach

We further conduct weak exogeneity tests for each exchange rate series based on an error correction model. The idea is that although there is one common stochastic trend for the exchange rates on related spot and future markets, these exchange rates may have temporary deviation from the common trend due to various market frictions. Such exchange rate dynamics across relate markets can be modeled in an error correction model with *n - 1* cointegrating relations (or *n - 1* error correction terms) for *n* exchange rates:

$$\Delta p_t = Bz^*_{t-1} + \varsigma_1 p_{t-1} + \varsigma_2 p_{t-2} + ... + \varsigma_{p-1} p_{t-p+1} + \varepsilon_t$$

where B is the (n x (n – 1)) matrix of adjustment coefficients and the error correction terms in z^*_{t-1} can be specified using two price differentials involving the spot prices. Specifically, for n = 3,

$$Bz^*_{t-1} = \begin{pmatrix} b_{12} & b_{13} \\ b_{22} & b_{23} \\ b_{32} & b_{33} \end{pmatrix} \begin{pmatrix} (p_{1t} - p_{2t}) - \mu_2 \\ (p_{1t} - p_{3t}) - \mu_3 \end{pmatrix}$$

where μ_i is the average price differential or mean deviation for i = 2, 3. The coefficients for the error correction terms (or so-called adjustment coefficients, given by the B matrix) measure the adjustment speeds by which each variable adjusts itself toward the long-run equilibrium. As pointed out in Eun and Sabherwal (2003), the magnitude of adjustment coefficients can be used to assess the contribution of a particular market to price discovery. A market which has zero (i.e., weakly exogenous) or a smaller (in absolute value) adjustment coefficient than those of other markets is a more dominant source of information in the price discovery process in the long run.

Estimated adjustment coefficients of the error correction models (Table V) further confirm our results. As shown in Panel A, there are two findings worth noting for the Euro/US$. First, on average, the coefficient estimates on the spot error-correction terms are not significant at the 0.05 level and thus weakly exogenous, while the estimates on the regular futures and E-mini futures error correction terms are significant at the 0.01 and 0.05 levels, respectively. Second, on average, the absolute values of the adjustment coefficient estimates are higher for the futures markets relative to the spot market. The results suggest that error-correcting adjustments to price differentials occur mainly in the regular futures and E-mini futures markets, which is in line with the leading price discovery role of the spot market. Panel B provides very similar results to those in Panel A. The Yen/US$ regular futures markets provide statistically significant adjustment coefficient estimates with a magnitude (in the absolute value) larger than the estimates for the spot market. Therefore, similarly to the Euro/US$ market, error correcting adjustments to price differentials also occur mainly in the futures markets. In summary, the results confirm that the spot market leads the regular futures and E-mini futures markets in the price discovery process.

Figure 3 further presents the time plots of t-statistics of the adjustment coefficient estimates for both currencies. Consistent with the results in Table V, these graphs reveal that over the majority of trading days, it is primarily the futures markets rather than the spot markets that adjust to price differentials across markets.

CONCLUSIONS

Given much recent evidence of the superiority of electronic trading, it is interesting to ask the question: among these markets trading electronically, which one leads the price discovery process? This paper attempts to answer this question on the foreign exchange market. Using intra-day (tick by tick) data, this paper investigates the contribution to the price discovery on the Japanese Yen and the Euro exchange rates of three electronically traded foreign exchange markets: the CME electronically-traded GLOBEX regular futures, electronically-traded small-denomination futures (E-Minis), and the inter-dealer spot market. The results show that transaction prices in the inter-dealer spot foreign exchange market are more informative than the prices in both the regular futures and the E-mini futures markets and thus the spot foreign exchange market leads the price discovery process for both exchange rates during the sample period.

The findings of this study are justifiable by the sheer size of the interdealer spot market compared with the futures markets and the use of EBS interdealer currency spot data as EBS has become the major trading platform for both the Yen and the Euro. However, the results stand in sharp contrast to recent studies that currency futures markets might lead the currency spot markets in price discovery. In particular, although this study confirms the recent finding of Tse, Xiang and Fung (2006) in favor of the spot markets for the Yen, the finding on the Euro here contradicts that of Tse, Xiang and Fung (2006). Nevertheless, the result of Tse et al. (2006) might not be very surprising given the fact that their spot rate data are from the CMC retail platform, which is unlikely to have informed traders.

