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Some Evidence that a Tobin Tax on Foreign Exchange Transactions May *Increase* Volatility ⋆

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1. Introduction

More than two decades ago, James Tobin suggested imposing a tax on all foreign exchange transactions (Tobin, 1978). Similar proposals for imposing transaction tax on trading of other securities (see Schwert and Seguin, 1993 for a review) are also often made by eminent economists (Stiglitz, 1989; Summers and Summers, 1989). One of the putative benefits of a transaction tax is that this may decrease the volatility of prices. The intuitive rationale behind this, believed to be first articulated by Keynes in 1936, is that a transaction tax would hurt the speculators disproportionately more because they tend to trade much more frequently. An implicit assumption in this argument is that speculative trading is on average destabilizing which in turn causes prices to be more volatile. A contrasting view is offered by Milton Friedman who argued (Friedman, 1953) that rational speculators may in fact help stabilize prices. The relative merits of these opposing views can only be judged by analyzing this issue empirically.

The empirical evidence on the effect of transactions taxes on volatility of prices is rare. Umlauf (1993), using Swedish stock market data from the 1980s, shows that the introduction of, or an increase in Swedish tax, led to an increase in volatility of stock prices; Jones and Seguin (1997) show that the reduction in the commission

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portion of the transactions costs in 1975 led to a decrease in volatility (and increase in volume) of stock prices. However, there appears to be no empirical evidence in the extant literature on the effect of a transaction tax in the foreign exchange market on the volatility of exchange rates. In this paper, we provide some evidence. Our results, suggest that a Tobin tax on foreign exchange transactions may, in fact, lead to an *increase* in the volatility of exchange rates which is exactly the opposite to the claim made by Tobin and proponents of his suggestion such as Jeffrey Frankel who recently resurrected Tobin's argument (see Frankel, 1996).

We estimate the effective transactions costs in the foreign exchange market for the period 1977 to 1999 using foreign currency futures data. Our approach in estimating the transactions costs in the foreign exchange market makes a contribution in two ways. First, we improve upon the previous approaches for estimating the transactions costs in the foreign exchange market (Frenkel and Levich, 1975, 1977, 1979 and McCormick, 1979). Second, we measure transactions costs faced by the marginal investors that set prices in the foreign exchange markets which is unlike the previous approaches which, if implemented correctly, would measure transactions costs in foreign exchange market that are faced by commercial customers of banks. While the estimates of transactions costs useful for judgements about the impacts of alternative exchange rate regimes on the levels of trade, might be those incurred by commercial firms, the estimates of cost relevant for determining prices, in contrast, are the smaller costs incurred by large commercial banks who are likely to be marginal investors determining prices in the foreign exchange market. We estimate that transactions costs over the last two decades on average were no more than one-twentieth of one percent, and in the last decade may have fallen to as low as one-fiftieth of one percent.

We then, using our approach, construct time series of monthly estimates of effective transactions costs for four currencies, the British Pound, the Deutsche Mark, the Japanese Yen and the Swiss Franc. We also construct time series of monthly volatility (i.e., standard deviation) of foreign currency futures returns and monthly volume (i.e., number of futures contracts traded) for the four currencies. Using regression analysis, we document that volatility is positively associated with the level of transactions costs and that volume is negatively associated with the level of transactions costs. Thus our results are consistent with the notion that an increase in transactions costs does indeed lead to a reduction in volume of trading as one might expect, but its effect on volatility is exactly opposite of what proponents of Tobin tax would have liked to see.

2. Measuring Transactions Costs in the Foreign Exchange Market

Transactions costs in the foreign exchange market are not explicit, as in the markets with standardized commissions like the home real estate market and organized security and commodity exchanges. Instead, transactions costs are implicit, as in the over-the-counter security market, and are collected by broker-dealers, primarily the large commercial banks, in the spreads between the prices at which they buy and sell foreign exchange. The transactions costs in the foreign exchange market may differ by the pair of currencies involved, by the size of the transaction, by the customer buying the foreign exchange, by the bank selling the foreign exchange, and even by the center in which a particular transaction such as the purchase of dollars with sterling occurs. However, from the point of view providing insights about the effect of transactions costs on exchange rate volatility, the key consideration is the estimate of transactions costs incurred by marginal investors those who pay the lowest costs – the banks in their transactions with each other.

We first discuss previous approaches in the measurement of transactions costs in the foreign exchange market. We then present a new approach to estimate the transactions costs using futures prices.

2.1. PREVIOUS APPROACHES

2.1.1. *Bid-ask spreads*

One approach to estimation of transactions costs in the foreign exchange market is based on the bid-ask spread quoted by banks to commercial or non-bank customers (See Glassman, 1987 and Boothe, 1988). Let S_b and S_a denote the bid and the ask prices expressed in dollars of a unit of foreign currency, say Deutsche Mark, quoted by a bank. Let S denote the price of one unit of DM if the customer faced no transactions costs. If we let C denote the proportional transactions costs, then

$$\frac{S - S_b}{S} = C \Leftrightarrow S_b = S(1 - C) \tag{1}$$

$$\frac{S_a - S}{S} = C \Leftrightarrow S_a = S(1 + C). \tag{2}$$

Eliminating S from the above two equations, we get

$$C = \frac{S_a - S_b}{S_a + S_b}.$$

This approach permits comparisons both of the transactions costs involving different pairs of currencies and the costs of forward contracts of different maturities with each other and with the costs of spot exchange contracts.

However, there is no assurance that the rates quoted are those actually charged by the banks; transactions between banks and non-bank customers may occur at prices within these quotes. Second, the buyers and sellers of foreign exchange may incur various costs in addition to those charged by broker-dealers; these costs might include payments for the expertise deemed necessary to cope with exchange market uncertainties, including the costs of exchange rate forecasting services and exposure management services.

2.1.2. *Triangular arbitrage*

A second approach infers transactions costs using a model of triangular arbitrage. In the absence of transactions costs, the following condition must hold for there to be no arbitrage opportunities.

$$S^{\$/£} = S^{\$/DM} \; S^{DM/£}, \tag{3}$$

where $S^{x/y}$ denotes the price in terms of currency x of one unit of currency y.

If, however, transactions costs are not absent, then, Frenkel and Levich (1975, 1977) suggest, that the transactions costs can be inferred from the upper limit of the absolute discrepancy between the two sides of Equation (3). The percentage discrepancy, d, can be expressed as follows.

$$d = 1 - \frac{S^{\$/DM} \; S^{DM/£}}{S^{\$/£}}. \tag{4}$$

In order to further understand the implications of this methodology for estimating transactions costs, it is useful to understand the mechanics of currency trading. Almost all trading of convertible currencies takes place with respect to the U.S. dollar (Grabbe, 1991). The dollar has a unique role as a vehicle currency. Just as money developed to enhance efficiency in payments, so the development of dollar as an intermediate currency can be attributed to the demand for greater efficiency in international payments and especially to economize on inventories of foreign exchange maintained by broker-dealers. So, for instance, both the £ and the DM are traded with prices quoted in terms of the dollar. If a commercial customer asks for a £ price in terms of the DM, this cross rate is determined from the two dollar rates.[1] The bid and ask prices of £ in terms of the DM then can be expressed as follows[2]:

$$S_b^{DM/£} = S_b^{\$/£} S_b^{DM/\$} = \frac{S_b^{\$/£}}{S_a^{\$/DM}}, \tag{5}$$

$$S_a^{DM/£} = S_a^{\$/£} S_a^{DM/\$} = \frac{S_a^{\$/£}}{S_b^{\$/DM}} \; . \tag{6}$$

The first question is which spot rates – bid or ask – should be used in (4). In Frenkel and Levich (1975) for all rates involving the U.S. dollar, closing *quoted* bid prices are used. For rates not involving the dollar, the rates used are mid-points of the quoted bid and ask rates (see their footnote 2). Thus for their case, we can write

$$d = 1 - \frac{S_b^{\$/DM}}{S_b^{\$/£}} \left[\frac{S_b^{DM/£} + S_a^{DM/£}}{2} \right].$$

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1 This description is fairly accurate for much of the time period studied in our analysis.

2 Note that $S_b^{x/y} = 1/S_a^{y/x}$.

For simplicity let us assume that transactions costs are identical for all currencies. Substituting from (5), (6), (1) and (2) into above and simplifying, we get:

$$|d| = \frac{2C^2}{1 - C^2} \simeq 2C^2 \simeq 0$$

where C represents one-half of the *quoted* bid-ask spread in percent. Thus the estimate measures 2 times the *square* of percentage transactions costs as measured by one-half of the quoted bid-ask spreads.

Frenkel and Levich (1977) and McCormick (1979) use mid-points of the bid and ask rates for all three rates in (4). In that case, we can write

$$d = 1 - \frac{S_b^{\$/DM} + S_a^{\$/DM}}{S_b^{\$/£} + S_a^{\$/£}} \left[\frac{S_b^{DM/£} + S_a^{DM/£}}{2} \right].$$

Again making the substitutions from (5), (6), (1) and (2) and simplifying, we get

$$|d| = \frac{2C^2}{1 - C^2} \simeq 2C^2 \simeq 0.$$

Here again, the estimate measures 2 times the *square* of percentage transactions costs as measured by one-half of the quoted bid-ask spreads. It appears to us that errors in data, caused by non-synchronous recording of various prices, may have produced the estimates of transactions costs in the foreign exchange market in Frenkel and Levich (1975, 1977), and in McCormick (1979). Notice that Frenkel and Levich (1977) observe that that the estimates of transactions costs in what they call the "turbulent period" are higher than the estimates in the "tranquil period"(see Table I in Frenkel and Levich, 1977). The data being non-synchronous would result in larger estimates in periods with higher volatility of exchange rates because the data errors are larger. The evidence documented in McCormick (1979) in Table I is also consistent with this conjecture.

