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Informed Traders, Intervention, and Price Leadership: A Deeper View of the Microstructure of the Foreign Exchange Market

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ABSTRACT

This article identifies price leadership patterns in foreign exchange trading, with a focus on central bank intervention as an informational trigger for leadership positioning. Granger causality tests applied to DM/US$ spot rate quotes reveal Deutsche Bank as a price leader up to 60 minutes prior to Bundesbank interventionary reports. By the minus 25-minute mark, interbank quote adjustments become two-way Granger-causal. These results suggest that central bank activity is revealed in stages: first to the price leader, then to competitors, and lastly to the general public.

INFORMATION-BASED MICROSTRUCTURE THEORY views the trading process for financial assets as a strategic game involving players who adjust order flows and prices based on asymmetric information regarding the underlying asset's true value. Unfortunately, we can only verify such theories empirically if we have access to high-frequency data. For this reason, empirical studies of information asymmetry have focused predominantly on the equity markets (see Hasbrouck (1991) and Easley, O'Hara, and Srinivas (1993) for recent examples). However, with the recent availability of continuous time spot rate data, it has now become possible to apply tests of microstructure trading theories to the foreign exchange market.

This study aims to shed light on strategic foreign exchange trader behavior by focusing on spot rate revisions around an exogenous news event. Specifically, we will show that central bank intervention establishes certain bank traders as price leaders because they are perceived to be better informed about future changes in the exchange rate than some other agents.

Charles Goodhart (1988) has asserted the importance of information asymmetries in short-term interactions among foreign exchange trading banks. From interviews with foreign exchange specialists in London, he concluded the following:

> *A further source of informational advantage to the traders is their access to, and trained interpretation of, the information contained in the order*

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flow . . . Some market actions may indicate central bank involvement. Each bank seeks to interpret the activity of other banks in the market; some have a reputation of being able to position themselves well in certain currencies, and their perceived operations may cause others to follow their lead (emphasis added). *Each bank will also know what their own customer enquiries and orders have been in the course of the day, and will try to deduce from that the positions of others in the market, and overall market developments as they unfold* (p. 456).

Hence, if there is any evidence of information-based leadership in the foreign exchange market, it should be observable through systematic changes in order flows, i.e., quantities traded, around key market events—central bank intervention in particular. However, in the foreign exchange market, only indicative price quotes, and not positions, are publicly available. Since theory predicts information-based order flows to be reflected in price adjustments (see Kyle (1985) and Glosten and Milgrom (1985)),[1] we test Goodhart's (1988) leadership hypothesis from a "pricing" perspective by using a continuously sampled series of DM/US$ spot rate indications.[2] As in Goodhart (1988), the event focus is on central bank activity, or more specifically, reported Bundesbank interventions.

Granger-type regressions on a cross-section of individual bank quotes provide empirical evidence of Deutsche Bank price leadership between 60 and 25 minutes prior to Bundesbank intervention reports. Thereafter, strategic quote interactions prevail across banks, as evidenced by two-way Granger causalities. These preannouncement quote dynamics indicate the existence of information asymmetries in the foreign exchange market: Central bank activity is revealed to the market well before a public announcement, with Deutsche Bank perceived to be the early information insider to Bundesbank intervention. Once information is more broadly disseminated to the market, less informed banks learn from the informed trader's order flows and revise their prices for profit-taking. These results are in line with the market microstructure theory of pricing following Kyle (1985) and Glosten and Milgrom (1985).

The next section highlights the role of central bank intervention in a world of heterogeneously informed traders. Section II reviews the nature of high-frequency foreign exchange data and defines the sampling horizon within which we will examine intervention-dependent price leadership effects. Section III analyzes the cross-section of banks considered for price leadership analysis. Deutsche Bank's unique position in the DM/US$ market is discussed in Section IV. Section V identifies distinct subsamples of quoting patterns surrounding Bundesbank intervention reports. Section VI presents time-vary-

[1] There also exists empirical evidence that this relationship holds in the foreign exchange market. Refer to Lyons (1995), whose results are based on proprietary data of one trader's transactions prices.

[2] Although banks that post indicative quotes are not committed to trading them, reputational concerns ensure that foreign exchange transactions occur at prices close to those advertised (see Goodhart and Payne (1996) for details).

ing Granger-causality specifications to test the hypothesis of Deutsche Bank price leadership. Empirical results are reported in Section VII, with economic interpretations provided in Section VIII. Section IX concludes.

I. Informational Asymmetry and Intervention

In contrast to the rich equity market literature on informational asymmetry (see O'Hara (1995) for a literature review), foreign exchange market research has only recently developed theories of strategic trading behavior. While stock markets are centralized exchanges and based on specialist systems, foreign exchange trading is largely decentralized and organized around interbank direct dealer networks.[3] Decentralized trader interactions might impact the price discovery process, as shown by Wolinsky (1990). Furthermore, trading motives in the foreign exchange market are a bit different, as they involve both speculative and liquidity aspects.

According to Lyons (1997), "speculative" or informed traders can privately distinguish between own-customer orders that are liquidity-based and those that reflect superior information regarding the fundamental determinants of the spot exchange rate. Hence, informed agents are optimally qualified to take advantage of short-term profit opportunities. "Liquidity" or uninformed traders, on the other hand, are driven by customer needs for financing international trade and corporate transactions. Their strategies are designed to minimize losses when dealing with informed traders.

This study aims to examine how interactions between informed and uninformed foreign exchange traders give rise to short-term sole price leadership during periods of central bank intervention. In a modification to Kyle's (1985) model, suppose that central bank order flows provide an intermediary bank trader, y, with a one-time exogenous information advantage. Since y has private information regarding the authority's intended market correction, Δp, it will adjust order flows and prices first, thereby extracting positive economic rents from its insider information. Further suppose that uninformed competitor banks, x, view y's price adjustment as a signal that they are dealing with an informed trader. To minimize their losses, banks x follow bank y's price revision and adjust their positions accordingly. Based on this sequence of price reactions, trader y emerges as a Stackelberg-type price leader. Trader y's leadership status will persist until all central bank operations are revealed to follower banks, thereby resolving intervention-related informational differences between uninformed banks x and informed bank y.

One may question whether interventions are indeed newsworthy events to banks. Past empirical findings related to the effects of intervention on exchange rates have been inconclusive. Edison (1993) reviews this large literature and concludes

[3] Dealers can also trade through foreign exchange brokers. The brokers' market will be discussed in further detail in Section IV.

. . . as with any empirical work, existing models and the quality of the available data may not be sophisticated enough to resolve properly the questions asked. These qualifications seem consistent with the observation that exchange-market participants appear to believe that central-bank intervention is important and that they therefore react to news of intervention (p. 55).

Until recently, intervention studies had to rely on lower-frequency data, defined in hours, days, or even weeks. There is only a brief literature that has analyzed intervention news in a very short-run context.[4] Goodhart and Hesse (1993) use three months of high-frequency Reuters quotes (April through June 1989 data) to assess exchange rate movements immediately following central bank intervention. In their case, "immediate" refers to half-hourly and one-hour mean returns following a Reuters report. Based on their small sample of intervention periods, they find that intervention has "no immediate, or short-term, systematic effect" (p. 384) on DM/US$ and ¥/US$ returns.

This article expands upon Goodhart and Hesse (1993) by evaluating high-frequency foreign exchange quotes for only a specific subgroup of traders and by using a more refined sampling methodology. Under the hypothesis that central bank interventions are newsworthy events to bank traders, this article will examine to-the-minute subsamples around reported intervention to discern information asymmetries in interbank quoting behavior.

II. The Data

The exchange rate data in this study are tick-by-tick DM/US$ spot quotes, as posted on the Reuters "FXFX" screen between October 1, 1992 and September 30, 1993 (a total of 1,466,946 observations). Each data record includes the date and time to the nearest second of quote recording (in Greenwich Mean Time (GMT)), the bid and the ask quote, as well as codes for the country/city branch location and the name of the quoting bank. For a summary of the stylized facts underlying continuous time quote characteristics, see Guillaume et al. (1994).

News on central bank intervention is gathered from the Reuters "AAMM" headline screen. A search was conducted for all reports of Bundesbank (BUBA) intervention over the 1992–1993 data period. Since each report also carries a date and time-per-second stamp, it can be easily matched to the Reuters FXFX quote records.

