Micro Effects of Macro Announcements: Real-Time Price Discovery in Foreign Exchange

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Using a new data set consisting of six years of real-time exchange-rate quotations, macroeconomic expectations, and macroeconomic realizations, we characterize the conditional means of U.S. dollar spot exchange rates. In particular, we find that announcement surprises produce conditional mean jumps; hence high-frequency exchange-rate dynamics are linked to fundamentals. The details of the linkage are intriguing and include announcement timing and sign effects. The sign effect refers to the fact that the market reacts to news in an asymmetric fashion: bad news has greater impact than good news, which we relate to recent theoretical work on information processing and price discovery. (*JEL* F3, F4, G1, C5)

How is news about fundamentals incorporated into asset prices? The topic confronted by this question—characterization of the price discovery process—is of basic importance to all of financial economics. Unfortunately, it is also one of the least well-understood issues. Indeed, some influential empirical studies have gone so far as to suggest that for some assets—notably foreign exchange—prices and fundamentals are largely disconnected.[1]

In this paper we provide an empirical examination of price discovery in the challenging context of foreign exchange. Using a newly constructed data set consisting of six years of real-time exchange-rate quotations, macroeconomic expectations, and macroeconomic realizations (announcements), we characterize the conditional means of U.S. dollar spot exchange rates for German Mark, British Pound, Japanese Yen, Swiss Franc, and the Euro. In particular, we show that announcement surprises (that is, the difference between expectations and realizations, or "news") produce conditional mean jumps, and we provide a detailed analysis of the speed and pattern of adjustment.

We show that conditional mean adjustments of exchange rates to news occur quickly, effectively amounting to "jumps," in contrast to conditional variance adjustments, which are much more gradual, and that an announcement's impact depends on its timing relative to other related announcements, and on whether the announcement time is known in advance. We find,

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[1] The classic statement is of course Richard A. Meese and Kenneth Rogoff (1983). For a good survey of the subsequent empirical exchange-rate literature through the early 1990's, see Jeffrey A. Frankel and Andrew K. Rose (1995). In later work, Nelson C. Mark (1995) and Mark and Donggyu Sul (2001) find that fundamentals matter in the long run but not in the short run. Martin D. D. Evans and Richard K. Lyons (2002) find that order flow matters in the short run but fail to link order flow to fundamentals.

moreover, that the adjustment response pattern is characterized by a sign effect: bad news has greater impact than good news. Finally, we relate our results to recent theoretical and empirical work on asset return volatility and its association with information processing and price discovery.

The paper relates to earlier work in intriguing ways, but at least three features differentiate our findings from previous results along important dimensions. These include our focus on foreign exchange markets, our focus on conditional mean as opposed to conditional variance, dynamics and the length and breadth of our sample of exchange-rate and announcement data. Let us discuss them briefly in turn.

First, we focus on foreign exchange markets as opposed to stock or bond markets, and we address the central open issue in exchange-rate economics—the link between exchange rates and fundamentals. It is comforting, however, that a number of recent papers focusing largely on bond markets reach conclusions similar to ours. Pierluigi Balduzzi et al. (2001), for example, examine the effects of economic news on prices in the U.S. interdealer government bond market, finding strong news effects and quick incorporation of news into bond prices, while Michael J. Fleming and Eli M. Remolona (1997, 1999) show that the largest bond price movements stem from the arrival of news announcements.[2]

Second, we focus primarily on exchange-rate conditional means as opposed to conditional variances. That is, we focus primarily on the determination of exchange rates themselves, as opposed to their volatility. We maintain this focus both because the conditional mean is of intrinsic interest, and because high-frequency discrete-time volatility cannot be extracted accurately unless the conditional mean is modeled adequately. Hence our work differs in important respects from that of Louis H. Ederington and Jae Ha Lee (1993), Richard Payne (1996), Andersen and Bollerslev (1998), and Bollerslev et al. (2000), for example, who examine calendar and news effects in high-frequency asset-return volatility but do not consider the effects of news on returns themselves.

Third, we use a new data set which spans a comparatively long time period, and includes a broad set of exchange rates and macroeconomic indicators.

Notwithstanding the improvements obtained through the above consideration, our results are quite consistent with prior related work. Indeed, several studies have linked macroeconomic news announcements to jumps in exchange rates, and our findings may be viewed as providing confirmation and elaboration. Charles Goodhart et al. (1993), for example, examine one year of high-frequency Dollar/Pound exchange rates and two specific news events—a U.S. trade figure announcement and a U.K. interest-rate change—and conclude in each case that the news caused an exchange-rate jump. Similarly, Alvaro Almeida et al. (1998) in their study of three years of high-frequency DM/Dollar exchange rates and a larger set of news announcements, document systematic short-lived news effects. Finally, Kathryn M. Dominguez (1999) argues that most large exchange-rate changes occur within ten seconds of a macroeconomic news announcement, and that close timing of central bank interventions to news announcements increases their effectiveness.

We proceed as follows. In Section I we describe our high-frequency exchange-rate and macroeconomic expectations and announcements data. In Section II we characterize the speed and pattern of exchange-rate adjustment to macroeconomic news, and we document, among other things, the sign effects (i.e., a larger exchange-rate response to bad than good news). In Section III we relate the sign effects to recent theories of information processing and price discovery. We conclude in Section IV.

I. Real-Time Exchange Rates, Expected Fundamentals, and Announced Fundamentals

Throughout the paper we use data on exchange-rate returns in conjunction with data on expectations and announcements of macroeconomic fundamentals. The data are novel in several respects, such as the simultaneous high frequency and long calendar span of the exchange-rate returns, as well as the real-time nature of the expectations and announcements of fundamentals. Here we describe them in some detail.

[2] Also, in concurrent related work for T-bond futures, Nikolaus Hautsch and Dieter Hess (2001) report highly significant, but short-lived, price and volatility impacts in response to new and revised employment figures.

A. *Exchange-Rate Data*

The raw 5-minute CHF/\$, DM/\$, Euro/\$, Pound/\$, and Yen/\$ return series were obtained from Olsen and Associates. The full sample consists of continuously recorded 5-minute returns from January 3, 1992 through December 30, 1998, or 2,189 days, for a total of 2,189 · 288 = 630,432 high-frequency foreign exchange (FX) return observations. As in Ulrich A. Müller et al. (1990) and Michel M. Dacorogna et al. (1993), we use all of the interbank quotes that appeared on the Reuters screen during the sample period to construct our 5-minute returns. Each quote consists of a bid and an ask price together with a "time stamp" to the nearest second. After filtering the data for outliers and other anomalies, we obtain the average log price at each 5-minute mark by linearly interpolating the average of the log bid and the log ask at the two closest ticks. We then construct continuously compounded returns as the change in these 5-minute average log bid and ask prices. Goodhart et al. (1996) and Jon Danielsson and Payne (1999) find that the basic characteristics of 5-minute FX returns constructed from quotes closely match those calculated from transaction prices (which are not generally available for the foreign exchange market).

It is well known that the activity in the foreign exchange market slows decidedly during weekends and certain holiday nontrading periods; see Müller et al. (1990). Hence, as is standard in the literature, we explicitly excluded a number of days from the raw 5-minute return series. Whenever we did so, we always cut from 21:05 GMT the night before to 21:00 GMT that evening. This particular definition of a "day" was motivated by the ebb and flow in the daily FX activity patterns documented in Bollerslev and Ian Domowitz (1993) and keeps the daily periodicity intact. In addition to the thin weekend trading period from Friday 21:05 GMT until Sunday 21:00 GMT, we removed several fixed holidays, including Christmas (December 24–26), New Year's (December 31–January 2), and July Fourth. We also cut the moving holidays of Good Friday, Easter Monday, Memorial Day, July Fourth (when it falls officially on July 3), and Labor Day, as well as Thanksgiving and the day after. Although our cuts do not account for all of the holiday market slowdowns, they capture the most important daily calendar effects.

Finally, we deleted some of the returns contaminated by brief lapses in the Reuters data feed. This problem, which occurs almost exclusively during the earliest part of the sample, manifests itself as sequences of zero or constant 5-minute returns in places where missing quotes had been interpolated. To remedy this, we simply removed from each exchange-rate series the days containing the 15 longest zero and constant runs. Because of the overlap among sets of days defined by this criterion, we actually removed only 25 days.

In the end we are left with 1,724 days of data, containing $T = 1{,}724 \cdot 288 = 496{,}512$ high-frequency 5-minute return observations. Standard descriptive statistics reveal that the 5-minute returns have means that are negligible and dwarfed by the standard deviations, and that they are approximately symmetric but distinctly non-Gaussian, due to excess kurtosis. Ljung-Box statistics indicate serial correlation in both returns and absolute returns.

To assess the economic relevance of the temporal dependencies in the return series, we turn to the autocorrelations in column one of Figure 1. The raw returns display tiny, but nevertheless statistically significant, serial correlation at the very shortest lags, presumably due to microstructure effects. However, the short-lag return serial correlation is negligible relative to the strong serial correlation in absolute returns, shown in column two of Figure 1. The sample autocorrelations of absolute returns display very slow decay and pronounced diurnal variation, in line with the results of Dacorogna et al. (1993) and Andersen and Bollerslev (1998). Interestingly, not only the shapes but also the amplitudes of the diurnal patterns in absolute return autocorrelations differ noticeably across currencies.

B. *Expected Fundamentals, Announced Fundamentals, and News*

We use the International Money Market Services (MMS) real-time data on expected and realized ("announced") macroeconomic fundamentals, defining "news" as the difference between expectations and realizations. Every week since 1977, MMS has conducted a Friday telephone survey of about 40 money managers, collected forecasts of all indicators to be re-

