**Dynamic Relations between International Equity and Currency Markets: The Role of Currency Order Flow**[1]

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**Abstract**

Previous research on the dynamic linkages between international financial markets focused on bivariate inter-equity or inter-currency relationships and do not allow a specific role for the currency or equity market, respectively. In this paper we hypothesize that there are important, yet not well understood, dynamic relationships between international equity and currency markets and that these are driven by information spillover via the mechanism of currency order flow. Using a trivariate asymmetric GARCH framework, we find that the relationships between equity and currency markets are significant, bi-directional, and pervasive. These relationships, which co-exist with the relationships between US and foreign equity markets, are much stronger in the volatilities than in the means. Importantly, we find strong support for our information-spillover hypothesis where currency order flow is the economic mechanism by which information is transmitted.



*JEL classification*: G12, G14, G15, F31

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## I. Introduction

In a recent BusinessWeek article entitled "The Currency Game Has Brand-New Rules," it was noted that a quarter-point increase in the Eurozone interest rate by the European Central Bank defied convention when the euro declined against the dollar.[2] However, the announcement of the $183 billion takeover of Germany's Mannesmann by the British mobile phone giant Vodafone AirTouch PLC caused the euro to increase by 2.5 cents against the dollar. The article noted that the impact of deals and stock prices on exchange rates became "powerfully apparent" in 1999 when the yen failed to react to policy initiatives by the Bank of Japan, but reacted significantly to stock and deal news. On the other hand, the impact of the currency market on the equity market is highlighted in another article that partly attributes the underperformance of the US stock market in late 2000 to the third-quarter 2000 downward revisions in earnings due in part to a weak euro.[3]

The above occurrences within the international financial markets suggest that there may be important, yet not fully understood, price transmission channels from the equity to the currency market. While several studies have examined spillovers in mean and/or volatility across currency markets (e.g., Bollerslev (1990), Baillie and Bollerslev (1990), Engle, Ito, and Lin (1990)), they have not allowed for an influence from the equity markets. Similarly, studies that have examined the spillovers between international equity markets (e.g., King, Sentana, and Wadhwani (1994), Lin, Engle, and Ito (1994), Hamao, Masulis, and Ng (1990), and King and Wadhwani (1990)) have either treated the currency market as exogenous or do not ascribe a specific role to the currency market in shaping these interdependencies. Given the design of these studies, there is a general lack of evidence of the dynamic relationships between the currency, foreign equity, and domestic equity markets and, more specifically of the impact of changes in the equity (currency) market on the currency (equity) market. This oversight in the research design

[2] See BusinessWeek, February 21, 2000, p.128.
[3] See BusinessWeek, December 4, 2000, p.157.

leads us to question how well the linkage(s) from currency to equity markets is understood, even though considerable effort has been expended in establishing this relationship(s).

In this paper, we address the issue of spillovers between currency and equity markets by seeking answers to the following questions. First, is there a significant price transmission from the equity market to the currency market? Second, does the currency market impact the equity markets in ways other than those suggested by established theoretical models? An important, yet rarely examined, aspect of spillovers between international financial markets is the economic factor(s) that leads to this interdependency. The third question that we examine is: what is the underlying economic mechanism that links these markets? A more complete understanding of these issues is of importance not only to academics, but also to investors, corporate treasurers, central banks, and regulatory authorities.

In seeking answers to these questions, we estimate mean and volatility spillovers between several groupings of financial markets with each group containing the US equity market, a foreign equity market, and the corresponding bilateral exchange rate as dependent variables. The foreign countries included in this study are Canada, Germany, Japan, and the UK. Our analysis is based on the notion that information shocks are transmitted across financial markets (e.g., Fleming, Kirby, and Ostdiek (1998)). Thus, our maintained hypothesis is that spillovers between the currency market and domestic and foreign equity markets are due to information flow. Consistent with several recent works (e.g., Evans and Lyons (2002a,b), Rime (2001)) that are reviewed in the next section, we posit that unexpected currency order flow is the vehicle by which information is transmitted between these three markets.

Currency order flow is defined as the net purchase of a foreign currency. It may be thought of as "signed volume" in the sense that each purchase is signed as positive and each sale as negative volume (Evans and Lyons (2002a,b)). Evans and Lyons (2002b) show that, while order flow helps to transmit macro news to exchange rates and has a greater impact on exchange rates on the arrival of macro news, order flow also transmits information that is not in macro news.[4] We posit that it is the (non-public) information in order flow that is not due to macro news that accounts for the interdependence between international markets. This hypothesis follows from the "portfolio shifts" model of Evans and Lyons (2002a). Assume that investors optimally allocate funds across several markets. For reasons such as a change in investors' appetite for risk, a change in hedging demand, or liquidity needs, a subset of investors may decide to rebalance their portfolios. As Evans and Lyons (2000b) point out, the decision to rebalance and the actual quantities are private information. Order flow innovations represent signals about the stochastic portfolio rebalancing of this subset of investors and their portfolio shifts can only be identified from (or revealed by) these signals. Further, because other market participants need to absorb the demand change due to the rebalancing, the impact of order flow innovations on prices arising from the rebalancing is persistent (Evans and Lyons (2002b)).[5]

In light of the above, the intuition behind private information shocks leading to spillovers between domestic and foreign equity markets and the exchange rate is straightforward. Consider, say, a set of US investors who invest in both domestic and foreign equity markets. Assume that these investors have fixed resources and do not hold cash.[6] Suppose that, for some private reason, these investors were to rebalance their portfolios, by reducing (increasing) their holdings in the domestic equity market and increasing (reducing) their foreign equity position. This transaction would cause investors to generate a foreign-currency purchase (sell) order. Thus, the act of portfolio rebalancing links all three financial markets.

We hypothesize that it is unanticipated currency order flow that is the transmission vehicle by which the private information about the portfolio rebalancing from one market gets impounded into the

[4] An example of order flow that transmits non-public information is the order flow due to central bank intervention. Evans and Lyons find that 60% of the variation in daily deutsche mark/$ exchange rates is due to order flow and 40% is due to other factors. Order flow unrelated to macro news accounts for over half of the former variation.
[5] Our results can also be explained by order flow without the dependence on "portfolio rebalancing." For instance, if speculators who hold net zero investments were to short the US stock market and go long the German market, these actions would generate a currency order flow and could possibly lead to spillovers between the two markets.
[6] Similar to Evans and Lyons (2002a), assume that they are large enough (perhaps, institutional investors) to affect prices.

prices of another market (Evans and Lyons (2002a,b), Rime (2001)).[7] It is important to note that information flow is the underlying factor that links the capital markets, but currency order flow is the economic mechanism through which this information is transmitted between markets. This information may have a lagged impact on the financial markets because participants in both the currency and equity markets heterogeneously interpret the information in order flow and require a learning period before fully acting on the information. This conjecture is consistent with the finding of Froot and Ramadorai (2002b) that, although exchange rates appreciate immediately following a shock to order flow, it takes up to 70 days for the full impact to be incorporated into currency changes. The importance of this is that innovations in order flow have predictive power for exchange rate changes (Froot and Ramadorai (2002b), Rime (2001)) and equity returns (Froot and Ramadorai (2002a)). Further, since order flow innovation is the transmission vehicle for private information and the variance of prices equals the rate of information flow (Ross (1989)), its impact on the volatilities may be even more pronounced relative to the impact on the means.

Our paper contributes in several ways to the international finance literature, in general, and, in particular, to the literature that examines the interdependencies between international financial markets. First, we use a multivariate approach that allows for the endogeneity of the exchange rate and domestic and foreign equity markets, whereas previous studies generally treat exchange rate as exogenous (e.g., Jorion (1990), and Griffin and Stulz (2001)). By design, this approach allows us to assess the empirical significance of the less well-established, but perhaps important, impact of equity markets on currency markets. At the same time, we are able to shed additional light on the international equity market spillovers having now allowed exchange rate to have an explicit effect.

Second, our investigation of the linkages between exchange rate changes and equity returns considers both mean and volatility relationships within a conditional framework. Previous studies of the impact of exchange rates on stock returns, such as Jorion (1990), Griffin and Stulz (2001), among others,

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[7] Froot and Ramadorai (2002a) also find that international equity order flow has information about future fundamentals pertaining to equities. However, although Froot and Ramadorai (2002b) find that order flow has

usually use an unconditional framework and focus only on mean relationships. Finally, and perhaps most important, we provide evidence on whether information flow, through the mechanism of currency order flow, is the underlying factor that links these international financial markets.

Our analysis proceeds in two steps. First, we determine if there are interdependencies between the currency and two associated stock markets. Next, anticipating our results, we investigate the extent to which they can be explained by information flows via the mechanism of currency order flow. In our estimation, we employ a trivariate GJR-GARCH(1,1) model (Glosten, Jagannathan, and Runkle (1993)). The advantages are that, it is more efficient than univariate models that are often used to examine spillovers in financial markets (e.g., Hamao et al. (1990)), it accounts for asymmetric volatility, and it allows us to endogenize each of the three markets. Thus, unlike other studies that examine the impact of order flow on exchange rate changes (e.g., Evans and Lyons (2002a, b) and Froot and Ramadorai (2002b)) or equity returns (Froot and Ramadorai (2002a)), we simultaneously examine the impact of order flow on the means and volatilities of both equity and exchange rates.

We find significant, bi-directional mean and volatility spillovers between currency and equity markets and between US and foreign equity markets. In the means, we find significant spillovers from the Canadian, German, Japanese, and UK equity markets to at least one of these countries' exchange rates against the US dollar. Similarly, we find significant spillovers from changes in the Canadian dollar, the mark, the pound, and the yen exchange rates to the US and foreign equity returns. Further, the evidence indicates that all foreign equity markets significantly predict the US and all are in turn predicted by the US equity market. This is in stark contrast to the typical finding of unidirectional spillovers from the US to the other major equity markets documented in previous studies (e.g., Hamao et al. (1990)) or the absence of mean spillovers between foreign and US equity markets (e.g., Susmel and Engle (1994)). One possible reason for this is that most studies fail to endogenize exchange rates, which have spillover effects of broadly similar magnitude, but opposite sign, to those from the associated foreign equity returns. This

information relevant to future exchange rates they argue it is not information about fundamentals.

is supported by the finding that the spillover from changes in an exchange rate to equity returns is greatest where the exchange rate and the associated foreign equity returns are both endogenous variables.

The volatility results are much stronger. There are significant volatility spillovers from the US and foreign stock markets to the volatility of the currency markets. The evidence also indicates that the lagged volatility of each of the four currencies has a significant impact on the current volatility of both the US and foreign stock markets. In almost all cases, the spillover from currency volatility to equity volatility is much stronger than the reverse. This leads us to believe that a possible explanation for the failure of several previous studies to find exchange rate as a significant explanatory variable for equity returns is that they focused almost entirely on the first moment (e.g., Griffin and Stulz (2001)).[8] There are also strong bi-directional volatility spillovers between the equity markets. Further, there is asymmetry in the spillovers in that they tend to intensify following periods of negative shocks in the equity markets. The finding of strong dynamic relationships between currency and equity markets indicates that the results of prior studies that treat either the exchange rate or equity markets as exogenous are mis-specified, which partly accounts for the generally weak results previously reported.

When we control for information effects, by including unanticipated order flow in the model, there is a dramatic diminution in both the mean and volatility spillovers. As expected, order flow innovations economically and statistically significantly predict equity returns as well as changes in exchange rates. In keeping with our portfolio-rebalancing hypothesis, a positive shock to order flow typically leads to an appreciation of the foreign currency and a gain in the foreign equity market. While there is a reduction in both mean and volatility spillovers across the various systems of equations, the reduction is larger and more consistent in the volatilities. This is consistent with Ross (1989), who argues that the variance of prices is related to the flow of information and provides strong support for the hypothesis that innovations in order flow reflect information and that spillovers between the currency and the domestic and foreign equity markets are due to information flow.

[8] Evidence in Dumas and Solnik (1995), De Santis and Gerard (1998), and others, indicate that another reason is that the tests almost always take an unconditional approach.

The remainder of this paper contains six sections. Section II briefly discusses the related literature, section III outlines the methodology, and section IV describes the data. We present the empirical results in sections V and VI. The paper's summary and conclusions are in section VII.

## II. Literature Review

The dependence of equity returns on currency changes can be linked to two strands of the international finance literature. Theoretical work by Solnik (1974), Sercu (1980), and Adler and Dumas (1983), among others, show that currency risk should be a priced factor in explaining equity returns. In other words, developments in the currency market should affect the discount rate of firms. Although theoretically appealing, early empirical tests (e.g., Jorion (1991)) failed to find support for exchange rate changes impacting stock returns. More recently, Dumas and Solnik (1995), and De Santis and Gerard (1998) use conditional asset pricing models to show that currency risk (as measured by the conditional covariance between equity and currency returns) is important in explaining the variation in the *mean* of stock returns.

The other strand of literature is based on papers by Shapiro (1975), Levi (1994), and Marston (1998), among others. This literature argues that exchange rates should affect the competitiveness of firms and thus their market values. This impact is on the expected future cash flows of firms. Similar to the other strand of literature, empirical evidence in support of these theoretical works are at best weak (see, e.g., Jorion (1990), Bodnar and Gentry (1993), and Griffin and Stulz (2001)). This lack of empirical support is surprising given that Froot and Klemperer (1989), and Knetter (1993, 1994), among others, show that deviations from purchasing power parity lead to large movements in exchange rates and increase in profit margins for exporters resulting from price markups.

There are several possible reasons for this lack of strong empirical support for the theoretical constructs. Previous studies generally assume that the relationship(s) between the currency and equity markets is time-invariant, exists only between the first moments, and that exchange rate is exogenous. This approach has several weaknesses. First, the impact of exchange rate need not be constant over time.

Since developments in the currency market can have positive or negative effects on a firm as economic conditions change, these unconditional tests have low power and are unlikely to find significant net effects. Second, even if the mean of currency innovations has no impact on equity returns, it does not follow that their volatility also has no impact. In fact, given that currency changes may be a proxy for information about future fundamentals it is likely that currency volatility will be more influential in the volatility of stock returns.