One may question whether reports of intervention closely follow actual intervention operations. Goodhart and Hesse (1993) claim that the announcement lag is no longer than 15 to 30 minutes, while conversations with other foreign exchange traders suggest a maximum lag of 10 to 15 minutes. To be thorough, we will trace "interventionary" activity up to one hour before a

[4] Bossaerts and Hillion (1991) were among the first to provide a microstructural perspective on intervention in the foreign exchange market. Their model focuses on movements in the spread as a function of asymmetric intervention information.

Reuters report. Furthermore, we will consider "preinterventionary" dynamics by defining a −120 to −60 minute window (see Section VII for details).

Our upper boundary for postrelease effects will be 60 minutes after a given report. Such a small time horizon is in line with the evidence that interventionary effects on exchange rates are short-lived. Hence, our overall intervention sample will extend from −120 to +60 minutes surrounding time-stamped Reuters announcements.

The conditions for including a given BUBA intervention headline in our event sample are as follows: First, the associated AAMM Reuters report may not refer to so-called daily "fixings" by the Bundesbank.[5] Second, a reported intervention, INT1, may not overlap with another reported intervention, INT2, for the −120 to +60 minute time window surrounding the announcement of INT1 at time 0. The latter condition is vital to ensure that more current intervention announcements do not interfere with the identification of interbank quote patterns associated with previous reports. Based on these two selection criteria, 14 BUBA intervention announcements, reported by Reuters between Oct. 1, 1992 and Sept. 30, 1993, were chosen as relevant event samples. See Table I for their original Reuters headline listings.

III. Top Quoting Banks in the DM/US$ Market

Table II lists the six commercial banks with the most bid/ask quotes posted in the DM/US$ market. For this study, the key period within which we expect intervention-related market activity is the −60/+60 minute time window mentioned above. In the empirical analysis to follow, the intervention sample will be further segmented into subperiods −60/−25, −25/0, 0/+25, and +25/+60 to account for potential structural breaks in quoting patterns.[6] Two broader horizons of interest are the entire one-year data period as well as European business hours (8:00–16:00 GMT), i.e., the time period during which most Bundesbank interventions occur.

Deutsche Bank (DB) is by far the most active contributor to Reuters DM/US$ quotations. This holds for the smallest to the broadest time horizons considered. Over the entire sample period, 121,055 quotes are attributable to DB, which constitutes almost one-tenth of total DM/US$ quoting volume. During the −60/+60 window around Reuters reports, DB's quote frequency is more than forty percent larger than that of the next most active bank, Chemical Bank (CH). The next four banks by number of quote indications are Societe

[5] Fixings are routine institutional transactions by some Western European central banks in which currencies are traded with commercial banks in order to meet small customer needs. Bundesbank fixings in the DM/US$ market are reported daily between 12:00 and 12:30 GMT (standard time). Only in rare cases do fixings coincide with small-scale interventionary activities. Bundesbank officials claim that fixings have little or no effect on exchange rate movements.

[6] At −60 and −25 minutes before a report, around the time of the report (time 0), and around +25 minutes after, we observe clear breaks in interbank quoting patterns. Details on the choice of subsample periods are provided in Section V.

Table I

14 Bundesbank Interventions Considered for Modeling: As Reported by Reuters Between 10-01-1992 and 09-30-1993

The following is a listing of Reuters AAMM screen headlines describing the 14 Bundesbank intervention reports considered for empirical analysis. Reuters clock times are in Greenwich Mean Time. Subsequent tables will index Reuters time stamps as time 0. Foreign currencies traded by the Bundesbank are underlined for emphasis. Note that the Bundesbank is referenced as BUBA in Reuters listings.

Event	Date	Time	Reuters Report
1.	12-02-1992	8:47:36	"BUBA buys FF for marks."
2.	12-15-1992	12:05:34	"Mark strength prompts BUBA intervention (in FF)."
3.	12-17-1992	12:01:18	"BUBA buys FF."
4.	01-04-1993	15:03:54	"BUBA says intervenes to buy FF."
5.	02-03-1993	15:48:46	"Denmark, BUBA support crown in intervention."
6.	02-17-1993	14:28:14	"Peseta falls below 72/DM; (German)[a] intervention rumored."
7.	02-18-1993	9:05:16	"Peseta gains at open; (German)[a] intervention suspected."
8.	04-23-1993	12:34:26	"EMS central banks, BUBA intervene to help peseta."
9.	04-23-1993	15:22:34	"BUBA says buying pesetas in second round."
10.	07-22-1993	10:05:26	"BUBA buys FF in open market."
11.	07-22-1993	12:36:28	"BUBA says still buying FF."
12.	07-23-1993	14:18:18	"(European) central banks selling marks at FF 3.418-dealers."
13.	07-29-1993	14:41:28	"BUBA confirms concerted action in support of FF."
14.	07-30-1993	11:18:30	"BUBA buying FF-dealers."

[a] Reuters intervention headlines for 02-17-1993 and 02-18-1993 did not indicate the central bank of origin. Through alternative sources it was confirmed that these interventions refer to the Bundesbank.

Generale (SG), Rabobank (RB), Berliner Handels-und Frankfurter Bank (BH), and Den Norske Bank (DN).

Note that market activity is most heavily skewed toward DB in the period immediately preceding Reuters reports: compared to the aggregate −60/+60 period, indications by other banks relative to DB, fall by up to nine percent in the −25/0 period. This unusual decline in quote frequency is a first indication of shifts in market signals around intervention. We will return to a further discussion of this issue in Section VIII.

IV. Deutsche Bank's Unique Market Position

DB's dominance in quoting activity should be expected in the DM/US$ market. For this currency pair, *Euromoney* Magazine (June 1994) has reported DB as holding the largest European customer base in 1993. In the same year, DB also ranked as the 13th largest bank in the world in terms of shareholder equity and asset value.

DB's customer depth enhances the bank's ability to gain early access to new information as well as to disseminate such information quickly. Additionally,

Table II

Top Banks by Number of DM/US$ Spot Rate Quotations Posted Between 10-01-1992 and 09-30-1993

This table presents the six commercial banks with the largest number of Reuters DM/US$ spot rate quotations posted over the 1992–1993 sample period. These banks are: Deutsche Bank (DB), Chemical Bank (CH), Societe Generale (SG), Rabobank (RB), BHF Bank (BH), and Den Norske Bank (DN). Columns two through six list each bank's quote frequencies within 60 minutes before (−) and after (+) reported Bundesbank interventions, with frequencies pooled across the 14 Reuters reports identified in Table I. −60/−25, −25/0, 0/+25, and +25/+60 are time intervals in minutes which define subsamples *within* the aggregate −60/+60 minute intervention period. Each interval is mutually exclusive from another and counts frequencies by the tick. For instance, the column labeled "−60/−25" indicates that across all 14 Bundesbank interventions, DB posted a total of 303 DM/US$ quotes between −60:00 minutes and −25:01 minutes prior to a Reuters report at time 0. Column seven reports the number of bank quotes occurring during European business hours (GMT), and the last column summarizes counts over the entire one-year sample period.

	14 Bundesbank Intervention Samples					European Hours 8:00:00–16:00:00 GMT	All Quotes 0:00:00–23:59:59
Banks	−60/−25	−25/0	0/+25	+25/+60	−60/+60 min.		
Deutsche Bank (DB)	303	238	210	253	1,004	74,216	121,055
Chemical Bank (CH)	190	143	147	184	690	43,772	67,554
Societe Generale (SG)	192	127	131	167	617	60,059	72,891
Rabobank (RB)	198	123	102	133	556	57,274	57,274
BHF Bank (BF)	176	95	97	127	495	38,138	70,227
Den Norske Bank (DN)	145	103	97	128	475	34,144	38,958

its size advantage allows DB to provide more rapid liquidity and volume turnover than most competitors in the DM/US$ market.

Since there are no public records on Bundesbank interventionary transactions, one can only speculate about the commercial agents through which the Bundesbank executes its foreign exchange trades. For political reasons, banks of German nationality are prime candidates. Furthermore, we would expect market share and liquidity to be of important concern to the central bank. Based on these criteria, DB is likely to be a key intermediary to BUBA intervention order placements. Therefore, empirical tests of price leadership will be stated specifically with respect to Deutsche Bank.

It should be noted that in executing an intervention, a central bank can deal either directly with commercial banks as counterparties or go through the brokers' market. In dealing directly with commercial banks, the central bank chooses a particular counterparty who may then be allowed to make the intervention information public. Brokers, on the other hand, act as intermediaries who bring market makers together by accumulating limit orders. They also provide anonymity to the trading counterparties until after a transaction is completed. So when dealing through the brokers' market, the central bank chooses not to target a particular bank for its order placement and can delay the market revelation of the intervention.