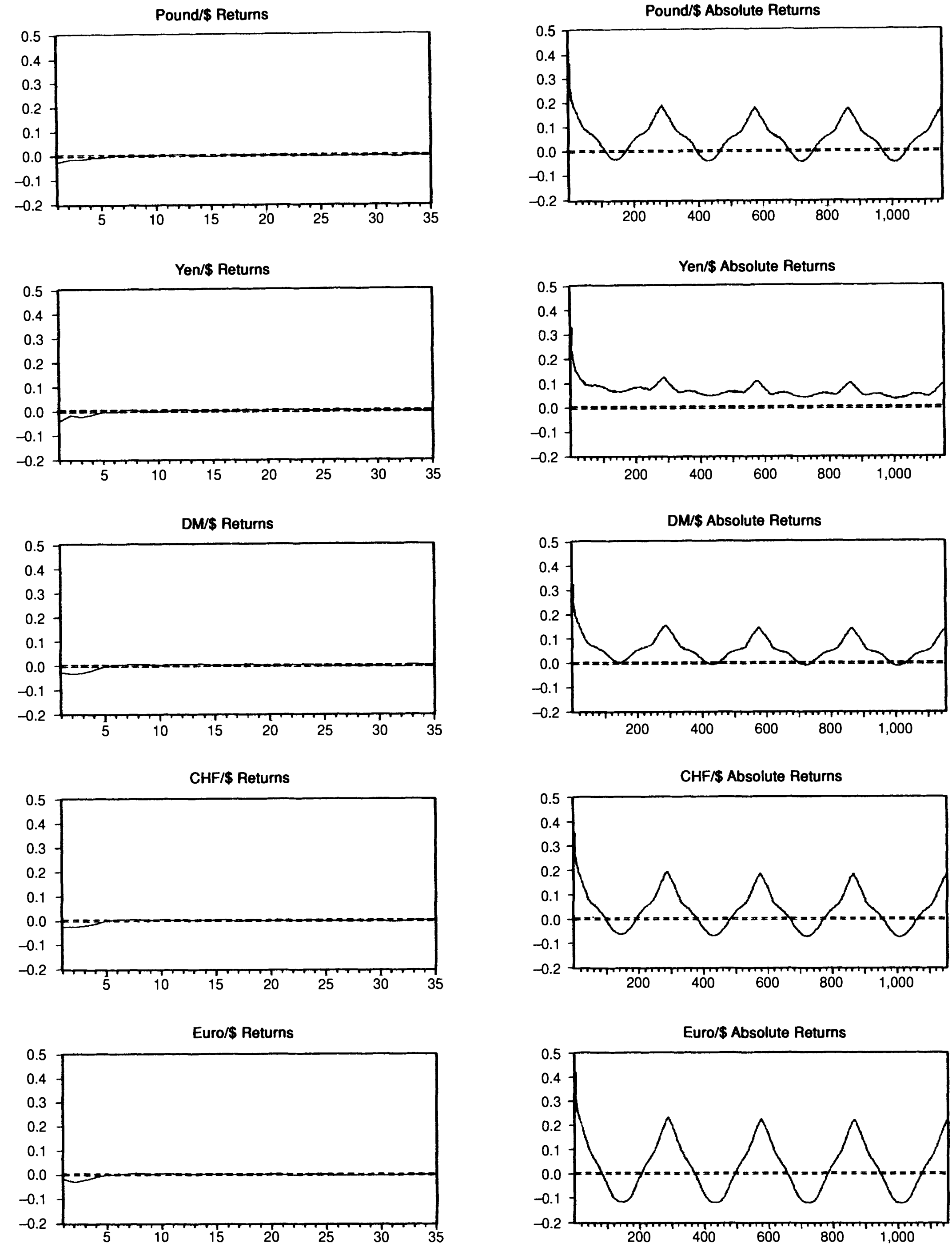

FIGURE 1. SAMPLE AUTOCORRELATION FUNCTIONS
RETURNS AND ABSOLUTE RETURNS

Notes: We plot the sample autocorrelations of returns and absolute returns for five currencies, together with Bartlett's approximate 95-percent confidence bands under the null hypothesis of white noise. In each graph, the vertical axis is the sample autocorrelation and the horizontal axis is displacement in 5-minute intervals. To avoid contamination from shifts in and out of daylight saving time, we calculate the sample autocorrelations using only days corresponding to U.S. daylight saving time.

leased during the next week, and reported the median forecasts from the survey. Numerous influential studies, from early work such as Thomas J. Urich and Paul Wachtel (1984) through recent work such as Balduzzi et al. (2001), have verified that the MMS expectations contain valuable information about the forecasted variable, and in most cases are unbiased and less variable than those produced from extrapolative benchmarks such as ARMA models.

Table 1 provides a brief description of salient aspects of U.S. and German economic news announcements. We show the total number of observations in our news sample, the agency reporting each announcement, and the time of the announcement release. Note that U.S. announcements times are known in advance, whereas only the day for the German announcements are known in advance but their timing within the day is variable and unknown a priori.

The target Fed funds rate deserves special mention. The Federal Open Market Committee's (FOMC) announcement of the federal funds rate target, although likely producing important news, is nonstandard and hence is not typically examined. It is nonstandard because prior to February 1994 it was not announced; instead, the FOMC *signaled* the target rate, but did not state it explicitly, through open market operations performed from 11:30 to 11:35 A.M. Eastern time on the day of the FOMC meeting. In February 1994, the FOMC began to announce changes in the target rate on meeting days, albeit at irregular times, and from 1995 onward it announced the target rate on meeting days regularly at 2:15 P.M. Eastern time, as described in Kenneth N. Kuttner (2001).

To assess the effects of FOMC news, we need to know announcement days and times, as well as the market's expected Fed funds rate target and the announced (or signaled) value. Determination of announcement days and times is relatively straightforward. We collected the irregular 1994 announcement times from Reuters.[3] Before 1994 we use an 11:30 A.M. Eastern announcement time, and after March, 1995 we use a 2:15 P.M. announcement time.[4] Determination of market expectations is similarly straightforward: we use MMS survey data on expected federal fund rate targets from January 1992 to December 1998.[5] The announcements themselves are trickier to construct, due to the pre-1994 FOMC secrecy; we use the announcement data constructed by Michael W. Brandt et al. (2001), kindly provided by Kenneth Kavajecz.

In Figure 2 we show the pattern of U.S. release dates throughout the month.[6] This is of potential importance, because there is some redundancy across indicators. For example, consumer and producer price indexes, although of course not the same, are nevertheless related, and Figure 2 reveals that the producer price index is released earlier in the month. Hence one might conjecture that producer price news would explain more exchange-rate return variation than consumer price news, as the typical amount of consumer price news revealed may be relatively small given the producer price news revealed earlier in the month.

Because units of measurement differ across economic variables, we follow Balduzzi et al. (2001) in using standardized news. That is, we divide the surprise by its sample standard deviation to facilitate interpretation. The standardized news associated with indicator k at time t is

$$S_{kt} = \frac{A_{kt} - E_{kt}}{\hat{\sigma}_k},$$

where A_{kt} is the announced value of indicator k, E_{kt} is the market expected value of indicator k as distilled in the MMS median forecast, and $\hat{\sigma}_k$ is the sample standard deviation of $A_{kt} - E_{kt}$. Use of standardized news facilitates meaningful

[3] The announcement times were 11:05 A.M. Eastern time on 02/04/94, 2:20 P.M. on 03/22/94 and 07/06/94, 2:30 P.M. on 11/15/94, 2:26 P.M. on 05/17/94, 2:23 P.M. on 12/20/94, 1:17 P.M. on 08/16/94, 2:22 P.M. on 09/27/94, 2:24 P.M. on 02/01/95.

[4] The FOMC can also surprise the market by changing the Fed funds target between FOMC meetings. Because this does not happen often in our sample (5 out of 62 times) and we do not have the exact timing of such policy changes, we do not account for them. Similarly, data limitations prevent us from investigating the effect of Fed open market operations; see Campbell R. Harvey and Roger D. Huang (2002) for a recent analysis involving the earlier 1982–1988 time period.

[5] One could also attempt to infer expectations from Fed funds futures prices, as in Glenn D. Rudebusch (1998) and Kuttner (2001).

[6] The design of the figure follows Chart 2 of Fleming and Remolona (1997).

TABLE 1—U.S. AND GERMAN NEWS ANNOUNCEMENTS

Announcement	Number of observations[a]	Source[b]	Dates[c]	Announcement time[d]
	U.S. Announcements			
	Quarterly Announcements			
1. GDP advance	47	BEA	05/22/87–10/30/98	8:30 A.M.
2. GDP preliminary	46	BEA	06/17/87–12/23/98	8:30 A.M.
3. GDP final	47	BEA	01/22/87–11/24/98	8:30 A.M.
	Monthly Announcements			
Real Activity				
4. Nonfarm payroll employment	144	BLS	12/05/86–12/04/98[e]	8:30 A.M.
5. Retail sales	145	BC	12/11/86–12/11/98	8:30 A.M.
6. Industrial production	145	FRB	12/15/86–12/16/98	9:15 A.M.
7. Capacity utilization	145	FRB	12/15/86–12/16/98	9:15 A.M.
8. Personal income	142	BEA	12/18/86–12/24/98[f]	10:00/8:30 A.M.[g]
9. Consumer credit	129	FRB	04/04/88–12/07/98	3:00 P.M.[h]
Consumption				
10. Personal consumption expenditures	143	BEA	12/18/86–12/24/98[i]	10:00/8:30 A.M.[j]
11. New home sales	117	BC	03/02/89–12/02/98	10:00 A.M.
Investment				
12. Durable goods orders	143	BC	12/23/86–12/23/98[k]	8:30/9:00/10:00 A.M.[l]
13. Construction spending	128	BC	04/01/88–12/01/98[m]	10:00 A.M.
14. Factory orders	127	BC	03/30/88–12/04/98[n]	10:00 A.M.
15. Business inventories	129	BC	04/14/88–12/15/98	10:00/8:30 A.M.[o]
Government Purchases				
16. Government budget deficit	124	FMS	04/21/88–12/21/98[p]	2:00 P.M.
Net Exports				
17. Trade balance	128	BEA	04/14/88–12/17/98	8:30 A.M.
Prices				
18. Producer price index	145	BLS	12/12/86–12/11/98	8:30 A.M.
19. Consumer price index	145	BLS	12/19/86–12/15/98	8:30 A.M.
Forward-looking				
20. Consumer confidence index	90	CB	07/30/91–12/29/98	10:00 A.M.
21. NAPM index	107	NAPM	02/01/90–10/01/98	10:00 A.M.
22. Housing starts	145	BC	12/30/86–12/30/98	8:30 A.M.
23. Index of leading indicators	145	CB	12/30/86–12/30/98	8:30 A.M.
	Six-Week Announcements			
FOMC				
24. Target federal funds rate	62	FRB	2/5/92–12/22/98	2:15 P.M.[q]
	Weekly Announcements			
25. Initial unemployment claims	384	ETA	07/18/91–12/31/98	8:30 A.M.
26. Money supply, M1	628	FRB	12/04/86–12/31/98	4:30 P.M.
27. Money supply, M2	563	FRB	03/03/88–12/31/98	4:30 P.M.
28. Money supply, M3	563	FRB	03/03/88–12/31/98	4:30 P.M.
	German Announcements[r]			
	Quarterly Announcements			
29. GDP	24	GFSO	03/09/93–12/03/98	Varies
	Monthly Announcements			
Real Activity				
30. Employment	59	FLO	04/06/93–12/08/98	Varies
31. Retail sales	59	GFSO	04/14/93–12/10/98	Varies
32. Industrial production	63	GFSO	05/04/93–12/07/98	Varies

TABLE 1—*Continued.*

Announcement	Number of observations[a]	Source[b]	Dates[c]	Announcement time[d]
Investment				
33. Manufacturing orders	62	GFSO	04/06/93–12/07/98	Varies
34. Manufacturing output	64	GFSO	03/02/93–12/07/98	Varies
Net Exports				
35. Trade balance	61	GFSO	07/13/93–12/11/98	Varies
36. Current account	61	BD	07/13/93–12/11/98	Varies
Prices				
37. Consumer price index	68	GFSO	03/01/93–12/23/98	Varies
38. Producer prices	65	GFSO	03/18/93–12/22/98	Varies
39. Wholesale price index	68	GFSO	03/16/93–12/16/98	Varies
40. Import prices	68	GFSO	03/26/93–12/21/98	Varies
Monetary				
41. Money stock M3	66	BD	03/18/93–12/18/98	Varies

Notes: We group the U.S. monthly news announcements into seven groups: Real activity, the four components of GDP (consumption, investment, government purchases, and net exports), prices, and forward-looking. Within each group, we list U.S. news announcements in chronological order.