Suppose now that we use actual transaction data for spot prices. This will have the advantage that we will be using actual prices faced by traders. If we do not know whether the transaction is a bid or the ask price then we can assume that each observed transaction price has an equal chance of being an *effective* (as opposed to quoted) bid or an ask price. Since there are three different rates in (4), there are eight different possible permutations. Suppose all three prices are bid prices. Then

$$d = 1 - \frac{S_b^{\$/DM} S_b^{DM/£}}{S_b^{\$/£}}. \tag{7}$$

Substituting from (5) in (7) and simplifying, we get

$$d = 1 - \frac{S_b^{\$/DM}}{S_a^{\$/DM}}.$$

For simplicity let us assume that C represents the effective percentage transactions costs for all currencies. Then, substituting from (1) and (2) in equation above, we get

$$|d| = \frac{2C}{1+C} \approx 2C.$$

We perform similar calculations for all eight permutations. The estimates of $|d|$ vary from 0 to $4C$ with a mean of $2C$. Thus a mean estimate of $|d|$, when actual transaction data for spot prices is used, provides an estimate of effective transactions costs.

2.2. TRANSACTIONS COSTS IMPLICIT IN FUTURES PRICES

Even when implemented correctly, the above approaches toward measuring transactions costs in foreign exchange market are directed at measuring the transactions costs incurred by the commercial customers of banks and ignore that much of the largest part of foreign exchange transactions, probably 90 to 95 percent, occurs between banks, and involves one bank as a buyer and another bank as a seller of foreign exchange. The costs incurred by banks on transactions undertaken for their own accounts are probably much smaller than any of the estimates of transactions costs suggested by quoted bid-ask spreads. Moreover, while it might seem that the banks would set their bid-ask spreads so that commercial customers would pay the costs of its foreign exchange department, it seems more likely that each bank compares these costs with total income from trading profits from "running the position" as well as from the bid-ask spread.

The approach we use has two features that overcome many of the problems that the previous approaches faced. First, we use prices on foreign currency futures. This has the advantage that we do not have to deal with any bid and ask price *quotes*. Futures contracts are traded on organized exchanges and there is a well defined price. Second, we use deviations from interest rate parity type relationships in estimating the transactions costs. The advantage of that is that we are measuring the transactions costs faced by the marginal investors that set prices in these markets. These marginal investors are likely to be large commercial banks and so the estimates of transactions costs we obtain are likely to the estimates of the minimum level of transactions costs.

In the absence of arbitrage opportunities the following interest rate parity condition must hold.

$$F(t,T) = S_t \frac{1+i(t,T)}{1+i^*(t,T)},$$

where $F(t,T) \equiv$ forward price at date t for a contract to deliver one unit of foreign currency at date T;[3] $S_t \equiv$ spot price of the currency at date t; $i(t,T) \equiv$ domestic

[3] Strictly speaking, the interest rate parity condition holds for forward contracts. The relation between forward and futures prices is discussed in Cox et al. (1981), French (1983) and Jarrow

spot risk-free interest rate for the period from t to T; $i^*(t, T) \equiv$ foreign spot risk-free interest rate for the period from t to T.

Taking natural logarithms we get the following familiar version of interest rate parity in which the percentage forward premium over the spot rate equals the interest rate differential:

$$\ln F(t, T) - \ln S_t \simeq i(t, T) - i^*(t, T). \tag{8}$$

Using (8), we get the following:

$$p_t \equiv \ln F(t, T_2) - \ln F(t, T_1) \simeq i(t, T_1, T_2) - i^*(t, T_1, T_2) \equiv \Delta_t \tag{9}$$

where $i(t, T_1, T_2) \equiv i(t, T_2) - i(t, T_1) \equiv$ domestic forward risk-free interest rate at date t for the period from T_1 to T_2; $i^*(t, T_1, T_2) \equiv i^*(t, T_2) - i^*(t, T_1) \equiv$ foreign forward risk-free interest rate at date t for the period from T_1 to T_2. Thus

$$d_t \equiv p_t - \Delta_t \simeq 0 \tag{10}$$

is a no arbitrage restriction in the absence of any transactions costs where p_t represents the percentage forward premium for the forward contract maturing at date T_2 over the forward rate for the contract maturing at date T_1 and Δ_t represents the forward interest rate differential. Notice that by eliminating spot currency prices, we side-step several potential problems. First, the futures and spot prices may not be observed simultaneously. Second, spot contracts are not traded on a unified exchange and do not have a well-defined price at any moment; we can only obtain bid and ask quotations by various commercial banks or institutions and these could differ across banks and across customers. Third, currency futures contracts for the nearest two maturities, that we use in our analysis, are heavily traded contracts that are extremely liquid. This reduces the possibility that the prices used for futures contracts with different maturities are non-synchronous.

If there are transactions costs, however, there may be deviations from the parity relationship (10):

$$-k \leq d_t \leq k.$$

Following Frenkel and Levich (1975, 1977) it follows that

$$k = C + C^* + C_{T_1} + C_{T_2}, \tag{11}$$

where $C \equiv$ percentage transactions costs in the eurodollar market; $C^* \equiv$ percentage transactions costs in the foreign eurocurrency market; $C_{T_1} \equiv$ percentage transac-

and Oldfield (1981). French (1983), however, shows that the difference between the two prices is empirically insignificant. So, in our analysis, we shall assume that futures prices equal forward prices.

tions costs in the futures market for a contract with maturity T_1; $C_{T_2} \equiv$ percentage transactions costs in the futures market for a contract with maturity T_2.[4]

If we make a simplifying assumption that percentage transactions costs are equal in all four markets (denoted C), then deviation from the parity relationship must be within a band that can be written as:

$$-4C \leq d_t \leq 4C.$$

Thus C can be estimated by estimating the range within which observations for d_t lie. Since, there may be some errors in data, we can estimate the band within which a large percentage (say 95%) of all observations for d_t fall. This is one approach we follow in our empirical analysis.

The second approach we use follows a simple variant of the approach used in Roll (1984). The precise distribution of d_t depends on whether each observed price in the parity relationship (9) is a bid or an ask price. Thus,

$$d_t \in \{-4C, -2C, 0, 2C, 4C\},$$

with a probability distribution

$$\left\{\frac{1}{16}, \frac{1}{4}, \frac{3}{8}, \frac{1}{4}, \frac{1}{16}\right\}.$$

Following Roll (1984), it is easy to show that the changes in d_t will have negative serial covariance, the estimate of which also provides an estimate of the percentage transaction cost C according to the following relationship:[5]:

$$C = \sqrt{-\text{cov}}/2 \equiv C_{\text{Roll}}.$$

2.2.1. *Data*

All the data were obtained from Datastream. Our sample period is from January 1, 1977 to December 31, 1999. The foreign exchange data consist of daily prices of per unit of four major currencies in the US dollar: the British pound, Deutsche mark, Japanese yen, and Swiss franc. For each currency, we construct two time series of futures prices traded on the Chicago Mercantile Exchange (CME),

[4] Deardoff (1979) and Mohsen-Oskooee and Das (1985) argue, and it was pointed out to us by Richard Levich, that one-way arbitrage together with the existence of non-trivial equilibria in the futures markets for contracts with both maturities and in the bond markets in both countries implies a narrower band which could be as low as zero. This is equivalent to the observation that d_t could equal zero for a particular combination of bid and ask prices for the four prices that appear in the parity relationship. As we shall see below, however, that when we use transaction prices, there will exist some combinations of bid and ask prices that make the band around the parity relation as large as the sum of transactions costs in each of the four markets as is expressed in (11).

[5] A formal proof of the exact derivation of this formula is available from the authors upon request.

$F(t, T_1)$ and $F(t, T_2)$. The first one, $F(t, T_1)$, is the closest-to-delivery futures contract and the second one, $F(t, T_2)$, is the next closest-to-delivery contract.[6]

We use the eurocurrency interest rates for the four currencies and the US dollar quoted by London Financial Times. We first obtain the continuously compounded annual yield of these rates with maturities in 1, 3, and 6 months, and then interpolate/extrapolate linearly to get a proxy of the interest rate for any maturity between 10 and 210 days.[7] In this way, we construct two time series of interest rates $i(t, T_1)$ and $i(t, T_2)$ for the domestic currency and $i^*(t, T_1)$ and $i^*(t, T_2)$ for each foreign currency.[8] Our constructed $i(t, T_1, T_2) \equiv i(t, T_2) - i(t, T_1)$ is basically a synthesized forward rate. We then use Δ_t to denote the difference of these synthesized forward rates. One can actually do a better job in approximating the forward rates with the interest futures. The major disadvantage of this approach is the limited availability of the data on interest futures. Another problem is the non-synchronous trading of the interest futures and the foreign exchange futures. Nonetheless, we take the longest possible time series of the futures price of the 3-month interest rates for the four foreign currencies and US dollar. We denote the difference between the domestic and the foreign forward rates using the implied forward rates from the interest futures as $\hat{\Delta}_t$.[9] We will use $\hat{\Delta}_t$ as a robustness check for our results.

2.2.2. *Results*

Figure 1 shows the time series plots of p_t and Δ_t for the four currencies. As seen in the figure, p_t and Δ_t track each other very closely. However, the plots of Δ_t are much smoother than those of p_t as there are dozens of spikes in p_t for each currency. These spikes are more evident in Figure 2 which shows the plots of d_t.

Table I reports the summary statistics and percentiles of d_t for the four foreign currencies for the whole sample period and two sub-sample periods, 1/1977–6/1988 and 7/1988–12/1999. One obvious fact is that the distribution of d_t is much tighter during the second sub-period, which can also been seen from the graphs of d_t. The large kurtosis of d_t's are mostly caused by the spikes observed in Figure 2. Figure 3 shows the central portions of the histograms of d_t for the four currencies.