Many studies of the relationships between currency and equity treat exchange rate as exogenous, perhaps because traditional theoretical models of the determination of exchange rates have not had a role for equity markets. However, as Frankel and Rose (1995) and Evans and Lyons (2002a) point out, traditional (macroeconomic) models of exchange rates have been a failure in explaining exchange rate movements.[9] Hence, "… we are driven to the conclusion that the most critical determinants of exchange rate variability are not macroeconomic" (Flood and Rose (1995)).

In extending the theoretical literature and providing a basis for the influence of domestic and foreign equity markets on the currency market, Zapatero (1995) and Hau and Rey (2002) develop theoretical models that endogenize exchange rates along with equity market returns. Both papers show that exchange rates are impacted by equity returns. Specifically, Zapatero shows that exchange rate changes depend on the volatility of the domestic stock market and the covariance between the domestic and foreign stock markets. Currency volatility in his model is a function of the volatilities of both equity markets. The model by Hau and Rey (2002) is more relevant to the current paper in that they specifically allow currency order flow to play a direct role in driving the dynamics between the financial markets.

The paper by Hau and Rey (2002) is just one of several recent papers in the international finance literature that addresses the issue of the impact of order flow on exchange rates and/or equity markets. Evans and Lyons (2002a) present an exchange rate model that explicitly incorporates a determinant from the field of microstructure – currency order flow. Their empirical results show that including order flow

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[9] As noted by Evans and Lyons (2002a), "In sample $R^2$ statistics as high as 10 percent are rare."

as an explanatory variable in determining exchange rate changes produces an $R^2$ statistic of about 60 percent. Further analyses show that nearly all of this variation in daily exchange rates is due to order flow. Although not explicitly tested, they argue that this impact is due to currency order flow acting as a vehicle for information flow. Evidence of the importance of order flow in explaining currency changes is also provided by Rime (2001).

In a follow-up paper, Evans and Lyons (2002b) explicitly test the hypothesis that macroeconomic news is a determinant of order flow and consequently that order flow's remarkable explanatory power is primarily due to its acting as a vehicle for information flow. They find that about two-thirds of the impact of macroeconomic news on exchange rates is transmitted via order flow. Additionally, they find that upon the arrival of news, the importance of order flow in the determination of exchange rate increases. They report that, together the two information channels of macro news (the direct channel and the channel via order flow) account for approximately 30 percent of the variation in exchange rates. However, more important to our paper, they also find that only a third of the impact of order flow on exchange rate changes is due to macro news, while the remaining two-thirds is not macro news related. Andersen, Bollerslev, Diebold, and Vega (2002) also provide evidence that macroeconomic news is transmitted via order flow and that the volatility of exchange rates increases when news arrives.

The role of currency order flow as an information vehicle is not limited to the currency markets. Froot, O'connell, and Seasholes (2001) find that daily international investment flows have a substantial effect on equity returns. As is the case with Evans and Lyons (2002a), they do not directly test if this explanatory power is due to information flow. However, in a more recent paper, Froot and Ramadorai (2002a) directly test this hypothesis and find strong evidence that the impact is due to information flow.

## III. Empirical Methods

A trivariate GJR-GARCH (1,1) model is used to estimate the mean and volatility spillovers between the US and a foreign stock market and the bilateral exchange rate between the two countries. A representative system of equations is specified as follows:

$$R_{1t} = a_1 + \sum_{i=1}^{5} b_{1i} R_{it-1} + \sum_{k=2}^{5} c_{1k} F_{1k,t-1} + e_{1t} \quad (1)$$

$$R_{2t} = a_2 + \sum_{i=1}^{5} b_{2i} R_{i,t-1} + \sum_{k=2}^{5} c_{2k} F_{1k,t-1} + e_{2t} \quad (2)$$

$$F_{12,t} = a_3 + \sum_{i=1}^{5} b_{3i} R_{i,t-1} + \sum_{k=2}^{5} c_{3k} F_{1k,t-1} + e_{3t} \quad (3)$$

$$\{e_{1t}, e_{2t}, e_{3t}\}' = \mathbf{e}_t \mid \Omega_{t-1} \sim \mathrm{N}(\mathbf{0}, \mathrm{H}_t) \quad (4)$$

$$h_{1t} = c_1 + \alpha_1 e_{1t-1}^2 + \beta_1 h_{1t-1} + \delta_1 e_{1_{t-1}}^{-2} + \gamma_{12} e_{2_{t-1}}^2 + \gamma_{13} e_{3_{t-1}}^2 + \lambda_{12} e_{2_{t-1}}^{-2} + \lambda_{13} e_{3_{t-1}}^{-2} \quad (5)$$

$$h_{2t} = c_2 + \alpha_2 e_{2t-1}^2 + \beta_2 h_{2t-1} + \delta_2 e_{2_{t-1}}^{-2} + \gamma_{21} e_{1_{t-1}}^2 + \gamma_{23} e_{3_{t-1}}^2 + \lambda_{21} e_{1_{t-1}}^{-2} + \lambda_{23} e_{3_{t-1}}^{-2} \quad (6)$$

$$h_{3t} = c_3 + \alpha_3 e_{3t-1}^2 + \beta_3 h_{3t-1} + \delta_3 e_{3_{t-1}}^{-2} + \gamma_{31} e_{1_{t-1}}^2 + \gamma_{32} e_{2_{t-1}}^2 + \lambda_{31} e_{1_{t-1}}^{-2} + \lambda_{32} e_{2_{t-1}}^{-2} \quad (7)$$

$$h_{ijt} = \rho_{ij} (h_{it} * h_{jt})^{.5} \qquad i \neq j\,. \quad (8)$$

Let $R_1$ represent the returns on the US stock market and $R_2$ to $R_5$ the returns on the stock markets of Canada, Germany, Japan, and the UK, respectively. Also, let $F_{1k}$ represent 100 times the log-first difference of the bilateral exchange rate between the US and countries $k = 2,\ldots,5$ (i.e., the Canadian dollar, the mark, the yen, and the pound, respectively, in foreign currency per US dollar).

We estimate four trivariate systems of equations, where the three dependent variables of each system are: the returns on the US stock market, $R_{1t}$, the local-currency returns on the stock market of one of the four foreign countries, $R_{2t},\ldots,R_{5t}$, respectively, and the changes in the bilateral exchange rate between the two countries whose stock market returns are also dependent variables, $F_{1k}$, $k = 2,\ldots,5$.

For instance, equations (1) to (3) represent the conditional means, where $(R_{1,t}\ \ R_{2,t}\ \ F_{12,t})$ are weekly returns on the US stock market, the Canadian stock market return in local currency, and changes in the Canadian dollar/US dollar exchange rate, respectively. Each mean equation - in what can be regarded as the "Canadian system" - contains a constant, one lag of the returns on each of the five stock markets, and one lag of each of the four currencies. Thus, each equation includes one lag of its dependent variable. The lagged dependent variable is included to reduce the probability that the residuals of the mean equations are autocorrelated. This is important because untreated autocorrelation could lead to a spurious finding of mean spillovers between markets. Each mean equation also contains one lag of each of the other two dependent variables. These represent the spillover terms from the other markets that complete the trivariate system. These are usually all the mean interdependence allowed between markets in multivariate models of intermarket spillovers (see, e.g., Karolyi (1995)). However, in recognition of the facts that the markets considered in the current paper are well integrated and that previous papers have examined mean spillovers between various subsets of these markets, we also include one lag of each of the other equity returns and currency changes as independent variables in each mean equation. This specification provides a richer set of intermarket dynamics and reduces the probability that observed spillovers from one market arise because it is a proxy for an omitted market.

As shown by equation (4), the residuals from the conditional mean equations, $\mathbf{e}_t = (e_{1t}, e_{2t}, e_{3t})'$, are assumed to be conditionally multivariate normally distributed, with means of zero and variance-covariance $\boldsymbol{H}_t$. Theses are employed in the variance process to represent the volatility spillovers.

The conditional variance is modeled as a trivariate system of equations, where the variances are those of the dependent variables in the mean equations. These are specified as in equations (5) to (7). Each market's variance is modeled as a function of a constant, the square of last period's own residuals, the own lagged conditional variance, and an own asymmetric volatility term representing the first four expressions on the right hand side. The $e_{i\,t-1}^{-2}$ term is the squared unexpected returns on market *i* in weeks when there is bad news. In particular, bad news is represented as $e_{t-1}<0$. This implies that the actual return $R_{it}$ is less than the expected (predicted) return as estimated by, for example, $a_1 + \sum_{i=1}^{5} b_{1i} R_{it-1} + \sum_{k=2}^{5} c_{1k} F_{1k,t-1}$. The assumption is that when the return on the market is less than expected (that is, there is bad news) its volatility is higher in the next period. The coefficient δ is expected to be positive if there is this asymmetry in the volatility. In the case of changes in the exchange rate, the interpretation is different. A change in the exchange rate represents an appreciation of the US dollar relative to the foreign currency. If the dollar's appreciation (foreign currency depreciation) turns out to be less than expected, then $e_{3t-1}<0$. In this case, we could expect that the dollar will be less volatile, thus the asymmetric coefficient would be negative.

To capture the volatility spillovers we extend the basic GJR model. We follow Engle, Ito, and Lin (1990) and include, for say the first market $h_{1t}$, the lagged squared return surprises, $\gamma_{12}e_{2_{t-1}}^{2}$, $\gamma_{13}e_{3_{t-1}}^{2}$, and the asymmetric terms, $\lambda_{12}e_{2_{t-1}}^{-2}, \lambda_{13}e_{3_{t-1}}^{-2}$, from the other two markets. These will indicate if there are volatility spillovers and if the magnitude of the volatility spillover is different in periods of bad news and good news. We also need to model the three conditional covariances between the various markets because we use a multivariate system. In equation (8), the conditional covariance between each pair of markets is modeled as a function of the product of their constant correlation and their conditional standard deviations.[10]

To estimate the coefficients in the above models we maximize the log likelihood function from the conditional normal specification and calculate a covariance matrix of the parameters that is robust to the distribution (e.g., non-normality) of the errors (i.e., we use a quasi-maximum likelihood (QML) approach similar to Bollerslev and Wooldridge (1992)). We use several model diagnostics, the coefficients, and graphs of the conditional variances (not reported) to guide us in the estimation process and to increase the probability of the model converging at the global maximum.

## IV. Data

We use weekly value-weighted returns in local currency for the US, British, Canadian, German, and Japanese stock markets and weekly changes in the value of the currency of each country against the US dollar (British pound (GBP), Canadian dollar (CAD), deutsche mark (DEM), Japanese yen (JPY), per US dollar). The data are obtained from Morgan Stanley Capital International (MSCI) and cover the

[10] Although a constant correlation does not in general hold, we believe it is a reasonable assumption over short sample periods. We provide diagnostic tests below that strongly support our assumption.

period January 1994 to December 2001.[11] Stock returns are measured as the log-first differences of the stock indices and the currency changes are measured as the log-first differences of the exchange rates.

The order flow data are from the US Treasury and represent currency trading by large foreign exchange market participants. A major participant (bank) is one who has the equivalent of at least $50 billion in foreign exchange contracts on the last business day of any quarter during the previous year. These contracts include the amounts of foreign exchange spot contracts bought and sold, foreign exchange forward contracts bought and sold, foreign exchange futures bought and sold and one half the notional amount of foreign exchange options bought and sold. We use weekly observations on the net volume of purchases and sales of spot, forward, and futures contracts. These data are available only since January 1994, hence the restriction on our sample period.

Table 1 contains summary statistics for returns on the stock market indices, percentage changes of the exchange rates, and currency order flow data. Statistics for the equity markets are presented in Panel A. They show that over the period the US had the highest weekly return (0.393%) reflecting its bull market, while Japan had the lowest (-0.089%) reflecting the prolonged bear market that characterized the Japanese economy over the sample period. Each series is free of autocorrelation at the 5% level of significance. The autocorrelations of squared returns, shown in the third column from the right, are characteristically larger and more persistent (generally up to the twelfth lag) than the autocorrelations in the returns. Importantly, the *p*-values are generally less than 0.05, suggesting that there are ARCH errors in all the series. The Jarque-Bera test for normality indicates that the returns are not normally distributed, as they all have excess kurtosis and most are skewed.

[11] The German order flow data end in December 1998 because of the introduction of the Euro in January 1999. Since Germany is one of the largest financial markets and its equity and currency markets have significant spillover effects on the US, we report the results related to the 1994 to 1998 period as our main results. However, when we exclude German data and extend the period covered from 1994 to 2001, the hypothesis that order flow accounts for a significant portion of the interdependencies between international markets continues to be strongly supported. This is not surprising since Evans and Lyons (2002b) argue that the types of information conveyed by order flow, in particular the types with persistent price effects, are unlikely to change with the evolution of the foreign exchange market. As they assert, the information conveyed by order flow has to do more with the asset being traded than with the market structure.

Summary statistics for the changes in exchange rates are presented in Panel B. The data show that on average the CAD and JPY experience weekly depreciation over the sample period, while the DEM and the GBP appreciated over the period. However, none of the changes is significantly different from zero at conventional levels. As expected, equity returns are more volatile than exchange rate changes. An implication of these findings is that we may only find unidirectional causality from the more volatile equity markets to the currency markets.

Except for the JPY, the exchange rate changes do not have significant autocorrelation, suggesting that information is impounded without a lag. This is not surprising and is probably due to the relatively large size and substantial liquidity of the currency market. The squared exchange rate changes do not display the large autocorrelation characteristic of equities, but univariate ARCH models of all the currency series (results not reported) confirm strong ARCH errors. The finding of ARCH errors in both the equity and currency series supports the choice of a GARCH framework for our estimation. Similar to the equity series, the Jarque-Bera test for normality indicates that the exchange rate changes are generally not normally distributed, as they all have excess kurtosis and/or skewness. Our methodology accounts for both the autocorrelation and non-normality observed in the series.

Panel C contains summary statistics of the currency order flow. These are based on the net of purchases and sales. The data shown are measured in terms of the foreign currency. The net positions indicate that, on average, US residents purchased more Canadian dollars, deutsche marks, and pounds than they sold. The reverse holds for the yen. As expected, the net positions are relatively small given the well-known fact that dealers attempt to maintain a net zero inventory. However, on average they are statistically significantly different from zero.

