Price discovery and liquidity for competing exchange rates

Iñaki Rodríguez Longarela and Geir Bjønnes

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Abstract

For many countries trading on news on their fundamentals mainly occurs via two competing channels, namely, their currency's exchange rate with either the Euro or the US dollar. This paper presents a framework to examine price discovery across these two alternatives. Our empirical implementation suggests that during the early/mid 2000's for the Swiss Franc most price discovery seem to take place via its exchange rate with the Euro whereas the opposite was true for the Japanese Yen. Furthermore, we establish a link of unusual strength between relative liquidity and the daily (and cross-sectional) variation in informational advantage among these two channels. Subsequent analysis finds a plausible mechanism driving this prominent role of liquidity based on a novel measure of staleness.

Key words: Exchange rates; price discovery; currencies; liquidity; bid-ask spread.

1 Introduction

Foreign exchange gravitates to a very large extent around two major monetary vehicles, namely, the US dollar and the Euro. Trading involving at least one of these two currencies exceeds 95% of the world's foreign exchange market turnover with the eurodollar absorbing around a quarter of it.[1] As a result, for most countries outside Euroland and US, news about the relative health of their economies will find an immediate reflection in their currency's exchange rate with the Euro or the USD whereas cross rates are usually mere followers.

There is a large body of literature examining what is known as *currency* competition. The focus of these contributions is to build theories and empirical work which may help understanding how the above status quo comes into place, that is, what makes the US dollar and the Euro the two main *vehicle currencies*. Early work dating back to Krugman (1980) establishes as main driving force past or present economic dominance in a model where transaction costs are key and are assumed to decrease with trading volume. More recently, Lyons and Moore (2009) present a theoretical framework where information is key. Their conclusion establishes that this vehicle role will decline with the relative price impact of its use for indirect trading.

The goal of this paper is to study *exchange rate* competition. Given the current status quo, there are two major channels for any information about the fundamentals of a country to flow. It becomes thus relevant to establish which one of its exchange rates with the US dollar and Euro has the most prominent role and what makes one of them the main *vehicle exchange rate*. To our knowledge and as opposed to currency competition, this problem has received little (if any) attention in the literature.

Our approach relies on well-known tools for the evaluation of price discovery,

[1] Bank For International Settlements, Triennial Central Bank Survey, Septermber 2016, https://www.bis.org/publ/rpfx16fx.pdf.

namely, information shares (Hausbruck, 1995) and component shares (Harris et al, 2002). We proceed by comparing each exchange rate with its implied rate (obtained by using its competing alternative and the Eurodollar) to lay the foundations of our framework. The implied rates of the two optional channels are equally affected, for all relevant purposes, by movements in the Eurodollar. Hence, a comparison of the two information/component shares will exclusively depend on the relative behavior of the two competing exchange rates thereby delivering a sensible measure of "vehicleness". Endowed with this tool we proceed to implement a descriptive analysis using high-frequency EBS data covering the years 2003, 2004 and 2005 to find that the EUR/CHF and the USD/JPY seem to clearly play the role of vehicle exchange rates for Switzerland and Japan, respectively. A companion striking result is that the average bid-ask spread explains nearly the totality of cross-sectional variation in average information/component shares at all frequencies.

A subsequent econometric analysis is developed in order to determine the major drivers of the daily evolution of this vehicleness. Our findings indicate that after controlling for trading activity and volatility, the dominant role of an exchange rate presents a contemporaneous correlation, with the above measure of liquidity, of outstanding strength and robustness. Previous work examining the price discovery role of derivatives versus their associated spot markets (the most related empirical framework) finds a much weaker connection (if any) with the bid-ask spread. For example, Chakravarty et al. (2004) for options and Kryzanowski et al. (2017) for credit default swaps analyze information shares with respect to their underlying equity whereas competition in price discovery between spot futures markets for exchange rates and government bonds are examined in Chen and Gau (2010) and Mizrach and Neely (2008), respectively. Such solid empirical connection is also absent in price discovery studies involving trading of an identical financial asset in more than one market (see e.g., Frijns et al, 2015; Wang and Yang, 2011; Hupperets and Menkveld, 2002).

Finally, we develop a measure of quote staleness whose correlation with the bid-ask spread is easily motivated and whose empirical presence we confirm. This link allows us to produce an explanation which seems plausible when explaining not only the strength or our results but also its unprecedented nature.

The paper is organized as follows. Section 2 presents the methodological arguments. Section 3 discusses the data and a first descriptive look at our results while a deeper analysis is presented in Section 4. A discussion follows in Section 5 and Section 6 contains our conclusions.

2 Methodological preliminaries

Hasbrouck (1995) develops an econometric method aimed at estimating the contribution to price discovery of any number of competing markets where identical or similar assets are traded. These *information shares* are more formally defined as the fraction of the variance of the shocks to the unobserved efficient asset price explained by the shocks to the observed asset price in each market. This model crucially relies on the co-integration of the observed prices which is realistically assumed due to a trivial no-arbitrage relationship. His approach can however be easily extended to assets linked by less direct relationships like an observed exchange rate and its associated implied (also known as synthetic) rate derived from a triangular no-arbitrage relationship. With a different aim, this extension was previously exploited by De Jong et al (1998).

In addition, Harris et al (2002) present what is now known as the component share. Their model is identical to Hausbrouck's (1995) but their measure of price discovery relies on different estimates. For the sake of robustness, our analysis will make use of both measures.

2.1 Information and component shares

Let v the (unobserved) efficient value underlying both (observed) actual and implied rates and denote them by p_1 and p_2, respectively. We will assume that we can write

$$p_t \equiv \begin{bmatrix} p_{1t} \\ p_{2t} \end{bmatrix} = \begin{bmatrix} v_t + e_{1t} \\ v_t + e_{2t} \end{bmatrix} \tag{1}$$

and

$$v_t = v_{t-1} + u_t,$$

where u_t is assumed to be zero-mean and serially uncorrelated. The other error terms e_{st} and $e_{\iota t}$ are zero-mean with a $k - th$ order autocovariance matrix that depends only on k. Then, by the Granger representation theorem the two co-integrated rates obey a VECM specification which has the form

$$\triangle p_t = \alpha\beta' p_{t-1} + \sum_{i=1}^{M} B_i \triangle p_{t-i} + \epsilon_t, \tag{2}$$

where α and β are two-dimensional vectors containing the error correction and cointegrating terms, respectively, the M 2×2 matrices B_i contain coefficients determinining the short-term dynamics of the process and ϵ_t is a two-dimentional vector of serially-uncorrelated error terms whose variance-covariance matrix will be denoted by $\Omega = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix}$. Furthermore, since the implied and actual rates are directly comparable, it follows that $\beta = [1, -1]$.