To check the robustness of our results, we also estimate d_t using the forward interest rates implied in the interest futures prices, which is denoted by $\hat{d}_t$. Table II

[6] We stop using the closest-to-delivery contract to be $F(t, T_1)$ and switch to the next-closest-to-delivery contract on the first day of the delivery month. The foreign exchange futures are on March, June, September, and December cycles. For example, in February, the March and June contracts are used. On the first day of March and thereafter (until September 1), we choose the June and September contracts.

[7] The range for all maturities of the futures contracts is between 13 to 202 days for our sample.

[8] The sample size for Japanese yen is slightly shorter than others since data on the interest rates of Japanese yen was not available until July, 1978.

[9] The data of 3-month interest rate futures are available from 11/1982, 5/1993, 6/1989, 2/1991, and 4/1981 for British pound, Deutsche mark, Japanese yen, Swiss franc, and US dollar respectively. The Deutsche mark series ends in 12/1996.

Table I. Sample statistics for d_t. This table reports the sample statistics and percentiles of d_t for the four foreign currencies for the whole sample period and two sub-sample periods

	1/1/1977–12/31/1999					
	Mean	S.D.	Skew	Kurt	Max	Min
British Pound	-2.2×10^{-4}	9.9×10^{-4}	−1.24	92	0.019	−0.023
Deutsche Mark	-2.5×10^{-4}	9.9×10^{-4}	−2.75	259	0.026	−0.031
Japanese Yen	-3.5×10^{-4}	12.2×10^{-4}	7.93	217	0.033	−0.018
Swiss Franc	-2.4×10^{-4}	11.7×10^{-4}	−3.29	190	0.018	−0.036
	Percentiles					
	0.5	2.5	5	95	97.5	99.5
British Pound	-3.54×10^{-3}	-2.07×10^{-3}	-1.60×10^{-3}	0.83×10^{-3}	1.40×10^{-3}	3.41×10^{-3}
Deutsche Mark	-3.30×10^{-3}	-2.03×10^{-3}	-1.60×10^{-3}	0.68×10^{-3}	0.97×10^{-3}	2.40×10^{-3}
Japanese Yen	-3.92×10^{-3}	-2.59×10^{-3}	-2.05×10^{-3}	0.69×10^{-3}	1.46×10^{-3}	3.34×10^{-3}
Swiss Franc	-4.12×10^{-3}	-2.37×10^{-3}	-1.74×10^{-3}	0.83×10^{-3}	1.42×10^{-3}	3.85×10^{-3}

	1/1/1977–6/30/1988					
	Mean	S.D.	Skew	Kurt	Max	Min
British Pound	-3.7×10^{-4}	12.5×10^{-4}	−1.36	67	0.019	−0.023
Deutsche Mark	-5.3×10^{-4}	12.4×10^{-4}	−1.81	207	0.026	−0.031
Japanese Yen	-5.2×10^{-4}	14.5×10^{-4}	3.66	91	0.029	−0.018
Swiss Franc	-4.9×10^{-4}	14.1×10^{-4}	−3.91	166	0.018	−0.036
	Percentiles					
	0.5	2.5	5	95	97.5	99.5
British Pound	-4.30×10^{-3}	-2.76×10^{-3}	-2.03×10^{-3}	1.29×10^{-3}	1.94×10^{-3}	3.59×10^{-3}
Deutsche Mark	-3.83×10^{-3}	-2.47×10^{-3}	-2.00×10^{-3}	0.72×10^{-3}	1.38×10^{-3}	2.68×10^{-3}
Japanese Yen	-4.63×10^{-3}	-3.11×10^{-3}	-2.47×10^{-3}	1.47×10^{-3}	2.07×10^{-3}	4.04×10^{-3}
Swiss Franc	-4.41×10^{-3}	-2.95×10^{-3}	-2.25×10^{-3}	1.22×10^{-3}	1.84×10^{-3}	3.82×10^{-3}

	7/1/1988-12/31/1999					
	Mean	S.D.	Skew	Kurt	Max	Min
British Pound	-6.6×10^{-5}	6.0×10^{-4}	3.66	87	0.011	−0.007
Deutsche Mark	-3.3×10^{-5}	5.3×10^{-4}	−5.91	173	0.005	−0.014
Japanese Yen	-2.1×10^{-4}	9.6×10^{-4}	20.2	650	0.033	−0.005
Swiss Franc	-1.5×10^{-6}	8.0×10^{-4}	2.54	122	0.017	−0.013
	Percentiles					
	0.5	2.5	5	95	97.5	99.5
British Pound	-1.77×10^{-3}	-1.03×10^{-3}	-0.79×10^{-3}	0.61×10^{-3}	0.77×10^{-3}	2.09×10^{-3}
Deutsche Mark	-1.37×10^{-3}	-0.91×10^{-3}	-0.70×10^{-3}	0.67×10^{-3}	0.79×10^{-3}	1.26×10^{-3}
Japanese Yen	-3.03×10^{-3}	-0.97×10^{-3}	-0.73×10^{-3}	0.42×10^{-3}	0.55×10^{-3}	0.93×10^{-3}
Swiss Franc	-2.22×10^{-3}	-0.97×10^{-3}	-0.73×10^{-3}	0.66×10^{-3}	0.83×10^{-3}	3.91×10^{-3}

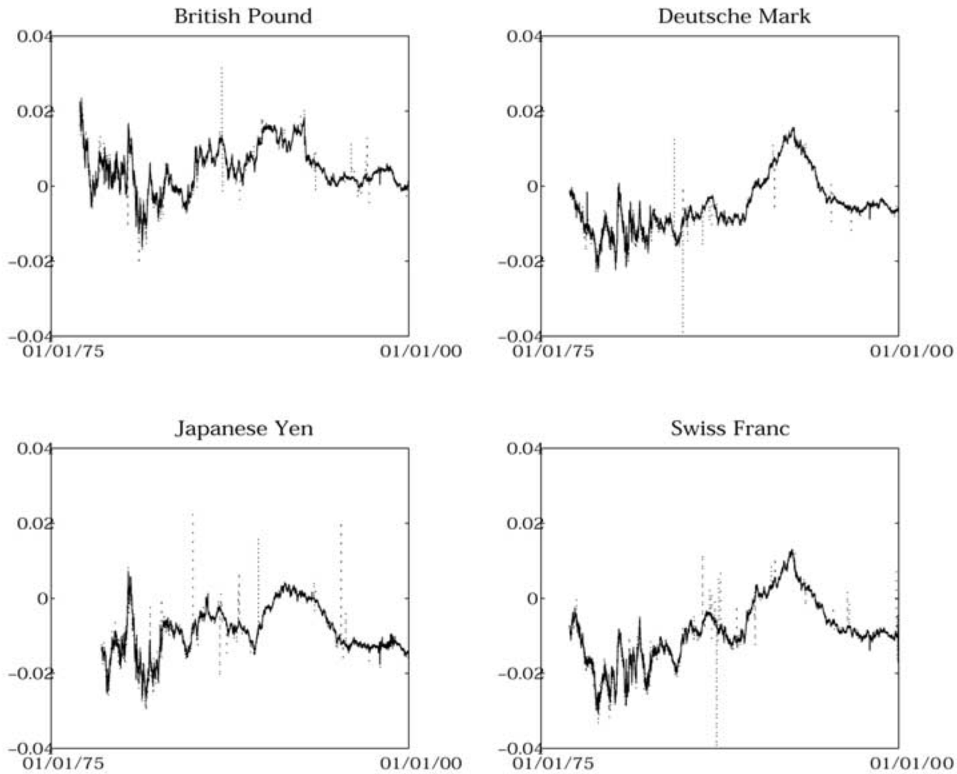

Figure 1. The plots of p_t and Δ_t for the four foreign currencies between 1/1/1977 and 12/31/1999, The dotted lines represent p_t, and the solid lines represent Δ_t.

reports the summary statistics of $\hat{d}_t$ for the currencies for their longest possible sample periods. The sample statistics for Deutsche mark, Japanese yen, and Swiss franc are very close to their corresponding values in Table I for the second sub-period. The sample statistics for British pound are comparable but not very close to those in Table I for the whole sample period. This can be easily seen from Figure 4 which shows the plot of Δ_t and $\hat{\Delta}_t$. For all currencies except British pound, Δ_t and $\hat{d}_t$ track each other closely. For British pound, Δ_t and $\hat{\Delta}_t$ are pretty close except in the late 80's when $\hat{\Delta}_t$ is constantly higher than Δ_t.