[a] Total number of observations in the announcements sample.

[b] Bureau of Labor Statistics (BLS), Bureau of the Census (BC), Bureau of Economic Analysis (BEA), Federal Reserve Board (FRB), National Association of Purchasing Managers (NAPM), Conference Board (CB), Financial Management Office (FMO), Employment and Training Administration (ETA), German Federal Statistical Office (GFSO, Statistisches Bundesamt Deutschland), Federal Labor Office (FLO, Bundesanstalt für Arbeit), Bundesbank (BD).

[c] Starting and ending dates of the announcements sample.

[d] Eastern Standard Time. Daylight saving time starts on the first Sunday of April and ends on the last Sunday of October.

[e] 10/98 is a missing observation.

[f] 11/95, 2/96, and 03/97 are missing observations.

[g] In 01/94, the personal income announcement time moved from 10:00 A.M. to 8:30 A.M.

[h] Beginning in 01/96, consumer credit was released regularly at 3:00 P.M. Prior to this date the release times varied.

[i] 11/95 and 2/96 are missing observations.

[j] In 12/93, the personal consumption expenditures announcement time moved from 10:00 A.M. to 8:30 A.M.

[k] 03/96 is a missing observation.

[l] Whenever GDP is released on the same day as durable goods orders, the durable goods orders announcement is moved to 10:00 A.M. On 07/96 the durable goods orders announcement was released at 9:00 A.M.

[m] 01/96 is a missing observation.

[n] 10/98 is a missing observation.

[o] In 01/97, the business inventory announcement was moved from 10:00 A.M. to 8:30 A.M.

[p] 05/88, 06/88, 11/98, 12/89, and 01/96 are missing observations.

[q] Beginning in 3/28/94, the Fed funds rate was released regularly at 2:15 P.M. Prior to this date the release times varied.

[r] Prior to 1994 the data refer only to West Germany. Beginning in 1994, the data refer to the unified Germany. The timing of the German announcements is not regular, but they usually occur between 2:00 A.M. and 8:00 A.M. Eastern Standard Time.

comparisons of responses of different exchange rates to different pieces of news. Operationally, we estimate the responses by regressing asset returns on news; because $\hat{\sigma}_k$ is constant for any indicator k, the standardization affects neither the statistical significance of response estimates nor the fit of the regressions.

Before proceeding, we pause to discuss in greater detail the possibility that the MMS forecasts may not capture all information available immediately before the announcement. Surely information does not stop flowing between the time that the MMS forecast is produced and the time that the macroeconomic indicator is realized; hence the MMS forecasts may be "stale." Just how stale they are, however, is an empirical matter. This issue has been investigated already in the context of news effects on interest rates by Balduzzi et al. (1998), who regress the actual announcement, A_i, on the median forecast of the MMS survey, F_i, *and* the change in the (very announcement-sensitive) ten-year note yield from the time of the survey to the time of the announcement, Δy:

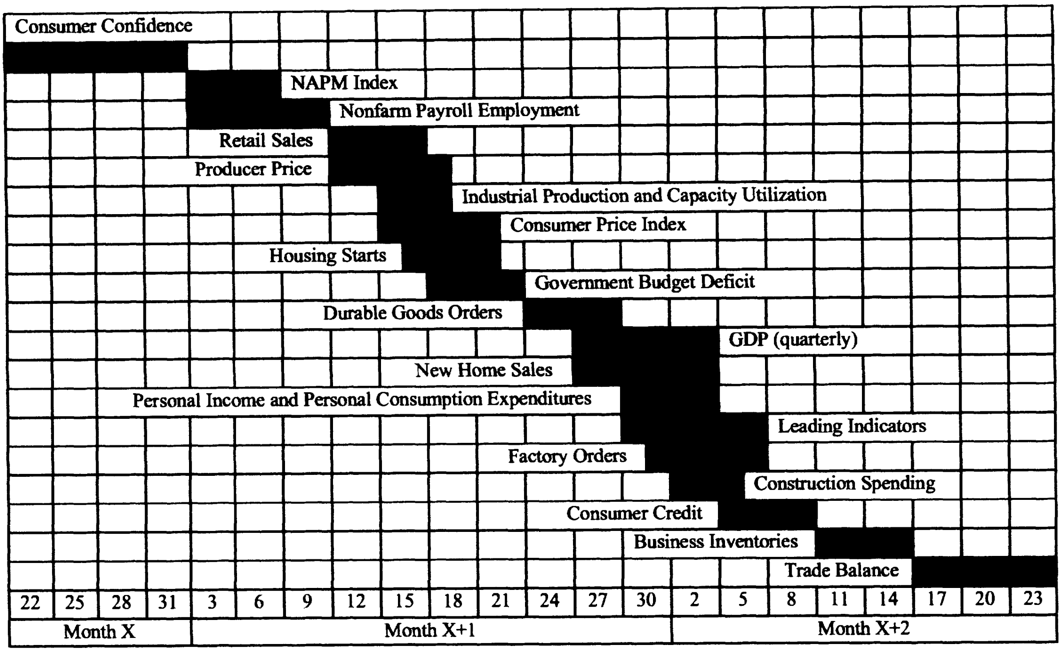

FIGURE 2. U.S. MACROECONOMIC ANNOUNCEMENT RELEASE DATES DATA FOR MONTH X

Notes: We show the sequence of announcement dates corresponding to data for month X, for most of the economic indicators used in the paper. For example, March (month X) consumer credit data are announced between May (month X + 2) 5 and May 10. GDP data are special, because they are released only quarterly. Hence, the GDP data released in a given month are either advance, preliminary, or final depending on whether the month is the first, second, or third of the quarter. For example, first quarter Q1 GDP advance data are announced between April (month X + 1) 27 and May 4, first quarter GDP preliminary data are announced between May (month X + 2) 27 and June 4, and first quarter GDP final data are announced between June (month X + 3) 27 and July 4. The table is based on 2001 Schedule of Release Dates for Principal Federal Economic Indicators, produced by the U.S. Office of Management and Budget and available at http://clinton4.nara.gov/textonly/OMB/pubpress/pei2001.html.

$$A_{it} = \alpha_{0i} + \alpha_{1i}F_{it} + \alpha_{2i}\Delta y_t + e_{it}.$$

This particular regression facilitates the testing of several hypotheses. First, if there is information content in the MMS survey data, the coefficient estimates α_{1i} should be positive and significant. Second, if the survey information is unbiased, the α_{0i} coefficient estimates should be insignificant, and the slope terms α_{1i} should be insignificantly different from unity. Finally, if expectations are revised between the survey and the announcement, there should be a reaction in the bond price at the time of the forecast revision, and we should see a relationship between the change in yield and the announcement. As already mentioned, Balduzzi et al. (2001) find, as have many others, that most of the MMS forecasts contain information and are unbiased.[7] More importantly for the issue at hand, however, they also find that for most indicators the hypothesis that $\alpha_{2i} = 0$ cannot be rejected, indicating that the MMS forecasts do not appear significantly stale.

II. Exchange Rates and Fundamentals

We will specify and estimate a model of high-frequency exchange-rate dynamics that allows for the possibility of news affecting both the conditional mean and the conditional variance. Our goal is to determine whether

[7] In addition to being unbiased, Douglas K. Pearce and V. Vance Roley (1985) and Grant McQueen and Roley (1993) also find that the MMS surveys are more accurate, in the sense of having lower mean squared errors, than the forecasts from standard autoregressive time-series models.

high-frequency exchange-rate movements are linked to fundamentals, and if so how. Our motivations are twofold. The first motivation is obviously the possibility of refining our understanding of the fundamental determinants of exchange rates, the central and still largely unresolved question of exchange-rate economics. The second motivation is the possibility of improved high-frequency volatility estimation via allowance for jumps due to news, as misspecification of the conditional mean (for example by failing to allow for jumps, if jumps are in fact present) will produce distorted volatility estimates in discrete time.[8]

A. *Modeling the Response of Exchange Rates to News*

We model the 5-minute spot exchange rate, R_t, as a linear function of I lagged values of itself, and J lags of news on each of K fundamentals:

$$(1)\quad R_t = \beta_0 + \sum_{i=1}^{I} \beta_i R_{t-i} + \sum_{k=1}^{K} \sum_{j=0}^{J} \beta_{kj} S_{k,t-j} + \varepsilon_t, \quad t = 1, \dots, T.$$

As discussed earlier, $K = 41$ and $T = 496{,}512$. We chose $I = 5$ and $J = 2$ based on the Schwarz and Akaike information criteria.[9]

We allow the disturbance term in the 5-minute return model (1) to be heteroskedastic. Following Andersen and Bollerslev (1998), we estimate the model using a two-step weighted least-squares (WLS) procedure. We first estimate the conditional mean model (1) by ordinary least-squares regression, and then we estimate the time-varying volatility of ε_t from the regression residuals, which we use to perform a weighted least-squares estimation of (1). We approximate the disturbance volatility using the model:

$$(2)\quad |\hat{\varepsilon}_t| = c + \psi \frac{\hat{\sigma}_{d(t)}}{\sqrt{288}} + \sum_{k=1}^{K} \sum_{j'=0}^{J'} \beta_{kj'} |S_{k,t-j'}| + \left(\sum_{q=1}^{Q} \left(\delta_q \cos\left(\frac{q2\pi t}{288}\right) + \phi_q \sin\left(\frac{q2\pi t}{288}\right)\right) + \sum_{r=1}^{R} \sum_{j''=0}^{J''} \gamma_{rj''} D_{r,t-j''}\right) + u_t.$$

The left-hand-side variable, $|\hat{\varepsilon}_t|$, is the absolute value of the residual of equation (1), which proxies for the volatility in the 5-minute interval t. As revealed by the right-hand side of equation (2), we model 5-minute volatility as driven partly by the volatility over the day containing the 5-minute interval in question, $\hat{\sigma}_{d(t)}$, partly by news $S_{k,t}$, and partly by a calendar-effect pattern consisting largely of intraday effects that capture the high-frequency rhythm of deviations of intraday volatility from the daily average. Specifically, we split the calendar effects into two parts. The first is a Fourier flexible form with trigonometric terms that obey a strict

[8] In this paper, we are primarily interested in exchange-rate volatility only insofar as it is relevant for inference regarding exchange-rate conditional mean dynamics. We have reserved for future work a detailed analysis of volatility in relation to conditional mean and variance jumps. For a discussion of the effects of conditional mean and variance jumps on realized volatility, see Andersen et al. (2003).

[9] We also tried allowing for negative J, to account for announcement leakage before the official time, and more generally to account for the fact that the MMS forecasts might not capture all information available immediately before the announcement, but doing so proved unnecessary. This accords with the earlier-discussed finding of Balduzzi et al. (2001) that, to a good approximation, the MMS forecasts *do* capture all information available immediately before the announcement. Moreover, if leakage *is* present (and introspection, if not the empirics, suggests that there is likely some leakage, however small) then our estimated news response coefficients, which correspond only to the impact at the time of the official announcement, are lower bounds for the total news impact.

periodicity of one day.[10] The second is a set of dummy variables $D_{r,t}$ capturing the Japanese lunch, the Japanese open, and the U.S. late afternoon during U.S. daylight saving time.