By following Hasbrouck (1995) and Baillie et al (2002), it can be proved that the variance of the innovation to the efficient value is given by $\psi' \Omega \psi$ where ψ is a 2-dimensional vector which is proportional to $\alpha_\perp = [\gamma_1, \gamma_2]$, an orthogonal vector to α. Note that for the purpose of the computation of the ratio giving the information share, it is only necessary to specify the values in ψ up to a constant. [2] If the covariance σ_{12} can be assumed to be zero, one can obtain the information share of the actual and implied rates in a straightforward manner by computing the ratios

$$IS_i = \frac{\gamma_i^2 \sigma_i^2}{\gamma_1^2 \sigma_1^2 + \gamma_2^2 \sigma_2^2}, \; i = 1, 2.$$

However, the two error terms in ϵ_t are likely to be correlated. In such case, we can consider the Cholesky decomposition $\Omega = FF'$ where it is easy to confirm thatt

$$F = \begin{bmatrix} \sigma_1 & 0 \\ \rho\sigma_2 & \sigma_2 \left(1 - \rho^2\right)^{1/2} \end{bmatrix},$$

with ρ denoting the correlation between the two error terms in ϵ_t. Note also that for the purpose of the computation of the ratio giving the information share, it is only necessary to specify the values in ψ up to a constant. Hence, we can pick $[\gamma_1, \gamma_2] = [\alpha_2, -\alpha_1]$. One could then compute the two information shares as

$$IS_1 = \frac{\alpha_2^2\sigma_1^2 + \alpha_1^2\sigma_2^2\rho^2 - 2\alpha_2\alpha_1\sigma_{12}}{\alpha_2^2\sigma_1^2 + \alpha_1^2\sigma_2^2 - 2\alpha_2\alpha_1\sigma_{12}} \qquad IS_2 = \frac{\alpha_1^2\sigma_2^2 - \alpha_1^2\sigma_2^2\rho^2}{\alpha_2^2\sigma_1^2 + \alpha_1^2\sigma_2^2 - 2\alpha_2\alpha_1\sigma_{12}}.$$

However, the order of the two elements in the vector $\triangle p_t$ becomes consequential since the corresponding information share of the actual rate is different if its associated process is located in first place. In fact, assuming that the correlation ρ is positive and that the coefficients α_1 and α_2 have different sign,[3] such information share turns out to be always larger when placed in that position. As a result, although this method does not allow for a direct determination of the information share, it does deliver upper and lower bounds which, in the case

[2]Note that for the purpose of the computation of the ratio giving the information share, it is only necessary to specify the values in ψ up to a constant.

[3]Given the model dynamics, α_1 should be negative and α_2 positive.

of the actual rate, are given by

$$IS_{u1} = \frac{\alpha_2^2\sigma_1^2 + \alpha_1^2\sigma_2^2\rho^2 - 2\alpha_2\alpha_1\sigma_{12}}{\alpha_2^2\sigma_1^2 + \alpha_1^2\sigma_2^2 - 2\alpha_2\alpha_1\sigma_{12}} \qquad IS_{l1} = \frac{\alpha_2^2\sigma_1^2 - \alpha_2^2\sigma_1^2\rho^2}{\alpha_2^2\sigma_1^2 + \alpha_1^2\sigma_2^2 - 2\alpha_2\alpha_1\sigma_{12}}. \quad (3)$$

Empirically, we proceed by first estimating the model in (2) equation by equation with OLS for a predetermined number of lags chosen by using the Akaike information criterion.[4] An orthogonal vector to $\hat{\alpha}$ is then computed and $\hat{\Omega}$ follows from the estimated residuals of the two OLS regressions. This delivers all the necessary ingredients to be plugged into the upper bound and lower bound formulas of the information share above. More details are provided in the empirical section and in the section below.

An alternative measure of price discovery, the component share, can be produced by exclusively relying on the error correction coefficients. The measure results from computing the ratios

$$CS_1 \equiv \frac{\gamma_1}{\gamma_1 + \gamma_2} = \frac{\alpha_2}{\alpha_2 + |\alpha_1|} \qquad CS_2 \equiv 1 - CS_1.$$

One obvious advantage of component shares is that they do not suffer from the indetermination problem above and they give an exact estimate and not just an interval. For a discussion of the relative merits of these two alternatives see De Jong (2002), Harris et al (2002) and Mizrach and Neely (2008).

2.2 Implied exchange rates

For our purposes, the computation of the implied rate will involve three currencies: the US Dollar, the Euro and a third one which we will denote by C. Let A_{EC} denote the price of one Euro in units of currency C (in the sequel referred to as euro rate) and let A_{UE} be the price of one US dollar again in units of cur-

[4]Lags are computed in book time.

rency C (the Dollar rate). A natural triangular relationship implicitly defines their associated implied rates I_{EC} and I_{UC}, and for example,

$$A_{EC} = A_{EU}A_{UC} \equiv I_{EC}$$

where the first equality must hold in the absence of arbitrage and the second one defines I_{EC}. The eurodollar rate, A_{EU}, plays the role of *exchange rate numeraire* in our analysis. Also, we can manipulate the above no-arbitrage equality to find the implied rate associated with A_{UC} as

$$A_{UC} = \frac{A_{EC}}{A_{EU}} \equiv I_{UC}.$$

Acknowledging the realistic existence of a bid-ask spread, requires defining instead implied bid and ask rates, something that one can easily do by extending these definitions in a direct manner. The implied ask of the euro rate will thus be given by

$$I^a_{EC} \equiv A^a_{EU}A^a_{UC}$$

where A^a_{EU} and A^a_{UC} denote now actual ask rates. The logic of this implied rate is sound since one can always obtain one euro with units of C by buying first the exact amount of dollars with units of currency C that are required to purchase exactly one euro. This amount happens to be $A^a_{EU}A^a_{UC}$. An identical argument justifies that the implied bid rate is defined as $I^b_{EC} \equiv A^b_{EU}A^b_{UC}$. Similarly, the implied bid and ask rates associated with the Dollar are obtained as

$$I^a_{UC} \equiv \frac{A^a_{EC}}{A^a_{EU}} \qquad I^b_{UC} \equiv \frac{A^b_{EC}}{A^b_{EU}}. \tag{4}$$