The overall findings of this study are also only partially in line with that of Rosenberg and Traub (2007). Interestingly, while Rosenberg and Traub (2007) found currency futures market can lead the spot market in price discovery using the interdealer spot transactions from the Reuters Dealing 2000-1 system from May to August 1996, they also report that the spot market leads futures market using spot market quotes from Bloomberg over the period from March to May 2006. A possible explanation for their result is that "greater transparency is generally associated with more informative prices" (Madhavan, 2000). A market with low transparency is typically associated with lower degree of price discovery. As pointed out by Rime (2003), the interdealer direct trading platform by Reuters Dealing 2000-1 has a relatively low level of price transparency. However, the spot market might have become more transparent over time. Hence, it might not be surprising that based on the data from 1996, the futures market leads the spot market in price discovery, while using the data from 2006, the spot market leads the futures market as the spot market becomes more transparent. Nevertheless, as discussed earlier, our findings based on the EBS dataset should be most relevant and representative for the two exchange rates under consideration.

Furthermore, we also find *electronically traded* regular futures (on average) contribute (a bit) more than the E-mini futures and the E-mini futures (on average) contribute the least to the price discovery in the Euro/US$ and the Yen/US$ markets (while the spot market contributes the most). The finding is contradictory to the finding on the role of E-mini futures in the equity markets (e.g., Hasbrouck, 2003; Kurov and Lasser, 2004; Ates and Wang, 2005).

Finally, future research may gain further insight by considering the role of order flow in the price discovery process in foreign exchange markets, as suggested by Evans and Lyons (2002). Given the fact that most studies using high frequency data are limited to sample periods spanning only a few months, it may also be an area of fruitful research to explore potential time variation in contributions of each market to the price discovery process by using a longer period of intraday data.

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Table I
Trading Statistics on CME Futures

Symbol	Type	Trading	Globex ADV 7:05am - 4:00pm (contracts)	Globex ADV 5:00pm - 7:05pm (contracts)	Globex ADV 5:00pm - 4:00pm (contracts)	Floor ADV 7:20am - 2:00pm (contracts)	Globex "Day" % of Globex Total	Globex % of Total Trading
E7 (Euro)	E-Mini	Globex	2956	526	3482	0	0.83	1.00
EC (Euro)	Regular	Pit & Globex	100675	33704	134379	4788	0.74	0.97
J7 (Yen)	E-Mini	Globex	13	4	17	0	0.73	1.00
JY (Yen)	Regular	Pit & Globex	28169	9593	37762	3307	0.74	0.94

Note:

1. ADV is the Average Daily Volume.
2. "Day" = 7:05am - 4:00pm.
3. Percentages are also period averages.
4. Sample period is from April 4th, 2005 to July 29th, 2005.

Table II

Summary Statistics (daily averages)

	Spot	Regular futures	E-mini futures
Euro			
Number of observations	4514	6478	1468
Mean	1.248	1.250	1.250
Standard Deviation	0.002	0.002	0.002
Skewness	-0.027	0.090	0.004
Kurtosis	-0.532	1.428	-0.516
Japanese Yen			
Number of observations	3566	2594	42
Mean	0.0092344	0.0092848	0.0092796
Standard Deviation	0.0000094	0.0000096	0.0000095
Skewness	0.037	0.041	-0.108
Kurtosis	-0.644	-0.678	-0.336

Correlation coefficients for the prices (daily averages)

	Spot	Regular futures	E-mini futures
Euro			
Spot	1	0.991	0.987
Regular futures		1	0.987
E-mini futures			1
Japanese Yen			
Spot	1	0.989	0.690
Regular futures		1	0.692
E-mini futures			1

Note: Sample period is from April 4th, 2005 to July 29th, 2005.