Officials in Frankfurt have claimed that the Bundesbank uses a mix of both broker and direct bank contacts to place intervention orders. However, independent research by Humpage (1994) and Dominguez and Frankel (1993) reveals that since the mid-1980s, most G-7 central banks deal directly with bank dealers to allow for a more rapid information flow about intervention activities. This institutional development makes it feasible that a bank can gain insider information from direct central bank contact—a key condition to the price leadership hypothesis examined here.

V. Identifying Relevant Time Segments Around Intervention Reports

Empirical analysis focuses on quote returns, defined as the percentage change in the midpoint of DM/US$ bid-ask quotes.[7] Descriptive statistics for the first four moments of the tick-by-tick returns are consistent with the high-frequency time-series properties documented by Goodhart and Figliouli (1991) and Bollerslev and Domowitz (1993).[8]

In Figure 1, we plot the market's return volatility around intervention, based on five-minute standard deviation averages over 14 BUBA intervention reports. The time period covered is −60 minutes before to +25 minutes after a given intervention report.[9]

Figure 1 indicates a distinct news effect. Of particular interest is the statistically significant one-basis point volatility increase at −5 minutes prior to BUBA intervention reports. This is consistent with the findings by Ederington and Lee (1993) and DeGennaro and Shrieves (1995) who have shown that private information leakages cause foreign exchange volatility to increase just prior to official news reports. A theoretical underpinning for this finding is provided in the information-asymmetry model by Ross (1989).

Following the peak observed at −5, market volatility tapers off quickly. This finding is consistent with the claim by Edison (1993) and Goodhart and Hesse (1993) that the news content of interventionary activities is transitory.

It should be noted that between October 1, 1992 and September 30, 1993, the European exchange markets were in the midst of a crisis that called into question the validity of the European Monetary System's (EMS) exchange rate bands. All 14 intervention reports used in the empirical portion of this article involve efforts to sell Deutsche Marks and buy European currencies. Most interventions were clustered around the new year 1992/1993 and again around July 1993, when the French Franc threatened to fall below the FF/DM ex-

[7] The bid and the ask may not move in unison since at a given point in time, a trader is interested in either buying or selling. To smooth these transactions-related biases in the data series, it is most appropriate to use the average of the bid and the ask.

[8] Results are available from the author upon request.

[9] In this graph and subsequent illustrations (see Figures 2 and 3), "time 0" refers to the precise time in seconds at which an intervention was reported on the Reuters screen. An extension of the plot to the +25/+60 time horizon following intervention reports did not add any new information to the stylized facts and was, therefore, omitted from this article.

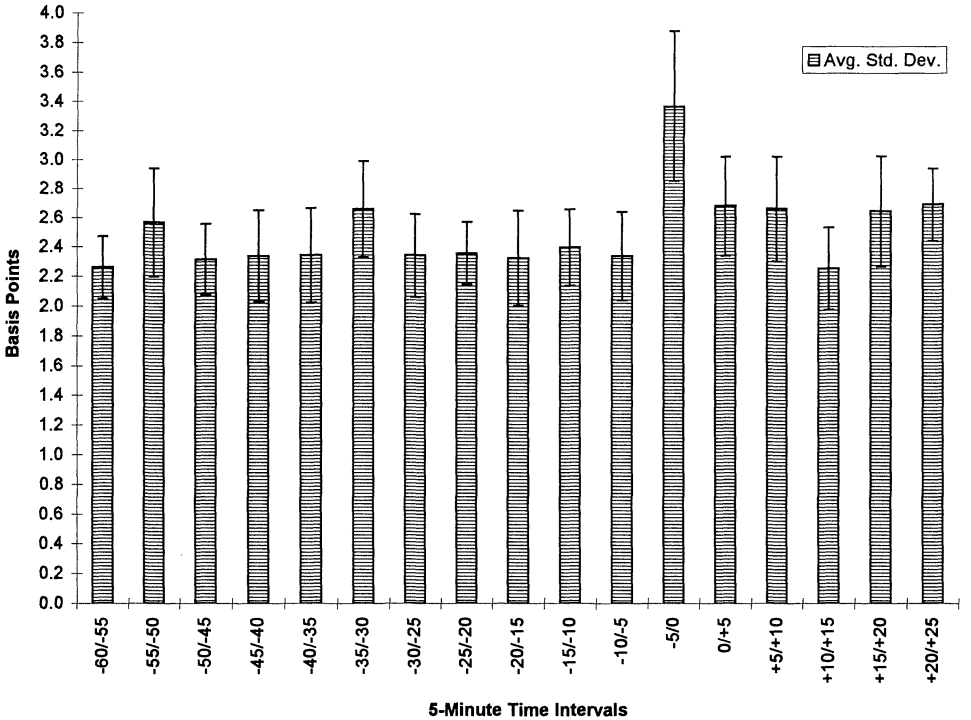

Figure 1. Mean DM/US$ quote volatility around Bundesbank intervention. This plot presents standard deviations of tick-by-tick DM/US$ quote revisions, averaged per five-minute interval across 14 pooled Bundesbank intervention periods. Quote revisions are based on percentage changes in bid-ask midpoint quotes across all Reuters FXFX screen entries between Oct. 1, 1992 and Sept. 30, 1993. Five-minute average standard deviations are in basis points and capture all quotes between −60 minutes before and +25 minutes after a given intervention report. The time stamp on Reuters intervention headlines is denoted as time 0. Lines at the top of each bar denote ± one standard error around the standard deviation means.

change rate level permitted under EMS rules. Between October 1, 1992 and September 30, 1993, no specific DM/US$ interventions were reported by Reuters. However, the European currency interventions clearly had a spillover effect on the U.S. Dollar, as evidenced by the volatility pattern in Figure 1.

This study is not as interested in intervention-linked market fluctuations as it is in evaluating the timing of quote revisions by individual players. Figures 2 and 3 focus on average quote changes by the six most frequently quoting banks identified in Section III.

As shown in Figure 2, the pattern of midpoint quote revisions for DB, CH, and SG does not suggest any clear correlation among these three banks. Prior to −25 minutes and again after time 0, DB, CH, and SG display divergent quote return patterns, with DB raising DM/US$ quotes and CH and SG

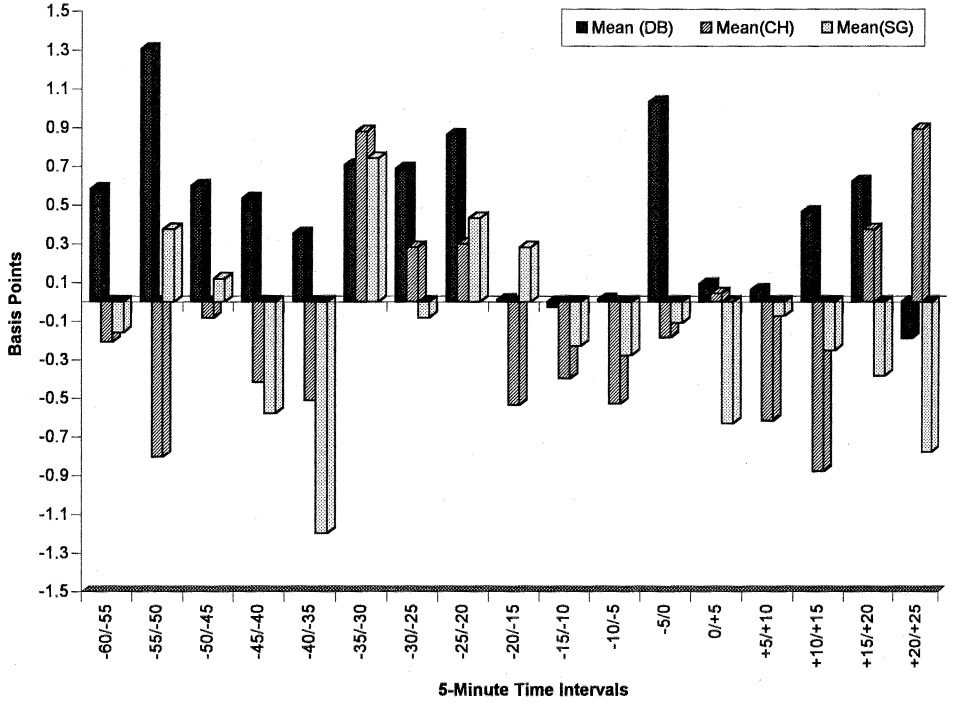

Figure 2. Mean DM/US$ quote revisions by Deutsche Bank, Chemical Bank, and Societe Generale around Bundesbank intervention. This plot depicts tick-by-tick DM/US$ quote revisions by Deutsche Bank (DB), Chemical Bank (CH), and Societe Generale (SG), averaged per five-minute interval across 14 pooled Bundesbank intervention periods. Five-minute bank averages are in basis points and reflect percentage changes in bid-ask midpoint quotes between −60 minutes before and +25 minutes after a given intervention report. Each intervention is identified based on Reuters headlines between Oct. 1, 1992 and Sept. 30, 1993. The time stamp on Reuters entries is denoted as time 0.

lowering their price indications.[10] Between −25 and −5 minutes prior to intervention reports, however, the dispersion among quote returns narrows as all three banks tend to lower their DM/US$ quotes.