No-arbitrage imposes no equality between implied ask (bid) and actual ask (bid) rates. It does require though that the following inequalities are satisfied

$$I^a_{UC} > A^b_{UC} \qquad I^b_{UC} < A^a_{UC}, \tag{5}$$

and identical constraints should hold for the corresponding euro rates.

It will be useful for our empirical analysis to make use of implied rates for the numeraire eurodollar. Note that one could derive implied ask and bid rates for each currency C. Our choice in this case will be to set the implied ask (bid) rate equal to the minimum (maximum) value of all of them.

Our approach will rely on midquotes and two parallel analysis for every currency C with two associated 2-dimensional processes corresponding to equation (1) given by

$$p^{EC}_t \equiv \begin{bmatrix} ln\left[\left(A^a_{ECt} + A^b_{ECt}\right)/2\right] \\ ln\left[\left(I^a_{ECt} + I^a_{ECt}\right)/2\right] \end{bmatrix} \qquad p^{UC}_t \equiv \begin{bmatrix} ln\left[\left(A^a_{UCt} + A^b_{UCt}\right)/2\right] \\ ln\left[\left(I^a_{UCt} + I^b_{UCt}\right)/2\right] \end{bmatrix}.$$

The no-arbitrage restrictions in (5) seem to be enough to guarantee support for the assumption of co-integration that is necessary in order to legitimize the computation of the information shares.[5]Proceeding as indicated in the section above, it will thus be possible to obtain upper and lower bounds for the information shares of the actual midquote rates IS^{EC}_{u1}, IS^{EC}_{l1}, IS^{UC}_{u1} and IS^{UC}_{l1} and their associated component shares CS^{EC}_1 and CS^{UC}_1. These objects will constitute an important part of our empirical work together with the *relative*

[5]We have run extensive Augmented Dickey-Fuller tests in order to test the co-integration of the midquote series of actual rates and implied rates delivering overwhelming support for such hypothesis in all cases.

share of each currency C defined as[6]

$$RI^C \equiv \overline{IS}^{EC} - \overline{IS}^{UC} \qquad RC^C \equiv CS_1^{EC} - CS_1^{UC},$$

where $\overline{IS}^{EC}$ and $\overline{IS}^{UC}$ denote the average of the upper and lower bound of the information shares for the midquotes of the euro and dollar rates, respectively. These measures have the appeal of taking values in a bounded interval and they quantify in a straightforward manner the "vehicleness" of the euro rate with respect to its dollar counterpart. The closer to 1 (-1) they are, the more prominent the role of the euro (dollar) rate. We will use their log counterpart in our econometric estimations. In any case, both measures can be presented as a reasonable proxy for the extent of the dominance of either one of the two competing channels as vehicle exchange rate. This will allow us to establish to which extent news on the economic fundamentals of country C are first reflected in either its dollar rate or its euro rate. The values $\overline{IS}^{EC}$ and CS_1^{EU} ($\overline{IS}^{UC}$ and CS_1^{UC}) alone are also interesting as they establish to what extent news are immediately incorporated in the euro (dollar) rate or simply follow changes in its implied rate. However, they may be misleading in quantifying the prominence of the euro (dollar) rate. Indeed, its own implied value also depends on the movements of the Eurodollar and hence, its lagging or leading the numeraire exchange rate may bias downwards or upwards its value as vehicle in its competition with the dollar rate.[7] Both RI^C and RC^C alleviate this problem.

[6]As it will be shown later, given the granularity of our data, the covariance term σ_{12} will turn out to be relatively small and the upper and lower bounds of the information shares are very close, thereby making their averages a reliable estimate of the information shares.

[7]In particular, neither $\overline{IS}^{EC}$ and $\overline{IS}^{UC}$ nor CS_1^{EC} and CS_1^{UC} add up necessarily to one.

3 Data description and empirical preliminaries

Our data comes from Electronic Broking Services (EBS), a major electronic limit order book for currency trading. It contains second-by-second best bid and ask quotes and trades together with their associated volume from January 1, 2003 to December 31, 2005 for those rates for which EBS is the global benchmark, that is, EUR/USD, EUR/CHF, EUR/JPY, USD/CHF and USD/CHF. In order to lean on intervals of sufficient trading activity, we exclude all data outside the 3 AM to 11 AM New York time interval. [8] We also remove Saturdays and Sundays and all major US holidays as in Chaboud et al (2016) and seconds in which triangular arbitrage is present. Summaries of daily statistics, broken down by exchange rate, of trading activity, volatility and liquidity are presented in Table I.

Table I: Average daily trading activity and liquidity (January 1, 2003-December 31, 2005)

For each exchange rate, this table displays daily averages of trading activity and liquidity at EBS. Only the time interval 8:00-16:00 (GMT) during US winter time and 7:00-15:00 (GMT) during US summer time is considered on each date. Weekends and major US holidays are excluded. The first two rows respectively report the number of market orders and limit orders in thousands while daily trade size in million $ is displayed in row 3. The next three rows report three measures of liquidity, namely, average bid-ask spread, average effective spread and average price impact (at 60 seconds) all three in basis points. Finally, volatility (standard deviation of five-minute returns) is presented in the last row.