We further check if the distribution of d_t is affected by the liquidity of the futures markets. To this end, we examine the trading volume of the two futures contracts from Datastream. Although the closest-to-delivery contract is actively traded most of time, the second-closest-to-delivery contract is not as heavily traded as the first one. We test a number of filter rules which restrict our sample to certain dates when

Table II. Sample Statistics for $\hat{d}_t$. This table reports the sample statistics and percentiles of $\hat{d}_t$ for the four foreign currencies for their longest possible sample periods. The sample periods for British pound, Deutsche mark, Japanese yen, and Swiss franc are 11/4/1982–12/31/1999, 5/6/1993–12/27/1996, 6/30/1989–12/31/1999, and 2/7/1991–12/31/1999 respectively

	Mean	S.D.	Skew	Kurt	Max	Min
British Pound	-9.0×10^{-4}	10.8×10^{-4}	0.35	34.9	0.017	−0.016
Deutsche Mark	9.9×10^{-5}	4.1×10^{-4}	−2.08	67.7	0.005	−0.005
Japanese Yen	1.1×10^{-5}	8.1×10^{-4}	26.8	1099	0.033	−0.006
Swiss Franc	1.9×10^{-4}	8.2×10^{-4}	3.92	107	0.017	−0.007
	Percentiles					
	0.5	2.5	5	95	97.5	99.5
British Pound	-3.47×10^{-3}	-3.18×10^{-3}	-2.99×10^{-3}	0.30×10^{-3}	0.65×10^{-3}	1.38×10^{-3}
Deutsche Mark	-0.67×10^{-3}	-0.49×10^{-3}	-0.41×10^{-3}	0.45×10^{-3}	0.48×10^{-3}	0.11×10^{-3}
Japanese Yen	-1.79×10^{-3}	-0.96×10^{-3}	-0.70×10^{-3}	0.60×10^{-3}	0.93×10^{-3}	1.08×10^{-3}
Swiss Franc	-1.78×10^{-3}	-1.02×10^{-3}	-0.82×10^{-3}	0.74×10^{-3}	0.81×10^{-3}	3.98×10^{-3}

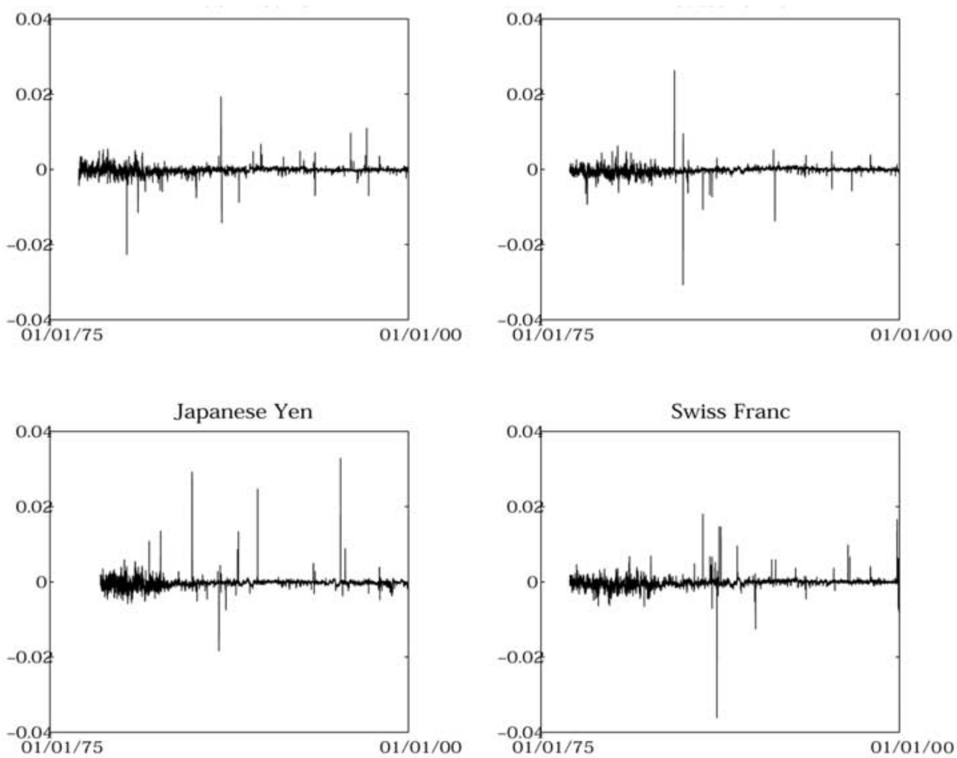

Figure 2. The plots of d_t for the four foreign currencies between 1/1/1977 and 12/31/1999.

the two contracts are both actively traded.[10] Our estimates (not reported here) are not much different from the those reported in Table I.

Table III reports the serial covariance of the changes in d_t, cov $\equiv$ Cov$(\Delta d_{t+1}, \Delta d_t)$, and its square root, $\sqrt{-\text{cov}}$, for the four foreign currencies.

Table IV reports the estimates of the transaction cost of foreign exchange market for the four foreign currencies considered. The first three measures are based on the sample distribution of d_t. For example, $C_{100-\alpha}$ is defined as:

$$C_{100-\alpha} \equiv \frac{1}{4}\left\{\frac{d_{100-\alpha/2} + (-d_{\alpha/2})}{2}\right\},$$

where $\alpha \in \{1, 5, 10\}$ and d_y represents the y percentile of the sample distribution of d_t. The last measure is the effective transactions costs estimated using the Roll (1984) method and is defined by $C_{\text{Roll}} \equiv \sqrt{-\text{cov}}/2$ where cov is the serial covariance of the changes in d_t. All the estimates are in percentage.

[10] The filters include lower bounds in trading volumes and lower bounds for ratios of trading volumes.

Table III. cov and $\sqrt{-\text{cov}}$. This table reports cov and $\sqrt{-\text{cov}}$ for the four foreign currencies for the whole sample period and two sub-periods, where cov is the serial covariance of the changes in d_t

	British Pound	Deutsche Mark	Japanese Yen	Swiss Franc
		1/1/1977–12/31/1999		
cov	-5.3×10^{-7}	-6.8×10^{-7}	-1.0×10^{-6}	-8.8×10^{-7}
$\sqrt{-\text{cov}}$	0.73×10^{-3}	0.83×10^{-3}	1.01×10^{-3}	0.94×10^{-3}
		1/1/1977–6/30/1988		
cov	-8.3×10^{-7}	-1.2×10^{-6}	-1.4×10^{-6}	-1.3×10^{-6}
$\sqrt{-\text{cov}}$	0.91×10^{-3}	1.12×10^{-3}	1.20×10^{-3}	1.12×10^{-3}
		7/1/1988–12/31/1999		
cov	-2.4×10^{-7}	-1.3×10^{-7}	-6.7×10^{-7}	-5.0×10^{-7}
$\sqrt{-\text{cov}}$	0.49×10^{-3}	0.36×10^{-3}	0.82×10^{-3}	0.70×10^{-3}

Table IV. Estimates of the transactions cost. This table reports the estimates of the transactions costs in the foreign exchange market for the four foreign currencies for the whole sample period and two sub-periods. All estimates are in percentage

	$C_{99\%}$	$C_{95\%}$	$C_{90\%}$	C_{Roll}
		1/1/1977–12/31/1999		
British Pound	0.087	**0.043**	0.030	**0.036**
Deutsche Mark	0.071	**0.038**	0.029	**0.041**
Japanese Yen	0.091	**0.051**	0.034	**0.051**
Swiss Franc	0.100	**0.047**	0.032	**0.047**
		1/1/1977–6/30/1988		
British Pound	0.099	**0.059**	0.042	**0.046**
Deutsche Mark	0.081	**0.048**	0.034	**0.056**
Japanese Yen	0.108	**0.065**	0.049	**0.060**
Swiss Franc	0.103	**0.060**	0.043	**0.056**
		7/1/1988–12/31/1999		
British Pound	0.048	**0.023**	0.018	**0.024**
Deutsche Mark	0.033	**0.021**	0.017	**0.018**
Japanese Yen	0.050	**0.019**	0.014	**0.041**
Swiss Franc	0.077	**0.023**	0.017	**0.035**

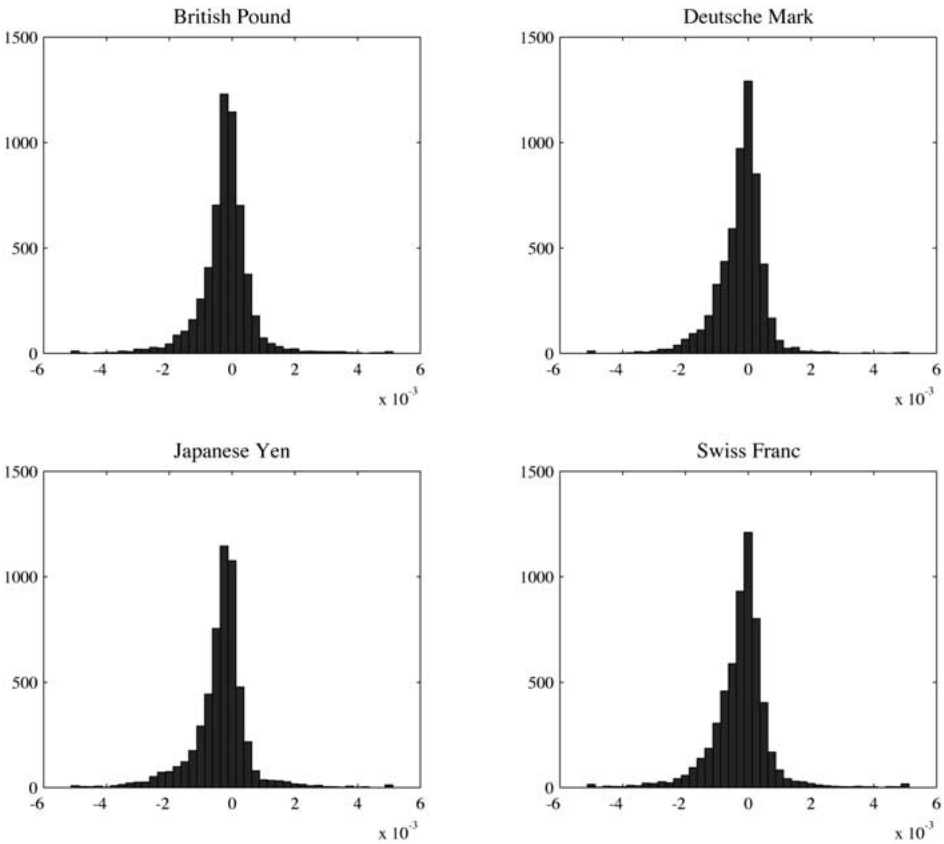

Figure 3. The histograms of d_t for the four foreign currencies between 1/1/1977 and 12/31/1999.