Table 2 presents cross-correlation results. Several previous studies (e.g., Karolyi (1995), Lin et al. (1994)) report cross-correlation between the returns of the major equity markets and thus we do not repeat them here. Instead, we focus on the relationships between currency and equity returns. Panel A contains the cross-correlation between the US equity returns and the changes in exchange rates, along with cross-correlations between the foreign equity markets and their corresponding exchange rate with the dollar. First, as indicated by the *p*-values (*p*(-2 to 2)) there is significant cross-correlation at the 5% level between the US equity and the CAD, DEM, and JPY over the sample period. Second, judging from the size of the coefficients on the contemporaneous unconditional correlation, US equities are most highly correlated with the DEM (0.318). Further, the contemporaneous correlation between US equity returns and currency changes is stronger than the cross-correlation when the US equity returns lead (lag = -1, -2) or lag (lag = 1, 2) the currency changes. Notwithstanding, the evidence indicates that both the JPY and the CAD lead US stock returns, while the US stock returns lead the CAD.

Significant cross-correlations are also evident between the foreign equity returns and their respective currency. With the exception of the Japanese market, there is significant cross-correlation (*p*(-2 to 2)) at the 1% level, which is driven almost totally by the contemporaneous correlation. However, the CAD leads the Canadian equities. The existence of these lead-lag relationships, albeit unconditional, between the currency and equity markets suggests the possibility of conditional cross-market dependence in the mean.

As preliminary evidence of the relationships between volatilities, we present cross-correlations between the squared currency changes and squared equity returns in Panel B. Columns 1 through 4 contain results of squared US equity returns and squared changes in the currencies of the four other countries relative to the US dollar. Columns 5 to 8 report results of the remaining countries and their own currency. There is evidence that the yen and the Canadian dollar significantly lead the US equity market and the equity markets of Japan and Canada, respectively. Consistent with our earlier findings, in several cases there is significant contemporaneous correlation between squared equity returns and squared currency changes. Interestingly, only the Canadian equities lead the currency market.

In summary, the foregoing unconditional correlation analyses indicate that there is a significant, predominantly contemporaneous, relationship between the major equity and foreign exchange markets. The results also indicate that there is a stronger tendency for the currency market to lead the equity market than vice versa. This suggests that we may not find significant spillovers from the equity to the currency markets. However, this conclusion would be premature because the correlations analyzed above are unconditional. As shown by De Santis and Gerard (1998), and others, results obtained from unconditional models can be dramatically different from those obtained from conditional models where conditional cross-correlations are used instead of unconditional correlations.

The findings that the US equity market lags the JPY and CAD in levels and squares and that the Canadian, German, and UK equity returns are contemporaneously correlated with changes in their currency have several implications. First, they suggest that the documented lagged foreign equity spillovers to the US (see, e.g., Karolyi (1995)) may be overstated and in fact may even be an exchange-rate effect. Second, they suggest that any documented relationship between the US equity market and currency markets where the effects of the foreign equity markets have not been filtered out may give a biased picture of the true relationship between the US equity returns and foreign currencies. In the estimation below, we filter out the effects of the foreign equity returns on the currencies so that the currencies' impact on the US equity returns can be independently assessed.

## V. Empirical Results

### *A. Mean and Volatility Spillovers between Equity and Currency Markets*

Our objective in this sub-section is to establish whether or not there are significant spillovers between currency and equity markets and between equity markets. Table 3 presents the GJR-GARCH (1,1) results of the grouping comprised of the returns on the US and German equity markets and the changes in the DEM exchange rate as dependent variables. Overall, we find strong evidence of previously undocumented spillovers from equity to currency markets. We also find significant spillovers from currency to equity markets and between the major equity markets. Panel A indicates that there are significant mean spillovers from the Canadian, German, and Japanese equity markets to the DEM exchange rate. This finding is consistent with the casual empiricism mentioned in the opening paragraph and may be the result of the microstructure explanation of exchange rate determination (see, e.g., Lyons and Evans (2002a, 2002b) and Hau and Rey (2002)). This is addressed below.

Further strengthening the evidence of linkages between equity and currency markets are the results that show that a depreciation of the mark predicts a subsequent decline in US stock market, whereas a depreciation of the Canadian dollar predicts a gain. Somewhat surprising are the findings that changes in the value of the mark have no significant predictive power for the German equity market, but a depreciation of the Canadian dollar leads to a subsequent increase in the German equity market.

There is also evidence of significant bi-directional spillovers of roughly similar magnitude between the US and German equity markets. Further, the Canadian market predicts both the US and German equity markets and Japanese stock returns predict German stock returns. These significant and pervasive mean spillovers are inconsistent with the results of most of the received literature, which has, in general, failed to find mean dependence between the major equity markets (e.g., Hamao et al. (1990), Susmel and Engle (1994)). Finally, changes in the Canadian dollar, Japanese yen, and British pound do not have predictive power for changes in the mark/dollar exchange rate. This is not surprising, given that the “meteor shower” hypothesis of spillovers between currencies relates to volatilities rather than to the means (Engle et al. (1990)).

The results of the conditional variance equations in Panel B display strong evidence of volatility spillovers between markets. Unlike the mean results, the lagged volatility of the US stock market, as well as that of the German stock market, significantly predicts the conditional volatility of changes in the DEM exchange rate. The asymmetric volatility terms also indicate that there are significant spillovers from the equity markets to the currency market when there is bad news in the equity market. A possible explanation of this is that if investors’ appetite for risk changes with bad news in one equity market, then this increases the intensity of portfolio rebalancing across markets. It should be noted that this should lead to an increase in currency order flow (Evans and Lyons (2002a)).

There are also significant volatility spillovers from the exchange rate to both the US and German stock market volatilities and the spillovers are substantially higher when the dollar appreciates (mark depreciates) less than expected. There are also significant bi-directional spillovers between the volatilities of the US and German stock markets. The impact of the US on the German equity volatility is about twice that of the German volatility on the US market volatility. The asymmetric spillover terms indicate that spillovers increase significantly when there is a negative shock to either market. Finally, all own asymmetric terms are highly significant. This suggests that the conditional volatilities of both stocks and exchange rates are impacted differently by good and bad news, even though the phenomenon is stronger for stocks.

The strong evidence of bi-directional volatility spillovers between equity and currency markets is important for several reasons. First, to the extent that the variance of prices reflects the rate of information flow (Ross (1989)), these findings support our conjecture that the cross-market dependencies are due to information spillover. Second, it suggests that the general lack of evidence of exchange rates having an impact on equity markets (see, e.g., Jorion (1991) and Griffin and Stulz (2001)) may be because both empirical and theoretical works focus only on the first moment and not on the second. Third, finding that currency and equity markets are conditionally cross-correlated is broadly consistent with the De Santis and Gerard (1998) result that exchange rate is a priced factor for equity returns in conditional asset pricing models. Finally, the currency/equity market volatility has implications for US trading in German equity derivatives, and vice versa, as the value of these securities is impacted more by volatility than by the mean of the DEM exchange rate.

Table 4 reports the results when the US and Japanese equity markets and the JPY exchange rate form the grouping. The results contained in Panel A indicate some evidence of mean spillovers between the equity and currency markets. Specifically, while neither the US nor Japanese equity returns predict changes in the yen/dollar exchange rate, the evidence indicates that there is statistically significant spillover from the German equity market to the yen. In addition to the spillover from the stock markets to the exchange rates, there are also significant spillovers from changes in exchange rates to equity returns. That is, the US stock market experiences significant spillover from changes in the value of the yen, while there is significant spillover to the Japanese equities market from changes in the Canadian dollar and the British pound.

There are also mean spillovers between the equity markets. The US stock market exhibits significant spillover effects from the UK equity market, a result that is consistent with that reported by Hamao et al. (1990), but not with Susmel and Engle (1994). In addition, there is spillover to the Japanese equity market from the US and UK equity markets. This contrasts somewhat with Hamao et al. (1990) who find a significant spillover effect from the US, but not from the UK, market to the Japanese market. It is also inconsistent with Lin, Engle, and Ito (1994) who find no significant (lagged) spillover, in either direction, between US and Japanese equities. Finally, there is mean spillover between the currency markets as past changes in the dollar/pound exchange rate significantly predict changes in the value of the yen.

The volatilities of equity returns and exchange rate changes also display significant spillover effects. The conditional volatility of the JPY exchange rate is significantly predicted by the lagged volatility of the US and Japanese equity markets. On the other hand, the results also show that the volatility of both equity markets is predicted by the lagged volatility of the JPY exchange rate, at the 10% significance level. Further, from the asymmetric volatility spillover coefficients, when the yen depreciates less than expected, it also leads to volatility spillover from the yen to the Japanese equity market.

There is also interdependence in volatility between equity markets. Unlike the result reported in Hamao et al. (1990), current volatility of Japanese stock returns predicts the volatility of the US equity market, even though the magnitude of the predictability in the reverse direction is about three times larger.

Table 5 reports the results where the dependent variables are the US and UK equity markets and the GBP exchange rate. Panel A indicates that although there is no mean spillover to the GBP exchange rate changes from the US or UK equity returns, there is significant spillover from the Japanese equity returns. There are also spillovers from currency changes to equity returns. Changes in the pound predict the returns on the US equity market and changes in the Canadian dollar predict the returns on the UK equity market. The means of the equity returns also display substantial cross-market dependence. There are significant spillovers to the US equity market returns from the returns on the UK and German equity markets, while the UK market is predicted by the US, Canadian, and Japanese equity markets. Similar to the results for the deutsche mark/dollar exchange rate, we uncover no evidence of significant spillovers to the GBP exchange rate from any other currency.

The results of the volatility spillover tests in Panel B also indicate significant cross-market dependencies between the currency and equity markets and between equity markets. Both the US and UK equity market volatilities have (small) predictive power for the volatility of the pound and bad news in either equity market leads to a subsequent decline in the volatility of the pound. Similarly, the lagged volatility of the GBP exchange rate predicts higher volatility for both equity markets. The evidence also indicates that there is significant bi-directional volatility spillover of equal magnitude between the US and UK stock markets. Further, the asymmetric volatility terms indicate that in periods when the US market experiences a negative shock the volatility spillover to the UK increases significantly.

Our finding of bi-directional mean and volatility spillovers between the US and UK equity markets is inconsistent with the findings of several previous papers. Susmel and Engle (1994) find no significant mean or volatility spillovers between the UK and US stock markets, while Hamao et al. (1990) find only unidirectional volatility spillovers from the US to the UK and Japan. There are several possible explanations for the differences in the results. First, in our analysis the GBP, along with other exchange rates, is allowed to have an independent effect on the interdependence between the US and UK equity markets. Thus, we are able to disentangle possible opposite effects of the pound/dollar exchange rate and UK equity returns on the mean of the US equity returns. Second, we include a broader set of major equity markets in the mean equations, allowing us to more efficiently capture the role played by each individual market in the interdependence between markets. Third, we use a multivariate GARCH framework thereby increasing the amount of information that is used in the variance-covariance matrix relative to the univariate models of Hamao et al. (1990) and Susmel and Engle (1994). Finally, our sample covers a more recent period. Therefore, it is possible that the nature of the information flow and, consequently, the volatility linkages have changed over the more recent period.

Table 6 reports results for the case where the dependent variables are the US and Canadian equity returns and changes in the CAD exchange rate. Consistent with our previous results, we find evidence of significant spillovers from equity markets to the currency market. In the conditional mean equations, although neither the US nor the Canadian equity market predicts changes in the exchange rate, both the German and UK equity markets have statistically significant (though economically small) predictive power for changes in the CAD exchange rate. Together with results from Tables 3 and 5, where it was shown that changes in the CAD exchange rate have statistically and economically significant predictive power for the means of the German and UK equity returns, the current results suggest that there is indeed a strong link between the German and UK equity markets and the CAD exchange rate. In the current system of equations, there is also evidence of spillovers to equity markets from the changes in the exchange rates. Returns on the US equity market are significantly predicted by changes in the value of the yen, while the Canadian equity returns are predicted by changes in the Canadian dollar, the yen, and the pound.

Turning to the relationships between Canadian and US equities, we find that the US equity returns are significantly (though economically marginally) predicted by the Canadian equity returns. Consistent with Karolyi (1995), the Canadian equity returns are also predicted by US equity returns. Judging from the magnitude of the coefficients, past US returns have over twice the impact on current Canadian returns than the latter have on future US returns. The evidence also indicates that US stock market returns are predicted by the German and Japanese stock markets, while the Canadian market returns are predicted by the German, Japanese, and UK market returns.

In the conditional volatilities reported in Panel B, we observe a broadly similar pattern of spillovers between equity and currency markets as in the previous systems of equations. While there is generally no volatility spillover from the US or Canadian equities to the CAD exchange rate, in periods when either equity market experiences a negative shock, there is some (small) volatility spillover to the exchange rate, as indicated by the significant asymmetric volatility spillover terms. On the other hand, there is no ambiguity in the role of past currency volatility in the current equity volatility. For instance, a one-unit increase in the volatility of the CAD exchange rate leads to a 0.48 units increase in the future volatility of the US equity market and about a 0.36 units increase in the volatility of the Canadian market. Similarly, there is economically large asymmetric volatility spillover from the exchange rate changes to the equities. However, this is statistically significant only in the volatility of the Canadian equity market.

There is also statistically significant and economically large bi-directional volatility spillover of roughly equal magnitude between the US and Canadian equity markets. Further, the evidence indicates that there is a tendency for these interdependencies to increase when there is bad news in either equity market.

The strong cross-market dependencies between the US and Canadian financial markets are probably due to the geographic proximity and the relatively close economic and financial ties between these two countries. Canada is the largest trading partner of the US and US investors readily invest in the Canadian stock market either through direct cross-border transactions or by way of the Canadian stocks that are listed on the US exchanges. The latter is facilitated by the fact that, of the major industrialized countries, Canada has the largest proportion (45%) of stock market capitalization listed in the US (Ahearne, Griever, and Warnock (2000)).