	EUR/CHF	EUR/JPY	EUR/USD	USD/CHF	USD/JPY
#m. Orders (000's)	1.643	1.892	10.330	2.429	4.668
#l. Orders (000's)	5.326	9.362	18.116	9.456	11.439
av. tr. size (mill.$)	2.345	1.963	3.452	2.127	2.636
av. bid-ask spread (bps)	1.094	2.130	0.921	2.239	1.280
av. eff. Spread (bps)	0.793	1.353	0.851	1.526	1.044
av. pri. Impact (bps)	0.357	0.699	0.420	0.789	0.536
volatility (%)	0.017	0.039	0.044	0.050	0.039

For each day, the information share of all five exchange rates is computed using all seconds available in the chosen daily interval. Figure 1 (top graphs) presents the evolution of these daily shares over our entire data time interval.

[8] Wang and Yang (2011) using a sample period that overlaps with hours finds that this period of the daily session dominates the price discovery process for the trading of four major currencies against the US dollar, including the JPY and the Euro.

The EUR/USD consistently displays a value near one over the entire period which is compatible with its role as numeraire. Also, the EUR/CHF and the USD/JPY seem to stand as vehicle exchange rates for the Swiss frank and the Japanese Yen, respectively. Perhaps the most striking feature of these graphs is the behavior of the EUR/CHF. Note that given its comparatively low trading activity (see Table 1) one would expect its share to be much less prominent. At the same time its volatility is smaller than that exhibited by its competing dollar rate. As a result, its implied rate is much more volatile. As De Jong et al (1998) point out, this increases the informational value of the actual rate since it results in a larger correlation with the random walk component and in a reduced presence of noise. Figure 1 (bottom graphs) illustrates the corresponding progression of the component shares whose behavior is very similar.[9]

[9] The only visible exception in this common behavior is the spike in the informations shares of EUR/CHF, USD/CHF and EUR/USD which takes place on October 18, 2005. That date the USD/CHF experiences a peak both in its volatility and its liquidity. The relative log bid-ask spread for the CHF also displays a clear peak on that date as a result.

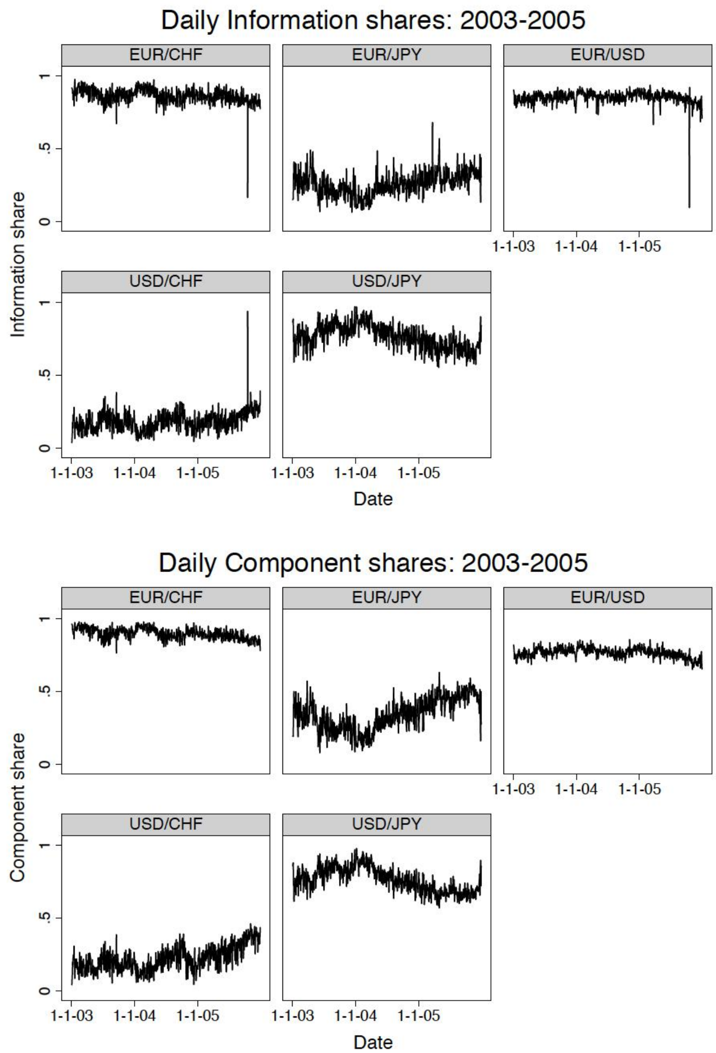

Figure 1: Information and component shares

Summary statistics for these two sets of time series and their associated relative shares are reported in Table 2. They confirm the patterns emerging from the previous plots. Note that even though information and component shares seem to slightly deviate in evaluating the leading role of each actual exchange rate over its implied counterpart, the net result summarized in the resulting relative shares for the Franc and Yen is almost identical with a correlation of

0.97 and 0.99, respectively.

Table II: Summary statistics of Information and Component shares

Summary statistics of daily information and component shares are presented in Panel A and B, respectively, broken down by exchange rate. Panel C displays summary statistics for relative information shares and relative component shares for the Swiss Franc and the Japanese Yen. T-tests testing the hypothesis that the euro rate's average share is larger than its dollar counterpart are performed and their associated P-values are reported in parentheses.

	Average	St.Deviation	Min	Max
	Panel A: Information Shares (%)			
	Average	St.Deviation	Min	Max
EUR/CHF	86.45%	5.12%	16.54%	97.56%
EUR/JPY	25.90%	7.97%	6.43%	67.96%
EUR/USD	85.26%	4.34%	9.63%	93.61%
USD/CHF	18.26%	6.60%	3.67%	93.89%
USD/JPY	76.46%	8.18%	55.47%	97.15%
	Panel B: Component Shares (%)			
	Average	St.Deviation	Min	Max
EUR/CHF	89.81%	3.80%	76.59%	97.88%
EUR/JPY	34.34%	11.08%	8.04%	63.12%
EUR/USD	76.61%	3.38%	65.33%	85.77%
USD/CHF	22.27%	8.35%	4.18%	46.14%
USD/JPY	76.22%	8.34%	57.10%	97.86%
	Panel C1: Relative Information Shares (%)			
	Average	St.Deviation	Min	Max
CHF	66.15%	11.85%	-77.60%	91.31%
	(0.000)			
JPY	-50.29%	15.35%	-87.32%	7.78%
	(1.000)			
	Panel C2: Relative Component Shares (%)			
	Average	St.Deviation	Min	Max
CHF	70.24%	10.77%	-77.10%	92.67%
	(0.000)			
JPY	-50.82%	15.52%	-88.48%	8.58%
	(1.000)			
	Number of dates: 750			