Table III
Information Shares

Panel A: Euro
Information Shares

	Spot Trade Price			Regular Contract Price			E-Mini Contract Price		
	Min	Mid	Max	Min	Mid	Max	Min	Mid	Max
Median	0.28	0.61	0.91	0.05	0.33	0.61	0.01	0.23	0.45
Mean	0.31	0.60	0.90	0.06	0.32	0.58	0.03	0.22	0.42
Std. Dev.	0.18	0.11	0.07	0.06	0.12	0.20	0.03	0.10	0.19

Disturbance Correlation Matrix

	Spot Trade Price	Regular Contract Price	E-Mini Contract Price
Spot Trade Price	1	0.576	0.522
Regular Contract Price		1	0.455
E-Mini Contract Price			1

Panel B: Japanese Yen
Information Shares

	Spot Trade Price			Regular Contract Price		
	Min	Mid	Max	Min	Mid	Max
Median	0.56	0.75	0.94	0.06	0.25	0.44
Mean	0.55	0.73	0.91	0.09	0.27	0.45
Std. Dev.	0.18	0.13	0.08	0.08	0.13	0.18

Disturbance Correlation Matrix

	Spot Trade Price	Regular Contract Price
Spot Trade Price	1	0.449
Regular Contract Price		1

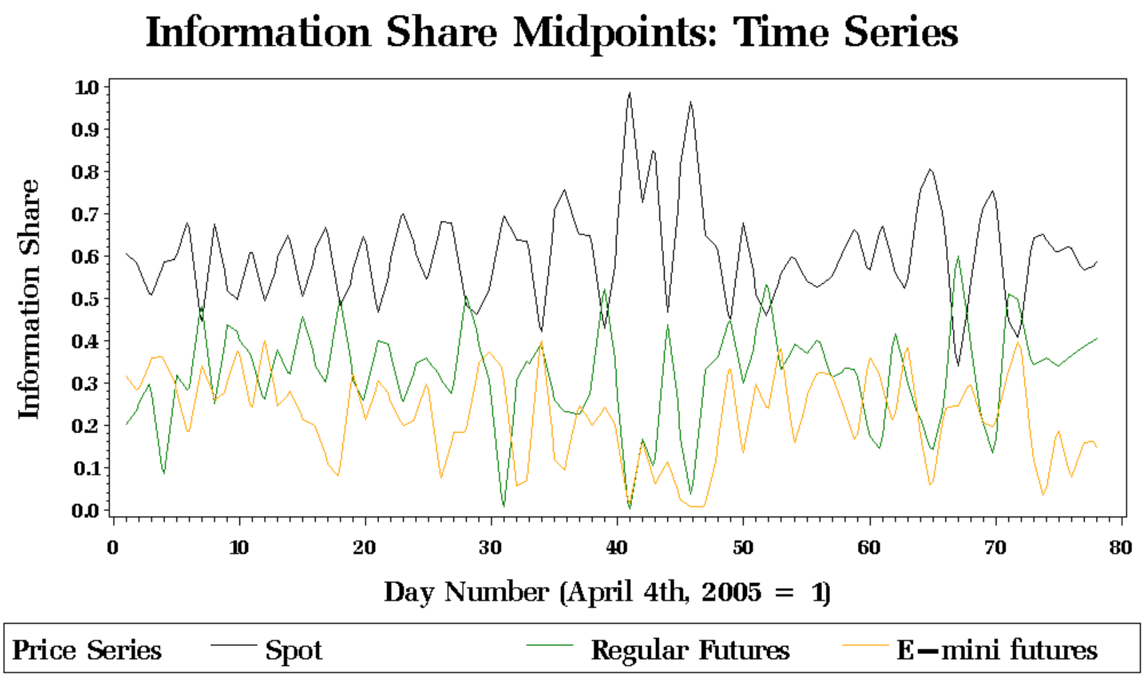
Table IV

Gonzalo-Granger Factor Weights

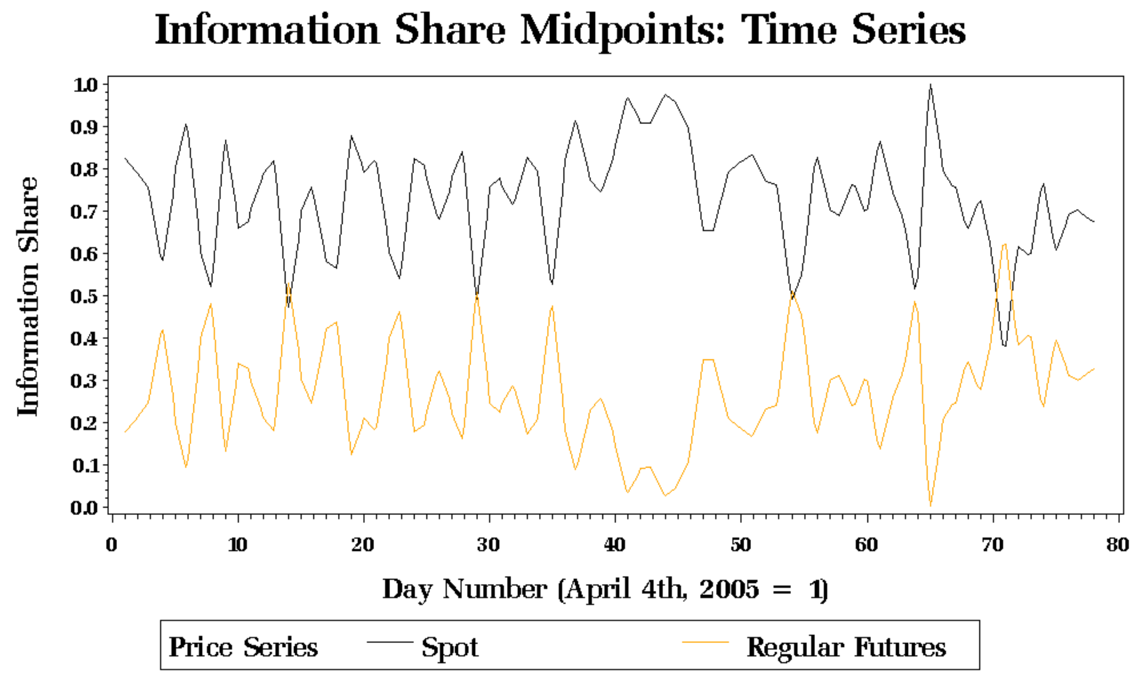
Panel A: Euro			
Gonzalo-Granger Common Factor Weights			
	Spot	Regular Futures	E-mini futures
Mean	0.85	0.34	0.17
Min	0.38	-0.02	-0.49
Max	1.00	0.89	0.70
Std. Dev.	0.13	0.21	0.26