Let us explain in greater detail. Consider first the daily volatility, $\hat{\sigma}_{d(t)}$, which is the one-day-ahead volatility forecast for day $d(t)$ (the day that contains time t) from a simple daily conditionally Gaussian GARCH(1, 1) model using spot exchange-rate returns from January 2, 1986 through December 31, 1998. Because $\hat{\sigma}_{d(t)}$ is intended to capture the "average" level of volatility on day $d(t)$, it makes sense to construct it using a GARCH(1, 1) model, which is routinely found to provide accurate approximations to daily asset return volatility dynamics.[11]

Now consider the Fourier part for the calendar effects. This is a very flexible functional form that may be given a semi-nonparametric interpretation (A. Ronald Gallant, 1981). The Schwarz and Akaike information criteria chose a rather low $Q = 4$ for all currencies, which achieves parametric economy and promotes smoothness in the intraday seasonal pattern.

Finally, consider the news effects S and non-Fourier calendar effects D. To promote tractability while simultaneously maintaining flexibility, we impose polynomial structure on the response patterns associated with the $\beta_{kj'}$ and $\gamma_{rj''}$ parameters.[12] For example, if a particular news surprise affects volatility from time t_0 to time $t_0 + J'$, we can represent the impact over the event window $\tau = 0, 1, \ldots, J'$ by a polynomial specification, $p(\tau) = c_0 + c_1\tau + \ldots + c_P\tau^P$. For $P = J'$ this would imply the estimation of $J' + 1$ polynomial coefficients and would not constrain the response pattern in any way. Use of a lower-ordered polynomial, however, constrains the response in helpful ways: it promotes parsimony and hence tractability, retains flexibility of approximation, and facilitates the imposition of sensible constraints on the response pattern. For example, we can enforce the requirement that the impact effect slowly fades to zero by imposing $p(J') = 0$.

Polynomial specifications ensure that the response patterns are completely determined by the response horizon J', the polynomial order P, and the endpoint constraint imposed on $p(J')$. For news effects S, we take $J' = 12$, $P = 3$, and $p(J') = 0$.[13] The last condition leads to a polynomial with one less parameter; substituting $\tau = 12$ into $p(\tau)$ we have, $p(\tau) = c_0[1 - (\tau/12)^3] + c_1\tau[1 - (\tau/12)^2] + c_2\tau^2[1 - (\tau/12)]$. We estimate each polynomial separately for all announcements and for each exchange rate. For example, payroll employment polynomial parameter estimates are $(\hat{c}_0, \hat{c}_1, \hat{c}_2) = (0.177175, -0.0645, 0.008367)$ for the DM/\$, $(0.163146, -0.05544, 0.00704)$ for the CHF/\$, $(0.114488, -0.03795, 0.00477)$ for the Pound/\$, $(0.108867, -0.03186, 0.004003)$ for the Euro/\$, and $(0.11717, -0.04619, 0.006289)$ for the Yen/\$. Finally, $\beta_{kj'} = \gamma_k p_k(j')$, where γ_k is the coefficient estimate in equation (2). As for the non-Fourier calendar-effect response patterns D, for the Japanese market opening we use $J'' = 6$, $P = 1$, $p(J'') = 0$, for the Japanese lunch hour we use $J'' = 0$ (i.e., a standard dummy variable with no polynomial response), and for the U.S. late afternoon during U.S. daylight saving time we use $J'' = 60$, $P = 2$, and $p(0) = p(J'') = 0$.[14]

In closing this subsection, we note that we could have handled the volatility dynamics differently. In particular, instead of estimating explicit parametric models of volatility dynamics, we could have simply estimated equation (1) using heteroskedasticity- and serial-correlation

[10] We also translate the Fourier terms leftward as appropriate during U.S. daylight saving time. (Only North America and Europe have daylight saving time.)

[11] For surveys of GARCH modeling in financial environments, see Bollerslev et al. (1992) and Diebold and Jose Lopez (1995). Other possibilities, also explored with little change in qualitative results, include use of daily realized volatilities as in Andersen et al. (2001) and Andersen et al. (2001a, 2003).

[12] This is particularly important in the case of conditional variance as opposed to conditional mean dynamics, because conditional variances turn out to adjust to shocks more slowly than do conditional means, thereby involving longer distributed lags, as we will subsequently emphasize. Hence, although tractability did not require the imposition of polynomial shape on the conditional mean distributed lags, it greatly enhances the accuracy of the conditional variance estimates.

[13] The "constraint" that volatility news effects linger for at most an hour ($J' = 12$) is nonbinding. Initial experimentation allowing for $J' = 36$ revealed that one hour was enough for full adjustment, for all indicators and currencies.

[14] The Japanese opening is at 8 P.M. Eastern daylight saving time, the Japanese lunch hour is 11 P.M. through 12:30 A.M. Eastern daylight saving time, the U.S. late afternoon during daylight saving time is defined to start at 3 P.M. Eastern daylight saving time.

consistent (HAC) standard errors. We find that approach less attractive than the one we adopted, for at least three reasons. First, we are interested not only in performing heteroskedasticity-robust inference about the coefficients (done both by our WLS and by HAC estimation) in equation (1), but also in obtaining the most efficient estimates of those coefficients. Second, although HAC estimation is asymptotically robust to residual heteroskedasticity of unknown form, its general robustness may come at the price of inferior finite-sample performance relative to the estimation of a well-specified parametric volatility model.[15] Third, despite the fact that they are not central to the analysis in the present paper, both the intra- and interday volatility patterns are of intrinsic financial economic interest and hence one may want estimates of these in other situations. Notwithstanding all of these a priori arguments against the use of HAC estimation in the present context, as a check on the robustness of our results, we also performed all of the empirical work related to the mean effects using HAC estimation, with no change in any of the qualitative results (although a number of the coefficients were no longer statistically significant).

B. *News Effects I: News Announcements Matter, and Quickly*

The model (1)–(2) provides an accurate approximation to both conditional mean and conditional variance dynamics. Since the model contains so many variables and their lags, it would prove counterproductive to simply report all of the parameter estimates. Instead, Figure 3 shows the actual and fitted average intraday volatility patterns, which obviously agree fairly closely. Further, in Figure 4 we present graphically the results for the most important indicators, and we discuss those results (and some others, not shown in the figure) in what follows.

Let us first consider the effects of U.S. macroeconomic news. Throughout, news exerts a generally statistically significant influence on exchange rates, whereas expected announcements generally do not. That is, only *un*anticipated shocks to fundamentals affect exchange rates, in accordance with the predictions of rational expectations theory. Many U.S. indicators have statistically significant news effects across all currencies, including payroll employment, durable goods orders, trade balance, ini-

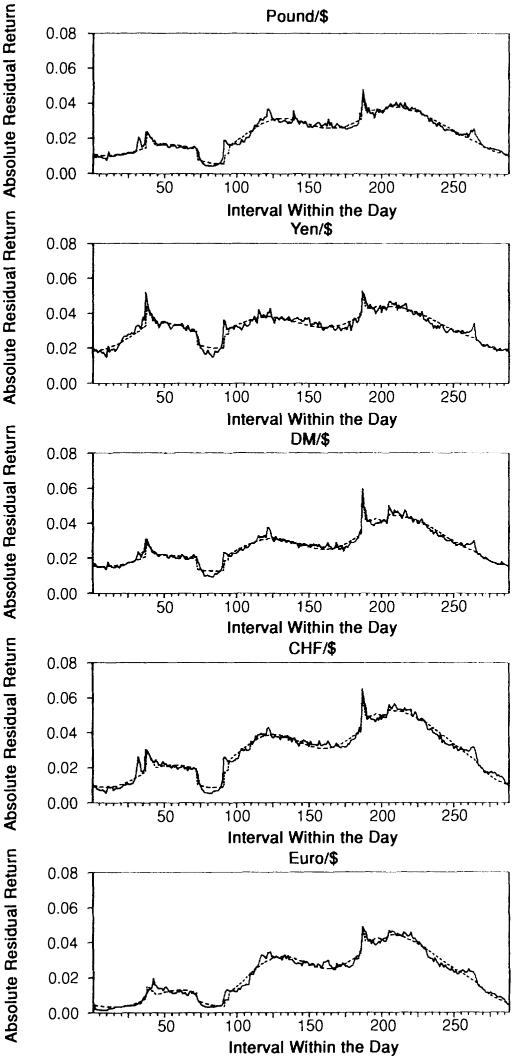

FIGURE 3. ACTUAL AND FITTED INTRADAY VOLATILITY PATTERNS

Notes: The solid line is the average intraday pattern of the absolute residual return $|\hat{\varepsilon}_t|$ over the 288 5-minute intervals within the day, where $\hat{\varepsilon}_t$ is the residual from the exchange-rate conditional mean model (1) in the text. The dashed line is the fitted intraday pattern of $|\hat{\varepsilon}_t|$ from the exchange-rate volatility model (2) in the text. To avoid contamination from shifts in and out of daylight saving time, we construct the figures using only days corresponding to U.S. daylight saving time.

[15] See C. Radhakrishna Rao (1970) and Andrew Chesher and Ian Jewitt (1987).