4 Drivers of "vehicleness"

We turn now to identify the major determinants of the prominent role of any of the two competing channels associated with the Franc and the Yen. In doing so, it will be useful to first examine the cross-section of information shares for the five exchange rates in our analysis. An important lead in this task can be found by putting together Table 1 and Table 2. The more liquid an exchange rate is, the larger its associated share seems to be. Figure 2 makes an overwhelming illustration of this point by plotting the bid-ask spread against the corresponding information shares for all five exchange rates as reported in those two tables. The graph depicts an almost perfect linear relationship.

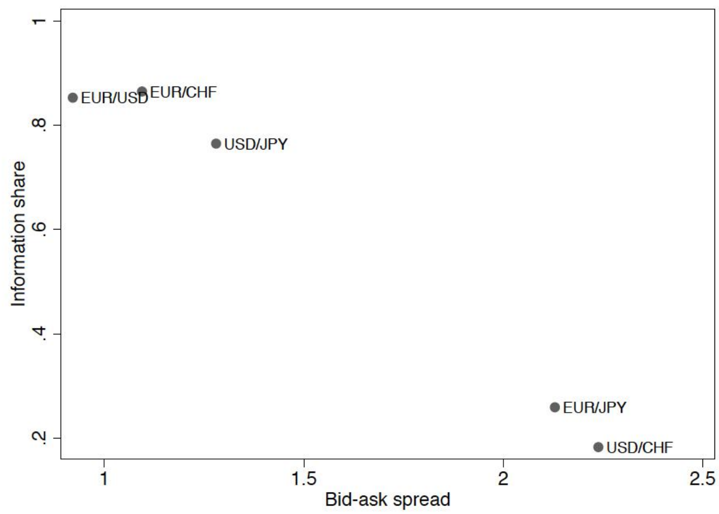

Figure 2: Average of daily information shares vs. average of average daily bid-ask spread over January 1, 2003 to December 31, 2005

This relationship appears to hold when averages are taking at smaller frequencies. A computation of correlations between these two variables when averages are taking at a yearly, monthly, weekly and even daily frequency uncovers a solid pattern as it can be seen in Table 3. There seems to be a very strong linear relationship over the cross-section of exchange rates linking liquidity and price discovery.

Table 3: Bid-ask spread and information shares

This table displays summary statistics for the correlation between the average of daily information shares and the average of the (daily average of) bid-ask spread for the five exchange rates over different frequencies.

	Obs	Mean	St. Deviation	Min	Max
Daily	750	-0.970	0.043	-0.999	-0.009
Weekly	156	-0.979	0.014	-1.000	-0.909
Monthly	36	-0.982	0.010	-0.999	-0.959
Yearly	3	-0.986	0.006	-0.992	-0.982

Liquidity and in particular, the bid-ask spread is clearly a strong candidate to act as determinant when it comes to explaining the daily evolution of the relative information shares for our two target currencies. Besides relative liquidity, our focus will lie on measures of relative trading activity. Our econometric modeling will thus contain as main elements in its left-hand side the log of the ratio of the values for the euro rate to the dollar rate of any given variable that is reasonable to consider in this context. The use of logs is mostly motivated by the nature of the dependent variable. We will explore several specifications but our main model will be given by

$$LRIS_{ct} = a_0 + a_1 LRBas_{ct} + a_2 LRVol_{ct} + a_3 LRLim_{ct} + a_4 LRTsize_{ct} + b'X_{ct} + \varepsilon_{ct} \tag{6}$$

where $LRIS_{ct}, LRBas_{ct}, LRVol_{ct}, LRLim_{ct}$ and $LRTsize_{ct}$ denote log ratios of the information share, average bid-ask spread, volatility (standard deviation of five-minute returns), number of limit orders and average trade size in US dollars, respectively, at day t for currency C. Our analysis will also replaced $LRIS_{ct}$ by the log ratio of the component shares, $LRCS_{ct}$ and it will also examine the significance of two other liquidity variables: the log ratios of the effective spread and price impact, $LREfs_{ct}$ and $LRPi_{ct}$, respectively. The vector of control variables includes a weekly fixed effect, a currency fixed effect, a time trend, the log of the volatility of the eurodollar and the log of its bid-ask spread. The latter two variables are also interacted with the country dummy in order to capture potential asymmetric effects. Our main variables are standard measures of market quality which are incorporated in studies of price discovery.

The role of relative liquidity is in principle uncertain from a theoretical point of view. If informed trading takes place in a given exchange rate, market makers may react by widening the spread in fear of being adversely selected. At the same time, lower transaction costs may attract informed trading and this would imply that price discovery is increased with tighter spreads. Our preliminary results for the cross-section of exchange rates seem to favor this second possibility. It also seems reasonable to hypothesize that relative trading volume should contribute to a larger relative informational share whereas the log ratio of the volatilities will have the opposite effect. As to the number of limit orders, it is harder to speculate about the direction of its influence but it is reasonable to include it as potentially relevant.