Notice that the estimates using the 95% bounds, $C_{95\%}$, are remarkably similar to the estimates using the Roll (1984) approach, C_{Roll}. These estimates are highlighted in boldface in Table IV. Using these estimates, we can make the following conclusions. For a foreign currency trade valued at $100,000, the average transaction costs, estimated using the data for the period 1977–1999, indicate that these costs were between $36 and $51. The estimates of the transactions costs for a similar sized trade, estimated using the data for the period 1988–1999, indicate that these costs may have been as low as $18 and perhaps no more than $35. Thus, not only have we established that transactions costs in the foreign exchange market are extremely small, but also that they have been falling substantially over the years.

3. Transactions Costs, Volatility and Volume

We construct monthly time series of transactions cost, volatility, and volume as following. For each month, we use the sub-sample of d_t in that month to calculate

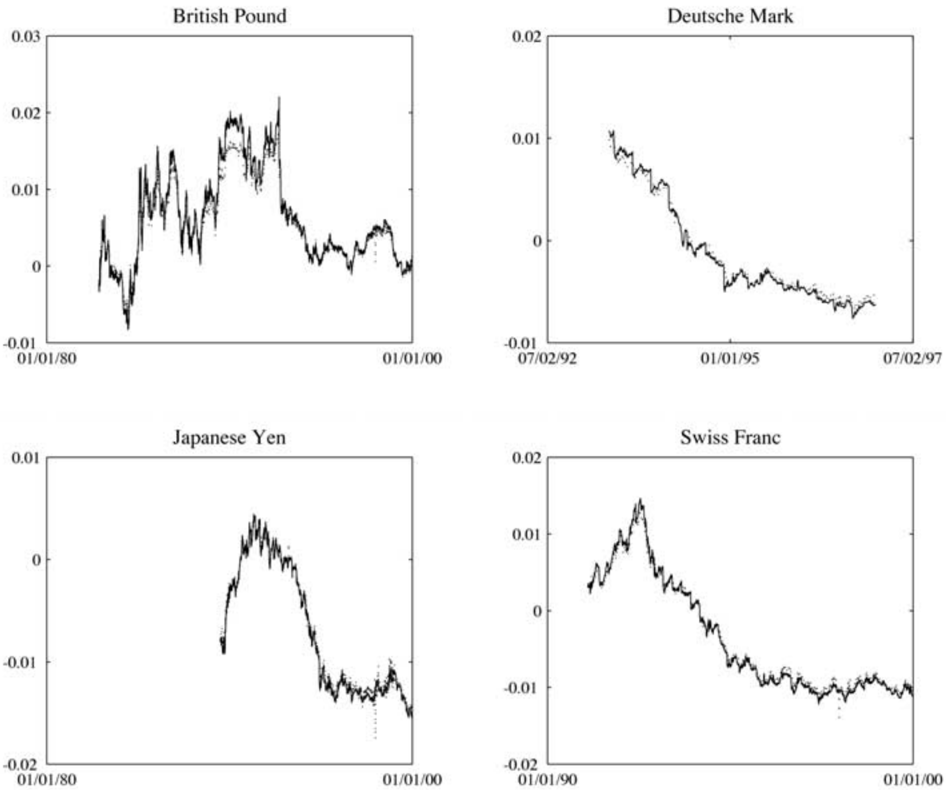

Figure 4. The plots of Δ_t and $\hat{\Delta}_t$ for the four foreign currencies, where Δ_t is the synthesized 3-month forward rate and $\hat{\Delta}_t$ is the 3-month forward rate implied in the 3-month interest rate futures. The dotted lines represent Δ_t, and the solid lines represent $\hat{\Delta}_t$.

$C_{95\%}$ and C_{Roll}.[11] Since the autocovariance of d_t is not always less than zero, C_{Roll} is not well defined for about a dozen months for each currency. We treat these months as missing observations.[12] The volatility is constructed as the standard deviation of daily returns in that month on the closest maturing futures contract. Since the volatility of interest rate differential is relatively very small, the volatility of the futures price should be close to the volatility of the spot rate. We annualize the volatility and report it in percentage. The volume is defined to be the average of daily volume (i.e., number of contracts) on the closest maturing futures contract in that month.

[11] As there are only about 22 observations of d_t in a month, we apply linear interpolation to find the 2.5% and 97.5% percentiles of the sample.

[12] The autocovariance is very small but positive in these months. Because the number of such observations is small, we decided not to address this issue more rigorously. A rigorous treatment of the Roll measure is available in Schultz (2000).

Table V. Sample statistics for transactions cost, volatility, and volume. This table reports the sample mean, standard deviation (S.D.), and first autocorrelation coefficient (ρ_1) for the series of transactions cost measures ($C_{95\%}$ and C_{Roll}), volatility, and trading volume for four foreign currencies, the British Pound (BP), the Deutsche Mark (DM), the Japanese Yen (JY) and the Swiss Franc (SF), for the period 01/1977–12/1999, where the volatility is monthly (annualized) standard deviation of percentage changes in the prices of the nearest maturing futures contract and volume is average daily trading volume of the nearest maturing futures contract. Both transactions cost and volatility are in percentage. N represents the number of observations

Panel A: Transactions cost								
	$C_{95\%}$				C_{Roll}			
	BP	DM	JY	SF	BP	DM	JY	SF
Mean	0.031	0.029	0.034	0.035	0.023	0.020	0.027	0.027
S.D.	0.038	0.038	0.048	0.044	0.031	0.028	0.042	0.042
ρ_1	0.173	0.213	0.165	0.221	0.191	0.187	0.128	0.199
N	276	276	258	276	264	269	244	262
Panel B: Volatility								
Mean	10.22	10.44	11.27	12.17				
S.D.	4.054	3.656	4.296	3.903				
ρ_1	0.544	0.460	0.389	0.439				
N	276	276	258	276				
Panel C: Volume								
Mean	7770	19698	15245	13483				
S.D.	4065	14105	8924	7315				
ρ_1	0.837	0.884	0.825	0.824				
N	276	276	258	276				

Table V reports the summary statistics for the time series of transactions cost, volatility and volume for four major foreign currencies. The transactions costs are mildly autocorrelated with first autocorrelation coefficient about 0.2. The first autocorrelation coefficients for volatility are around 0.45. The volume series are highly autocorrelated.

Table VI, Panel A, reports the results of OLS regressions of Volatility on Transactions Costs. Since the volatility series is autocorrelated, we also include Lagged Volatility as an independent variable; as expected the coefficients on Lagged Volatility are positive and highly significant. More interestingly, however, Volatility appears to be positively related to the level of Transactions Costs (both measures); the coefficients are positive for all four currencies and significant for all currencies except the Deutsche Mark. In Panel B, in addition to Transactions Costs and Lagged Volatility, we also include Volume and a Time Trend variable as independent variables. Volume appears to be positively related to Volatility. Also, we detect a secular decline in Volatility over time which is statistically significant for three out of four currency pairs. However, Transactions Costs and Lagged Volatility continue to be significant in explaining the variation in Volatility.

We notice that in Figure 2, the estimates of d_t have a few very large spikes which are likely to be caused by errors. To ensure that our results are not being driven by outliers, for each month, we exclude observations of d_t that are at least three standard deviations away from the mean of the month. Then $C_{95\%}$ and C_{Roll} are constructed as before. Table VII repeats the OLS regressions reported in Table VI using the filtered data. The results for Transactions Costs are even more significant now.[13]

One might suspect that residuals from the regressions for the four currencies may be correlated across currencies. In Table VIII, we run the same regressions as those reported in Table VI but we estimate the coefficients using the seemingly unrelated regression method. The results are similar to those reported in Table VI.

Table IX reports the results of regressions of Volume on Transactions costs. Since the volume series is autocorrelated, we also include Lagged Volume as an independent variable; as expected the coefficients on Lagged Volume are positive and highly significant. We also include Volatility as an independent variable as one might expect higher volume of trading when the volatility of exchange rates is high;[14] indeed the coefficients for Volatility are positive and significant for all currencies. The marginal contribution of Transactions Costs on Volume is negative and significant (for all currencies except the Deutsche Mark for which it is significant at 90% level) as one might expect.

Are these results economically significant? Some simple back-of-the-envelope calculations suggest the following. Let us say a typical coefficient on the relation between Volatility and Transactions Cost – from Table VI – is 15. If the transactions costs increase by 0.02 percent, this would imply an increase of 0.3% in volatility. However, we must also take care of the lagged effect. Say the typical coefficient on Lagged Volatility in Table VI is 0.4. The total effect of an increase in transactions costs then would be 0.3% times the factor 1/(1–0.4) which equals 0.5%. Let us now compute the effect of an increase in transactions costs of 0.02 percent on Volume. Let us say the typical coefficient on the relation between Volume and Transactions Cost is -2. This implies that Volume will decrease by 400 contracts. Taking into the effect of Lagged Volume, as the typical coefficient is 0.8, the total effect on Volume is 400 contracts times a factor 1/(1–0.8) which equals a decrease of 2000 contracts. So to summarize, even a modest increase of 0.02 percent in the transactions costs can increase the volatility of the exchange rates (which from

[13] We have also examined other filter rules (such as excluding outliers from the whole sample of d_t and then constructing $C_{95\%}$ and C_{Roll}) and our results remain essentially the same.

[14] Karpoff (1987) summarizes evidence of such a relationship in equity market trading.