Overall, the evidence indicates that significant mean and volatility spillovers are an important feature of the relationships between currency markets and domestic and foreign equity markets. This is an important finding on several accounts. First, it supports the theoretical constructs of Zapatero (1995) and Hau and Rey (2002) that currency markets are significantly impacted by equity markets. Second, it suggests that a possible explanation for the lack of convincing evidence of exchange rates impacting equity returns may be because most of the previous literature ignored the relationship between the conditional variances and have also not allowed for the endogeneity of the currency market.

Third, papers that examine interdependence between the US and foreign equity markets, but have not allowed for the endogeneity of the bilateral exchange rate, have, in all likelihood, drawn erroneous conclusions. This is because in three of the four systems in the present paper (except the US, Japan, JPY system) the foreign equity and exchange rate coefficients in the conditional mean of the US equities are of opposite signs. Thus, excluding the exchange rate could have led to the conclusion that the foreign equity returns do not impact the mean of the US equity, because with the exclusion of the exchange rate the spillover coefficient would represent the joint equity and currency impacts. Similarly, studies of interdependence between currencies that exclude equity market returns may also erroneously conclude that there are interdependence between currencies, or at least overstate the strength of such dependence. This is because what could appear to be spillover between currencies could be equity-to-currency spillovers, but the research design is incapable of capturing this. This is supported by our results of strong mean spillover from equity market returns to changes in exchange rates, coupled with the nearly non-existent (mean) spillovers between currencies.

*B. Model Diagnostics*

To ensure the reliability of the conclusions reached, we include a host of diagnostics in our models. Panel C of Tables 3 to 6 (and Tables 7 to 10 below) reports the more important model diagnostics. Overall, the diagnostics indicate that the GARCH models are well specified. Therefore, we can conclude that these results are not an artifact of model misspecification. Specifically, in all models the mean of the residuals is not statistically significantly different from zero and is much smaller than the mean of the raw series reported in Table 1. The Ljung-Box chi-square test indicates that the model removes the autocorrelation from practically all the raw residuals (10 out of 12 series). In addition, there is no remaining autocorrelation in the squared residuals, suggesting the absence of ARCH errors in the residuals. Though the model fails to remove most of the skewness and excess kurtosis from the series, the QML estimation procedure corrects the standard errors of the coefficients for the non-normal distribution of the standardized errors. Hence, we can make the usual statistical inferences. In our estimation, we assume that the correlation between the dependent variables in each system is constant (see the estimated correlation coefficients at the bottom of Panel B). If this specification is reasonable, then the cross-product of residuals standardized by the relevant covariance should have a mean of one and should not be autocorrelated (Bollerslev (1990)). The absence of autocorrelation indicates that the correlation is not predictable (i.e., is constant). The lower section of Panel C indicates that the means are all close to one. Further, in unreported tests, we cannot reject the null hypothesis that they are equal to one. Additionally, we cannot reject the null of the absence of autocorrelation in the residual cross-products in almost all cases. Several hypotheses tests are reported in Panel D. They present evidence as to the joint significance of various sets of coefficients and provide strong support for the robustness of our results.

## VI. Can Order Flow Explain the Interdependence between Equity and Currency Markets?

In this section, we examine the extent to which our results are driven by the flow of private information between the three capital markets, where the information is conveyed by innovations in currency order flow. If the mean and volatility linkages are due to information flow and order flow is the transmission mechanism (Evans and Lyons (2002a, 2002b) and Froot, O'connell, and Seasholes (2001)), then there should be a significant decline in the interdependence between the markets after entering order flow as a control variable in the models. It is worth noting that the aggregate order flows used in this paper represent all categories of transactions, including the proprietary data related to international equity portfolio flows that have been used by other authors. Thus, we expect that there will be some noise in the information channel. For example, Tien (2003) finds that aggregate order flow obscures the information content of specific components, such as the flows related to hedging demand. Nevertheless, this should not prevent us from finding strong support for our hypothesis. On the other hand, by including order flow in the mean equations we may also be controlling for some other process that caused a diminution in the spillovers between some markets. In this case, we could actually observe an increase in the magnitude of some of the spillovers.

To test our hypothesis, each system of equations is re-estimated with unanticipated order flow added as an explanatory variable in the conditional mean equations. As discussed above, we use the unanticipated component of order flow because only the unexpected order flow should predict currency changes and equity returns since the expected component should already be reflected in the prices (Evans and Lyons (2002a) and Rime (2001)).[12] As a proxy for unexpected order flow, we use the residuals from ARMA($p$, $q$) models applied to each series of order flow.[13] Specifically, innovations in order flow related to each of the four foreign currencies in our sample are included as regressors in each of the mean equations within the system of equations. This is motivated by the finding of Evans and Lyons (2002c) that international currency markets are informationally integrated as the order flow related to a given currency has explanatory power for the variations of other currencies. The new mean specification (for the first market) is given as follows:

$$\begin{aligned} R_{1t} &= a_1 + \sum_{i=1}^{5} b_{1i} R_{it-1} + \sum_{k=2}^{5} c_{1k} F_{1k,t-1} + \\ &d1c * CADFL_{t-1} + d1d * DEMFL_{t-1} + d1g * GBPFL_{t-1} + d1j * JPYFL_{t-1} + e_{1t} \end{aligned} \quad (9)$$

where CADFL, DEMFL, GBPFL, and JPYFL are, respectively, order flow innovations for the Canadian, German, British, and Japanese currencies.

*A. Does Currency Order Flow Have Predictive Power for Equity and Currency Markets?*

The results in Panel A (columns 10-13) of Tables 7 to 10 provide strong evidence that order flow has statistically significant predictive power in all systems of equations. A closer examination of the tables reveals some interesting results. First, lagged innovations in currency order flow have significant predictive ability not only for currency changes, but also for equity returns. This finding is consistent with results from Froot and Ramadorai (2002a,b). While innovations in the various currency order flows are generally significant in the mean of the US equities in each of the four systems of equations, there is some variation in the significance and signs of the coefficients across the various systems. The variation in significance and sign of the coefficients reflect the fact that each system has different information (e.g., the dependent variables).

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[12] Evans and Lyons (2002a) and Rime (2001) find that it is the *unexpected* component of order flow that explains changes in exchange rates.

[13] Similar to Rime (2001), who also uses ARMA models, some series required detrending before the application of the ARMA model. Results from these models are available on request.

Second, and perhaps more important to our hypothesis, except for the Canadian system, a positive shock in the order flow related to the currency of the foreign equity market leads to a significant increase in the returns of the foreign equity market. Moreover, innovations in the mark and yen order flow, DEMFL and JPYFL, have a greater impact on the returns of German and Japanese equity markets than on US market returns. These results are consistent with our portfolio-rebalancing hypothesis and suggest that currency order flow has a significant influence on the dynamic relations between international financial markets.

Third, although the exchange rate is also predicted by a shock to order flow, the response to order flow seems weaker for currencies than for equities as the currency changes are impacted by fewer of the order flow variables. Consistent with the results reported by Rime (2001), we find that the yen is most significantly affected by lagged shocks to order flow. In contrast, the CAD exchange rate is not significantly affected by any of the order flow variables. It is interesting that both the yen and the mark, which are significantly affected by their own order flows, experience an appreciation subsequent to a positive shock. Again, this result is consistent with our main hypothesis. One implication of the relatively weak impact of order flows on exchange rates is that the currency markets may be less informationally integrated than Evans and Lyons (2002c) suggest.[14] Alternatively, it could be that there is a greater tendency for exchange rates to respond contemporaneously to shocks in currency order flow, whereas equity market participants tend to require more time to absorb the information in shocks to order flow.

*B. Does Information Flow Account for the Mean Spillovers between Equity and Currency Markets?*

Given the above evidence suggesting that order flow affects the dynamics between international equity and currency markets, we now directly examine our main hypothesis. That is, in this sub-section we focus on whether or not information flow, as represented by innovations in currency order flow, can explain the mean spillovers between international equity markets and exchange rates. From Panel A of Table 7, where the dependent variables are the US and German market returns and the DEM exchange rate, there is a reduction in the magnitude and statistical significance of several of the spillover coefficients. The most important change in the mean spillovers to the DEM exchange rate is the reduction by two-thirds of the spillover from the Canadian equity market. Further, this equity spillover is no longer significant. Another notable change in the spillovers to the DEM exchange rate is the reduction, by about a half, of the spillovers from the UK equity returns and changes in the CAD exchange rate, even though these economically large coefficients are not statistically significant. Also noteworthy is that even though the spillover from the German equity returns is similar in magnitude before and after accounting for order flow, it is no longer statistically significant.

Controlling for currency order flow has an even larger effect on the interdependence between the US and German equity markets. This is evidenced by the result that the spillover from the German and Canadian stock markets and the British pound to the US market has declined by more than a half relative to the earlier results. Likewise, the spillovers to the German equity returns from the stock market returns of the US, Canada, and the UK, and from the DEM, the CAD, and the GBP exchange rates, have declined in several cases by much more than a half. These results are striking. To the extent that currency order flow is a vehicle for information transmission, we find strong support for the hypothesis that mean spillovers between equity and currency markets and between US and international equity markets are due to a large extent to information flow.

In Panel A of Table 8, where the dependent variables are the US and Japanese market returns and changes in the the JPY exchange rate, the reduction in the magnitude of the spillovers is broadly similar, though less dramatic. The results indicate that the spillovers to the yen from the US, Canadian, German, and UK markets and the British pound have declined by 10 to 50%. In contrast, there are substantially greater spillovers from the mark and the Japanese equity markets. Not surprising, after accounting for

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[14] Evans and Lyons (2002c) suggest that if changes in the value of a currency are significantly explained by currency order flow other than that related to the particular currency, then that implies that the currency markets are

order flow the changes in the spillover between the US and Japanese equity returns are similarly mixed. While the spillover from the Japanese market to the US market has disappeared, and that from the yen is now much smaller than before, the spillovers to the US market from the Canadian, German, and UK markets and the pound have increased significantly. For the Japanese stock market, after accounting for order flow, the spillover from the US equities is less than 30% its previous magnitude and is no longer statistically significant. Similarly, the previously large spillover from the Canadian dollar has disappeared, in both magnitude and statistical significance. Smaller, but economically important, reductions in spillover from the DEM and GBP exchange rates to the Japanese market are also noticeable. However, as in the case of the US market, we observe large increases in spillovers from the German and UK markets and the yen/dollar exchange rate to the Japanese market.

The results in Panel A of Table 9, where the focus is on the British system, are quite similar to those for the Japanese system. The spillovers to the GBP exchange rate are marginally affected by the inclusion of order flow, except that the spillovers from the DEM and the CAD currencies have increased significantly. The spillovers to the US and UK equity markets provide mixed results. The spillover from the UK to the US has declined by about 50%, and the spillover from the US to the UK is no longer significant, even though the magnitude has not changed. In contrast, the spillovers from the Canadian, German, and Japanese markets and the CAD exchange rate to the US and UK markets have increased.

Our finding that spillovers between some markets increase after controlling for the flow of information, as represented by innovations in order flow, suggests that by directly including order flow in the mean equations we have controlled for some unknown factor(s) that previously prevented the interdependence between these particular markets from achieving their full potential. Further, that some spillover coefficients remain significant, even where they declined after controlling for information flow, suggests that the flow of information is not the sole reason for the interdependence between international financial markets. Alternatively, this may be related to the fact that we use aggregate order flows. In the case of the Japanese equity market, this could have a particularly confounding effect because during our

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"informationally integrated." Their study is based on order flow covering approximately three months in 1996.

sample period, 1994 to 1998, Japan was experiencing a decade-long recession. Perhaps, due to the ongoing poor performance of the Japanese equity market, only a relatively small fraction of aggregate order flow is related to equity portfolio rebalancing in this period.

Turning to the Canadian system (Panel A of Table 10), the evidence indicates that, as before, there are no economically important mean spillovers to the CAD exchange rate. In contrast, the spillovers from the US market to the Canadian market, and vice versa, have experienced about a 30% reduction after controlling for order flow. In addition, the spillovers from the German, Japanese, and UK equity markets to both the US and Canadian equity markets have now declined by as much as 50% (in the case of the spillovers from the Japanese equities). However, as in the two previous systems of equations, both the US and Canadian markets now display greater dependence on the Canadian and British currencies.

*C. Can Information Flow Account for the Volatility Spillovers between Equity and Currency Markets?*

It is widely held view that the variance of prices is related to the rate of flow of information (Ross (1989)). As previously stated, we assume that unanticipated order flow reflects information flow. Hence, relative to the reduction in the mean spillovers, we expect to observe a significantly greater decline in the volatility interdependencies across markets after controlling for unanticipated order flow. Results reported in Panel B of Tables 7 to 10 overwhelmingly confirm our conjecture as the inclusion of order flow innovations in the mean equations leads to a more dramatic reduction in volatility spillovers than that which occurred in the mean spillovers. This diminution of the spillover effects is noticeable even for the UK and Japanese systems, even though the reductions are most noticeable for the German and Canadian systems.

For example, in Panel B of Table 7, the volatility spillovers from equity markets to the DEM exchange rate and from the DEM exchange rate to the equity markets have fallen by up to 90%. Similarly, the volatility spillovers from the German market to US equity volatility is only 20% its original size, while US volatility spillover to German equity volatility is only 10% its original magnitude. The spillover coefficients associated with the asymmetric volatility terms have also been reduced by similar magnitudes. Overall, all but one of the coefficients (which remains the same) in the German system experience sharp declines after controlling for order flow. Similarly, from the Canadian system in Table 10, all the spillover coefficients in the volatilities of the US and Canadian equity markets have declined by 40 to 80%.

Previously, we observed that in the Japanese system the mean of the Japanese market exhibited greater dependence on some markets after controlling for order flow (Panel A of Table 8). In contrast (from Panel B of Table 8), all spillover coefficients in the Japanese equity volatility equation are smaller after controlling for order flow. For example, the coefficients associated with the lagged volatilities of the US market and yen exchange rate are now 80% and 74% lower than before. Similarly, the reduction in the US market and yen asymmetric volatility spillover terms is over 90%.