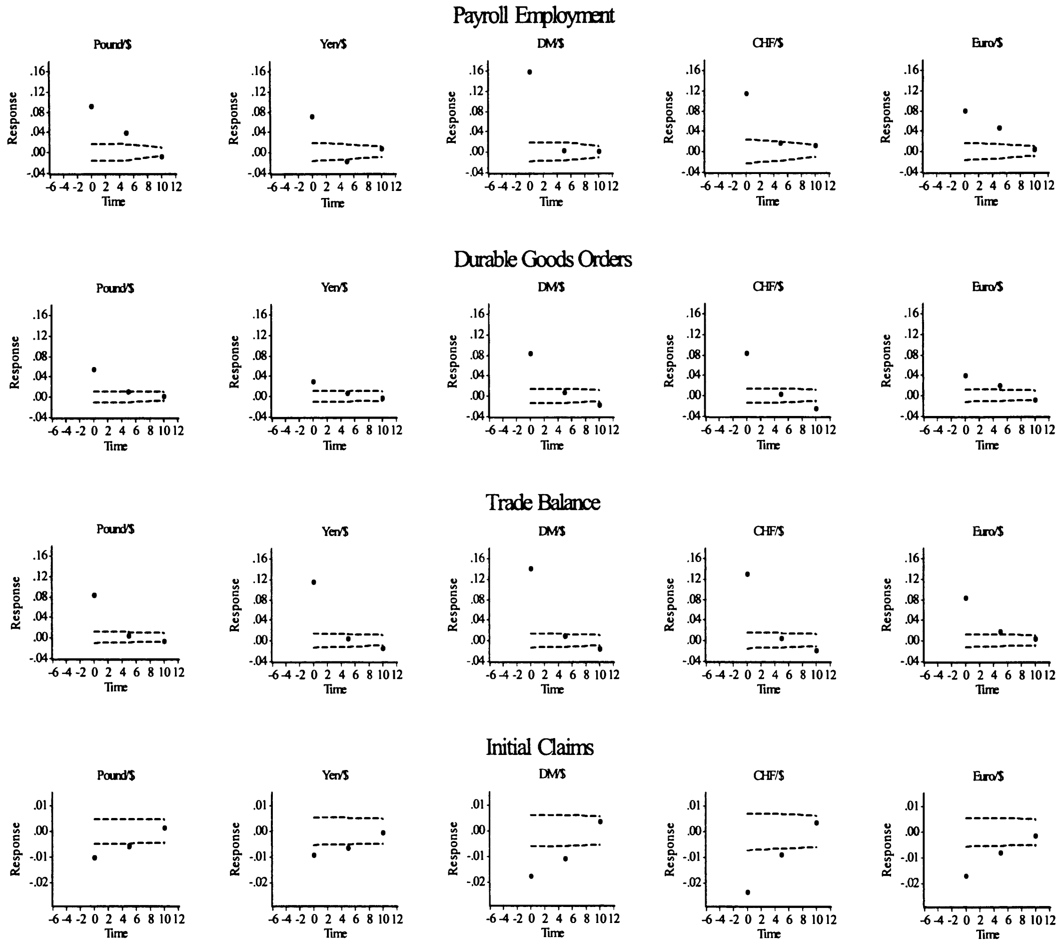

FIGURE 4. EXCHANGE-RATE RESPONSES TO U.S. NEWS

Notes: We graph the three news response coefficients associated with the exchange-rate conditional mean regression (1), corresponding to responses at the announcement, five minutes after the announcement, and ten minutes after the announcement. We also show two standard error bands, under the null hypothesis of a zero response, obtained using the weighted least-squares estimation method described in the text.

tial unemployment claims, NAPM index, retail sales, consumer confidence, and advance GDP.

The general pattern is one of very quick exchange-rate conditional mean adjustment, characterized by a jump immediately following the announcement, and little movement thereafter. Favorable U.S. "growth news" tends to produce dollar appreciation, and conversely. This is consistent with a variety of models of exchange-rate determination, from simple monetary models (e.g., Mark, 1995) to more sophisticated frameworks involving a U.S. central bank reaction function displaying a preference for low inflation (e.g., John B. Taylor, 1993).[16] One can see from the center panel of the first row of Figure 4, for example, that a one standard deviation U.S. payroll employment surprise tends to appreciate (if positive) or depreciate (if negative) the dollar against the DM by 0.16

[16] For most of our macroeconomic indicators, including those on which we primarily focus, the sign of a "good shock" is clear: movements associated with increased real U.S. economic activity are good for the dollar. Sometimes, however, it is not obvious which direction should be viewed as good, as perhaps with consumer credit.

percent.[17] This is a sizeable move, from both statistical and economic perspectives. On the statistical side, we note that only 0.7 percent of our 5-minute returns show an appreciation or depreciation bigger than 0.10 percent. On the economic side, we note that 0.16 percent is also large relative to the average DM/$ spread, which tends to be around 0.06 percent during the period we study (see, Hendrik Bessembinder, 1994, and Joel Hasbrouck, 1999, Table 1).

It is important to note that, although closely timed news events are highly correlated, the correlation does not create a serious multicolinearity problem except in a few specific instances. For example, industrial production and capacity utilization are released at the same time, and they are highly correlated (0.64). In general, however, the event that two announcements within the same category (e.g., real activity) are released simultaneously is rare.

Now let us focus on the DM/$ rate in some detail. It is of particular interest both because of its central role in the international financial system during the period under study, and because we have news data on both U.S. and German macroeconomic indicators.[18] First consider the effects of U.S. macroeconomic news on the DM/$ rate. News announcements on a variety of U.S. indicators significantly affect the DM/$ rate, including payroll employment, durable goods orders, trade balance, initial claims, NAPM index, retail sales, consumer confidence, CPI, PPI, industrial production, leading indicators, housing starts, construction spending, federal funds rate, new home sales, and GDP (advance, preliminary, and final).

Now consider the effect of *German* macroeconomic news on the DM/$ rate.[19] In sharp contrast to the large number of U.S. macroeconomic indicators whose news affect the DM/$ rate, only very few of the German macroeconomic indicators have a significant effect (M3 and industrial production). We conjecture that the disparity may be due to the fact, detailed in Table 1, that the release times of U.S. macroeconomic indicators are known exactly (day and time) but only inexactly for Germany (day but not time). Uncertain release times may result in less market liquidity (and trading) around the announcement times, hence resulting in smaller news effects around the announcements, ultimately producing a more gradual adjustment, perhaps for a few hours after the announcements. Alternatively, greater preannouncement leakage in Germany may result in adjustments taking place gradually in the days prior to the actual announcement.

Most of the explanatory power of the exchange-rate conditional mean model (1) comes from the lagged values of the dependent variable and the contemporaneous news announcement. Hence, although 58 percent of the days in our sample contain a news announcement, to a good approximation the news predicts only the direction and magnitude of the exchange-rate movement during the 5-minute post-release intervals, which correspond to only two-tenths of one percent of the sample observations. To focus on the importance of news during announcement periods, we now estimate the model

$$R_t = \beta_k S_{kt} + \varepsilon_t, \qquad (3)$$

where R_t is the 5-minute return from time t to time $t + 1$ and S_{kt} is the standardized news corresponding to announcement k ($k = 1, \dots, 41$) at time t, and the estimates are based on only those observations (R_t, S_{kt}) such that an announcement was made at time t.

We show the estimation results in Table 2, which contains a number of noteworthy features. First, news on many of the fundamentals exerts a significant influence on exchange rates. This is of course expected, given our earlier estimation results for equation (1) as summarized in Figure 4. News from FOMC deliberations, for example, clearly influences exchange rates: the large and statistically significant coefficients, and the high R^2's, are striking. Their positive signs indicate that, as expected for example in a standard monetary model, Fed tightening is associated with dollar appreciation.[20]

[17] We interpret a one-standard-deviation surprise as "typical."

[18] German news is the only non-U.S. news that is readily available from MMS.

[19] To a first approximation, German news is relevant only for DM/$ determination, in contrast to U.S. news, which is relevant for the determination of all U.S. dollar exchange rates.

[20] It would be interesting (with a longer sample of data) to examine the stability of the response coefficient over different stages of the business cycle; see, e.g., McQueen and Roley (1993). According to the standard U.S. business-cycle chronology produced by the National Bureau of Economic Research, the United States was in an expansion from March of 1991 until March of 2001; hence our entire sample.

TABLE 2—U.S. AND GERMAN CONTEMPORANEOUS NEWS RESPONSE COEFFICIENTS AND R^2 VALUES

	Pound/$		Yen/$		DM/$		CHF/$		Euro/$	
Announcement	β_k	R^2	β_k	R^2	β_k	R^2	β_k	R^2	β_k	R^2
U.S. Announcements										
Quarterly Announcements										
1. GDP advance	0.029	0.098	0.036	0.102	0.08*	0.301	0.079*	0.307	0.061*	0.420
2. GDP preliminary	0.038	0.134	0.022	0.081	0.055*	0.185	0.057*	0.207	0.017	0.048
3. GDP final	−0.004	0.004	0.019	0.048	0.017	0.029	0.010	0.007	0.006	0.010
Monthly Announcements										
Real Activity										
4. Nonfarm payroll employment	0.098*	0.189	0.084*	0.214	0.161*	0.237	0.144*	0.269	0.08*	0.232
5. Retail sales	0.048*	0.225	0.019	0.066	0.067*	0.241	0.059*	0.170	0.041*	0.193
6. Industrial production	0.020*	0.105	0.019*	0.078	0.029*	0.131	0.034*	0.147	0.018*	0.086
7. Capacity utilization	0.017	0.061	0.016	0.055	0.021	0.046	0.023	0.058	0.018	0.041
8. Personal income	0.007	0.015	0.001	0.000	0.006	0.007	0.003	0.001	−0.005	0.005
9. Consumer credit	0.002	0.002	0.009	0.019	0.004	0.012	0.002	0.002	−0.002	0.004
Consumption										
10. Personal consumption expenditures	−0.003	0.003	0.005	0.006	−0.007	0.010	−0.011	0.012	0.007	0.008
11. New home sales	0.002	0.002	0.011	0.030	0.01	0.015	−0.002	0.001	0.005	0.003
Investment										
12. Durable goods orders	0.055*	0.266	0.027*	0.081	0.088*	0.363	0.085*	0.355	0.043*	0.237
13. Construction spending	0.019*	0.087	0.01*	0.026	0.031*	0.091	0.017*	0.034	0.015	0.030
14. Factory orders	0.011	0.024	0.006	0.006	0.018	0.038	0.019	0.041	0.031*	0.102
15. Business inventories	−0.004	0.008	0.01	0.029	0.009	0.012	0.002	0.001	0.007	0.015
Government Purchases										
16. Government budget deficit	0.007*	0.057	0.008	0.038	0.002	0.003	0.010	0.050	0.003	0.006
Net Exports										
17. Trade balance	0.092*	0.529	0.112*	0.370	0.138*	0.585	0.124*	0.480	0.084*	0.414
Prices										
18. Producer price index	0.005	0.003	0.000	0.000	0.019	0.020	0.017	0.017	0.018*	0.046
19. Consumer price index	0.016	0.048	0.012	0.033	0.031*	0.101	0.035*	0.104	0.015	0.027
Forward-looking										
20. Consumer confidence index	0.037*	0.174	0.022*	0.103	0.058*	0.222	0.054*	0.214	0.035*	0.189
21. NAPM index	0.028*	0.199	0.012*	0.036	0.039*	0.141	0.036*	0.146	0.025*	0.074
22. Housing starts	0.006	0.008	0.005	0.007	0.017	0.028	0.02*	0.033	0.008	0.009
23. Index of leading indicators	0.012	0.031	0.009	0.006	0.012	0.009	0.011	0.005	−0.005	0.005
Six-Week Announcements										
24. Target federal funds rate	0.048*	0.229	0.050*	0.162	0.072*	0.259	0.072*	0.230	0.032	0.142
Weekly Announcements										
25. Initial unemployment claims	−0.014*	0.025	−0.012*	0.019	−0.022*	0.036	−0.026*	0.046	−0.019*	0.058
26. Money supply, M1	0.000	0.000	0.000	0.000	0.004*	0.020	0.004*	0.019	0.002*	0.009
27. Money supply, M2	0.000	0.000	−0.001	0.001	0.004*	0.019	0.005*	0.030	0.002*	0.013
28. Money supply, M3	0.000	0.000	0.001	0.002	0.002	0.004	0.004*	0.023	0.002*	0.011
German Announcements										
Quarterly Announcements										
29. GDP	−0.004	0.042	−0.002	0.001	−0.007	0.022	−0.011	0.068	−0.004	0.015
Monthly Announcements										
Real Activity										
30. Employment	0.000	0.000	0.002	0.001	0.000	0.000	0.01*	0.045	0.003	0.003
31. Retail sales	0.001	0.001	0.004	0.008	−0.003	0.004	−0.002	0.003	−0.01*	0.091
32. Industrial production	−0.011*	0.059	−0.009	0.036	−0.017*	0.172	−0.015*	0.105	−0.005	0.015