Gonzalo-Granger Common Factor Weights (Normalized)			
	Spot	Regular Futures	E-mini futures
Mean	0.60	0.23	0.17
Min	0.25	0.00	0.00
Max	1.00	0.59	0.44
Std. Dev.	0.15	0.13	0.12
Panel B: Japanese Yen			
Gonzalo-Granger Common Factor Weights			
	Spot	Regular Futures	
Mean	0.90	0.36	
Min	0.41	-0.28	
Max	1.00	0.91	
Std. Dev.	0.11	0.22	
Gonzalo-Granger Common Factor Weights (Normalized)			
	Spot	Regular Futures	
Mean	0.72	0.28	
Min	0.31	0.00	
Max	1.00	0.69	
Std. Dev.	0.14	0.14	

Table V
VECM Estimation Results – Adjustment Coefficients

Panel A: Euro			
$b_{i,2}$			
	Spot	Regular Futures	E-mini futures
Mean	-0.0500	0.1747	-0.0602
	[-1.54]	[5.00]	[-2.20]
Min.	-0.1526	0.0059	-0.1702
	[-3.64]	[1.52]	[-4.91]
Max.	0.0147	0.8063	0.0315
	[0.64]	[11.18]	[1.01]
$b_{i,3}$			
	Spot	Regular Futures	E-mini futures
Mean	-0.0094	-0.0239	0.0827
	[-0.47]	[-0.82]	[5.17]
Min.	-0.0553	-0.3772	0.0091
	[-2.85]	[-3.71]	[2.47]
Max.	0.0353	0.0305	0.1611
	[2.00]	[1.57]	[8.55]
Panel B: Japanese Yen			
$b_{i,2}$			
	Spot	Regular Futures	
Mean	-0.031310	0.077889	
	[-1.76]	[5.04]	
Min.	-0.138170	0.020805	
	[-4.43]	[2.35]	
Max.	0.006013	0.177656	
	[1.00]	[9.11]	