Table VI. OLS Regressions of volatility on transactions costs. This table reports estimates of ordinary least square regressions for four foreign currencies, the British Pound (BP), the Deutsche Mark (DM), the Japanese Yen (JY) and the Swiss Franc (SF), for the period 01/1977–12/1999. Both transactions cost and volatility are in percentage. In Panel A, volatility is regressed on transactions cost and its own lag. In Panel B, volatility is regressed on transactions cost, its own lag, volume and time (in months). We report the estimates of the coefficients (and the t-statistics in parentheses). The left and right panels show the results for the two measures of transactions cost, $C_{95\%}$ and C_{Roll} respectively. We also report R^2 and number of observations N for each regression

	$C_{95\%}$				C_{Roll}			
	BP	DM	JY	SF	BP	DM	JY	SF
Panel A								
Transactions cost	12.12	2.767	16.79	13.11	13.69	6.542	22.59	11.86
	(2.246)	(0.533)	(3.253)	(2.780)	(1.990)	(0.924)	(3.710)	(2.342)
Lagged volatility	0.552	0.456	0.359	0.427	0.562	0.434	0.348	0.416
	(10.94)	(8.402)	(6.246)	(7.984)	(10.52)	(7.933)	(5.823)	(7.686)
R^2	0.310	0.213	0.185	0.218	0.302	0.200	0.197	0.206
N	275	275	257	275	263	268	243	261
Panel B								
Transactions cost	16.23	6.012	23.26	14.78	18.29	12.52	29.65	12.73
	(2.973)	(0.799)	(4.361)	(3.080)	(2.644)	(0.834)	(4.707)	(2.526)
Lagged volatility	0.432	0.366	0.341	0.372	0.437	0.339	0.328	0.368
	(8.355)	(5.455)	(6.052)	(6.906)	(8.085)	(4.977)	(5.581)	(6.759)
Volume/1000	0.449	0.082	0.149	0.145	0.479	0.088	0.137	0.138
	(6.047)	(3.463)	(3.906)	(4.030)	(6.311)	(3.758)	(3.549)	(3.757)
Time trend	−0.017	−0.007	−0.005	−0.009	−0.018	−0.007	−0.003	−0.010
	(−4.586)	(−1.873)	(−1.007)	(−2.722)	(−4.832)	(−1.946)	(−0.628)	(−2.907)
R^2	0.393	0.271	0.246	0.263	0.395	0.269	0.256	0.249
N	275	275	257	275	263	268	243	261

Table VII. OLS regressions of volatility on transactions costs using filtered data. This table reports estimates of ordinary least square regressions for four foreign currencies, the British Pound (BP), the Deutsche Mark (DM), the Japanese Yen (JY) and the Swiss Franc (SF), for the period 01/1977–12/1999. For each month, we exclude observations of d_t that are at least three standard deviations away from the mean of the month. Then $C_{95\%}$ and C_{Roll} are constructed as before. Both transactions cost and volatility are in percentage. In Panel A, volatility is regressed on transactions cost and its own lag. In Panel B, volatility is regressed on transactions cost, its own lag, volume and time (in months). We report the estimates of the coefficients (and the t-statistics in parentheses). The left and right panels show the results for the two measures of transactions cost, $C_{95\%}$ and C_{Roll} respectively. We also report R^2 and number of observations N for each regression

	$C_{95\%}$				C_{Roll}			
	BP	DM	JY	SF	BP	DM	JY	SF
Panel A								
Transactions cost	24.30	1.679	22.24	20.74	21.46	6.078	27.65	6.539
	(2.556)	(0.164)	(2.086)	(2.164)	(1.828)	(0.459)	(2.410)	(0.648)
Lagged volatility	0.557	0.460	0.368	0.430	0.561	0.438	0.347	0.426
	(11.04)	(8.562)	(6.319)	(7.989)	(10.50)	(8.055)	(5.671)	(7.866)
R^2	0.314	0.213	0.165	0.209	0.299	0.198	0.157	0.196
N	275	275	257	275	262	268	242	260
Panel B								
Transactions cost	45.66	23.51	83.23	46.81	39.46	44.32	86.47	17.36
	(3.986)	(1.842)	(5.745)	(3.877)	(2.811)	(2.567)	(5.704)	(1.564)
Lagged volatility	0.443	0.363	0.285	0.353	0.443	0.330	0.270	0.370
	(8.664)	(6.564)	(5.029)	(6.565)	(8.151)	(5.942)	(4.534)	(6.831)
Volume/1000	0.485	0.090	0.220	0.197	0.491	0.101	0.201	0.156
	(3.986)	(4.897)	(5.479)	(5.032)	(6.044)	(5.397)	(5.030)	(4.072)
Time trend	−0.013	−0.005	0.002	−0.007	−0.016	−0.005	0.003	−0.010
	(−3.513)	(−1.697)	(0.341)	(−2.111)	(−3.926)	(−1.519)	(0.559)	(−3.006)
R^2	0.408	0.277	0.283	0.277	0.395	0.279	0.274	0.247
N	275	275	257	275	262	267	242	260

Table V is about 10–12% a year) by one-half percentage on an annualized basis and lead to a decrease in the daily volume (which from Table V is about 8,000–10,000 contracts) by 2000 contracts.

3.1. DEALING WITH ENDOGENEITY

One might argue that the positive relation we find between volatility and transactions costs might in fact be a result of higher fundamental volatility causing

Table VIII. Seemingly unrelated regressions of volatility on transactions costs. This table reports estimates of seemingly unrelated regressions for four foreign currencies, the British Pound (BP), the Deutsche Mark (DM), the Japanese Yen (JY) and the Swiss Franc (SF), for the period 01/1977–12/1999. Both transactions cost and volatility are in percentage. In Panel A, volatility is regressed on transactions cost and its own lag. In Panel B, volatility is regressed on transactions cost, its own lag, volume and time (in months). We report the estimates of the coefficients (and the t-statistics in parentheses). The left and right panels show the results for the two measures of transactions cost, $C_{95\%}$ and C_{Roll} respectively. We also report R^2 and number of observations N for each regression

	$C_{95\%}$				C_{Roll}			
	BP	DM	JY	SF	BP	DM	JY	SF
Panel A								
Transactions cost	13.04	2.803	15.43	13.72	14.35	4.999	19.85	12.23
	(3.141)	(1.169)	(3.392)	(6.139)	(2.673)	(1.348)	(3.666)	(4.462)
Lagged volatility	0.475	0.433	0.419	0.401	0.497	0.438	0.421	0.415
	(11.53)	(12.12)	(8.238)	(11.18)	(11.31)	(11.67)	(7.885)	(10.91)
R^2	0.304	0.213	0.181	0.217	0.297	0.199	0.191	0.204
N	275	275	257	275	263	268	243	261
Panel B								
Transactions cost	14.20	3.732	21.67	11.68	15.42	8.074	25.78	9.787
	(3.371)	(1.401)	(4.782)	(4.831)	(2.853)	(1.986)	(4.810)	(3.432)
Lagged volatility	0.393	0.381	0.378	0.359	0.400	0.364	0.374	0.362
	(9.279)	(10.15)	(7.879)	(9.800)	(9.002)	(9.343)	(7.412)	(9.396)
Volume/1000	0.393	0.051	0.152	0.089	0.416	0.060	0.151	0.099
	(6.391)	(4.771)	(4.652)	(4.066)	(6.740)	(5.244)	(4.500)	(4.085)
Time trend	−0.014	−0.003	−0.003	−0.005	−0.017	−0.005	−0.003	−0.008
	(−4.393)	(−1.247)	(−0.664)	(−1.968)	(−5.075)	(−1.958)	(−0.721)	(−2.886)
R^2	0.387	0.262	0.242	0.254	0.391	0.260	0.251	0.243
N	275	275	257	275	263	268	243	261

Table IX. Regressions of volume on transactions costs. This table reports estimates of regressions for four foreign currencies, the British Pound (BP), the Deutsche Mark (DM), the Japanese Yen (JY) and the Swiss Franc (SF), for the period 01/1977–12/1999. Both transactions cost and volatility are in percentage. In Panel A, OLS regression of volume on transactions cost, volatility and its own lag is reported. In Panel B, seemingly unrelated regression of volume on transactions cost, volatility and its own lag is reported. We report the estimates of the coefficients (and the t-statistics in parentheses). The left and right panels show the results for the two measures of transactions cost, $C_{95\%}$ and C_{Roll} respectively. We also report R^2 and number of observations N for each regression

	$C_{95\%}$				C_{Roll}			
	BP	DM	JY	SF	BP	DM	JY	SF
Panel A: OLS								
Transactions cost	−1.269	−1.865	−2.447	−1.815	−1.471	−2.637	−2.847	−1.583
× 10000	(−3.568)	(−1.829)	(−3.666)	(−3.267)	(−3.230)	(−1.826)	(−3.633)	(−2.708)
Volatility × 1000	0.114	0.485	0.371	0.263	0.120	0.494	0.378	0.245
	(3.554)	(4.541)	(5.192)	(4.217)	(3.610)	(4.439)	(5.142)	(3.839)
Lagged volume	0.782	0.850	0.779	0.795	0.779	0.847	0.788	0.823
	(23.31)	(30.01)	(22.46)	(23.99)	(22.27)	(28.59)	(22.66)	(25.04)
R^2	0.733	0.808	0.722	0.714	0.724	0.804	0.732	0.728
N	275	275	257	275	263	268	243	261
Panel B: SUR								
Transactions cost	−0.310	−0.075	−1.130	−0.667	−0.506	−0.117	−1.516	−0.629
× 10000	(−1.204)	(−0.137)	(−2.370)	(−2.369)	(−1.522)	(−0.139)	(−2.510)	(−1.838)
Volatility × 1000	0.127	0.498	0.376	0.282	0.135	0.510	0.399	0.274
	(5.117)	(6.968)	(7.181)	(7.080)	(5.226)	(6.663)	(6.918)	(6.196)
Lagged volume	0.786	0.845	0.781	0.805	0.771	0.829	0.776	0.803
	(29.66)	(44.60)	(29.13)	(37.11)	(27.77)	(40.61)	(27.43)	(34.43)
R^2	0.724	0.805	0.716	0.708	0.717	0.801	0.726	0.723
N	275	275	257	275	263	268	243	261