Figure 3 displays markedly different inferences for the interrelations of DB with RB, DN, and BH. These three banks seem to follow DB over the entire −60/+25 minute time span. From −25 to −5, the overall convergence in quoting patterns is most pronounced. After time 0, the dispersion among quote returns reverts to initial levels, with DB leading RB, DN, and BH.

Figures 2 and 3 contain important information for the subsequent regression analysis: First, they provide cursory evidence of DB price leadership with

[10] The divergent quote patterns displayed in the figures should not be confused with arbitrage opportunities. Note that the data plots are based on midpoints of *indicative* bid/ask prices computed as *averages* over five-minute intervals. Furthermore, differences across banks are of such a small magnitude relative to the typical market spread that they are unlikely to exceed the transactions costs of arbitrage.

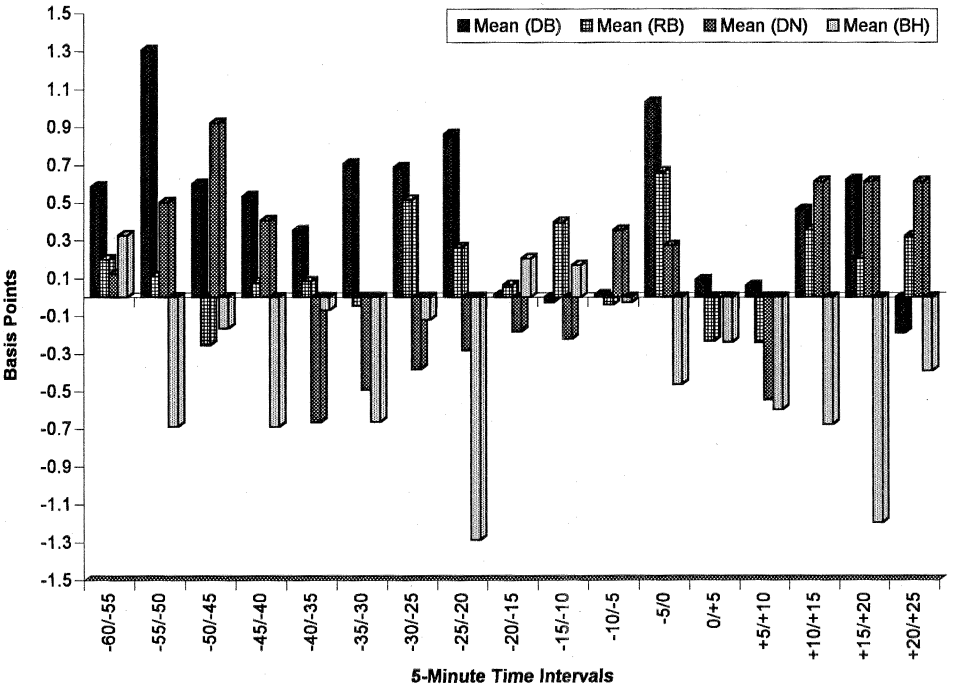

Figure 3. Mean DM/US$ quote revisions by Deutsche Bank, Rabobank, Den Norske Bank, and BHF Bank around Bundesbank intervention. This plot depicts tick-by-tick DM/US$ quote revisions by Deutsche Bank (DB), Rabobank (RB), Den Norske Bank (DN), and BHF Bank (BH), averaged per five-minute interval across 14 pooled Bundesbank intervention periods. Five-minute bank averages are in basis points and reflect percentage changes in bid-ask midpoint quotes between −60 minutes before and +25 minutes after a given intervention report. Each intervention is identified based on Reuters headlines between Oct. 1, 1992 and Sept. 30, 1993. The time stamp on Reuters entries is denoted as time 0.

respect to at least four other banks, in particular CH, RB, DN, and BH. Second, the charts identify distinct bandwagon effects of trading between −25 and −5 minutes prior to Reuters reports. These visually evident breaks in quoting patterns will form the basis for the sampling technique introduced in Section II and applied in the empirical analysis below.

VI. Granger-Causality Tests in a Time-Varying Framework

The empirical investigation of the price leadership hypothesis formulated in Section I is based on Granger-causality tests of quote return interrelations across banks. Following Granger (1969), a *necessary* condition for price leadership by a particular bank, y, involves the premise that its current return pattern, y_t, be uncorrelated to past revisions by other market participants, x_{t-i}. Banks x fail to "Granger-cause" bank y if past modifications that have altered the time-varying process of x_{t-i} do not affect the contemporaneous conditional distribution of y_t.

As a *sufficient* condition for price leadership, we might expect lagged observations y_{t-i} to have a positively significant effect on the contemporaneous series x_t. For our data, however, we need not impose a positive restriction on the coefficient sign for y_{t-i} to establish price leadership by bank y. This is due to the nature of interventions recorded over the 1992/1993 data period.

As mentioned in Section V and shown in Table I, the 14 Bundesbank interventions in our sample are exclusively in EMS currencies and not in the U.S. Dollar. Of those 14 interventions, nine are in support of the French Franc, four to help stabilize the Spanish Peseta, and one to promote the Danish Crown. This type of cross-currency intervention might result in follower banks selling a different currency than the leader bank, with one side selling Dollars and the other selling Marks. Therefore, the expected direction of DM/US$ quote adjustments by follower banks, x, in response to price leader, y, is ambiguous.[11] Econometrically, then, bank y meets the sufficient condition of price leadership as long as its past quote revisions, y_{t-i}, have a statistically significant impact on the contemporaneous bank series, x_t, regardless of sign.

A. *Periodicity of Quote Indications*

In this study, causality tests will be constructed for the six most active DM/US$ bank traders identified in Section III: DB, CH, SG, RB, DN, and BH. Before an empirical model can be defined, however, we need to address the issue of heterogeneous quote frequencies across banks. Tick-by-tick quote sampling is not driven by clock time, t, but rather by bank indications that are irregularly spaced in time, i.e., driven by "event time" τ. As shown in Table II, DB inputs quotes much more frequently than the other five banks in our sample. Hence, Granger-causality testing would likely skew predictive power in favor of DB.

Conventional time-series analysis requires equal periodicities across input observations. This is accomplished by standardizing all bank quote revision series by the length of the time interval between each bank's current and last

[11] As an illustration of how a negative, rather than a positive, sign might arise with regard to the leader's lagged quote changes, consider a case where the Bundesbank intervenes by buying French Francs with Marks. If bank y is the first to observe Bundesbank's order flow, it will exploit this temporary information advantage by taking a long position in the FF against the DM. To attract counterparties, bank y will therefore raise its DM/FF quote. Other things equal, this will be associated with a rise in bank y's DM/US$ quote. Now suppose that anticipation of further Franc weakening has led some other, uninformed, bank x to short the Franc against the Dollar. If this bank interprets bank y's quote adjustment as insider knowledge of Franc appreciation, it will react by covering its position through Franc purchases. This will be reflected in lower FF/US$ quotes and, other things equal, in lower DM/US$ quotes by bank x. Thus, intervention-induced information asymmetries will cause DM/US$ quote adjustments by bank x to follow bank y's DM/US$ quote adjustments. However, these quote adjustments will be negatively related due to differences in underlying cross-currency positions. Certainly, there exist cases where we would expect a positive sign on bank y's DM/US$ causality coefficient (such as banks x and y holding opposite positions in the same currency pair). Without knowing actual positions and trading volumes, however, we can only look for a nonzero coefficient, rather than any particular sign, as evidence of bank y's price leadership.

preceding quote entry. Let us define banks j = Deutsche Bank (DB), Societe Generale (SG), Chemical Bank (CH), Rabobank (RB), Den Norske Bank (DN), and Berliner Handels-und Frankfurter Bank (BH). If S^j_τ is the percentage change in bank j's midpoint DM/US$ quote between indication time τ and $\tau - 1$ (measured in seconds), then each bank's smoothed return, QM^j_τ, is defined as:

$$\mathrm{QM}^j_\tau = \frac{S^j_\tau}{[(\tau - (\tau - 1)^j)/60]}. \tag{1}$$

QM^j_τ reflects quote revisions on a per-minute basis—a standardized input measure for comparing bank series of different quoting periodicities.