From Panel B of Table 9, where the results are based on the British system, the spillovers are also markedly lower after accounting for order flow. For example, three of the four spillover coefficients in the UK equity volatility have declined by more than 40% and two of four spillover coefficients in the US equity volatility are up to 80% lower.

In summary, our results indicate that the mean and volatility spillovers across domestic and foreign equity and currency markets are significantly affected both statistically and economically by currency order flow. Given the evidence by Evans and Lyons (2002a, b), Froot and Ramadorai (2002a), and Rime (2001) that currency order flow is a valid vehicle for the transmission of information, our findings provide strong support for our hypothesis that a significant part of the volatility spillover is a result of information spillover. Our finding that equity and currency volatilities are impacted by information flow also supports the theoretical construct of Ross (1989) that the variance of prices is related to information arrival. However, even though order flow impacts the currency market, the more important effects of order flow are on the equity markets. Additionally, our results are consistent with the findings of Fleming et al. (1998) who examine cross-market spillovers in the context of domestic capital markets.

## VII. Summary and Conclusions

This paper investigates the dynamic relationships between the major currencies and equity markets. Specifically, we test for bi-directional mean and volatility spillovers between the US stock market, a foreign equity market, and their bilateral exchange rate. The foreign markets are the Canadian, German, Japanese, and UK equity markets, respectively, with their corresponding currencies, the Canadian dollar, the German mark, the Japanese yen, and the British pound. Additionally, we examine whether or not the mean and volatility spillovers between these markets can be attributed to information spillover, where the innovations in currency order flow conveys this information.

There are two main sets of results. The first can be summarized as follows. There are significant, bi-directional mean and volatility spillovers between currency and equity markets and between US and foreign equity markets. In the means, we find significant spillovers from the Canadian, German, Japanese, and UK equity markets to at least one exchange rate. On the other hand, we find significant spillovers from changes in the Canadian dollar, the mark, the pound, and the yen exchange rates to the US and foreign equity returns. Further, the evidence indicates that, in general, foreign equity markets significantly predict the US equity market and all are in turn predicted by the US equity market. There are also significant volatility spillovers from the US and foreign stock markets to the currency markets and from the currency markets to the US and foreign stock markets. The spillover from currency volatility to equity volatility is much stronger than the reverse. There are also significant bi-directional volatility spillovers between the equity markets and these spillovers strengthen following periods of negative shocks in the equity markets. These spillovers between the US and major equity markets are robust to filtering for the exchange-rate effect.

The essence of the second set of results is that a substantial portion of cross-market dependencies in mean and volatility can be attributed to information spillover through the mechanism of currency order flow. When we control for information flow, by including unanticipated order flow in the model, there is a dramatic reduction in both the mean and volatility spillover coefficients. While there is a reduction in both mean and volatility spillovers across the various systems of equations, the reduction is larger and more consistent in the volatilities. This supports the notion that innovations in order flow reflect information and that spillovers between the currency and the domestic and foreign equity markets are due to information flow.

It is clear from our results that the relationships between currency and equity markets are significant, bi-directional, pervasive, and coexist with the relationships between equity markets. Furthermore, these relationships are better captured in the conditional second moments. There are two broad implications of these results. First, they suggest that one reason that macroeconomists have failed to fully understand the determinants of exchange rates, is that up to now there is little, if any, role for the dynamics of the equity market in their models. Second, researchers in the area of (international) asset pricing have in general underestimated the impact of currency markets on equities because they have focused on the impact of currency markets on the mean of equity returns and have ignored the second moment.

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## TABLE 1 Summary Statistics for Equity, Exchange Rates, and Currency Flows

### A Equity Returns

| | Mean | SD | SK | XKU | J-B | Auto(L) | LB(4) | LB(12) | Auto(S) | LB(4) | LB(12) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| USR | 0.393 | 1.954 | -0.826 | 2.844 | 115.85 | -0.049 | 1.825 | 11.68 | 0.059 | 29.01 | 81.55 |
| | (0.001) | | (0.000) | (0.000) | (0.000) | -0.036 | (0.768) | (0.472) | 0.216 | (0.000) | (0.000) |
| CNR | 0.230 | 1.874 | -0.879 | 2.153 | 82.68 | 0.057 | 2.864 | 8.712 | 0.164 | 52.37 | 98.40 |
| | (0.051) | | (0.000) | (0.000) | (0.000) | -0.001 | (0.581) | (0.727) | 0.099 | (0.000) | (0.000) |
| GMR | 0.248 | 2.128 | -0.772 | 1.406 | 46.67 | -0.055 | 3.347 | 14.69 | 0.192 | 44.89 | 103.9 |
| | (0.063) | | (0.000) | (0.000) | (0.000) | 0.060 | (0.502) | (0.259) | 0.221 | (0.000) | (0.000) |
| JPR | -0.089 | 2.362 | 0.486 | 1.885 | 48.17 | -0.092 | 5.032 | 10.34 | 0.100 | 10.09 | 15.17 |
| | (0.545) | | (0.002) | (0.000) | (0.000) | 0.052 | (0.284) | (0.586) | 0.080 | (0.039) | (0.232) |
| UKR | 0.199 | 1.831 | -0.253 | 0.502 | 5.453 | -0.042 | 5.818 | 12.95 | 0.145 | 62.38 | 161.6 |
| | (0.082) | | (0.099) | (0.105) | (0.065) | 0.075 | (0.213) | (0.372) | 0.261 | (0.000) | (0.000) |

### B Exchange Rate Changes

| | Mean | SD | SK | XKU | J-B | Auto(L) | LB(4) | LB(12) | Auto(S) | LB(4) | LB(12) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEM | -0.015 | 1.259 | -0.180 | 1.288 | 19.14 | -0.003 | 2.624 | 15.42 | -0.037 | 0.437 | 16.80 |
| | (0.852) | | (0.242) | (0.000) | (0.000) | 0.073 | (0.623) | (0.220) | 0.010 | (0.979) | (0.157) |
| CAD | 0.062 | 0.638 | 0.120 | 0.519 | 3.505 | -0.011 | 6.389 | 13.26 | 0.195 | 12.48 | 37.90 |
| | (0.119) | | (0.435) | (0.094) | (0.173) | 0.026 | (0.172) | (0.351) | 0.067 | (0.014) | (0.000) |
| JPY | 0.007 | 1.779 | -1.475 | 9.854 | 1133 | -0.004 | 9.737 | 15.29 | -0.011 | 0.355 | 9.042 |
| | (0.950) | | (0.000) | (0.000) | (0.000) | 0.107 | (0.045) | (0.226) | 0.001 | (0.986) | (0.699) |
| GBP | -0.044 | 0.973 | 0.405 | 0.508 | 9.793 | 0.015 | 5.820 | 15.95 | -0.078 | 2.377 | 7.045 |
| | (0.465) | | (0.008) | (0.101) | (0.007) | -0.039 | (0.213) | (0.194) | -0.052 | (0.667) | (0.855) |

### C Net Purchase of Foreign Currencies

| | Mean | SD | SK | XKU | J-B | Auto(L) | LB(4) | LB(12) |
|---|---|---|---|---|---|---|---|---|
| DEM | 6298.654 | 22802.383 | 1.644 | 3.185 | 224.337 | 0.974 | 933.26 | 2307.3 |
| | (0.000) | | (0.000) | (0.000) | (0.000) | 0.955 | (0.000) | (0.000) |
| CAD | 4390.510 | 3086.386 | -0.035 | 0.105 | 0.172 | 0.832 | 1056.7 | 2772.1 |
| | (0.000) | | (0.818) | (0.735) | (0.917) | 0.813 | (0.000) | (0.000) |
| JPY | -3313180.354 | 2157944.106 | -1.703 | 2.498 | 190.95 | 0.959 | 1448.5 | 3496.7 |
| | (0.000) | | (0.000) | (0.000) | (0.000) | 0.944 | (0.000) | (0.000) |
| GBP | 5490.222 | 4639.056 | 0.648 | -0.598 | 21.832 | 0.925 | 1307.4 | 3482.5 |
| | (0.000) | | (0.009) | (0.054) | (0.000) | 0.898 | (0.000) | (0.000) |

All figures in bracket are *p*-values associated with the null hypothesis that the respective statistic is equal to zero. SD is standard deviation, SK is skewness (*p*-value), and XKU is excess kurtosis (*p*-value). J-B is the Jarque-Bera test of normality (*p*-value). Auto(L) are the autocorrelation coefficients of the returns (in level) on the respective series, at the first (top) and second (below) lags. LB(x) are the Ljung-Box test of significance of autocorrelation at x lags (*p*-value). Similarly, Auto(S) are the autocorrelation of the squared returns (*p*-value). The returns on the equity series are computed as 100 times the log-first difference of the stock market index. USR, CNR, GMR, JPR, and UKR are the US, Canadian, German, Japanese, and UK stock market returns, respectively. CAD, DEM, GBP, and JPY, respectively, are changes in the Canadian, German, UK, and Japanese exchange rates, expressed as foreign currency per dollar, and computed as 100 times the log-first difference of the exchange rate. The "net purchase of foreign currencies" (order flow) represents purchase minus sale of the foreign currency expressed in units of foreign currency. The data cover the period January 1994 to December 1998 (258 weekly observations).

## Table 2 Cross-Correlation between Currency and Equity Markets

### A Correlation between Equity Returns and Currency Changes

| | US equity returns and foreign currency changes | | | | GM equity returns | JP equity returns | UK equity returns | CDN equity returns |
|---|---|---|---|---|---|---|---|---|
| Lag | DEM | JPY | GBP | CAD | DEM | JPY | GBP | CAD |
| -2 | -0.021 | -0.018 | 0.007 | -0.120 | 0.068 | -0.028 | 0.003 | -0.102 |
| -1 | 0.023 | 0.026 | 0.039 | 0.084 | 0.047 | 0.018 | 0.061 | 0.076 |
| 0 | 0.318 | 0.184 | 0.127 | -0.111 | 0.449 | 0.059 | 0.304 | -0.220 |
| 1 | -0.068 | -0.119 | -0.081 | -0.111 | -0.027 | 0.092 | -0.014 | -0.130 |
| 2 | 0.043 | -0.073 | -0.010 | -0.169 | 0.090 | -0.071 | -0.018 | -0.142 |
| *p*(1 to 2) | 0.425 | 0.079 | 0.418 | 0.005 | 0.314 | 0.170 | 0.934 | 0.008 |
| *p*(-2 to -1) | 0.884 | 0.876 | 0.818 | 0.060 | 0.413 | 0.865 | 0.618 | 0.121 |
| *p*(-2 to 2) | 0.000 | 0.015 | 0.275 | 0.002 | 0.000 | 0.451 | 0.0001 | 0.000 |

### B Correlation between Squared Equity Returns and Squared Currency Changes

| | US equity returns and foreign currency changes | | | | GMR equity returns | JPR equity returns | UKR equity returns | CNR equity returns |
|---|---|---|---|---|---|---|---|---|
| Lag | DEM | JPY | GBP | CAD | DEM | JPY | GBP | CAD |
| -2 | -0.022 | 0.001 | -0.013 | 0.009 | 0.005 | 0.037 | 0.026 | 0.139 |
| -1 | 0.027 | 0.098 | -0.024 | 0.103 | 0.032 | 0.013 | -0.043 | 0.197 |
| 0 | 0.162 | 0.266 | 0.025 | 0.182 | 0.259 | 0.065 | 0.028 | 0.295 |
| 1 | -0.036 | 0.035 | 0.013 | 0.280 | 0.014 | 0.145 | -0.006 | 0.244 |
| 2 | 0.042 | 0.259 | 0.004 | 0.058 | -0.031 | 0.376 | -0.082 | 0.086 |
| *p*(1 to 2) | 0.671 | 0.000 | 0.975 | 0.000 | 0.861 | 0.000 | 0.415 | 0.000 |
| *p*(-2 to -1) | 0.851 | 0.288 | 0.906 | 0.247 | 0.872 | 0.817 | 0.719 | 0.001 |
| *p*(-2 to 2) | 0.161 | 0.000 | 0.995 | 0.000 | 0.003 | 0.000 | 0.758 | 0.000 |

The change and squared change of each exchange rate is cross-correlated with the returns and squared returns, respectively, on the equity series above it. *p*(x to y) is the *p*-value from the Ljung-Box test of significance of the cross-correlation. "lag" refers to the number of periods by which the currency series *lags* the equity series. That is, the correlation between equity($t$) and currency($t$-lag). Hence, *p*(1 to 2) is the *p*-value of the null hypothesis that the equity series does not lag (at $t$) the currency series (at $t$-1 and $t$-2 ), while *p*(-2 to -1) is that the equity series does not lead the currency series. The returns on the equity series are computed as 100 times the log-first difference of the stock market index. USR, CNR, GMR, JPR, and UKR are the US, Canadian, German, Japanese, and UK stock market returns, respectively. CAD, DEM, GBP, and JPY, respectively, are changes in the Canadian, German, UK, and Japanese exchange rates, expressed as foreign currency per dollar, and computed as 100 times the log-first difference of the exchange rate. The data cover the period January 1994 to December 1998 (258 weekly observations).