TABLE 2—*Continued.*

Announcement	Pound/$ β_k	Pound/$ R^2	Yen/$ β_k	Yen/$ R^2	DM/$ β_k	DM/$ R^2	CHF/$ β_k	CHF/$ R^2	Euro/$ β_k	Euro/$ R^2
Investment										
33. Manufacturing orders	−0.007	0.025	−0.008	0.029	−0.011	0.061	−0.01	0.042	−0.002	0.002
34. Manufacturing output	−0.001	0.001	−0.017*	0.091	−0.007	0.041	−0.009	0.048	−0.007	0.034
Net Exports										
35. Trade balance	−0.004	0.018	0.001	0.000	0.000	0.000	0.001	0.001	−0.005	0.019
36. Current account	−0.003	0.009	0.006	0.019	−0.006	0.035	−0.006	0.033	−0.006	0.031
Prices										
37. Consumer price index	−0.020*	0.159	−0.004	0.016	0.000	0.000	0.007	0.016	−0.001	0.001
38. Producer prices	−0.002	0.003	0.003	0.012	−0.003	0.003	−0.004	0.011	−0.008	0.015
39. Wholesale price index	0.000	0.000	0.003	0.003	−0.011	0.039	−0.003	0.005	0.004	0.012
40. Import prices	0.007	0.079	−0.009	0.049	0.003	0.005	0.006	0.019	−0.003	0.003
Monetary										
41. Money stock M3	−0.02*	0.215	0.000	0.000	−0.033*	0.181	−0.02*	0.113	−0.023*	0.161

Notes: We estimate the contemporaneous exchange-rate news response model, $R_t = \beta_k S_{kt} + \varepsilon_t$, where R_t is the 5-minute return from time t to time $t + 1$ and S_{kt} is the standardized news corresponding to announcement k ($k = 1, \ldots, 41$) made at time t. We estimate the regression using only those observations (R_t, S_{kt}) such that an announcement was made at time t. We report the $\hat{\beta}_k$ and R^2 values, and we mark with an asterisk those coefficients that are statistically significant at the 5-percent level, using heteroskedasticity- and autocorrelation-consistent standard errors.

Second, unlike the R^2 values for equation (1), which are typically very small, the R^2 values for equation (3) are often quite high. News announcements occur comparatively rarely and have a nonnegligible but short-lived impact on exchange rates; hence the R^2 in an equation such as (3) must be low when computed across all 5-minute observations. In contrast, one naturally expects higher R^2 values when computed using only announcement observations, although the precise size is of course an empirical matter. Table 2 reveals R^2 values that are often around 0.3 and sometimes approaching 0.6.

Finally, it is interesting to note that the results of Yin-Wong Cheung and Clement Yuk-Pang Wong (2000) and Cheung and Menzie David Chinn (2001), obtained by surveying traders, cohere reassuringly with the model-based results documented here. In particular, Cheung and Chinn (2001) report that traders believe that exchange rates adjust almost instantaneously following news announcements, and that news regarding real variables is more influential than news regarding nominal variables, which is entirely consistent with the empirical results reported in Table 2.

C. *News Effects II: Announcement Timing Matters*

One might wonder whether, within the same general category of macroeconomic indicators, news on those released earlier tend to have greater impact than those released later. To evaluate this conjecture, we grouped the U.S. indicators into seven types: real activity, consumption, investment, government purchases, net exports, prices, and forward-looking. Within each group, we arranged the announcements in the chronological order described in Figure 2. The conjecture is generally verified. In the estimates of equation (3) within each indicator group, the announcements released earliest tend to have the most statistically significant coefficients and the highest R^2 values.[21] In Figure 5 we plot the R^2 of equation (3) within each indicator group, as a function of the announcement timing. The clearly prevalent downward slopes reveal that the early announcements do indeed have the greatest impact.

The fact that "announcement timing matters"

[21] One exception is the nominal group; the consumer price index seems more important than the producer price index, despite its earlier release date.

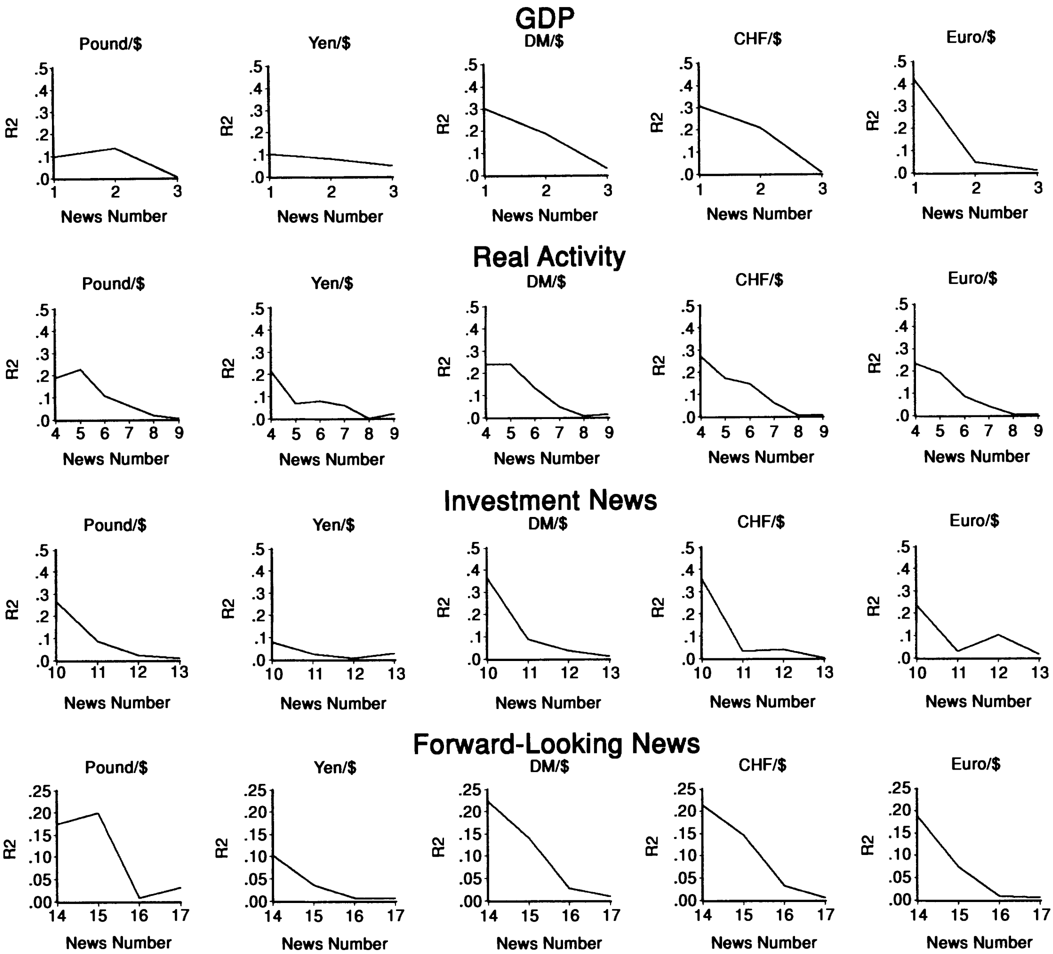

FIGURE 5. U.S. NEWS EFFECTS AS A FUNCTION OF RELEASE TIME

Notes: We estimate the contemporaneous exchange-rate news response model, $R_t = \beta_k S_{kt} + \varepsilon_t$, where R_t is the 5-minute return from time t to time $t + 1$ and S_{kt} is the standardized news corresponding to announcement k ($k = 1, \dots, 17$) made at time t. We estimate the regression using only those observations (R_t, S_{kt}) such that an announcement was made at time t. On the vertical axis we display the R^2 values, and on the horizontal axis we display macroeconomic news announcements in the chronological order documented in Table 2. The "news numbers" are as follows:

GDP	Real Activity	Investment	Forward-Looking
1. GDP advance	4. Payroll employment	10. Durable goods orders	14. Consumer confidence
2. GDP preliminary	5. Retail sales	11. Construction spending	15. NAPM index
3. GDP final	6. Industrial production	12. Factory orders	16. Housing starts
	7. Capacity utilization	13. Business inventories	17. Index of leading indicators
	8. Personal income		
	9. Consumer credit		

helps with the interpretation of our earlier-reported empirical results in Table 2, which indicate that only seven of the 40 announcements significantly impacted all the currency specifications. The reason is that many of the announcements are to some extent redundant, and the market then only reacts to those released earlier. Hence, for example, U.S. durable goods

TABLE 3—RETURN AND VOLATILITY NEWS RESPONSE COEFFICIENTS

Announcement	Pound/$	Yen/$	DM/$	CHF/$	Euro/$
	Contemporaneous Return Response, β_{k0}				
Nonfarm payroll employment	0.092*	0.072*	0.159*	0.115*	0.081*
Durable goods orders	0.055*	0.029*	0.084*	0.083*	0.041*
Trade balance	0.083*	0.115*	0.142*	0.131*	0.084*
Initial unemployment claims	−0.010*	−0.009*	−0.018*	−0.024*	−0.017*
	Contemporaneous Volatility Response, β_{k0}				
Nonfarm payroll employment	0.058*	0.053*	0.084*	0.077*	0.058*
Durable goods orders	0.017*	0.010*	0.027*	0.018*	0.018*
Trade balance	0.023*	0.040*	0.034*	0.031*	0.026*
Initial unemployment claims	0.003*	0.004*	0.010*	0.010*	0.005*
	Cumulative Volatility Response, $\Sigma_{j'=0}^{J'} \beta_{kj'}$				
Nonfarm payroll employment	0.356*	0.328*	0.519*	0.476*	0.356*
Durable goods orders	0.106*	0.060*	0.163*	0.114*	0.108*
Trade balance	0.139*	0.244*	0.210*	0.191*	0.161*
Initial unemployment claims	0.021*	0.023*	0.059*	0.060*	0.033*

Notes: We estimate the exchange-rate conditional mean model (1), $R_t = \beta_0 + \Sigma_{i=1}^{I} \beta_i R_{t-i} + \Sigma_{k=1}^{K} \Sigma_{j=0}^{J} \beta_{kj} S_{k,t-j} + \varepsilon_t$, and we report estimates of the contemporaneous response of exchange-rate returns to news, β_{k0}. We also estimate the disturbance volatility model (2),

$$|\hat{\varepsilon}_t| = c + \psi \frac{\hat{\sigma}_{d(t)}}{\sqrt{288}} + \sum_{k=1}^{K} \sum_{j'=0}^{J'} \beta_{kj'} |S_{k,t-j'}| + \left(\sum_{q=1}^{Q} \left(\delta_q \cos\left(\frac{q 2\pi t}{288} \right) + \phi_q \sin\left(\frac{q 2\pi t}{288} \right) \right) + \sum_{r=1}^{R} \sum_{j''=0}^{J''} \gamma_{rj''} D_{r,t-j''} \right) + u_t,$$

and we report estimates of the contemporaneous response of exchange-rate volatility to news, $\beta_{k0} = \gamma_k p_k(0)$, as described in the text. Finally, we also report estimates of the cumulative volatility response, $\Sigma_{j'=0}^{12} \gamma_k p_k(j')$, as described in the text. Asterisks denote statistical significance at the 5-percent level.

orders matter for all currency pairs but U.S. factory orders, which are released later, do not.