B. Time-Varying Parameter Specification

The appropriate Granger-causality model for this study has to account for yet another timing feature governing bank indications. Consider the impact of varying time differences between Granger-causing bank observations, QM^k, where banks $k \neq j$, and the dependent variable bank's current observations, QM^j. We would expect "older" quote revisions by regressor banks, k, to have a smaller impact on the dependent variable bank's current quote revisions than more recent bank k quote adjustments. Accordingly, we propose the following model:

$$\mathrm{QM}^j_\tau = a + \sum_{k=1}^{5} \sum_{i=1}^{2} b^k_i \mathrm{QM}^k_{(\tau-i)^k} + \sum_{i=1}^{5} c^j_i \mathrm{QM}^j_{(\tau-i)^j} \tag{2}$$

where the regressor coefficients vary linearly such that

$$b^k_i = e^k_i + \frac{f^k_i}{[(\tau - (\tau - i)^k)/60]} \tag{3}$$

$$c^i_j = g^j_i + \frac{h^j_i}{[(\tau - (\tau - i)^j)/60]} \tag{4}$$

In equations (2) through (4), we define subscripts i as lagged quote revisions. Superscripts denote bank affiliations. QM^j_τ measures the per-minute percentage change in bank j's DM/US$ midpoint quotes between time $\tau - 1$ and τ; $\mathrm{QM}^k_{(\tau-i)^k}$ denotes the ith preceding per-minute quote revisions by banks $k \neq j$, and $\mathrm{QM}^j_{(\tau-i)^j}$ represents bank j's own lagged indications. f^k_i and h^j_i are coefficients that proxy the time lapse since the last quote revision by regressor bank k in relation to the dependent variable bank, j, at time τ.

Equation (2) serves to test the hypothesis that DB's current quote changes are not Granger-caused by lagged quote revisions of other banks, k, whereas DB's lagged adjustments Granger-cause current quote changes by banks $k \neq$ DB. As outlined in Section VI, the necessary condition for the hypothesis

of sole price leadership by DB entails $\Sigma b_i^k = 0$ for dependent variable bank DB, with $\Sigma b_i^{DB} \neq 0$ for dependent variable banks $k \neq$ DB as the sufficient condition.

The time-varying coefficient effect of regressor banks, k, on dependent variable bank j can be illustrated by assuming that bank j's current quote revision follows bank $k = 1$'s previous quote change by 10 seconds but follows bank $k = 2$'s last revision by 100 seconds. If the time-varying model captures the passage of time since the last quote revision, then the combined marginal effect of bank $k = 2$ on j, indicated by parameter $b_i^{k=2}$ (see equation (3)), ought to be smaller than the marginal effect of bank $k = 1$ on j. On the other hand, if the age of quotes is irrelevant in establishing Granger-causality, then $f_i^k = 0$ such that $b_i^k = e_i^k$. Similarly, for the own lags of the dependent variable bank j, $h_i^j = 0$ so that $c_i^j = g_i^j$.[12]

VII. Empirical Results

It is commonly known that high-frequency financial data exhibit autoregressive conditional heteroskedasticity (ARCH)-type dynamics in the residuals (see Bollerslev, Chou and Kroner (1992)). Ljung-Box diagnostics on squared residuals show that time-dependent heteroscedasticity also underlies the quote revisions in equation (2). To obtain robust standard errors, the model is estimated using a Newey–West (1987) covariance adjustment.[13] Due to the complex parameterization of equation (2), it was found that this approach outperforms standard ARCH/GARCH models in goodness-of-fit.

The appropriate choice of lag length, i, was determined through experimentation with alternative lag structures. Based on under- and overfitting the model, we found that $i = 2$ for regressor banks, $k \neq j$, and $i = 5$ for dependent variable banks' own lags provide the best econometric fit.

Qualitative results of equation (2) are summarized in Tables III and IV. Due to space constraints, parameter estimates are reported only for Deutsche Bank as the hypothesized price leader (see Appendix Table A.I) and for Societe Generale as a representative follower bank (see Appendix Table A.II).[14]

Within the −60/+60 intervention period, we define four subsample horizons: −60/−25, −25/0, 0/+25, and +25/+60. These time windows are based on structural breaks in quoting patterns, as identified in Figures 2 and 3. Furthermore, a −120/−60 minute interval is constructed to identify interbank quoting patterns in a "preinterventionary" time period. This control sample is

[12] It is possible that differential quote frequencies across banks could lead to spurious Granger causality where the more frequently quoting bank—DB in our case—would naturally emerge as the price leader. Section VII will show that the banks' coefficient patterns fluctuate over different subsamples but the relative frequency of DB quotes vis-a-vis other banks does not (see Table II). This rules out spurious causality as an explanation for our empirical findings.

[13] I thank Tim Bollerslev for suggesting the Newey–West (1987) approach to attaining robust standard errors.

[14] Complete estimation results for all banks are available either from the author upon request or can be referenced on *The Journal of Finance* World Wide Web site.

Table III

Constant Coefficient Model: Summary of Granger-Causality Tests for Deutsche Bank Price Leadership

This table summarizes interbank dependencies in quoting patterns around Bundesbank intervention reports. Results are based on Granger-causality tests with constant coefficient specifications, as detailed in Appendix Tables A.I–A.VI. Per-minute DM/US$ quote revisions by banks j = Deutsche Bank (DB), Societe Generale (SG), Chemical Bank (CH), Rabobank (RB), Den Norske Bank (DN) and BHF Bank (BH) are regressed on two lagged per-minute quote revisions by banks $k \neq j$ and five own lags. No account is taken of the age of regressor banks' prior quote revisions. The sample comprises 14 pooled Bundesbank intervention periods between Oct. 1, 1992 and Sept. 30, 1993. −120/−60, −60/−25, −25/0, 0/+25 and +25/+60 are time intervals in minutes that define subsamples around Bundesbank intervention reports. The time stamp on intervention headline entries is denoted as time 0. L1 (L2) indicates that the first (second) lag of regressor bank $k \neq j$ Granger-causes time τ quote revisions by dependent variable bank j. * denotes statistically significant own first lags. In a given time period, bank j is not Granger-caused by other banks, k, if the associated regressor bank column is blank.

	Granger-Causing Regressor Banks																											
Bank	−120/−60 Minutes						−60/−25 Minutes						−25/0 Minutes						0/+25 Minutes						+25/+60 Minutes					
j	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH
DB	*						*				L1		*	L2	L2		L1		*						*					
SG		*					L1	*					L1, L2	*	L1, L2		L1			*	L1					*				
CH			*				L1		*					L2	*		L2				*		L2				*		L2	
RB				*		L2	L2			*			L1			*			L1		L1, L	*					*		
DN	L2	L1		L2	*	L2	L1		L1		*		L2	L2	L1		*	L2			L2		*		L2			*		
BH					L1	*	L1, L					*	L1	L1, L2	L1		L1	*						*	L1					*

Table IV

Time-Varying Coefficient Model: Summary of Granger-Causality Tests for Deutsche Bank Price Leadership

This table summarizes interbank dependencies in quoting patterns around Bundesbank intervention reports. Results are based on Granger-causality tests with time-varying coefficient specifications, as detailed in Appendix Tables A.I through A.VI. Per-minute DM/US$ quote revisions by banks j = Deutsche Bank (DB), Societe Generale (SG), Chemical Bank (CH), Rabobank (RB), Den Norske Bank (DN), and BHF Bank (BH) are regressed on two lagged per-minute quote revisions by banks $k \neq j$ and five own lags. Coefficients are allowed to vary with the age of regressor banks' prior quote revisions. The sample comprises 14 pooled Bundesbank intervention periods between Oct. 1, 1992 and Sept. 30, 1993. −120/−60, −60/−25, −25/0, 0/+25, and +25/+60 are time intervals in minutes that define subsamples around Bundesbank intervention reports. The time stamp on intervention headline entries is denoted as time 0. L1 (L2) indicates that the first (second) lag of regressor bank $k \neq j$ Granger-causes time τ quote revisions by dependent variable bank j. * Denotes statistically significant own first lags. In a given time period, bank j is not Granger-caused by other banks, k, if the associated regressor bank column is blank.