Table X. Futures volatility, transactions cost and spot volatility. Panel A reports the sample mean, standard deviation (S.D.), and first autocorrelation coefficient (ρ_1) for the spot volatility series for four foreign currencies, the British Pound (BP), the Deutsche Mark (DM), the Japanese Yen (JY) and the Swiss Franc (SF), for the period 01/1980–12/1999, where the spot volatility is the monthly (annualized) standard deviation of percentage changes in the daily spot exchange rate. The volatility is in percentage. We also report the correlation between the spot and futures volatilities. N is the number of observations. Panels B and C report estimates of ordinary least square regressions. In Panel B futures volatility is regressed on transactions cost and spot volatility. In Panel C futures volatility is regressed on transactions cost, spot volatility, volume and time (in months). We report the estimates of the coefficients (and the t-statistics in parentheses). The left and right panels show the results for the two measures of transactions cost, $C_{95\%}$ and C_{Roll} respectively. We also report R^2 and number of observations N for each regression

	BP	DM	JY	SF
	Panel A: Spot volatility: Summary statistics			
Mean	9.759	10.44	10.38	11.51
S.D.	4.065	3.816	4.027	3.911
ρ_1	0.579	0.427	0.413	0.392
Correlation with Futures volatility	0.892	0.872	0.903	0.834
N	240	240	240	240

	$C_{95\%}$				C_{Roll}			
	BP	DM	JY	SF	BP	DM	JY	SF
	Panel B: OLS Regression of futures volatility as dependent variable							
Transactions cost	12.89	3.290	6.440	11.56	16.12	6.145	8.888	11.06
	(4.403)	(1.138)	(2.558)	(4.127)	(4.278)	(1.507)	(2.960)	(3.666)
Spot volatility	0.883	0.812	0.964	0.790	0.880	0.802	0.958	0.780
	(31.47)	(27.26)	(31.79)	(23.69)	(30.58)	(26.47)	(30.80)	(22.44)
R^2	0.811	0.762	0.821	0.716	0.809	0.757	0.825	0.704
N	240	240	240	240	230	234	226	226
	Panel C: OLS regression of futures volatility as dependent variable							
Transactions cost	13.38	3.954	7.087	10.61	16.34	7.658	9.380	10.26
	(4.336)	(1.38)	(2.628)	(3.702)	(4.140)	(1.794)	(2.941)	(3.396)
Spot volatility	0.861	0.790	0.958	0.765	0.855	0.777	0.954	0.755
	(26.81)	(24.90)	(29.53)	(22.29)	(25.72)	(24.09)	(28.70)	(21.21)
Volume/1000	0.070	0.022	0.003	0.037	0.069	0.026	−0.001	0.034
	(1.525)	(2.205)	(0.135)	(1.534)	(1.437)	(2.501)	(−0.037)	(1.352)
Time trend	−0.003	−0.001	0.001	−0.006	−0.003	−0.002	0.001	−0.006
	(−1.179)	(−0.754)	(0.494)	(−2.796)	(−1.322)	(−0.814)	(0.446)	(−2.974)
R^2	0.813	0.767	0.821	0.726	0.811	0.764	0.825	0.715
N	240	240	240	240	230	234	226	226

Table XI. Simulating the bias in estimated coefficients. This table reports the mean percentage deviations in the estimates of coefficients θ_c and θ_s from their true theoretical values in the OLS regression:

$$\sigma_{f,t} = \theta_0 + \theta_c C_{f,t} + \theta_s \sigma_{s,t} + \varepsilon'_{f,t},$$

where the data are generated according to the model:

$$C_{f,t} = a_f + b_f \sigma_t + e_{f,t},$$
$$C_{s,t} = a_s + b_s \sigma_t + e_{s,t},$$
$$\sigma_{f,t} = \alpha_f + \beta_f \sigma_t + \gamma_f e_{f,t} + \varepsilon_{f,t},$$
$$\sigma_{s,t} = \alpha_s + \beta_s \sigma_t + \gamma_s e_{s,t} + \varepsilon_{s,t}.$$

The residuals are assumed to be independent white noises with mean 0 and standard deviation $\sigma_{e_{f,t}} = \sigma_{e_{s,t}} \equiv \sigma_e$ and $\sigma_{\epsilon_{f,t}} = \sigma_{\epsilon_{s,t}} \equiv \sigma_\epsilon$. The variable σ_t is normally distributed with mean 0 and standard deviation equal to 4. We fix other parameters as following: $a_s = a_f = 0.032$, $\alpha_s = \alpha_f = 11.02$, $b_s = b_f = 0.001$, $\beta_s = \beta_f = 1$, $\gamma_s = \gamma_f = 10$. Parameters $(\sigma_e, \sigma_\varepsilon)$ are chosen from the range $0.03 \leq \sigma_e \leq 0.05$, $1 \leq \sigma_\varepsilon \leq 1.6$. According to the model, the theoretical value of the regression coefficients are $\theta_c = 10$ and $\theta_s = 0.985$. To simulate, we generate data using the specified econometric model with a sample size of 250. We then estimate the regression on the simulated data. The same experiment is repeated 5000 times. We report the mean percentage bias in the estimated θ_c and θ_s, and the correlations between the simulated series $\sigma_{s,t}$ and $\sigma_{f,t}$

$\sigma_e \setminus \sigma_\epsilon$	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55	1.6
0.03	12.3	13.4	14.4	15.5	16.7	17.8	19.0	20.2	21.5	22.8	24.1	25.4	26.7
	−6.5	−7.1	−7.7	−8.3	−8.9	−9.6	−10.2	−10.9	−11.6	−12.3	−13.0	−13.7	−14.5
	0.936	0.931	0.925	0.919	0.913	0.906	0.900	0.893	0.886	0.879	0.872	0.865	0.858
0.032	11.0	11.9	12.9	13.8	14.8	15.9	16.9	18.0	19.1	20.2	21.3	22.5	23.7
	−6.6	−7.1	−7.7	−8.3	−9.0	−9.6	−10.3	−10.9	−11.6	−12.3	−13.0	−13.8	−14.5
	0.936	0.930	0.924	0.918	0.912	0.906	0.899	0.893	0.886	0.879	0.872	0.865	0.857
0.034	9.9	10.7	11.6	12.4	13.3	14.2	15.2	16.1	17.1	18.1	19.1	20.1	21.2
	−6.6	−7.2	−7.8	−8.4	−9.0	−9.6	−10.3	−11.0	−11.7	−12.4	−13.1	−13.8	−14.5
	0.935	0.929	0.923	0.918	0.911	0.905	0.899	0.892	0.885	0.878	0.871	0.864	0.857

Table XI. Continued

$\sigma_e \setminus \sigma_\epsilon$	1.1	05.1	1.1	15.1	2.1	25.1	3.1	35.1	4.1	45.1	5.1	55.1	6.
0.036	9.0	9.7	10.5	11.2	12.0	12.9	13.7	14.5	15.4	16.3	17.2	18.1	19.1
	−6.7	−7.3	−7.8	−8.4	−9.1	−9.7	−10.4	−11.0	−11.7	−12.4	−13.1	−13.9	−14.6
	0.934	0.928	0.923	0.917	0.911	0.904	0.898	0.891	0.884	0.878	0.871	0.863	0.856
0.038	8.2	8.9	9.5	10.2	11.0	11.7	12.4	13.2	14.0	14.8	15.6	16.4	17.3
	−6.8	−7.3	−7.9	−8.5	−9.1	−9.8	−10.4	−11.1	−11.8	−12.5	−13.2	−13.9	−14.6
	0.933	0.928	0.922	0.916	0.910	0.904	0.897	0.891	0.884	0.877	0.870	0.863	0.855
0.04	7.6	8.1	8.8	9.4	10.0	10.7	**11.4**	12.1	12.8	13.5	14.2	15.0	15.7
	−6.8	−7.4	−8.0	−8.6	−9.2	−9.8	**−10.5**	−11.2	−11.8	−12.5	−13.2	−14.0	−14.7
	0.932	0.927	0.921	0.915	0.909	0.903	**0.896**	0.890	0.883	0.876	0.869	0.862	0.855
0.042	7.0	7.5	8.1	8.6	9.2	9.8	10.4	11.1	11.7	12.4	13.0	13.7	14.4
	−6.9	−7.5	−8.1	−8.7	−9.3	−9.9	−10.6	−11.2	−11.9	−12.6	−13.3	−14.0	−14.8
	0.932	0.926	0.920	0.914	0.908	0.902	0.896	0.889	0.882	0.875	0.868	0.861	0.854
0.044	6.5	7.0	7.5	8.0	8.5	9.1	9.6	10.2	10.8	11.4	12.0	12.6	13.3
	−7.0	−7.6	−8.2	−8.7	−9.4	−10.0	−10.6	−11.3	−12.0	−12.7	−13.4	−14.1	−14.8
	0.931	0.925	0.919	0.913	0.907	0.901	0.895	0.888	0.881	0.875	0.868	0.860	0.853
0.046	6.0	6.5	6.9	7.4	7.9	8.4	8.9	9.5	10.0	10.5	11.1	11.7	12.2
	−7.1	−7.7	−8.2	−8.8	−9.4	−10.1	−10.7	−11.4	−12.1	−12.8	−13.5	−14.2	−14.9
	0.930	0.924	0.918	0.913	0.906	0.900	0.894	0.887	0.880	0.874	0.867	0.860	0.852
0.048	5.7	6.1	6.5	6.9	7.4	7.8	8.3	8.8	9.3	9.8	10.3	10.8	11.4
	−7.2	−7.8	−8.3	−8.9	−9.5	−10.2	−10.8	−11.5	−12.1	−12.8	−13.5	−14.3	−15.0
	0.929	0.923	0.917	0.912	0.905	0.899	0.893	0.886	0.880	0.873	0.866	0.859	0.851
0.05	5.3	5.7	6.1	6.5	6.9	7.3	7.8	8.2	8.7	9.1	9.6	10.1	10.6
	−7.3	−7.9	−8.4	−9.0	−9.6	−10.3	−10.9	−11.6	−12.2	−12.9	−13.6	−14.3	−15.1
	0.928	0.922	0.916	0.911	0.904	0.898	0.892	0.885	0.879	0.872	0.865	0.858	0.851

transactions costs to be high and not the other way round as we have interpreted. Suppose we have,

$$C_{f,t} = a_f + b_f \sigma_t + e_{f,t}$$

where σ_t represents fundamental volatility, $C_{f,t}$ represents transactions costs in the futures market, $e_{f,t}$ represents *exogenous* innovation in transactions costs. One might suspect that the coefficient b_f will be positive indicating that higher fundamental volatility will lead to higher transactions costs (perhaps because of increased adverse selection costs faced by investors and marker maker trading against potentially informed investors). We are, however, interested in measuring the effect of an *exogenous* increase in transactions costs on volatility. The regression that one would like to run is:

$$\sigma_{f,t} = \alpha_f + \beta_f \sigma_t + \gamma_f e_{f,t} + \varepsilon_{f,t}.$$

In the multiple regression above, the coefficient γ_f measures the effect of an exogenous increase in transactions costs on futures volatility, $\sigma_{f,t}$ controlling for the effects of fundamental volatility σ_t. Unfortunately, σ_t is an unobservable latent variable.