## Table 3 Spillovers between the US and German Equity Markets and DEM

### A. Spillovers in Mean

| | $USR_{t-1}$ | $GMR_{t-1}$ | $DEM_{t-1}$ | $CNR_{t-1}$ | $JPR_{t-1}$ | $UKR_{t-1}$ | $CAD_{t-1}$ | $JPY_{t-1}$ | $GBP_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|
| $USR_t$ | -0.2237 (0.01) | 0.2158 (0.00) | -0.1347 (0.03) | 0.2723 (0.01) | -0.0191 (0.63) | -0.0654 (0.57) | 0.1176 (0.00) | -0.0571 (0.57) | -0.1202 (0.57) | 0.3199 (0.00) |
| $GMR_t$ | -0.2896 (0.00) | 0.1113 (0.09) | -0.0879 (0.37) | 0.2803 (0.09) | -0.0123 (0.00) | 0.1084 (0.42) | 0.2056 (0.00) | 0.0297 (0.50) | -0.2033 (0.49) | 0.2567 (0.00) |
| $DEM_t$ | -0.0029 (0.99) | 0.0518 (0.00) | -0.0483 (0.00) | 0.1208 (0.03) | 0.0207 (0.00) | -0.1412 (0.33) | 0.3043 (0.19) | -0.0370 (0.30) | -0.0347 (0.30) | -0.1103 (0.40) |

### B. Spillovers in Variance

| | USR sq. error $_{t-1}$ | GMR sq. error $_{t-1}$ | DEM sq. error $_{t-1}$ | USR asymm.$_{t-1}$ | GMR asymm.$_{t-1}$ | DEM asymm.$_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | 0.2332 (0.00) | 0.0983 (0.00) | 0.1480 (0.00) | 0.4846 (0.00) | 0.1880 (0.00) | 0.2676 (0.00) | 0.4130 (0.00) | 0.1580 (0.00) |
| GMR volatility$_t$ | 0.1998 (0.00) | 0.2856 (0.00) | 0.2165 (0.00) | 0.2182 (0.00) | 0.3448 (0.00) | 0.3025 (0.00) | 0.3612 (0.00) | 0.2223 (0.00) |
| DEM volatility$_t$ | -0.1058 (0.00) | 0.0885 (0.00) | 0.4125 (0.00) | 0.1608 (0.00) | -0.0693 (0.09) | 0.0561 (0.03) | 0.4779 (0.01) | 0.2573 (0.00) |

| *Constant Correlation* | $USR_t$. & $GMR_t$ | $USR_t$. & $DEM_t$ | $GMR_t$ & $DEM_t$ |
|---|---|---|---|
| | 0.6102 (0.00) | 0.2963 (0.00) | 0.4734 (0.00) |

### C. Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-alue) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-alue) | $LB^2(3)$ (*p*-value) | $LB^2(12)$ (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | -0.02 (0.77) | -0.83 (0.00) | 1.27 (0.00) | 45.98 (0.00) | 1.71 (0.63) | 8.67 (0.73) | 3.87 (0.27) | 7.18 (0.85) |
| GMR residuals | 0.01(0.85) | -0.29 (0.06) | 0.95 (0.00) | 13.28 (0.00) | 3.86 (0.28) | 15.76 (0.00) | 5.21 (0.16) | 7.72 (0.81) |
| DEM residuals | 0.07 (0.34) | 0.12 (0.40) | 0.65 (0.04) | 5.16 (0.08) | 1.66 (0.65) | 15.67 (0.21) | 4.53 (0.21) | 12.91 (0.38) |
| *Residual cross-products* | | | | | | | | |
| USR – GMR residuals | 0.99 (0.00) | 3.46 (0.00) | 18.29 (0.00) | 4046.18 (0.00) | 2.22 (0.70) | 4.02 (0.98) | | |
| USR – DEM residuals | 0.90 (0.00) | 0.70 (0.00) | 6.67 (0.00) | 492.32 (0.00) | 1.17 (0.88) | 8.09 (0.79) | | |
| GMR – DEM residuals | 0.91 (0.00) | 2.09 (0.00) | 6.89 (0.00) | 686.09 (0.00) | 5.04 (0.28) | 12.49 (0.41) | | |

### D. Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8)* | No "other" equity effect on mean (3) | No "other" currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 498936.79 (0.00) | 16502.22 (0.00) | 767.92 (0.00) | 16784.49 (0.00) | 88.73 (0.00) | 175.02 (0.00) |
| GMR - $\chi^2$ (*p*-value) | 35334.86 (0.00) | 3563.45 (0.00) | 811.48 (0.00) | 273672.10 (0.00) | 84.25 (0.00) | |
| DEM - $\chi^2$ (*p*-value) | 37737.79 (0.00) | 446.97 (0.00) | 70.78 (0.00) | 3825.52 (0.00) | 204.27 (0.00) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB(*x*) [$LB^2(x)$] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag *x* in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD, DEM, JPY, and GBP are percentage changes of the Canadian dollar, deutsche mark, yen, and British pound, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. "Other" equities (currencies) are those that are not dependent variables in this equation system. "Other" asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).

## Table 4 Spillovers between the US and Japanese Equity Markets and Yen

### A. Spillovers in Mean

| | $USR_{t-1}$ | $JPR_{t-1}$ | $JPY_{t-1}$ | $CNR_{t-1}$ | $GMR_{t-1}$ | $UKR_{t-1}$ | $CAD_{t-1}$ | $DEM_{t-1}$ | $GBP_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|
| $USR_t$ | -0.1683 (0.00) | -0.0737 (0.76) | -0.1761 (0.00) | 0.1739 (0.37) | 0.0416 (0.82) | 0.0649 (0.02) | 0.1849 (0.42) | 0.0367 (0.88) | -0.1381 (0.67) | 0.4154 (0.00) |
| $JPR_t$ | 0.1775 (0.05) | -0.0317 (0.81) | 0.0316 (0.27) | -0.0550 (0.71) | 0.0967 (0.27) | -0.1438 (0.00) | -0.3091 (0.00) | -0.1564 (0.40) | 0.0587 (0.05) | -0.1780 (0.48) |
| $JPY_t$ | -0.2035 (0.55) | -0.0695 (0.71) | -0.0378 (0.86) | 0.1598 (0.16) | 0.2299 (0.01) | -0.1158 (0.45) | 0.1107 (0.79) | -0.1090 (0.21) | -0.0798 (0.00) | 0.1413 (0.41) |

### B. Spillovers in Variance

| | USR sq. error $_{t-1}$ | JPRsq. error $_{t-1}$ | JPYsq. error $_{t-1}$ | USR asymm. $_{t-1}$ | JPR asymm. $_{t-1}$ | JPYasymm. $_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | -0.0940 (0.01) | 0.0592 (0.05) | -0.0688 (0.10) | 0.2464 (0.01) | -0.0736 (0.41) | 0.0211 (0.82) | 0.8352 (0.00) | 0.4060 (0.00) |
| JPR volatility$_t$ | -0.1847 (0.05) | -0.0705 (0.14) | 0.1967 (0.00) | 0.2152 (0.38) | 0.2263 (0.00) | -0.1359 (0.00) | 0.8753 (0.00) | 0.3250 (0.00) |
| JPY volatility$_t$ | 0.0756 (0.02) | 0.0750 (0.00) | 0.1177 (0.02) | -0.0006 (0.98) | 0.0352 (0.41) | -0.0629 (0.62) | 0.6630 (0.00) | 0.0766 (0.03) |

*Constant Correlation*

| $USR_t$ & $JPR_t$ | $USR_t$ & $JPY_t$ | $JPR_t$ & $JPY_t$ |
|---|---|---|
| 0.3143 (0.00) | 0.1831 (0.06) | 0.0831 (0.70) |

### C. Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) | $LB^2(3)$ (*p*-value) | $LB^2(12)$ (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | -0.03 (0.69) | -0.77 (0.00) | 1.32 (0.00) | 43.92 (0.00) | 4.19 (0.63) | 9.59 (0.73) | 2.38 (0.27) | 14.11 (0.85) |
| JPR residuals | -0.01 (0.99) | -0.22 (0.15) | 0.35 (0.23) | 3.55 (0.16) | 3.95 (0.27) | 9.40 (0.67) | 1.24 (0.74) | 9.04 (0.69) |
| JPY residuals | -0.07 (0.28) | -0.55 (0.00) | 2.73 (0.00) | 91.54 (0.00) | 1.25 (0.74) | 6.23 (0.90) | 2.30 (0.51) | 8.39 (0.75) |

*Residual cross-products*

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) |
|---|---|---|---|---|---|---|
| USR– JPR residuals | 1.00 (0.00) | 1.62 (0.00) | 5.25 (0.00) | 403.11 (0.00) | 2.25 (0.70) | 8.05 (0.78) |
| USR–JPY residuals | 1.02 (0.00) | 3.00 (0.00) | 20.32 (0.00) | 4751.90 (0.00) | 2.13 (0.71) | 20.45 (0.06) |
| JPR– JPY residuals | 1.46 (0.10) | 3.99 (0.00) | 36.72 (0.00) | 14945.05 (0.00) | 4.78 (0.31) | 22.63 (0.03) |

### D Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8)* | No "other" equity effect on mean (3) | No "other" currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 184.72 (0.00) | 6.43 (0.09) | 12.6 (0.00) | 819.65 (0.00) | 44.74 (0.00) | 38.99 (0.00) |
| JPR - $\chi^2$ (*p*-value) | 67922.27 (0.00) | 42673.36 (0.00) | 1362.50 (0.00) | 1752.21 (0.00) | 10.12 (0.01) | |
| JPY - $\chi^2$ (*p*-value) | 225.92 (0.00) | 71.47 (0.00) | 33.69 (0.00) | 270.95 (0.00) | 6.89 (0.03) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB(*x*) [$LB^2(x)$] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag *x* in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD, DEM, JPY, and GBP are percentage changes of the Canadian dollar, deutsche mark, yen, and British pound, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. "Other" equities (currencies) are those that are not dependent variables in this equation system. "Other" asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).

## Table 5 Spillovers between the US and UK Equity Markets and GBP

### A Spillovers in Mean

| | $USR_{t-1}$ | $UKR_{t-1}$ | $GBP_{t-1}$ | $CNR_{t-1}$ | $GMR_{t-1}$ | $JPR_{t-1}$ | $CAD_{t-1}$ | $DEM_{t-1}$ | $JPY_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|
| USR | -0.2022 (0.00) | 0.1773 (0.00) | -0.2986 (0.00) | 0.0656 (0.25) | 0.0897 (0.00) | -0.0115 (0.79) | -0.0098 (0.81) | -0.0219 (0.18) | -0.0222 (0.16) | 0.2249 (0.09) |
| UKR | -0.2172 (0.00) | -0.0231 (0.75) | -0.0761 (0.28) | 0.1482 (0.00) | -0.0347 (0.24) | 0.0765 (0.06) | -0.1922 (0.00) | 0.0025 (0.95) | 0.0454 (0.64) | 0.1809 (0.03) |
| GBP | -0.0941 (0.23) | 0.0431 (0.55) | -0.0402 (0.65) | 0.0105 (0.78) | 0.0026 (0.83) | 0.0526 (0.03) | 0.1293 (0.17) | 0.0072 (0.78) | 0.0539 (0.23) | -0.0134 (0.78) |

### B Spillovers in Variance

| | USR sq. error $_{t-1}$ | UKR sq. error $_{t-1}$ | GBP sq. error $_{t-1}$ | USR asymm.$_{t-1}$ | UKR asymm.$_{t-1}$ | GBP asymm.$_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | 0.1159 (0.00) | 0.0593 (0.00) | 0.2143 (0.00) | 0.0560 (0.02) | 0.3230 (0.41) | 0.2348 (0.82) | 0.5456 (0.00) | 0.1743 (0.00) |
| UKR volatility$_t$ | 0.0551 (0.00) | 0.1384 (0.00) | 0.1320 (0.00) | -0.1413 (0.06) | 0.1922 (0.03) | 0.3322 (0.00) | 0.6714 (0.00) | 0.1832 (0.00) |
| GBP volatility$_t$ | 0.0260 (0.02) | 0.0558 (0.00) | -0.0403 (0.62) | -0.0307 (0.00) | -0.0773 (0.00) | 0.0788 (0.62) | 0.7353 (0.00) | 0.1985 (0.00) |

| *Constant Correlation* | $USR_t$ & $UKR_t$ | $USR_t$ & $GBP_t$ | $UKR_t$ & $GBP_t$ |
|---|---|---|---|
| | 0.6267 (0.00) | 0.0972 (0.37) | 0.3089 (0.00) |

### C Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) | $LB^2(3)$ (*p*-value) | $LB^2(12)$ (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | 0.07 (0.27) | -0.77 (0.00) | 0.81 (0.01) | 31.78 (0.00) | 2.04 (0.56) | 8.22 (0.77) | 4.88 (0.18) | 13.11 (0.36) |
| UKR residuals | -0.05 (0.44) | -0.46 (0.00) | 0.35 (0.26) | 10.06 (0.10) | 1.24 (0.74) | 8.75 (0.72) | 2.06 (0.56) | 9.88 (0.63) |
| GBP residuals | -0.02 (0.73) | 0.21 (0.17) | -0.05 (0.87) | 1.97 (0.37) | 4.85 (0.18) | 21.27 (0.05) | 1.71 (0.63) | 6.30 (0.90) |
| *Residual cross-products* | | | | | | | | |
| USR – UKR residuals | 1.06 (0.00) | 3.81 (0.00) | 23.56 (0.00) | 6489.29 (0.00) | 3.99 (0.40) | 12.95 (0.37) | | |
| USR – GBP residuals | 1.13 (0.10) | 2.15 (0.00) | 15.20 (0.00) | 2640.63 (0.00) | 0.45 (0.98) | 4.55 (0.97) | | |
| UKR– GBP residuals | 0.96 (0.00) | 2.04 (0.00) | 11.91 (0.00) | 1676.67 (0.00) | 2.56 (0.64) | 4.65 (0.03) | | |

### D Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8) | No "other" equity effect on mean (3) | No "other" currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 66447.99 (0.00) | 110.57 (0.00) | 8.25 (0.04) | 327.82 (0.00) | 127.47 (0.00) | 21.35 (0.00) |
| UKR - $\chi^2$ (*p*-value) | 186295.15 (0.00) | 4458.20 (0.00) | 3711.28 (0.00) | 1578.20 (0.00) | 370.51 (0.01) | |
| GBP - $\chi^2$ (*p*-value) | 2980.04 (0.00) | 71.47 (0.00) | 34.74 (0.00) | 9578.29 (0.00) | 474.05 (0.03) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB($x$) [$LB^2(x)$] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag $x$ in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD, DEM, JPY, and GBP are percentage changes of the Canadian dollar, deutsche mark, yen, and British pound, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. "Other" equities (currencies) are those that are not dependent variables in this equation system. "Other" asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).