	Granger-Causing Regressor Banks																											
Bank	−120/−60 Minutes						−60/−25 Minutes						−25/0 Minutes						0/+25 Minutes						+25/+60 Minutes					
j	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH	DB	SG	CH	RB	DN	BH
DB	*						*						*	L2	L2				*		L1				*					
SG		*					L1	*					L1, L2	*	L1, L2		L1			*	L1					*	L1		L2	
CH			*				L1		*				L2	L2	*		L2				*						*			
RB				*		L1, L2	L1, L2			*				L2	L1	*	L2		L1			*			L2			*		
DN	L2	L1		L2	*		L1, L2		L1		*				L1		*	L2	L1	L1	L2	L1	*		L2				*	
BH					L1	*	L2		L1	L1		*	L1	L2	L1	L1	L1	*	L1	L1	L1	L2		*	L1					*

preferred over sampling across nonintervention days since it contains no other news events of relevance that might affect quote dynamics. Note that the Appendix tables also report estimates for the *entire* −60/+60 minute sampling interval. The idea is to illustrate the potential for spurious inference when structural breaks are not accounted for.

A. Deutsche Bank as Dependent Variable

The first row of Tables III and IV summarizes the economic impact of competitor banks' quote revisions on DB. Underlying regressions are based on equation (2) with DB as the dependent variable. Detailed estimation results are presented in Appendix Table A.I, where adjusted R^2 statistics identify the time-varying model as the econometrically superior specification.

In the preinterventionary time period between −120 and −60, none of the competitor banks' quote revisions Granger-cause DB. Only DB's own first lag enters statistically significantly. Negative AR(1) processes are well-documented in high-frequency foreign exchange data and can be observed across all dependent variable banks and across all time periods considered in this study. Explanations for such systematic own quote reversals include order imbalances (see Bollerslev and Domowitz (1993)) and data noise (see Zhou (1996)).

Inferences over the −60 and −25 minute period are similar to the initial period. In the time-varying coefficient model (see Table IV), DB quote revisions remain empirically unexplained by competitors' quote adjustments. Only in the constant coefficient case (see Table III) do we find Den Norske's last lag as entering significantly.

Results for the period between −25 and the time of the announcement reflect a distinct structural break in DB quoting patterns. Over this time interval, DB quote revisions are Granger-caused by past returns of other banks, specifically by SG's and CH's two period lags. The fact that statistical significance occurs at the second, as opposed to the first, lag is of little economic relevance here. The explanation lies in the rapid frequency of quote entries: During turbulent market periods, such as during intervention, DB may not have observed the most recent indications by SG and CH as it updates its quotes at time τ.

Once Reuters announces a BUBA intervention at time 0, lagged quote revisions by SG and CH become statistically insignificant. Only in the time-varying model does the first lag of CH retain some predictive power. DB sensitivity to competitor quote revisions disappears altogether in the +25/+60 period. This result is identical to DB quoting behavior observed over the preinterventionary period.

Appendix Table A.I also presents results for the intervention period as a whole (−60/+60). These results would suggest that competitor banks are Granger-causing DB throughout. However, our *within-period* results contradict this finding, which reinforces the argument that high-frequency sampling should be used when analyzing interventionary dynamics.

B. Other Banks as Dependent Variables

The lack of Granger causality on DB prior to $t = -25$ is a necessary condition to establish DB as a price leader. It remains to show that other banks' quote adjustments are Granger-caused by DB to make the empirical case for price leadership.

Qualitative results for SG, CH, RB, DN, and BH are displayed in the lower rows of Tables III and IV. Based on regression diagnostics for the individual banks, the time-varying specification again proves to be statistically superior. For details on one bank's (SG) estimation results, refer to Appendix Table A.II.

In the preinterventionary period, $-120/-60$, previous competitor actions are insignificant in predicting dependent variable banks' quote patterns. The only exception is DN. These findings are consistent with the hypothesis of equalized information dissemination in the foreign exchange market. In a trading environment undisturbed by major news, there are no profit opportunities from tracking competitor moves.

Bank interactions change over the $-60/-25$ subsample, where DB is shown to Granger-cause quote revisions by SG, CH, RB, DN, and BH. Since no other bank Granger-causes DB over this time period (see first row of Table IV), DB meets the necessary and sufficient conditions to be considered a price leader from -60 to -25 minutes prior to a Reuters report.

Between -25 and the time of the news release, SG, CH, and BH continue to be affected by DB's past indications; but now a multitude of banks besides DB Granger-causes competitor banks' quote adjustments. Note that $-25/0$ is the same time period over which DB is Granger-caused by SG and CH (see first row of Table IV). Such "two-way" Granger-causality is consistent with the relative convergence of quote patterns seen in Figures 2 and 3.

Within 25 minutes after the intervention reports, bank traders resume quote patterns similar to those exhibited between -120 and -60 minutes. The speed of reversal appears most pronounced for CH (see Table IV). Implications for these distinct interbank behavioral shifts at -60, -25, and time 0 will be discussed next.

VIII. Implications of Empirical Results

Intervention is believed to move exchange rates, either by changing relative money supplies, as in the case of unsterilized intervention, or through signalling policy changes, as in the case of sterilized intervention. Note that this study considers a sample of Bundesbank interventions aimed at defending EMS cross-currencies. In the basic target zone literature, discussed by Svensson (1992), interventions are assumed to be unsterilized since target zone authorities use changes in fundamentals to keep exchange rates within bands.

In the case where a central bank prefers to keep fundamentals unchanged, "signaling" operates as the primary driver behind intervention-related foreign exchange dynamics. Further discussion of this issue is provided by Obstfeld (1990), Goodhart and Hesse (1993), and Dominguez and Frankel (1993). Under

the signaling hypothesis, central banks intervene in order to communicate future policy information to the market.

This study does not seek to explain the channeling device by which intervention activity moves exchange rates. Rather, this study is concerned with the information asymmetries created through interventionary activity. To explore this issue, we require knowledge of the microstructure relations between the central bank and foreign exchange traders.

The empirical results of this article suggest that certain commercial bank dealers have privileged information regarding central bank activities. In the case of the Bundesbank, intervention orders might be funneled largely through DB's trading desk. From BUBA's perspective, such selective dealing appears rational: DB's strong market presence and liquidity provide the central bank with more efficient transactions turnover than independent brokers (see discussion in Section IV). Based on the shift in regression results, initial BUBA order placements with DB occur up to 60 minutes prior to public knowledge of the intervention—a longer lag than suggested by Goodhart and Hesse (1993).

Over the next 35 minutes, DB's efforts to profit from interventionary order flows provide a signal to uninformed traders that the central bank has entered the market. Thus, competitor bank dealers follow DB's superior information lead in quote adjustments, as indicated by the results for the $-60/-25$ time period. This pattern precisely confirms Goodhart's (1988) claim that there can be temporary price leadership in the foreign exchange market.

As we get closer to the public announcement, however, quoting behavior evolves away from price leadership. There are two explanations for the two-way Granger-causalities observed between -25 and time 0: Under the first scenario, traders might be jockeying for strategic positions. Since DB knows that its insider status is transitory, its trading desk begins to track competitors closely in order to position itself optimally for profit-taking. Note especially DB's relationship to the larger banks, SG and CH, as shown in the first row of Tables III and IV. As time passes, the probability of information leakages increases. Market participation, proxied by quoting frequency, declines as competitor banks carefully position themselves to discern the future direction of the market (see Table II). Once the extent of interventionary activities is leaked sufficiently, small and large traders will enter the race for any remaining profits. Hence, the two-way causalities in quote revisions observed between -25 to 0.

An alternative explanation for the estimated two-way Granger causalities draws from Montgomery and Popper (1995). Their model shows that *sharing* of intervention information can increase the welfare of all traders, informed and uninformed alike. Accordingly, DB would have an incentive to actively promote its insider information with others: DB's expected payoff would be higher than under a strategy of information concealment. Empirically, sharing of information is difficult to distinguish from information leakage. Both would be consistent with the observed alignment of quote revisions. However, when news is shared openly, we would expect subsequent profit-reaping activities to die out faster.