To address this, we posit an econometric model similar to the one above for spot exchange rates as well. That is, we posit that:

$$\begin{aligned} C_{s,t} &= a_s + b_s \sigma_t + e_{s,t} \\ \sigma_{s,t} &= \alpha_s + \beta_s \sigma_t + \gamma_s e_{s,t} + \varepsilon_{s,t} \end{aligned}$$

where the subscript $_s$ denotes the corresponding variables for the spot exchange rates and the variables have similar interpretations as before. We will use the spot volatility $\sigma_{s,t}$ to proxy for fundamental volatility σ_t realizing the fact that $\sigma_{s,t}$ measures σ_t with error. We then run the following regression:

$$\sigma_{f,t} = \theta_0 + \theta_c C_{f,t} + \theta_s \sigma_{s,t} + \varepsilon'_{f,t}$$

Substituting for $C_{f,t}$ and $\sigma_{s,t}$, we can rewrite the above regression as:

$$\begin{aligned} \sigma_{f,t} &= \theta_0 + \theta_c[a_f + b_f \sigma_t + e_{f,t}] \\ &\quad + \theta_s[\alpha_s + \beta_s \sigma_t + \gamma_s e_{s,t} + \varepsilon_{s,t}] + \varepsilon'_{f,t} \\ &= (\theta_0 + \theta_s \alpha_s + \theta_c a_f) \\ &\quad + \theta_c e_{f,t} \\ &\quad + (\theta_s \beta_s + \theta_c b_f)\sigma_t \\ &\quad + \theta_s(\gamma_s e_{s,t} + \varepsilon_{s,t}) + \varepsilon'_{f,t} \end{aligned}$$

Then,

$$\begin{aligned}
\alpha_f &= (\theta_0 + \theta_s \alpha_s + \theta_c a_f) \\
\beta_f &= (\theta_s \beta_s + \theta_c b_f) \\
\gamma_f &= \theta_c \\
\varepsilon'_{f,t} &= \varepsilon_{f,t} - \theta_s(\gamma_s e_{s,t} + \varepsilon_{s,t})
\end{aligned}$$

Thus, the coefficient θ_c measures the desired coefficient γ_f. The presence of the error $\gamma_s e_{s,t} + \varepsilon_{s,t}$ in our proxy for fundamental volatility makes the estimate of θ_c biased. As we shall see, this bias is small if the variance of $\gamma_s e_{s,t} + \varepsilon_{s,t}$ is small compared to variance of σ_t (which will be the case if $\sigma_{s,t}$ and $\sigma_{f,t}$ are highly correlated).

We construct a measure of spot volatility $\sigma_{s,t}$ using spot exchange rates. We use Datastream to collect mid-points of daily exchange rates for the period 1980 to 1999 and construct the standard deviation of daily returns for every month for the spot exchange rates for the four currencies. We annualize the volatility and report it in percentage.

Panel A of Table X reports some summary statistics for the Spot Volatility series. First note that the volatilities of the spot rates are very similar to the futures volatilities reported in Panel B in Table V. Also, Panel A of Table X reports that the spot and futures volatility series are highly correlated. Finally, similar to the futures volatility, the first autocorrelation coefficient for the spot volatility series is around 0.4 to 0.5.

Panel B of Table X reports the results of OLS regressions of Volatility on Transactions Costs and Spot Volatility. As expected the coefficients on Spot Volatility are positive and highly significant. Similar to the results reported in Table VI, Volatility is positively related to the level of Transactions Costs (both measures); the coefficients are positive for all four currencies and significant for all currencies except the Deutsche Mark. Panel C of Table X adds Volume and Time Trend as regesssors with results qualitatively similar to those in Table VI.

3.2. SIMULATION EVIDENCE ON THE SIZE OF BIAS IN ESTIMATES

We now report some simulation results that indicate that the bias in coefficients we estimated in Table X is likely to be small – around 10–15%.

Assuming that the residuals are uncorrelated, we do the following experiment. We fix some of the model parameters: $a_s = a_f = 0.032$, $\alpha_s = \alpha_f = 11.02$, $b_s = b_f = 0.001$, $\beta_s = \beta_f = 1$, $\gamma_s = \gamma_f = 10$. The variable σ_t is normally distributed with mean 0 and standard deviation equal to 4. a_s and a_f are close to the mean of the transactions costs while α_s and α_f are close to the mean of the volatility series. The values of γ_s and γ_f are close to the regression estimates in Table X. The values for $\beta_s = \beta_f = 1$ are intuitively reasonable. The coefficients

b_s and b_f are determined in the following manner. First, the correlation between $\sigma_{f,t}$ and $\sigma_{s,t}$ should equal $\frac{\text{Var}(\sigma_t)}{\text{Var}(\sigma_{s,t})}$. Then, running a regression of $C_{f,t}$ on $\sigma_{s,t}$ should produce a slope coefficient of $b_f \frac{\text{Var}(\sigma_t)}{\text{Var}(\sigma_{s,t})}$. Estimating these suggests that $b_s = b_f = 0.001$ is the right order of magnitude for these parameters.

The parameters that we vary are the standard deviations of the residuals. We further assume that the residuals are normally distributed with mean 0 and standard deviation $\sigma_{e_{s,t}} = \sigma_{e_{f,t}} \equiv \sigma_e$ and $\sigma_{\epsilon_{s,t}} = \sigma_{\epsilon_{f,t}} \equiv \sigma_\epsilon$. We choose a reasonable range for $(\sigma_e, \sigma_\epsilon)$. The mid points of σ_e and σ_ϵ in Table XI are close to the sample estimates. To estimate σ_e, we regressed $C_{f,t}$ on $\sigma_{s,t}$. Since b_f is very small (of the order of 0.001), the variance of $e_{f,t}$ is very close to that of $C_{f,t}$. To estimate σ_ϵ, we note that the variance of ϵ'_t is about twice of that of σ_ϵ because θ_s is close to 1 and the variance of $e_{s,t}$ is very small. We then backed out σ_ϵ – which is approximately 1.3% – from the residual variance of our regression in Table X.

Then data are generated according to the specified econometric model. We then run the following regression on the simulated data:

$$\sigma_{f,t} \;=\; \theta_0 + \theta_c C_{f,t} + \theta_s \sigma_{s,t} + \varepsilon'_{f,t}.$$

The same experiment is repeated 5000 times. We report the mean percentage bias in the estimated θ_c and θ_s, and the correlations between the simulated series $\sigma_{s,t}$ and $\sigma_{f,t}$ in Table XI. Notice that bias in the estimates of θ_c is positive whereas θ_s is biased downward. However, the bias in the estimates of θ_c is small – no more than 10 to 15% – and thus is unlikely to reverse the quantitative interpretations of the estimates in Table X.

Thus we can conclude that an *exogenous* increase in transactions costs in the currency futures markets leads to higher futures volatility.

4. Conclusion

We propose a new approach for estimating transactions costs in the foreign exchange market that has the advantage of measuring transactions costs faced by the marginal investors that set prices in the foreign exchange markets. These marginal investors are likely to be large commercial banks and so the estimates of transactions costs we obtain are likely to the estimates of the minimum level of transactions costs. We estimate that average transactions costs over the last two decades were no more than one-twentieth of one percent, and in the last decade may have fallen to as low as one-fiftieth of one percent.

We construct time series of monthly estimates of effective transactions costs for four currencies, the British Pound, the Deutsche Mark, the Japanese Yen and the Swiss Franc for the period 1977 to 1999. We also construct time series of monthly volatility of foreign currency futures returns and monthly volume for the four currencies. We document that volatility is positively associated with the level of transactions costs and that volume is negatively associated with the level of transactions costs. Our results suggest that an increase in transactions costs does indeed lead to a reduction in volume of trading as one might expect, but its effect on volatility is exactly opposite of what proponents of Tobin tax would have liked to see; we find that higher transactions costs are associated with an *increase* in volatility of exchange rates. Some simple calculations suggest that even a modest increase of one-fiftieth of one percent in the transactions costs can lead to an increase in the annualized volatility of exchange rates, which is typically 10–12% a year, by one-half of one percent and lead to a decrease in the daily volume of trading, which is typically between 8,000 to 20,000 futures contracts, by 2000 contracts. Of course, the proponents of Tobin Tax suggest a much larger tax of about one-half of one percent. While we do not provide direct evidence on what effect a tax on foreign exchange transactions of this large a magnitude might have on volatility and volume of trading, the evidence that we do provide must temper the confidence with which advocates of Tobin Tax claim that such a tax would lead to a decrease in volatility of exchange rates.

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