These main variables are of common use in previous studies pursuing the drivers of informational stakes in comparable frameworks. A group of them set their interest in price discovery for the same financial asset across different venues or across different periods of the daily trading season. A second group sets their focus on informational value across spot and derivatives markets. Examples of the former are Frijns et al (2015) and Eun and Subharwall (2003) which examine a cross-section of Canadian firms trading in the Toronto Stock Exchange and NYSE, NASDAQ and AMEX. Both studies find a significant effect for both trading volume and liquidity in the direction reasoned above. Also, Ozturk et al (2017) examine the intraday price discovery of 50 S&P stocks across different US venues and report a significant negative effect of the bid-ask spread, a negative but weak effect of volatility whereas trade size displays no coherent pattern. Gau and Gu (2017) look at the effect of macroeconomic news on the price discovery relevance of Tokyo, Europe and US trading hours for the EUR/USD and USD/JPY exchange rates. Their results offer support for our presumed patterns only in the case of the latter exchange rate, a result which can perhaps be justified by the special role of the Eurodollar as numeraire. Mizrach and Neely (2008) on the other hand focus their attention on spot and futures markets for US government bonds and Chen and Gau (2010) look at the effect of macroeconomic news on the price discovery shares of the spot and futures markets for the EUR/USD and USD/JPY. Their findings are in line with our expectations in their signs although the latter study attributes no significance to the bid-ask spread. Volatility and the bid-ask spread also seem to decrease the informational share of equity versus their underlying credit default swaps for US firms as indicated by Kryzanowski et al. (2017). Finally, the effect of the number of limit orders is only examined by Frijns et al (2015) in comparable studies of price discovery. This variable is found to have a negative but insignificant impact.

Table 4: Drivers of the vehicle role of the euro rate vs dollar rate

This table displays the results of our Pooled OLS regressions for our two target currencies. The dependent variables are the log of the relative information share (Models 1-3) and the log of the relative component share (Model 4-6). The main explanatory variables are the daily log ratios of the average bid-ask spread (ask minus bid divided by midpoint), volatility (standard deviation of five minute returns), the number of limit orders and the average trading size in million \$. In these ratios the value of the variable for the euro rate is in the numerator whereas its counterpart for the dollar rate is in the denominator. Models 1 and 4 contains the main model while Models 2 and 4 add the log ratios of the effective spread and price impact. Model 3 and 6 use as unique explanatory variable the log ratio of the bid-ask spread. The vector of controls includes a weekly fixed effect, a currency fixed effect, a time trend, the log of the volatility of the Eurodollar and the log of its bid-ask spread. The latter two variables are also interacted with a dummy takin value 1 for the Japanese Yen. t-statistics in parenthesis are calculated based on Newey-West robust standard errors correcting for heteroscedasticity and serial correlation with 15 lags.

	Dependent Variable: *LRIS*			Dependent Variable: *LRCS*		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
LRTBas	-1.917***	-1.727***	-2.123***	-1.707***	-1.550***	-2.408***
	(-21.832)	(-15.647)	(-62.383)	(-19.174)	(-13.027)	(-56.327)
LRVol	-0.068	-0.041		-0.084	-0.075	
	(-0.975)	(-0.452)		(-1.065)	(-0.709)	
LRlim	-0.641***	-0.662***		-0.918***	-0.932***	
	(-6.964)	(-6.914)		(-9.194)	(-8.905)	
LRTsize	0.195*	0.217*		0.517***	0.540***	
	(2.373)	(2.559)		(6.042)	(6.029)	
LRPi		-0.022			-0.003	
		(-0.486)			(-0.056)	
LREfs		-0.214*			-0.187	
		(-2.099)			(-1.691)	
Controls	Yes	Yes	No	Yes	Yes	No
Observations	1500	1500	1500	1500	1500	1500
Adj. R-squared	96.4%	96.4%	94.0%	96.7%	96.7%	93.2%
Within R-squared	66.3%	66.5%	46.6%	64.3%	64.4%	37.4%

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

We estimate our model by using pooled OLS and compute Newey-West t-statistics. Our results are summarized in Table 4. Model 1 and 3 contain the outcome of our full specification where the dependent variable is the log of the relative information share and relative component share, respectively. Our findings are overall consistent with the arguments and evidence review above yet the high significance of the number of limit orders and the irrelevance of volatility is perhaps surprising. In any case, it is important to emphasize that we do not make any causal claims based on these results. Furthermore, multicollinearity is obviously rampant and this may hide, for example, the true relevance of volatility in the dynamics of price discovery.

Having said that, the dimension of our results that deserves a more elaborated comment is the overwhelming strength of the relationship between the information shares and the bid-ask spread that our t-statistics reveal. First, models 2 and 4 examine the role of the other two measures of liquidity by adding them as explanatory variables. Their presence does not alter much the coefficient and the significance of the bid-ask spread. [10]But our main point here is much better illustrated by reducing all explanatory variables to a single one: the bid-ask spread. This is done in Models 3 and 6 leading to the realization that this variable alone explains well above 90% the variability of our dependent variables. The fact that the forces behind the virtual totality of the daily variation of the relative information share may be fully incorporated in the relative bid-ask spread is highly remarkable. This is of an unprecedented nature and it leads to the reasonable suspicion that we might be confronting spurious regressions where no deep relationship actually exists beyond a common (possibly deterministic) trend.

Although these series are admittedly highly persistence, Philips-Perroni tests on both series clearly reject the null hypothesis of unit roots.[11] Another point worth making is that the R-squares become clearly lower when we isolate the time dimension of the panel by examining their *within* values as it can be seen in the last row of Table 4. The strong link in the cross-section that we uncover in our early analysis is behind this difference.

[10]In all fairness, unreported results show that both the effective spread and price impact are highly significant if they replace the bid-ask spread in (6) as the only measure of liquidity but this is probably due to their high correlation with the bid-ask spread. Also, using the log of the relative number of trades rather than its trading volume counterpart as proxy for trading activity leads to a significant and positive coefficient. However, if both variables are included the proxy based on the number of trades becomes insignificant.

[11]Augmented Dickey-Fuller tests are less conclusive but given that our sample is relatively large and the non-parametric nature of the Philips-Perroni test makes the latter a better suited guide. All these results are available upon request.

Table 5: Drivers of the vehicle role of the euro rate vs dollar rate (some robustness checks)

This table displays the results of our Pooled OLS regressions for our two target currencies. The dependent variables are the log of the relative information share (Model 1) and its first difference (Models 2 and 3) and the log of the relative component share (Model 4) and its first difference (Models 5 and 5). The main explanatory variables are the daily log ratios of the average bid-ask spread (ask minus bid divided by midpoint), volatility (standard deviation of five minute returns), the number of limit orders and the average trading size in million $. In these ratios, the value of the variable for the euro rate is in the numerator whereas its counterpart for the dollar rate is in the denominator. Models 1 and 4 add 15 lags of the dependent and the four main explanatory variables to the right-hand side while Models 2 and 5 examine the short-term relationship by taking first differences of the dependent and explanatory variables (when applicable). Model 3 and 6 use as unique explanatory variable the first difference of the log ratio of the bid-ask spread. The vector of controls includes a weekly fixed effect, a currency fixed effect, a time trend, the log of the volatility of the Eurodollar and the log of its bid-ask spread. The latter two variables are also interacted with a dummy takin value 1 for the Japanese Yen. t-statistics in parenthesis are calculated based on Newey-West robust standard errors correcting for heteroscedasticity and serial correlation with 15 lags.