Table A.I

Deutsche Bank: Time-Varying Effect of Competitor Banks' Quote Revisions

This table estimates DM/US$ quote revisions by Deutsche Bank (DB) as a function of two lagged quote revisions by competitor banks and five own lags:

$$\mathrm{QM}_{\tau}^{\mathrm{DB}} = a + \sum_{k=1}^{5}\sum_{i=1}^{2} b_i^k \mathrm{QM}_{(\tau-i)^k}^{k} + \sum_{\iota=1}^{5} c_{\iota}^{\mathrm{DB}} \mathrm{QM}_{(\tau-\iota)^{\mathrm{DB}}}^{\mathrm{DB}}$$

$$\text{where} \quad b_i^k = e_i^k + \frac{f_i^k}{(\tau-(\tau-i)^k)/60}; \qquad c_{\iota}^{\mathrm{DB}} = g_i^{\mathrm{DB}} + \frac{h_i^{\mathrm{DB}}}{(\tau-(\tau-i)^{\mathrm{DB}})/60}.$$

$\mathrm{QM}_{\tau}^{\mathrm{DB}}$ is measured as the per-minute percentage change in DB's midpoint quotes between time $\tau-1$ and τ; $\mathrm{QM}_{(\tau-i)^k}^{k}$ denotes the ith preceding per-minute quote change by competitor banks k = Societe Generale (SG), Chemical Bank (CH), Rabobank (RB), Den Norske Bank (DN), and BHF Bank (BH). $\mathrm{QM}_{(\tau-i)^{\mathrm{DB}}}^{\mathrm{DB}}$ represents DB's own lagged indications. f_i^k and h_i^{DB} are coefficients that capture the time lapse between regressor banks' lagged quote revisions and DB's adjustment at time τ. The sample comprises 14 pooled Bundesbank intervention periods between Oct. 1, 1992 and Sept. 30, 1993. $-120/-60$, $-60/-25$, $-25/0$, $0/+25$, $+25/+60$ and $-60/+60$ are time intervals in minutes that define subsamples around Bundesbank intervention reports. The time stamp on intervention headline entries is denoted as time 0. Due to the time-varying nature of the model, marginal effects are reported in lieu of individual coefficient estimates. For instance, $\delta\mathrm{QM}^{\mathrm{DB}}/\delta\mathrm{QM}_{(\tau-1)^{\mathrm{SG}}}^{\mathrm{SG}}$ measures the incremental impact of SG's time $\tau-1$ quote changes on DB's time τ quote revisions. DW is the Durbin–Watson measure. t-statistics are in parentheses. Statistical significance is denoted by * (**) at the 5 percent (1 percent) level using robust standard errors with Newey–West (1987) serial-correlation and heteroscedasticity correction.

Marginal Effects	−120/−60 Minutes		−60/−25 Minutes		−25/0 Minutes		0/+25 Minutes		+25/+60 Minutes		−60/+60 Minutes	
	$f_t^k = h_t^{DB} = 0$	$f_t^k \neq h_t^{DB} \neq 0$	$f_t^k = h_t^{DB} = 0$	$f_t^k \neq h_t^{DB} \neq 0$	$f_t^k = h_t^{DB} = 0$	$f_t^k \neq h_t^{DB} \neq 0$	$f_t^k = h_t^{DB} = 0$	$f_t^k \neq h_t^{DB} \neq 0$	$f_t^k = h_t^{DB} = 0$	$f_t^k \neq h_t^{DB} \neq 0$	$f_t^k = h_t^{DB} = 0$	$f_t^k \neq h_t^{DB} \neq 0$
a	0.05	0.06	−0.70	−0.66	−0.65	−0.65	0.39	0.41	0.27	0.51	−0.23	−0.15
	(0.12)	(0.26)	(−1.29)	(−1.37)	(−1.46)	(−1.53)	(0.84)	(0.95)	(0.54)	(1.01)	(−0.95)	(−0.64)
$\delta QM^{DB}/\delta QM^{SG}_{(\tau-1)}$ SG	0.04	0.03	0.07	0.10	0.004	0.04	−0.008	0.0005	0.05	−0.03	−0.02	−0.02
	(0.80)	(0.61)	(1.09)	(1.20)	(0.05)	(0.48)	(−0.10)	(0.006)	(−1.06)	(−0.68)	(−0.49)	(−0.76)
$\delta QM^{DB}/\delta QM^{SG}_{(\tau-2)}$ SG	0.07	0.06	0.08	0.06	0.16*	0.05*	−0.02	0.02	−0.03	−0.11	0.04	0.02
	(1.69)	(1.29)	(1.36)	0.71)	(1.97)	(1.99)	(−0.42)	(0.35)	(−0.23)	(−1.25)	(0.93)	(0.58)
$\delta QM^{DB}/\delta QM^{CH}_{(\tau-1)}$ CH	0.10	0.03	0.09	0.23	−0.05	−0.03	0.16	0.27*	0.14	0.16	0.08	0.08
	(1.57)	(0.53)	(0.74)	(1.69)	(−0.40)	(−0.22)	(1.32)	(2.16)	(0.73)	(0.82)	(1.29)	(1.31)
$\delta QM^{DB}/\delta QM^{CH}_{(\tau-2)}$ CH	0.08	0.02	−0.19	−0.08	0.18*	0.20**	0.01	0.08	0.02	0.03	−0.003	0.03
	(1.43)	(0.26)	(−1.70)	(−0.57)	(2.48)	(3.04)	(0.20)	(0.92)	(0.18)	(0.30)	(−0.07)	(0.54)
$\delta QM^{DB}/\delta QM^{RB}_{(\tau-1)}$ RB	0.02	−0.003	0.10	0.11	0.02	0.005	−0.19	−0.02	0.06	−0.02	0.06*	0.06*
	(0.20)	(−0.04)	(1.53)	(1.68)	(0.33)	(0.07)	(−0.23)	(−0.17)	(1.40)	(−0.31)	(2.03)	(2.32)
$\delta QM^{DB}/\delta QM^{RB}_{(\tau-2)}$ RB	0.008	−0.007	−0.03	−0.05	0.03	0.006	0.03	0.05	0.05	0.03	−0.004	−0.18
	(0.26)	(−0.20)	(−0.49)	(−0.78)	(0.98)	(0.11)	(0.56)	(0.46)	(1.48)	(0.86)	(−0.13)	(−0.50)
$\delta QM^{DB}/\delta QM^{DN}_{(\tau-1)}$ DN	0.22	0.13	0.30**	0.16	0.23*	0.27	0.22	0.22	0.005	−0.04	0.17**	0.12*
	(1.85)	(1.71)	(2.64)	(1.39)	(2.12)	(1.03)	(1.39)	(1.41)	(0.06)	(−0.58)	(3.13)	(2.26)
$\delta QM^{DB}/\delta QM^{DN}_{(\tau-2)}$ DN	0.14	0.05	−0.002	−0.11	0.07	0.21	0.0001	0.0004	−0.11	−0.17	0.01	−0.003
	(1.83)	(0.57)	(−0.02)	(−0.95)	(0.69)	(1.28)	(0.001)	(0.002)	(−0.87)	(−1.44)	(0.26)	(−0.05)
$\delta QM^{DB}/\delta QM^{BH}_{(\tau-1)}$ BH	0.03	0.17	0.37	0.54	0.29	0.25	0.09	0.04	−0.03	0.09	0.16	0.20
	(1.59)	(1.75)	(1.10)	(1.48)	(1.13)	(0.99)	(0.20)	(0.09)	(−0.13)	(0.34)	(1.16)	(1.45)
$\delta QM^{DB}/\delta QM^{BH}_{(\tau-2)}$ BH	0.03	−0.04	0.45	0.40	0.20	0.18	0.34	0.27	0.14	0.06	0.28*	0.23
	(0.43)	(−0.53)	(1.44)	(1.30)	(1.13)	(1.20)	(0.85)	(0.83)	(0.80)	(0.33)	(2.05)	(1.71)
$\delta QM^{DB}/\delta QM^{DB}_{(\tau-1)}$ DB	−0.07*	−0.09*	−0.22**	−0.29**	−0.21**	−0.30**	−0.34*	−0.30*	−0.12**	−0.18**	−0.20**	−0.23**
	(−1.98)	(−2.47)	(−3.72)	(−4.74)	(−3.27)	(−3.12)	(−2.40)	(−2.11)	(−2.71)	(−3.30)	(−5.06)	(−5.82)
$\delta QM^{DB}/\delta QM^{DB}_{(\tau-2)}$ DB	0.005	−0.02	0.006	−0.05	−0.22	0.10	−0.19	−0.15	−0.003	0.005	−0.02	−0.03
	(0.13)	(−0.51)	(0.15)	(−0.94)	(−0.26)	(−1.07)	(−1.28)	(−0.13)	(−0.08)	(0.12)	(−0.41)	(−0.63)
$\delta QM^{DB}/\delta QM^{DB}_{(\tau-3)}$ DB	0.03	0.01	0.08	0.10	−0.10	−0.08	−0.09	−0.16	−0.13	−0.11*	−0.004	0.007
	(0.60)	(0.27)	(0.89)	(1.08)	(−0.97)	(−0.89)	(−1.28)	(−1.53)	(−1.86)	(−2.25)	(0.08)	(1.13)
$\delta QM^{DB}/\delta QM^{DB}_{(\tau-4)}$ DB	0.04	0.004	0.03	0.05	0.06	0.06	−0.19	−0.33	0.09*	0.06	0.03	0.03
	(0.87)	(0.10)	(0.76)	(1.27)	(1.10)	(1.25)	(−1.50)	(−1.66)	(2.08)	(1.31)	(0.87)	(0.91)
$\delta QM^{DB}/\delta QM^{DB}_{(\tau-5)}$ DB	0.11	0.06	−0.03	−0.006	0.05	0.05	0.007	−0.05	−0.03	0.004	0.004	0.004
	(1.82)	(0.91)	(−1.08)	(−0.17)	(1.10)	(0.68)	(0.11)	(−0.42)	(−1.02)	(0.13)	(0.23)	(0.26)
N	437		303		238		210		253		1004	
$\bar{R}^2$	0.02	0.07	0.03	0.15	0.05	0.12	0.07	0.05	0.03	0.04	0.03	0.07
DW	2.04	2.02	2.04	2.09	2.00	2.06	2.01	2.06	2.00	2.03	2.00	2.01