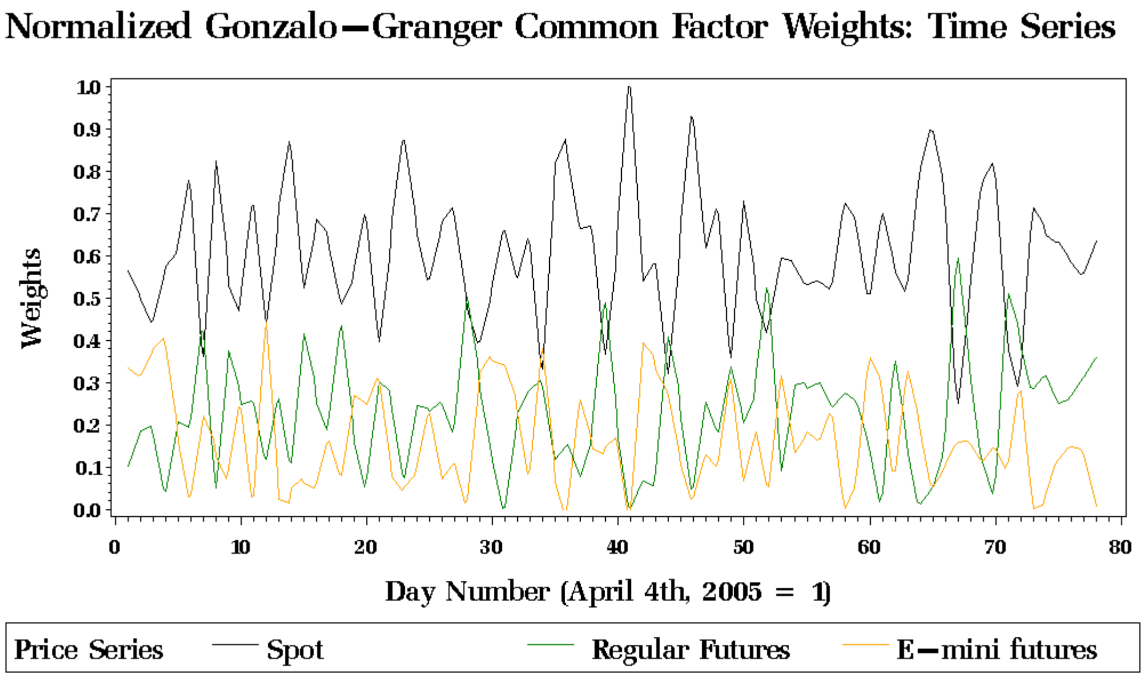


Panel A: Euro/$

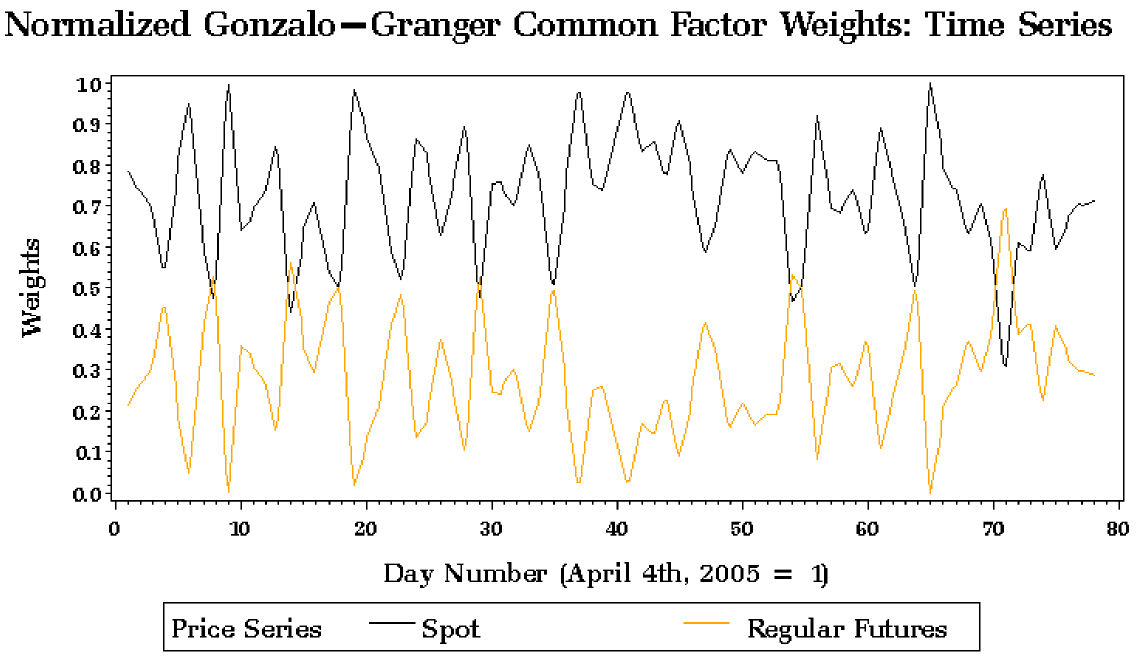


Panel B: Japanese Yen/$

Figure 1

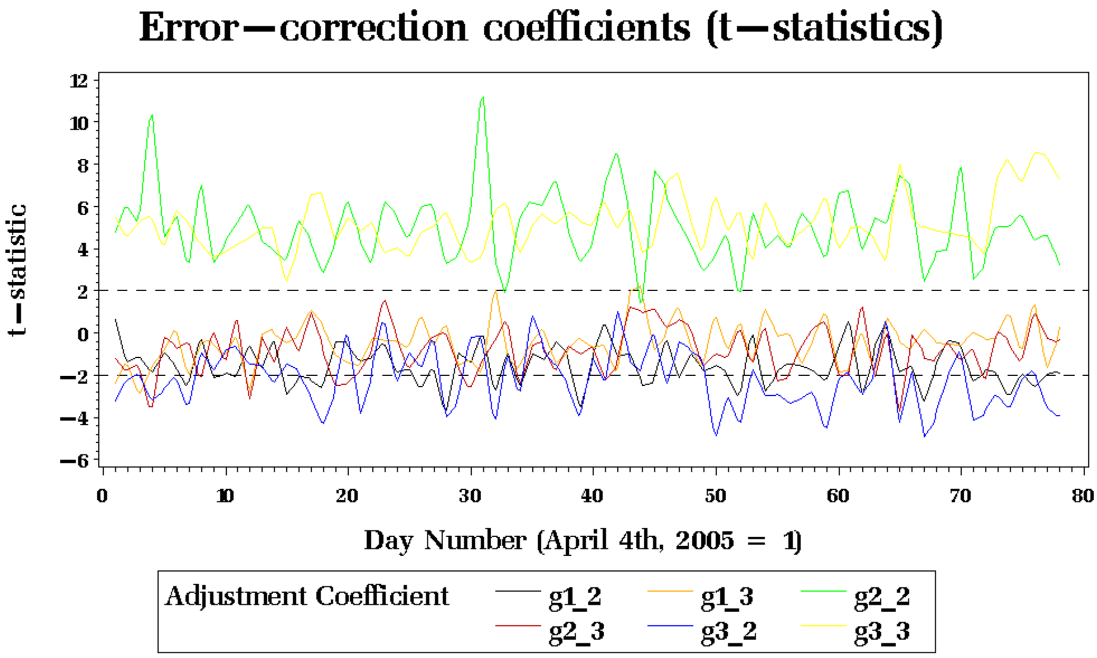


Panel A: Euro/$

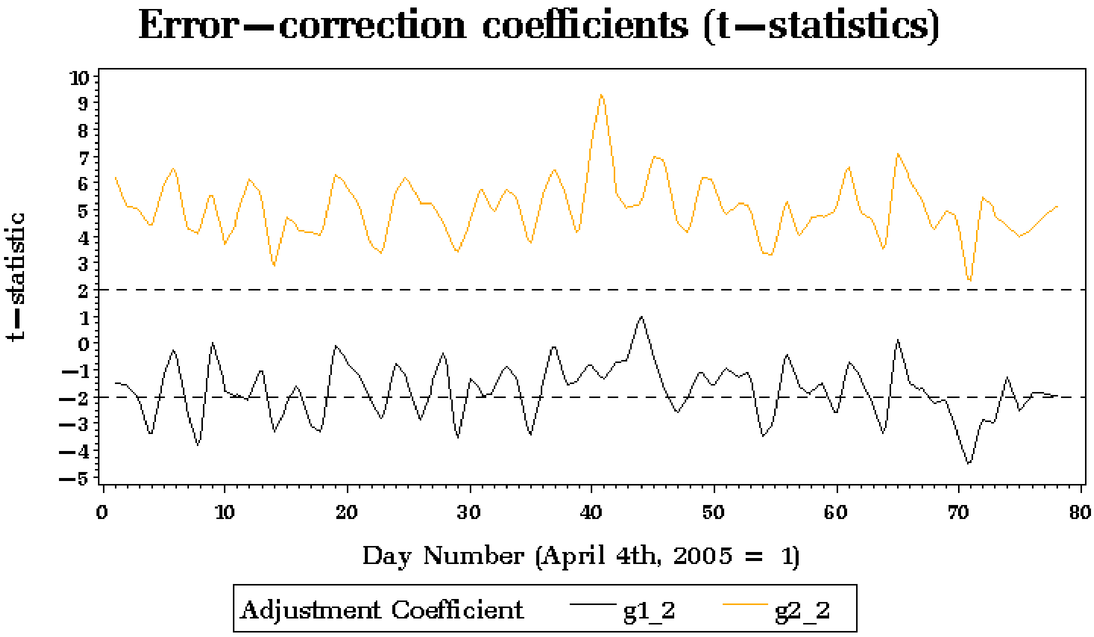


Panel B: Japanese Yen/$

Figure 2



Panel A: Euro/$



Panel B: Japanese Yen/$

Figure 3

Footnotes

[1] In the revised version of the paper, Rosenberg and Traub (2007) augmented their results using the spot market quotes from Bloomberg over a three-month period in 2006. They found that the spot market dominated price discovery.

[2] Currently, two electronic brokering systems are used globally for interdealer spot trading, one offered by EBS and the other offered by Reuters Dealing 3000. Euro/US$ and yen/US$ are traded primarily on EBS while sterling/US$ is traded mainly on Reuters (see Chaboud, Chernenko, Howorka, Krishnasami-Lyer, Liu, & Wright, 2004).