D. *News Effects III: Volatility Adjusts to News Gradually*

As discussed previously and documented in Figure 4, exchange rates adjust to news immediately. It is interesting to note, however, that exchange-rate *volatilities* adjust only gradually, with complete adjustment occurring only after $J' = 12$ 5-minute periods, or one hour.

We provide details in Table 3. As already noted, and as shown again in the top panel of the table, the contemporaneous return response coefficients are sizeable and statistically significant, and the full response occurs immediately. In contrast, the contemporaneous volatility response coefficients, although statistically significant, are smaller, as shown in the middle panel of the table. Importantly, however, the complete response of volatility to news occurs only after an hour or so, and it is noticeably larger than either the contemporaneous volatility response or the contemporaneous return response, as shown in the bottom panel of the table.

E. *News Effects IV: Pure Announcement Effects are Present in Volatility*

It is possible that the mere presence of an announcement might boost volatility, quite apart from the size of the associated surprise. To explore this possibility we add to the returns equation (1) J lags of announcement period dummies on each of K fundamentals, and we also add to the volatility equation (2) J' lags of announcement period dummies on each of K fundamentals. As shown in Table 4, the announcement dummies are generally insignificant in the returns equation (1) but generally significant in the volatility equation (2), in line with earlier results for bond markets such as Fleming and Remolona (1997, 1999). News effects are still important, however, in both conditional mean and variance dynamics.

TABLE 4—RETURN AND VOLATILITY NEWS RESPONSE COEFFICIENTS AND ANNOUNCEMENT DUMMY COEFFICIENTS

Announcement	Pound/$	Yen/$	DM/$	CHF/$	Euro/$
		Contemporaneous Return Response			
Nonfarm payroll employment					
β_{k0}	0.091*	0.071*	0.159*	0.115*	0.079*
θ_{k0}	0.018	0.008	0.029*	−0.002	0.020
Durable goods orders					
β_{k0}	0.052*	0.028*	0.082*	0.083*	0.039*
θ_{k0}	−0.023*	−0.004	−0.023*	−0.017	−0.010
Trade balance					
β_{k0}	0.086*	0.121*	0.144*	0.131*	0.085*
θ_{k0}	0.013	0.029	0.013	0.004	0.012
Initial claims					
β_{k0}	−0.009*	−0.009*	−0.017*	−0.023*	−0.017*
θ_{k0}	0.001	−0.010*	−0.005	−0.002	−0.006
		Contemporaneous Volatility Response			
Nonfarm payroll employment					
β_{k0}	0.0173*	0.0216*	0.0215*	0.0169*	0.015*
θ_{k0}	0.0566*	0.0436*	0.0873*	0.0837*	0.0597*
Durable goods orders					
β_{k0}	0.014*	0.0098*	0.023*	0.0148*	0.0144*
θ_{k0}	0.0042	0.0002	0.0048	0.0046	0.0043
Trade balance					
β_{k0}	0.0226*	0.0255*	0.0214*	0.0149*	0.0153*
θ_{k0}	0.0001	0.0174*	0.0162*	0.0198*	0.0141*
Initial claims					
β_{k0}	0.0005	−0.0005	0.0039*	0.0062*	0.002
θ_{k0}	0.0035*	0.0048*	0.0062*	0.0038*	0.0032*

Notes: We add to equation (1) J lags of announcement period dummies on each of K fundamentals, $R_t = \beta_0 + \sum_{i=1}^{I} \beta_i R_{t-i} + \sum_{k=1}^{K} \sum_{j=0}^{J} \beta_{kj} S_{k,t-j} + \sum_{k=1}^{K} \sum_{j=0}^{J} \theta_{kj} D_{k,t-j} + \varepsilon_t$, and we report estimates of the contemporaneous return response to news and to announcement periods, β_{k0} and θ_{k0}, respectively. We also add to equation (2) J' lags of announcement period dummies on each of K fundamentals,

$$|\hat{\varepsilon}_t| = c + \psi \frac{\hat{\sigma}_{d(t)}}{\sqrt{288}} + \sum_{k=1}^{K} \sum_{j'=0}^{J'} \beta_{kj'} |S_{k,t-j'}| + \sum_{k=1}^{K} \sum_{j'=0}^{J'} \theta_{kj'} D_{k,t-j'} + \left(\sum_{q=1}^{Q} \left(\delta_q \cos\left(\frac{q2\pi t}{288}\right) + \phi_q \sin\left(\frac{q2\pi t}{288}\right)\right) + \sum_{r=1}^{R} \sum_{j''=0}^{J''} \gamma_{rj''} D_{r,t-j''} \right) + u_t,$$

and report estimates of the contemporaneous return response to news and to announcement periods, β_{k0} and θ_{k0}, respectively. Asterisks denote statistical significance at the 5-percent level.

F. *News Effects V: Announcement Effects are Asymmetric—Responses Vary with the Sign of the News*

We have seen that news about macroeconomic fundamentals significantly affect high-frequency exchange rates. Thus far we have allowed only for constant news effects, but it is natural to go farther and ask whether the news effects vary with the sign of the surprise. To address this issue we generalize equation (3) by allowing the impact response coefficient β_k to be a linear function of the news surprise S_{kt}, allowing for a different constant and slope on each side of the origin,

$$\beta_k = \begin{cases} \beta_{0k} + \beta_{1k} S_{kt} & \text{if } S_t \leq 0 \\ \beta_{2k} + \beta_{3k} S_{kt} & \text{if } S_t > 0. \end{cases} \tag{4}$$

Inserting (4) into (3) yields the impact response specification,

$$R_t = \begin{cases} \beta_{0k} S_{kt} + \beta_{1k} S_{kt}^2 + \varepsilon_t & \text{if } S_t \leq 0 \\ \beta_{2k} S_{kt} + \beta_{3k} S_{kt}^2 + \varepsilon_t & \text{if } S_t > 0. \end{cases} \tag{5}$$

Following Robert F. Engle and Victor K. Ng (1993), we call the union of $\beta_{0k} S_{kt} + \beta_{1k} S_{kt}^2$ to the left of the origin and $\beta_{2k} S_{kt} + \beta_{3k} S_{kt}^2$ to the

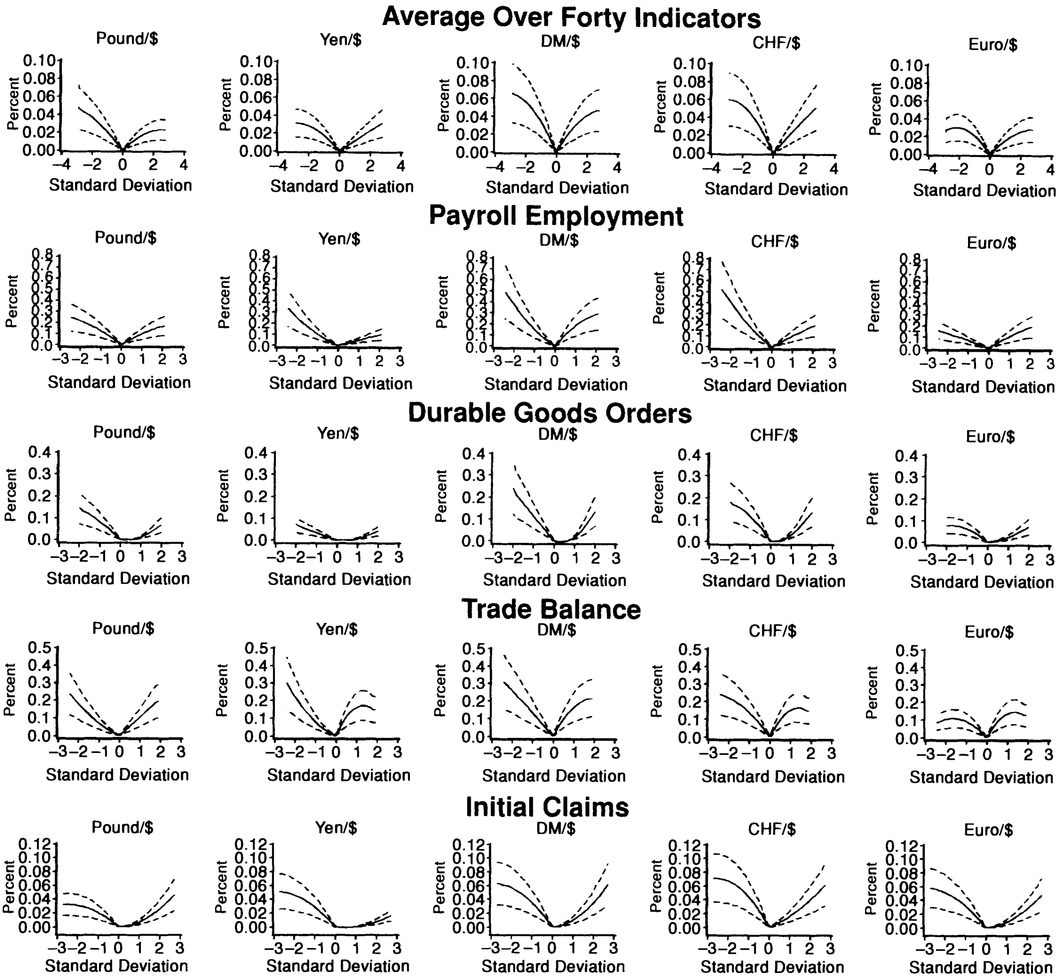

FIGURE 6. U.S. NEWS IMPACT CURVES

Notes: In the top row we show the news impact curves averaged across all macroeconomic fundamentals, $k = 1, \dots, 41$. In the remaining rows we show the news impact curves for payroll employment, trade balance, durable good orders, and initial claims. See text for details.

right of the origin the "news impact curve."[22] In the top row of Figure 6 we show the news impact curves averaged across all macroeconomic fundamentals, $k = 1, \dots, 41$. It is clear that, on average, the effect of macroeconomic news often varies with its sign. In particular, negative surprises often have greater impact than positive surprises.[23]

It is interesting to see whether the sign effect prevails when we look separately at the most

[22] Despite the superficial resemblance in terms of documenting asymmetric responses to news, our work is very different from that of Engle and Ng (1993) and many subsequent related studies. In particular, the Engle–Ng news impact curve tracks the *variance of equity* returns conditional upon the sign and size of *past returns* (with no allowance for a time-varying conditional mean return), whereas our news impact curve tracks the *mean* of foreign exchange returns conditional upon the sign and size of *macroeconomic news.*

[23] To the best of our knowledge, such sign effects have not previously been documented for the foreign exchange market. Evidence of asymmetric conditional-mean news effects exists in other contexts, however. For example, Jennifer Conrad et al. (2001) find asymmetric effects of earnings news on stock returns, while recent concurrent work by Hautsch and Hess (2001) details an asymmetric response to employment news in the T-bond futures market.

important news announcements. In the remaining rows of Figure 6 we show the news impact curves for payroll employment, trade balance, durable goods orders, and initial claims. The sign effect is generally maintained, although there is some variation across indicators and currencies. Asymmetry in the Yen/$, DM/$, and CHF/$ response to payroll employment and trade balance news, for example, is very pronounced, whereas it is largely absent in the Pound/$ and Euro/$ response.