## Table 6 Spillovers between the US and Canadian Equity Markets and CAD

### A Spillovers in Mean

| | $USR_{t-1}$ | $CNR_{t-1}$ | $CAD_{t-1}$ | $GMR_{t-1}$ | $JPR_{t-1}$ | $UKR_{t-1}$ | $DEM_{t-1}$ | $JPY_{t-1}$ | $GBP_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|
| $USR_t$ | -0.2571 (0.00) | 0.0650 (0.00) | -0.0491 (0.14) | 0.2321 (0.00) | -0.0987 (0.00) | 0.1167 (0.79) | -0.0010 (0.76) | -0.1480 (0.00) | -0.2825 (0.76) | 0.3161 (0.00) |
| $CNR_t$ | -0.1469 (0.00) | 0.0281 (0.75) | -0.2396 (0.00) | 0.1261 (0.00) | -0.0516 (0.00) | 0.1850 (0.00) | -0.0696 (0.95) | -0.0728 (0.00) | -0.1718 (0.00) | 0.2164 (0.00) |
| $CAD_t$ | 0.0008 (0.98) | -0.0051 (0.81) | 0.0197 (0.72) | 0.0322 (0.05) | -0.0078 (0.58) | -0.0384 (0.02) | 0.0400 (0.15) | -0.0075 (0.71) | 0.0771 (0.23) | 0.0825 (0.02) |

### B. Spillovers in Variance

| | USR sq. error $_{t-1}$ | CNR sq. error $_{t-1}$ | CAD sq. error $_{t-1}$ | USR asymm.$_{t-1}$ | CNR asymm.$_{t-1}$ | CAD asymm.$_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | -0.0575 (0.33) | 0.1639 (0.00) | 0.4817 (0.00) | 0.2239 (0.00) | 0.1624 (0.00) | -0.5107 (0.11) | 0.4787 (0.00) | 0.9402 (0.00) |
| CNR volatility$_t$ | 0.1326 (0.00) | 0.1553 (0.00) | 0.3579 (0.00) | 0.1294 (0.00) | 0.3625 (0.00) | 0.4447 (0.00) | 0.5382 (0.00) | 0.1576 (0.00) |
| CAD volatility$_t$ | 0.0246 (0.10) | -0.0002 (0.97) | 0.0340 (0.49) | -0.0400 (0.00) | 0.0177 (0.00) | 0.0451 (0.47) | 0.6885 (0.00) | 0.0593 (0.01) |

| *Constant Correlation* | $USR_t$ & $CNR_t$ | $USR_t$ & $CAD_t$ | $CNR_t$ & $GBP_t$ |
|---|---|---|---|
| | 0.7613 (0.00) | -0.1981 (0.00) | -0.2536 (0.00) |

### C. Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) | $LB^2(3)$ (*p*-value) | $LB^2(12)$ (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | 0.02 (0.75) | -0.69 (0.00) | 0.69 (0.03) | 25.64 (0.00) | 6.02 (0.11) | 13.76 (0.31) | 2.71 (0.44) | 8.42 (0.75) |
| CNR residuals | 0.01 (0.93) | -0.76 (0.00) | 1.94 (0.00) | 63.84 (0.00) | 4.15 (0.25) | 10.23 (0.59) | 2.55 (0.47) | 5.06 (0.96) |
| CAD residuals | -0.03 (0.68) | 0.05 (0.73) | -0.32 (0.30) | 1.23 (0.54) | 6.68 (0.08) | 13.29 (0.35) | 0.61 (0.89) | 14.96 (0.24) |
| *Residual cross-products* | | | | | | | | |
| USR – CNR residuals | 0.91 (0.00) | 5.06 (0.00) | 36.39 (0.00) | 15099.05 (0.00) | 3.18 (0.53) | 9.46 (0.87) | | |
| USR – CAD residuals | 0.89 (0.01) | 1.45 (0.00) | 6.05 (0.00) | 475.99 (0.00) | 4.28 (0.37) | 8.13 (0.97) | | |
| CNR– CAD residuals | 0.90 (0.00) | 2.57 (0.00) | 14.56 (0.00) | 2524.69 (0.00) | 0.60 (0.96) | 7.53 (0.82) | | |

### D. Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8)* | No "other" equity effect on mean (3) | No "other" currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 7138.11 (0.00) | 549.82 (0.00) | 175.83 (0.00) | 1339.35 (0.00) | 396.92 (0.00) | 315.82 (0.00) |
| CNR - $\chi^2$ (*p*-value) | 9567.92 (0.00) | 776.35 (0.00) | 52.41 (0.00) | 600.36 (0.11) | 632.94 (0.00) | |
| CAD - $\chi^2$ (*p*-value) | 87.49 (0.00) | 27.75 (0.00) | 15.22 (0.00) | 166.39 (0.00) | 9.82 (0.01) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB(*x*) [$LB^2(x)$] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag *x* in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD, DEM, JPY, and GBP are percentage changes of the Canadian dollar, deutsche mark, yen, and British pound, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. "Other" equities (currencies) are those that are not dependent variables in this equation system. "Other" asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).

## Table 7 Impact of Currency Order Flow on Spillovers between the US and German Equity Markets and the DEM

### A. Spillovers in Mean

| | $USR_{t-1}$ | $GMR_{t-1}$ | $DEM_{t-1}$ | $CNR_{t-1}$ | $JPR_{t-1}$ | $UKR_{t-1}$ | $CAD_{t-1}$ | $JPY_{t-1}$ | $GBP_{t-1}$ | $DEMFL_{t-1}$ | $JPYFL_{t-1}$ | $CADFL_{t-1}$ | $GBPFL_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $USR_{t}$ | -0.107 | 0.111 | -0.131 | 0.108 | -0.021 | -0.025 | -0.143 | -0.118 | 0.030 | 3.4E-5 | 2.5E-7 | 1.248 | 1.248 | 0.043 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.34) | (0.00) | (0.00) | (0.57) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| $GMR_t$ | -0.087 | -0.046 | 0.013 | 0.110 | 0.015 | 0.061 | 0.012 | -0.093 | 0.061 | 6.3E-5 | -5.5E-8 | 2.5E-5 | 9.8E-5 | 0.334 |
| | (0.00) | (0.15) | (0.61) | (0.00) | (0.33) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.83) | (0.00) | (0.00) | (0.00) |
| $DEM_t$ | 0.029 | 0.058 | -0.059 | 0.037 | 0.011 | -0.058 | 0.131 | -0.017 | 0.040 | -4.1E-5 | -1.7E-7 | 2.8E-5 | 1.1E-5 | -0.048 |
| | (0.55) | (0.20) | (0.47) | (0.49) | (0.73) | (0.16) | (0.23) | (0.73) | (0.00) | (0.00) | (0.18) | (0.49) | (0.76) | (0.47) |

### B. Spillovers in Variance

| | USR sq. error $_{t-1}$ | GMR sq. error $_{t-1}$ | DEM sq. error $_{t-1}$ | USR asymm.$_{t-1}$ | GMR asymm.$_{t-1}$ | DEM asymm.$_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | 0.032 (0.00) | 0.011(0.00) | 0.016 (0.00) | 0.065 (0.03) | 0.013 (0.00) | -8.1E-3 (0.33) | 0.853 (0.00) | 0.146 (0.00) |
| GMR volatility$_t$ | 0.021 (0.00) | 0.185 (0.00) | 0.046 (0.00) | 0.029 (0.00) | -0.064 (0.14) | 0.033 (0.00) | 0.785 (0.00) | 0.127 (0.00) |
| DEM volatility$_t$ | -0.068 (0.00) | 0.062 (0.00) | -0.047 (0.27) | 0.068 (0.00) | -0.061 (0.00) | 0.098 (0.17) | 0.750 (0.00) | 0.387 (0.00) |

*Constant Correlation*

| $USR_t$ & $GMR_t$ | $USR_t$ & $DEM_t$ | $GMR_t$ & $DEM_t$ |
|---|---|---|
| 0.6211 (0.00) | 0.3436 (0.00) | 0.4811 (0.00) |

### C. Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) | $LB^2(3)$ (*p*-value) | $LB^2(12)$ (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | -0.03 (0.65) | -0.79 (0.00) | 0.82 (0.00) | 33.46 (0.00) | 2.74 (0.43) | 9.70 (0.64) | 1.42 (0.70) | 6.57 (0.89) |
| GMR residuals | -0.02 (0.79) | -0.59 (0.00) | 0.62 (0.04) | 8.73 (0.00) | 3.07 (0.38) | 9.69 (0.64) | 1.65 (0.64) | 7.21 (0.81) |
| DEM residuals | 0.01 (0.95) | 0.11 (0.49) | 1.02 (0.00) | 11.54 (0.00) | 0.72 (0.87) | 15.14 (0.23) | 0.57 (0.91) | 17.00 (0.14) |
| *Residual cross-products* | | | | | | | | |
| USR – GMR residuals | 0.99 (0.00) | 3.81 (0.00) | 21.78 (0.00) | 5633.30 (0.00) | 0.58 (0.97) | 3.61 (0.99) | | |
| USR – DEM residuals | 0.93 (0.00) | 2.17 (0.00) | 7.98 (0.00) | 871.23 (0.00) | 2.08 (0.72) | 7.25 (0.84) | | |
| GMR – DEM residuals | 0.96 (0.00) | 2.85 (0.00) | 11.68 (0.00) | 1788.27 (0.00) | 2.79 (0.59) | 5.62 (0.93) | | |

### D. Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8)* | No "other" equity effect on mean (3) | No "other" currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 898.34 (0.00) | 74.91 (0.00) | 102.80 (0.00) | 1779.95 (0.00) | 1209.64 (0.00) | 31.47 (0.000) |
| GMR - $\chi^2$ (*p*-value) | 1321.26 (0.00) | 25.41 (0.00) | 15.63 (0.00) | 1727.18 (0.00) | 1636.89 (0.00) | |
| DEM - $\chi^2$ (*p*-value) | 8.15 (0.42) | 2.41 (0.49) | 2.29 (0.51) | 427.02 (0.00) | 161.77 (0.00) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB(*x*) [$LB^2(x)$] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag *x* in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD (CADFL), DEM (DEMFL), GBP (GBPFL), and JPY (JPYFL) is the percentage change (innovation in the order flow) of the Canadian dollar, deutsche mark, British pound, and yen, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. "Other" equities (currencies) are those that are not dependent variables in this equation system. "Other" asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).

## Table 8 Impact of Currency Order Flow on Spillovers between the US and Japanese Equity Markets and the JPY

### A. Spillovers in Mean

| | $USR_{t-1}$ | $JPR_{t-1}$ | $JPY_{t-1}$ | $CNR_{t-1}$ | $GMR_{t-1}$ | $UKR_{t-1}$ | $CAD_{t-1}$ | $DEM_{t-1}$ | $GBP_{t-1}$ | $DEMFL_{t-1}$ | $JPYFL_{t-1}$ | $CADFL_{t-1}$ | $GBPFL_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $USR_t$ | -0.196 | 7.6E-3 | -0.127 | 0.260 | 0.133 | -0.094 | -0.014 | 0.090 | -0.149 | 1.2E-5 | 4.2E-7 | 1.5E-5 | -9.4E-5 | 0.413 |
| | (0.00) | (0.83) | (0.00) | (0.00) | (0.00) | (0.00) | (0.51) | (0.05) | (0.00) | (0.09) | (0.11) | (0.13) | (0.00) | (0.00) |
| $JPR_t$ | 0.049 | -0.075 | 0.125 | 0.056 | 0.226 | -0.315 | 6.1E-3 | -0.045 | 0.037 | 5.0E-5 | 1.1E-6 | -1.9E-4 | -3.1E-5 | -0.114 |
| | (0.32) | (0.00) | (0.00) | (0.03) | (0.00) | (0.00) | (0.89) | (0.40) | (0.00) | (0.00) | (0.09) | (0.00) | (0.25) | (0.00) |
| $JPY_t$ | -0.182 | -0.182 | 0.143 | 0.136 | 0.213 | -0.070 | 0.118 | -0.181 | -0.035 | 4.0E-5 | -4.0E-7 | 3.8E-5 | -6.5E-5 | 0.053 |
| | (0.00) | (0.15) | (0.00) | (0.00) | (0.00) | (0.00) | (0.02) | (0.00) | (0.00) | (0.00) | (0.08) | (0.09) | (0.02) | (0.30) |

### B. Spillovers in Variance

| | USR sq. error $_{t-1}$ | JPR sq. error $_{t-1}$ | JPY sq. error $_{t-1}$ | USR asymm. $_{t-1}$ | JPR asymm. $_{t-1}$ | JPY asymm. $_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | -0.165 (0.01) | 0.102 (0.00) | -0.146 (0.01) | 0.296 (0.00) | 0.060 (0.00) | 0.099 (0.02) | 0.782 (0.00) | 0.259 (0.00) |
| JPR volatility$_t$ | -0.032 (0.30) | 0.033 (0.05) | 0.052 (0.00) | -1.1E-3 (0.97) | 0.166 (0.00) | -9.7E-3 (0.56) | 0.879 (0.00) | 0.139 (0.00) |
| JPY volatility$_t$ | 0.050 (0.00) | 0.090 (0.00) | 0.100 (0.00) | 0.011 (0.14) | 0.045 (0.00) | -0.060 (0.46) | 0.696 (0.00) | -0.060 (0.18) |

*Constant Correlation*

| $USR_t$ & $JPR_t$ | $USR_t$ & $JPY_t$ | $JPR_t$ & $JPY_t$ |
|---|---|---|
| 0.2850 (0.00) | 0.1610 (0.01) | 0.1361 (0.00) |

### C. Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) | $LB^2$(3) (*p*-value) | $LB^2$(12) (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | -0.03 (0.63) | -0.61 (0.00) | 0.44 (0.16) | 17.65 (0.00) | 4.00 (0.26) | 15.11 (0.24) | 1.06 (0.79) | 13.84 (0.31) |
| JPR residuals | -0.01 (0.96) | 0.19 (0.23) | 0.28 (0.37) | 2.30 (0.32) | 6.44 (0.09) | 11.34 (0.44) | 2.94 (0.40) | 9.15 (0.69) |
| JPY residuals | -0.04 (0.58) | -0.63 (0.00) | 2.68 (0.00) | 92.95 (0.00) | 3.36 (0.34) | 11.97 (0.44) | 1.41 (0.70) | 5.41 (0.94) |
| *Residual cross-products* | | | | | | | | |
| USR – JPR residuals | 1.01 (0.00) | 0.82 (0.00) | 4.50 (0.00) | 292.27 (0.00) | 0.53 (0.97) | 6.69 (0.88) | | |
| USR – JPY residuals | 0.10 (0.00) | 2.64 (0.00) | 18.76 (0.00) | 4018.41 (0.00) | 4.54 (0.34) | 20.20 (0.06) | | |
| JPR – JPY residuals | 0.95 (0.07) | 2.92 (0.00) | 21.72 (0.00) | 5353.13 (0.00) | 1.49 (0.83) | 24.75 (0.02) | | |

### D. Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8)* | No “other” equity effect on mean (3) | No “other” currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 3568.67 (0.00) | 309.83 (0.00) | 22.19 (0.00) | 6801.41 (0.00) | 193.98 (0.00) | 123.6972 (0.00) |
| JPR - $\chi^2$ (*p*-value) | 14458.21 (0.00) | 177.39 (0.00) | 2.47 (0.48) | 5511.91 (0.00) | 0.3388 (0.84) | |
| JPY - $\chi^2$ (*p*-value) | 1597.02 (0.00) | 612.99 (0.00) | 10.59 (0.01) | 1589.33 (0.00) | 20.044 (0.00) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB(*x*) [$LB^2$(*x*)] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag *x* in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD (CADFL), DEM (DEMFL), GBP (GBPFL), and JPY (JPYFL) is the percentage change (innovation in the order flow) of the Canadian dollar, deutsche mark, British pound, and yen, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. “Other” equities (currencies) are those that are not dependent variables in this equation system. “Other” asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).