[3] Not all trading days within the four-month sample period have been used in this study. Several days have been excluded from the estimation due to the lack of trading activity in all markets simultaneously. July 4th and July 11th through July 15th have been excluded since not all markets are open to trade on these days, and the econometric techniques rely on having a sufficient number of observations for all instruments for all days.

[4] The regular floor trading data during the sample period were also obtained. However, the floor trading is very infrequent compared with electronic trading (see Table I), thus the floor trading data are not used in the analysis, even though the analysis is restricted to the period of the floor trading hours.

[5] The results are available upon request.

[6] Tables III presents the average mean disturbance (price innovation) correlation matrix for the Euro/US$ and the Yen/US$. respectively. The triangularization is implemented since the off-diagonal terms are different from zero.

[7] For a few days during the sample period, the information shares of regular futures market are larger than those in the spot market with increasing transactions for both spot and futures markets. This switch in the relative importance of the information shares on spot and futures markets also sometimes coincides with the days with some identifiable economic news. Nevertheless, the exact reason why such switch occurs is not clear and worthy of pursuing in the future research.

[8] De Jong (2002) provides a detailed discussion about the relationship between the Gonzalo-Granger common factor coefficients and the Stock and Watson (1988) decomposition.

[9] This normalization was necessary to simplify the interpretation of the common-factor coefficients as measures of price discovery. After normalizing, the coefficients are all positive between 0 and 1 and they sum to one.