	Dependent Variable: *LRIS or DLRIS*			Dependent Variable: *LRCS or DLRCS*		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
LRTBas or *DLRTBas*	-1.709***	-1.830***	-1.662***	-1.725***	-1.890***	-1.762***
	(-12.010)	(-11.656)	(-13.646)	(-10.954)	(-10.379)	(-12.648)
LRVol or *DLRVol*	-0.073	-0.110		-0.100	-0.141	
	(-0.958)	(-1.248)		(-1.199)	(-1.394)	
LRlim or *DLRlim*	-0.721***	-0.742***		-0.892***	-0.858***	
	(-6.428)	(-5.657)		(-7.175)	(-5.698)	
LRTsize or *DLRTsize*	0.337***	0.414***		0.476***	0.518***	
	(3.334)	(3.403)		(4.331)	(3.933)	
Controls	Yes	Yes	No	Yes	Yes	No
Observations	1382	1492	1492	1382	1492	1492
R-squared	97,5%	39,2%	26,3%	97,7%	38,4%	24,0%
Within R-squared	74,1%	39,2%	26,3%	71,9%	38,4%	24,0%

* p<0.05, ** p<0.01, *** p<0.001

In any case, in order to fully avoid this as a concern, we have followed two different routes. First, we introduce 15 lags of the dependent and main explanatory variables in equation (6). Table 5 presents the results of this new estimation where only the contemporaneous coefficients are displayed. The significance and sign of our main variables remains and in addition, the value of their estimated coefficients is not largely altered. Second, we focus on the short-run relationship by replacing all time series in (6) with their first difference (when applicable) so that now the model tries to explain shocks to exchange rate vehicleness with the contemporaneous shocks of our main variables. Again, significance and signs of the specified driving forces stay untouched. The estimated coefficients are also remarkably close to their counterparts in levels.

5 Discussion: A measure of relative staleness

There are two questions that naturally arise after examining the reported results above. What is the mechanism that can explain such strong relationship between the relative bid-ask spread and the preponderance of a given exchange rate as the main vehicle of price discovery? Why previous studies on informational relevance across redundant venues/assets have not found this tenacious connection? Our arguments below will try to give a hopefully plausible answer to these enquiries.

As we have indicated earlier, no-arbitrage requires that

$$I^a_{UC} > A^b_{UC} \qquad I^b_{UC} < A^a_{UC},$$

and that identical constraints should hold for the corresponding euro rates. Note that even though no-arbitrage is compatible with the violation of the following inequalities

$$I^a_{UC} > A^a_{UC} \qquad I^b_{UC} < A^b_{UC}, \tag{7}$$

the "vehicleness" of a given exchange rate is facilitated whenever these restrictions also hold. Indeed, if the implied bid (ask) rate is larger (smaller) than the actual one, it pays off to use the indirect route in order to sell (buy) US dollars in exchange of units of currency C. In other words, those actual quotes that do not satisfy those inequalities are likely to be *stale* and a stale quote is plainly the opposite of a *leading* quote. It is thus self-evident that any measure of staleness based on this observation should capture to a certain degree the strength of price discovery of a given exchange rate. In other words, one would expect that the more stale the quotes of a given exchange rate are, the less informational value it has.

Now, after inspecting the inequalities in (7) again, the reader will probably notice that wide spreads are more likely to violate those restrictions than smaller spreads. Hence, in as much as wider spreads empirically happen to go hand in hand with staleness, the road for the bid-ask spread major relevance as a driver of price discovery is paved.

Table 6: Staleness, the bid-ask spread and information shares

This table presents in its first panel summary statistics of our measure of staleness (percentage of quotes, bid or ask, which are lower or higher than their corresponding implied quotes, respectively) for each one of our five exchange rates. Panel B displays summary statistics for the correlation between average daily staleness and the average of the (daily average of) bid-ask spread for the five exchange rates over different frequencies. Panel C replicates the same exercise for the correlation between daily information shares and the average of the (daily average of) bid-ask spread.

	Obs	Average	St.Deviation	Min	Max
Panel A: Staleness (%)					
EUR/CHF	750	17.17%	2.16%	11.59%	26.80%
EUR/JPY	750	44.11%	5.67%	30.73%	59.37%
EUR/USD	750	24.09%	3.90%	16.91%	53.93%
USD/CHF	750	48.94%	5.00%	36.81%	62.06%
USD/JPY	750	21.52%	3.71%	13.73%	48.56%
Panel B: Staleness and bid-ask spread					
	Obs	Average	St.Deviation	Min	Max
Daily	750	92.28%	7.06%	15.06%	99.11%
Weekly	156	92.91%	4.72%	71.03%	98.00%
Monthly	36	93.22%	4.31%	81.06%	97.57%
Yearly	3	93.66%	4.03%	89.03%	96.35%
Panel C: Staleness and Information shares					
	Obs	Average	St.Deviation	Min	Max
Daily	750	-95.82%	7.62%	-99.99%	23.81%
Weekly	156	-96.84%	3.86%	-99.82%	-79.70%
Monthly	36	-97.18%	3.51%	-99.78%	-83.07%
Yearly	3	-97.77%	2.17%	-99.35%	-95.30%

In order to investigate the empirical plausibility of this line of reasoning, for each day in our sample and every exchange rate, we compute the percentage of quotes (bid or ask) within the seconds of our focus daily interval which violate (7). Table 6 reports summary statistics of this proxy for staleness in its first panel. The EUR/CHF appears to be the least stale of all rates.[12] Panels B and

[12] It should not be forgotten that the Eurodollar implied rates are computed over two triangular relationships rather than just one as the other ones.