## Table 9 Impact of Currency Order Flow on Spillovers between the US and British Equity Markets and the GBP

### A. Spillovers in Mean

| | $USR_{t-1}$ | $UKR_{t-1}$ | $GBP_{t-1}$ | $CNR_{t-1}$ | $GMR_{t-1}$ | $JPR_{t-1}$ | $CAD_{t-1}$ | $DEM_{t-1}$ | $JPY_{t-1}$ | $DEMFL_{t-1}$ | $JPYFL_{t-1}$ | $CADFL_{t-1}$ | $GBPFL_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $USR_t$ | -0.131 | -0.085 | -0.275 | 0.163 | 0.270 | 0.046 | -0.137 | -0.027 | -0.089 | 6.2E-6 | 6.5E-8 | -2.9E-5 | -8.1E-5 | 0.280 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.83) | (0.51) | (0.00) | (0.00) | (0.06) | (0.90) | (0.00) | (0.00) | (0.00) |
| $UKR_t$ | -0.223 | -0.112 | -0.134 | 0.237 | 0.078 | 0.105 | -0.247 | 2.5E-4 | 8.9E-3 | 2.1E-6 | -6.7E-8 | -7.3E-5 | 4.5E-5 | 0.307 |
| | (0.32) | (0.00) | (0.00) | (0.03) | (0.00) | (0.00) | (0.89) | (0.99) | (0.72) | (0.83) | (0.91) | (0.00) | (0.01) | (0.00) |
| $GBP_t$ | -0.105 | 0.052 | -0.089 | 0.014 | 0.020 | 0.054 | 0.213 | 0.084 | 0.011 | -1.4E-5 | -1.4E-7 | 6.6E-5 | 1.9E-5 | -0.069 |
| | (0.29) | (0.18) | (0.31) | (0.94) | 0.67) | (0.25) | (0.00) | (0.00) | (0.65) | (0.60) | (0.72) | (0.05) | (0.41) | (0.30) |

### B. Spillovers in Variance

| | USR sq. error $_{t-1}$ | UKR sq. error $_{t-1}$ | GBP sq. error $_{t-1}$ | USR asymm.$_{t-1}$ | UKR asymm.$_{t-1}$ | GBP asymm.$_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | 0.151 (0.00) | 0.116 (0.00) | 0.270 (0.01) | 0.619 (0.00) | 0.070 (0.00) | 0.198 (0.02) | 0.447 (0.00) | 0.154 (0.00) |
| UKR volatility$_t$ | 0.072 (0.08) | 0.387 (0.05) | 0.052 (0.00) | -0.037 (0.45) | 0.152 (0.00) | 0.201 (0.56) | 0.493 (0.00) | 0.634 (0.00) |
| GBP volatility$_t$ | -0.030 (0.19) | 0.101 (0.00) | 0.105 (0.40) | 0.021 (0.51) | -0.121 (0.00) | 0.307 (0.08) | 0.423 (0.00) | 0.318 (0.00) |

| *Constant Correlation* | $USR_t$ & $UKR_t$ | $USR_t$ & $GBP_t$ | $UKR_t$ & $GBP_t$ |
|---|---|---|---|
| | 0.6736 (0.00) | 0.0539 (0.62) | 0.2733 (0.20) |

### C. Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) | $LB^2(3)$ (*p*-value) | $LB^2(12)$ (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | -0.01 (0.99) | -0.72 (0.00) | 0.74 (0.02) | 27.87 (0.00) | 6.85 (0.08) | 14.44 (0.27) | 6.45 (0.09) | 12.47 ( 0.41) |
| UKR residuals | -0.09 (0.51) | -0.41 (0.01) | 0.30 (0.34) | 7.96 (0.02) | 1.86 (0.60) | 9.48 (0.66) | 1.14 (0.77) | 13.97 (0.30) |
| GBP residuals | 0.02 (0.82) | 0.11 (0.47) | 0.37 (0.23) | 2.00 (0.37) | 4.43 (0.22) | 20.48 (0.60) | 8.71 (0.03) | 13.04 (0.37) |
| *Residual cross-products* | | | | | | | | |
| USR – UKR residuals | 0.89 (0.00) | 4.60 (0.00) | 36.59 (0.00) | 15061.65 (0.00) | 5.21 (0.27) | 13.03 (0.37) | | |
| USR – GBP residuals | 1.56 (0.19) | 1.83 (0.00) | 21.53 (0.00) | 3665.07 (0.00) | 0.75 (0.95) | 7.31 (0.83) | | |
| UKR – GBP residuals | 1.04 (0.00) | 2.63 (0.00) | 21.72 (0.00) | 5197.04 (0.00) | 2.96 (0.56) | 8.67 (0.73) | | |

### D. Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8)* | No "other" equity effect on mean (3) | No "other" currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 123320.07 (0.00) | 13900.72 (0.00) | 15.43 (0.00) | 429603.60 (0.00) | 701.34 (0.00) | 358.38 (0.00) |
| UKR - $\chi^2$ (*p*-value) | 63314.62 (0.00) | 1724.13 (0.00) | 1339.99 (0.00) | 12389.57 (0.00) | 782.94 (0.84) | |
| GBP - $\chi^2$ (*p*-value) | 1773.69 (0.00) | 76.01 (0.00) | 49.06 (0.00) | 1670.03 (0.00) | 44.61 (0.00) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB(*x*) [$LB^2(x)$] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag *x* in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD (CADFL), DEM (DEMFL), GBP (GBPFL), and JPY (JPYFL) is the percentage change (innovation in the order flow) of the Canadian dollar, deutsche mark, British pound, and yen, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. "Other" equities (currencies) are those that are not dependent variables in this equation system. "Other" asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).

## Table 10 Impact of Currency Order Flow on Spillovers between the US and Canadian Equity Markets and the CAD

### A. Spillovers in Mean

| | $USR_{t-1}$ | $CNR_{t-1}$ | $CAD_{t-1}$ | $GMR_{t-1}$ | $JPR_{t-1}$ | $UKR_{t-1}$ | $DEM_{t-1}$ | $JPY_{t-1}$ | $GBP_{t-1}$ | $DEMFL_{t-1}$ | $JPYFL_{t-1}$ | $CADFL_{t-1}$ | $GBPFL_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $USR_t$ | -0.180 | 0.047 | -0.313 | 0.190 | -0.044 | 0.094 | 4.7E-3 | -0.112 | -0.296 | 3.3E-5 | 2.4E-7 | -3.3E-5 | -1.3E-4 | 0.275 |
| | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.18) | (0.00) | (0.00) | (0.00) | (0.03) | (0.01) | (0.00) | (0.00) |
| $CNR_t$ | -0.096 | 0.044 | -0.361 | 0.107 | -0.014 | 0.115 | -3.5E-3 | -0.083 | -0.241 | 2.1E-5 | 3.9E-7 | -1.4E-5 | -9.6E-5 | 0.225 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.75) | (0.72) | (0.00) | (0.00) | (0.18) | (0.10) | (0.00) | (0.00) |
| $CAD_t$ | 0.036 | -3.1E-3 | -0.011 | -1.0E-3 | -0.022 | -0.031 | 0.080 | -0.057 | 0.092 | 4.6E-6 | 7.9E-8 | 1.3E-5 | 2.8E-5 | 0.093 |
| | (0.31) | (0.94) | (0.94) | (0.86) | (0.12) | (0.01) | (0.17) | (0.17) | (0.35) | (0.65) | (0.55) | (0.67) | (0.41) | (0.23) |

### B. Spillovers in Variance

| | USR sq. error $_{t-1}$ | CNR sq. error $_{t-1}$ | CAD sq. error $_{t-1}$ | USR asymm. $_{t-1}$ | CNR asymm. $_{t-1}$ | CAD asymm. $_{t-1}$ | Own volatility $_{t-1}$ | Constant |
|---|---|---|---|---|---|---|---|---|
| USR volatility$_t$ | 0.15 (0.00) | 0.06 (0.00) | 0.23 (0.01) | 0.13 (0.00) | 0.08 (0.00) | 0.30 (0.02) | 0.69 (0.00) | 0.12 (0.00) |
| CNR volatility$_t$ | 0.02 (0.00) | 0.13 (0.00) | 0.21 (0.00) | 0.02 (0.00) | 0.12 (0.00) | 0.24 (0.00) | 0.73 (0.00) | 0.12 (0.00) |
| CAD volatility$_t$ | 0.01 (0.00) | 0.01 (0.00) | 0.02 (0.62) | -0.03 (0.00) | 0.01 (0.18) | 0.08 (0.01) | 0.41 (0.04) | 0.14 (0.00) |

| *Constant correlation* | $USR_t$ & $CNR_t$ | $USR_t$ & $CAD_t$ | $CNR_t$ & $CAD_t$ |
|---|---|---|---|
| | 0.76 (0.00) | -0.19 (0.62) | -0.24 (0.20) |

### C. Standardized Residual Diagnostics

| | Mean (*p*-value) | Skewness (*p*-value) | Kurtosis (*p*-value) | J-B (*p*-value) | LB(3) (*p*-value) | LB(12) (*p*-value) | $LB^2(3)$ (*p*-value) | $LB^2(12)$ (*p*-value) |
|---|---|---|---|---|---|---|---|---|
| USR residuals | 0.04 (0.55) | -0.89 (0.00) | 1.37 (0.02) | 53.97 (0.00) | 5.71 (0.12) | 16.48 (0.17) | 3.16 (0.37) | 9.92 (0.62) |
| CNR residuals | 0.01 (0.89) | -0.61 (0.01) | 0.92 (0.00) | 24.55 (0.02) | 5.41 (0.14) | 12.07 (0.44) | 2.44 (0.49) | 5.03 (0.96) |
| CAD residuals | -0.06 (0.38) | 0.02 (0.47) | -0.04 (0.98) | 0.04 (0.98) | 7.90 (0.05) | 12.96 (0.37) | 1.20 (0.75) | 20.35 (0.06) |
| *Residual cross-products* | | | | | | | | |
| USR – CNR residuals | 0.97 (0.00) | 4.70 (0.00) | 29.72 (0.00) | 10284.59 (0.00) | 1.72 (0.79) | 5.70 (0.93) | | |
| USR – CAD residuals | 1.00 (0.00) | 1.18 (0.00) | 4.89 (0.00) | 312.64 (0.00) | 4.03 (0.40) | 10.36 (0.58) | | |
| CNR – CAD residuals | 1.03 (0.00) | 2.18 (0.00) | 10.53 (0.00) | 1376.29 (0.00) | 0.89 (0.93) | 7.63 (0.81) | | |

### D. Robust Wald Tests of Parameter Restrictions

| | No mean spillovers (8)* | No "other" equity effect on mean (3) | No "other" currency effect on mean (3) | No volatility spillovers (4) | No "other" asymmetric effect (2) | Joint test of no "own" asymmetric effect (3) |
|---|---|---|---|---|---|---|
| USR - $\chi^2$ (*p*-value) | 115896.21 (0.00) | 697.08 (0.00) | 3635.19 (0.00) | 926513.10 (0.00) | 343.51 (0.00) | 805.28 (0.00) |
| CNR - $\chi^2$ (*p*-value) | 463241.46 (0.00) | 9746.71 (0.00) | 1203.09 (0.00) | 1307.97 (0.00) | 486.07 (0.84) | |
| CAD - $\chi^2$ (*p*-value) | 440.57 (0.00) | 27.37 (0.00) | 5.85 (0.12) | 1197.98 (0.00) | 784.56 (0.00) | |

All *p*-values (in brackets) are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. All residual diagnostics are based on standardized residuals. LB($x$) [$LB^2(x)$] is the Ljung-Box chi-squared statistic (*p*-value) for testing the null hypothesis of zero autocorrelation up to lag $x$ in the [squared] standardized residuals. CNR, GMR, JPR, UKR, and USR are stock market returns in percentage for Canada, Germany, Japan, the UK, and the US, respectively. CAD (CADFL), DEM (DEMFL), GBP (GBPFL), and JPY (JPYFL) is the percentage change (innovation in the order flow) of the Canadian dollar, deutsche mark, British pound, and yen, respectively, expressed as foreign currency per US dollar. The residual cross-products are the products of the two residuals standardized by the respective covariance. "Other" equities (currencies) are those that are not dependent variables in this equation system. "Other" asymmetric effects are those other than the own asymmetric term. * Number in parentheses indicates the number of restrictions. The data cover the period January 05, 1994 to December 30, 1998 (258 weekly observations).