In the next section we explore more deeply the economics behind the asymmetric response. Recent theoretical models suggest that the asymmetry may be driven, in part, by the dynamics of uncertainty regarding the underlying state of the economy. It turns out that our MMS data set contains not only expectations, but also a measure of the cross-sectional *dispersion* of expectations, the standard deviation. Using the cross-sectional standard deviation as a proxy for state uncertainty, we can therefore directly assess a key mechanism thought to generate asymmetric response, to which we now turn.

III. Asymmetric Response, Information Processing, and Price Discovery

Two strands of literature imply asymmetry in the response of exchange rates to news. In particular, they imply that bad news in "good times" should have an unusually large impact, a view that is also common in the practitioner community, as emphasized by Conrad et al. (2001). Note that our entire sample takes place in good times—1992 through 1998. Hence the theoretical prediction that "bad news in good times should have unusually large effects," degenerates in our sample period to "bad news should have unusually large effects," which, to a reasonably good approximation, is what we found earlier.

The first strand of the literature is "behavioral" and focuses primarily on equities, at the firm level. Nicholas Barberis et al. (1998), for example, model investors as believing that firm earnings follow a two-state regime-switching process—erroneously, as earnings actually follow a random walk—with mean-reverting earnings in state 0 and upward-trending earnings in state 1. Hence a series of positive earnings leads investors to infer that state 1 holds, with the concomitant expectation of additional positive earnings. In such a situation, bad news generates a large negative response because it is a surprise, whereas good news generates little response because it is anticipated.

The second relevant strand of the literature uses a rational-expectations equilibrium approach and focuses more on the market level as opposed to the firm level, as in Pietro Veronesi (1999), Timothy C. Johnson (2001a, b), and Alexander David and Veronesi (2001). Veronesi (1999), in particular, models investors as (correctly) believing that the economy follows a two-state regime-switching process, with "low" and "high" states corresponding to recessions and expansions. Agents solve a signal extraction problem to determine the probability $\pi(t)$ of being in the high state, and equilibrium asset prices can be shown to be increasing and *convex* functions of $\pi(t)$. The intuition for this key result is simple. Suppose that $\pi(t - 1) \approx 1$, i.e., investors believe that the high state almost surely prevails. Then if bad news arrives at time t, two things happen: first, expected future asset values decrease, and second, $\pi(t)$ decreases (i.e., state risk increases). Risk-averse investors require additional returns for bearing this additional risk; hence they require an additional discount on the asset price, which drops by more than it would in a present-value model. Conversely, suppose investors are confident that the low state prevails, i.e., $\pi(t - 1) \approx 0$. Then if good news arrives at time t, expected future asset values increase, but $\pi(t)$ also increases (i.e., state risk again increases). As before, investors require additional returns for bearing this additional risk; hence they require a discount on the asset price, which increases by less than it would in a present-value model.

For a number of reasons, it is not our intention here to explicitly test the practitioner claim that prices respond most strongly to bad news in good times, or to directly implement Veronesi's model or to combine it with the Barberis-Shleifer-Vishy model. First, our data set is not well-suited to that purpose; as mentioned above, it contains only the expansionary 1990's. Second, Conrad et al. (2001) have already made admirable progress in that regard, finding general support for the assertion that (stock) prices respond most strongly to bad news in good times. Third, the Barberis-Schleifer-Vishny model is not particularly well-suited to the forex context relevant here, as it focuses on the earnings stream for an individual firm.

Instead, we take as true the practitioner claim that prices respond most strongly to bad news in good times, and we focus on the explanation embodied in Veronesi's model. We use an interesting feature of our MMS expectations data to assess the key alleged mechanism through which bad news in good times translates into large price moves: increased uncertainty about the state of the economy. In particular, we have data not only on the median expectations of macroeconomic fundamentals, but also on the associated standard deviations across the individual forecasters. Hence we can check directly whether uncertainty about the state of the economy, as proxied by the standard deviation of expectations across the individual forecasters, increases following the arrival of bad news in good times.[24] Before proceeding to examine the effect of bad news arrivals on subsequent forecast dispersion, however, two issues arise.

First, it is not clear what timing in the data matches the generic timing in the model. Clearly, bad news at time $t - 1$ means that expectations for time t are formed in a bad news environment, but what if the news at $t - 2$ was bad and the news at $t - 1$ was not? Perhaps agents have a memory that lasts longer than one announcement period, so that even the latter case could be viewed as a bad news environment. In general, we might say that we are in a bad news environment if the news was bad at any of times $t - 1, t - 2, \ldots, t - d$, for some d. Second, to enhance our chances of detecting the "Veronesi effect," if it exists, we may not want to track the arrival of all bad news, but rather only bad news that exceeds some minimal threshold, say the pth percentile of the distribution of bad news, where p, like d, must be chosen. As a benchmark, we simply set $d = 1$ and $p = 50$ percent (i.e., the median).

Figure 7 plots the corresponding standard deviation of the MMS payroll employment, durable goods orders, and trade balance forecasts. The shaded areas indicate a bad news environment using the criteria $d = 1$ and $p = 50$ percent. Analyst forecast dispersion is indeed

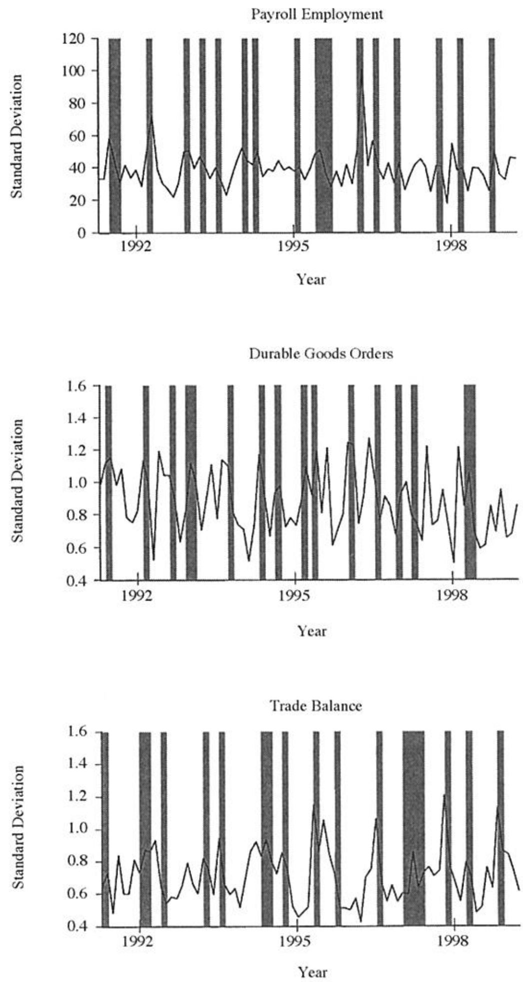

FIGURE 7. FORECAST UNCERTAINTY

Notes: We plot the time series of cross-sectional standard deviations of the Money Market Services forecasts. The shaded areas denote "bad news" times. See text for details.

higher following bad news than at other times; specifically, the uncertainty of payroll employment is 30 percent higher, the uncertainty of durable goods orders is 6 percent higher, and the uncertainty of the trade balance is 12 percent higher. These effects are robust to reasonable variation in p and d.

IV. Concluding Remarks and Directions for Future Research

The goal of the research on which this paper reports is to deepen our understanding of the links

[24] Of course, the notion of forecast uncertainty and the forecast dispersion across forecasters are not exactly equivalent concepts. Victor Zarnowitz and Louis A. Lambros (1987) show, however, that they are generally positively correlated.

between exchange-rate movements and news about fundamentals. To that end, in this paper we have documented important news effects, with asymmetric response patterns. Let us conclude by relating our results to work on order flow and drawing implications for future research.

In recent innovative work, Evans and Lyons (2002) show that signed order flow is a good predictor of subsequent exchange-rate movements. This work is important in that it enhances our understanding of the determinants of high-frequency exchange-rate movements, but less satisfying in that it remains ignorant about the determinants of high-frequency order flow. We, in contrast, have shown that news affects exchange rates. Combining our perspectives focuses attention on the causal links among news, order flow, and forex movements, which in our view is a prime candidate for future research. It will be of interest, for example, to determine whether news affects exchange rates via order flow or instantaneously.[25] In work done subsequently to the first draft of this paper, Evans and Lyons (2001) and Kenneth A. Froot and Tarun Ramadorai (2002) tackle precisely that issue.

A second key direction for future research is pushing farther with the implications of Veronesi (1999) for the analysis of high-frequency news effects. Presently we have verified that the key mechanism that amplifies the effects of bad news in good times in Veronesi's model—increased state uncertainty—is operative in the data. However, one could potentially go farther and exploit the broader implications of Veronesi's work for our approach, namely that news effects are in general a function of state uncertainty, by including interactions of news with state uncertainty in both our conditional mean and conditional variance specifications. This would be particularly interesting if data were available on exchange rates and fundamentals spanning bad as well as good times, but as of this writing, such data remain elusive.

Third, it would be of interest to explore not only the effects of regularly scheduled quantitative news on macroeconomic fundamentals, but also the effects of irregularly scheduled, qualitative "headline news," as prices, and perhaps order flow, may reasonably be expected to respond to both.[26] It is not obvious, however, how to do so in a compelling way; both the conceptual and the practical complications seem daunting.

Fourth, it will be of interest to attempt an analysis of structural stability, as the market may change its view about which news is important for exchange rates, or about how to interpret the sign of a surprise. In some interpretations, for example, a positive U.S. inflation surprise would tend to produce dollar depreciation (e.g., when the U.S. central bank reaction function assigns relatively low weight to the level of inflation), whereas in other interpretations it would produce dollar appreciation (e.g., when the U.S. central bank reaction function shows strong preference for low inflation, as in Taylor, 1993).

Finally, we look forward to characterizing the *joint* responses of the foreign exchange, stock, and bond markets to real-time news surprises. Responses have now been studied for each market in isolation: Fleming and Remolona (1999) and Balduzzi et al. (2001) study the bond market, Mark J. Flannery and Aris Protopapadakis (2002) study the stock market, and this paper, of course, studies the foreign exchange market. A multivariate framework, however, will facilitate analysis of cross-market movements and interactions, or lack thereof, which may for example shed light on agents' views regarding central bank reaction functions.

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Andersen, Torben G.; Bollerslev, Tim; Diebold,

[25] For instance, Kenneth R. French and Richard Roll (1986) and Fleming and Remolona (1999) both argue that publicly available news may be incorporated in prices instantaneously, even without trading.

[26] Indirect evidence is provided by Dirk Eddelbüttel and Thomas H. McCurdy (1998), who report significantly heightened foreign exchange-rate volatility in response to the mere frequency of headline news items on the Reuters news screen.

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