C of the table replicate the exercise performed in Table 3 for the correlation between the bid-ask spread and staleness and the bid-ask spread and the information shares.[13] The strength of these two cross-sectional bonds gives initial support to our arguments above. We also compute a measure of log relative staleness defined as

$$LRS_{ct} \equiv \ln S_{ct} - \ln S_{ct},$$

where S_{ct} and S_{ct} denote staleness of the dollar and euro rate with currency C at day t, respectively. Note that that higher values of this measure imply *lower* relative staleness of the euro rate. We define it in this way so that our presumed mechanism delivers a positive relationship between relative information shares and relative staleness. We proceed to use LRS_{ct} as dependent variable in (6) and we estimate the model together with the alternative specifications that we considered in the previous section. Our results are displayed in Table 7. The pattern of signs and significance for our main variables remarkably aligns with what we reported above for information shares and component shares. This completes our attempt to answer the first question.

[13] For the sake of brevity, we ignore in this discussion component shares. Nevertheless, our results also hold for them.

Table 7: Drivers of the relative staleness of the euro rate vs dollar rate

This table displays the results of Pooled OLS regressions for our two target currencies. The dependent variables are the log of the relative staleness (Models 1-4) and its first difference (Model 4-5). The main explanatory variables are the daily log ratios of the average bid-ask spread (ask minus bid divided by midpoint), volatility (standard deviation of five minute returns), the number of limit orders and the average trading size in million \$. In these ratios, the value of the variable for the euro rate is in the numerator whereas its counterpart for the dollar rate is in the denominator. Models 2 contains the main specification. Model 3 adds to the full specification the log ratios of the effective spread and price impact while Model 4 adds to such specification 15 lags of the dependent and the four main explanatory variables to the right-hand side. Model 1 and 6 use as unique regressor the bid-ask spread variable and its first-difference, respectively. Finally, Model 5 examines the short-term relationship for the full model by taking first differences of the dependent and explanatory variables (when applicable). The vector of controls includes a weekly fixed effect, a currency fixed effect, a time trend, the log of the volatility of the Eurodollar and the log of its bid-ask spread. The latter two variables are also interacted with a dummy taking value 1 for the Japanese Yen. t-statistics in parenthesis are calculated based on Newey-West robust standard errors correcting for heteroscedasticity and serial correlation with 15 lags.

	Dependent Variable: *LRS* or *DLRS*					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
LRTBas or *DLRTBas*	-1.447***	-0.913***	-0.954***	-1.073***	-1.064***	-1.078***
	(-69.179)	(-29.447)	(-23.857)	(-23.501)	(-23.096)	(-26.729)
LRVol or *DLRVol*		0.007	-0.004	0.033	0.027	
		(0.316)	(-0.143)	(1.446)	(1.031)	
LRlim or *DLRlim*		-0.237***	-0.232***	-0.238***	-0.204***	
		(-7.304)	(-7.078)	(-5.486)	(-4.883)	
LRTsize or *DLRTsize*		0.374***	0.371***	0.255***	0.210***	
		(10.113)	(9.294)	(7.521)	(5.112)	
LRPi			0.011			
			(0.957)			
LREfs			0.042			
			(0.757)			
Controls	No	Yes	Yes	Yes	Yes	No
Observations	1500	1500	1500	1382	1492	1492
Adj. R-squared	96.6%	98.9%	98.9%	99.0%	58.4%	54.4%
Within R-squared	65.3%	81.1%	81.2%	84.4%	63.0%	54.4%

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

In order to address the second enquiry, it is important to emphasize at this point that our main arguments in this discussion have made a basic assumption. Traders of the euro (dollar) rate may easily avoid bad quotes by trading instead the Eurodollar and the dollar (euro) rate. In particular, it should be possible to execute this alternative strategy at low risk. Trading fees beyond the bid-ask spread are also relevant. This is crucial for staleness and price discovery to be connected and it is through this remark that our second question may received a (admittedly speculative) answer. In a centralized limit order book like EBS, the two alternative trades that are required in order to improve a stale quote will take place in the same venue. Execution risk is in this context kept low relative to the one associated with a trading setup where competing investments are located in a different venue. This could thus explain the much weaker link found in the literature between the bid-ask spread and price discovery since those studies correspond to trading of the same financial asset (or a synthetic replica via derivatives markets) in different locations.

6 Conclusions

Up to our knowledge, exchange rate competition like the one described in this paper has remained under the radar of previous research in currency markets. In as much as this status is seen as undeserved, future contributions could develop theoretical modeling whose foundations could find its underpinnings in some of the reported empirical regularities. Note that this paper examines the evolution of price discovery in a particular setup but it says nothing on how the vehicle role of the euro (dollar) rate arises for the Swiss Franc (Japanese Yen). A model where both the bid-ask spread and informed trading are endogenous and jointly determined in equilibrium could thus be an interesting next step.

Furthermore, our discussion develops an explanation for the bond between the bid-ask spread and price discovery which relies on two main assumptions. First, a strong correlation between quote staleness and the bid-ask spread needs to be present. Second, bad quotes can be easily avoided by trading in an indirect route which involves the Eurodollar as intermediate exchange rate. This delivers testable predictions. For example, for a given correlation of the bid-ask spread and quote staleness, the strength of the relationship between the bid-ask spread and the price discovery value of two competing exchange rates should depend on execution cost and execution risk. Also, in as much as the minimum tick may influence the above correlation, its variations may also influence this link for a fixed execution cost and risk.

Hasbrouck (1995) states that “A market could conceivably have an information share of 100 percent, and yet have the widest spreads and the slowest lagged adjustment of prices”. Clearly, this exceptional behavior is not present in our data since we have provided evidence suggesting that wide spreads are actually coupled with low information shares. However, he also adds that “intuitively, the information share measures 'who moves first' in the process of price adjustment”. This opens an alternative and possibly complementary route to understand our findings. Indeed, market makers holding tighter spreads have stronger incentives to 'move first' whenever news arrive to the market since their quotes are otherwise more prone to produce arbitrage violations.

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