Table A.II

Societe Generale: Time-Varying Effect of Competitor Banks' Quote Revisions

This table estimates DM/US$ quote revisions by Societe Generale (SG) as a function of two lagged quote revisions by competitor banks and five own lags:

$$QM_{\tau}^{SG} = a + \sum_{k=1}^{5}\sum_{i=1}^{2} b_i^k QM_{(\tau-i)^k}^k + \sum_{i=1}^{5} c_i^{SG} QM_{(\tau-i)^{SG}}^{SG}$$

$$\text{where} \quad b_i^k = e_i^k + \frac{f_i^k}{(\tau-(\tau-1)^k)/60}; \qquad c_i^{SG} = g_i^{SG} + \frac{h_i^{SG}}{(\tau-(\tau-i)^{SG})/60}.$$

QM_{τ}^{SG} is measured as the per-minute percentage change in SG's midpoint quotes between time $\tau - 1$ and τ; $QM_{(\tau-i)^k}^k$ denotes the ith preceding per-minute quote change by competitor banks k = Deutsche Bank (DB), Chemical Bank (CH), Rabobank (RB), Den Norske Bank (DN), and BHF Bank (BH). $QM_{(\tau-i)^{SG}}^{SG}$ represents SG's own lagged indications. f_i^k and h_i^{SG} are coefficients that capture the time lapse between regressor banks' lagged quote revisions and SG's adjustment at time τ. The sample comprises 14 pooled Bundesbank intervention periods between Oct. 1, 1992 and Sept. 30, 1993. $-120/-60$, $-60/-25$, $-25/0$, $0/+25$, $+25/+60$, and $-60/+60$ are time intervals in minutes that define subsamples around Bundesbank intervention reports. The time stamp on intervention headline entries is denoted as time 0. Due to the time-varying nature of the model, marginal effects are reported in lieu of individual coefficient estimates. For instance, $\delta QM^{SG}/\delta QM_{(\tau-1)^{DB}}^{DB}$ measures the incremental impact of DB's time $\tau - 1$ quote changes on SG's time τ quote revisions. DW is the Durbin–Watson measure. t-statistics are in parentheses. Statistical significance is denoted by * (**) at the 5 percent (1 percent) level using robust standard errors with Newey–West (1987) serial-correlation and heteroscedasticity correction.

Marginal Effects	−120/−60 Minutes		−60/−25 Minutes		−25/0 Minutes		0/+25 Minutes		+25/+60 Minutes		−60/+60 Minutes	
	$f_t^k = h_t^{SG} = 0$	$f_t^k \neq h_t^{SG} \neq 0$	$f_t^k = h_t^{SG} = 0$	$f_t^k \neq h_t^{SG} \neq 0$	$f_t^k = h_t^{SG} = 0$	$f_t^k \neq h_t^{SG} \neq 0$	$f_t^k = h_t^{SG} = 0$	$f_t^k \neq h_t^{SG} \neq 0$	$f_t^k = h_t^{SG} = 0$	$f_t^k \neq h_t^{SG} \neq 0$	$f_t^k = h_t^{SG} = 0$	$f_t^k \neq h_t^{SG} \neq 0$
a	0.27	0.21	0.39	0.86	0.55	0.40	0.30	0.92	−0.60	−0.66	0.15	0.38
	(0.85)	(0.57)	(0.50)	(1.26)	(1.28)	(0.85)	(0.55)	(1.40)	(−1.04)	(−1.15)	(0.50)	(1.06)
$\delta QM^{SG}/\delta QM^{DB}_{(\tau-1)}$ DB	0.03	0.03	0.05**	0.01*	−0.02*	0.004*	−0.02	0.009	−0.10	−0.15	0.002	0.01
	(0.50)	(0.55)	(2.58)	(2.18)	(−2.34)	(2.08)	(−0.21)	(0.08)	(−1.54)	(−1.81)	(0.04)	(0.02)
$\delta QM^{SG}/\delta QM^{DB}_{(\tau-2)}$ DB	0.03	0.10	0.02	0.03	0.12*	0.08*	0.07	0.12	0.06	−0.04	0.07*	0.06*
	(0.50)	(1.32)	0.67)	(0.74)	(2.06)	(2.45)	(0.85)	(1.23)	(0.91)	(−0.44)	(2.40)	(2.11)
$\delta QM^{SG}/\delta QM^{CH}_{(\tau-1)}$ CH	0.11	0.07	0.20	0.21	−0.02*	0.01*	0.25**	0.31**	0.25	0.36*	0.14**	0.14**
	(1.35)	(0.83)	(1.79)	(1.32)	(−2.30)	(2.16)	(3.35)	(2.94)	(1.10)	(2.00)	(3.27)	(3.36)
$\delta QM^{SG}/\delta QM^{CH}_{(\tau-2)}$ CH	−0.04	−0.12	0.17	0.40	0.08*	−0.09*	0.04	0.18	−0.22	−0.16	−0.001	0.02
	(−0.80)	(−1.29)	(1.39)	(1.16)	(2.23)	(−2.28)	(0.67)	(1.65)	(−1.48)	(−0.92)	(−0.04)	(0.43)
$\delta QM^{SG}/\delta QM^{RB}_{(\tau-1)}$ RB	0.14	0.12	−0.14	−0.06	0.14	0.13	−0.07	0.01	0.08	−0.05	0.0001	0.008
	(1.38)	(1.13)	(−0.81)	(−0.48)	(0.82)	(1.23)	(−1.26)	(0.19)	(0.66)	(−0.37)	(0.01)	(0.12)
$\delta QM^{SG}/\delta QM^{RB}_{(\tau-2)}$ RB	−0.04	−0.057	0.03	0.09	0.07	0.12	−0.03	0.003	0.02	−0.007	0.03	0.04
	(−0.62)	(−0.59)	(0.58)	(0.72)	(1.02)	(1.07)	(−0.68)	(0.06)	(0.38)	(−0.14)	(1.10)	(0.87)
$\delta QM^{SG}/\delta QM^{DN}_{(\tau-1)}$ DN	0.25	0.18	−0.05	0.01	0.16*	−0.14*	−0.17	−0.20	−0.01	−0.05	−0.02	−0.04
	(1.12)	(1.00)	(−0.41)	(0.11)	(2.17)	(−2.04)	(−1.68)	(−1.86)	(−0.14)	(−0.55)	(−0.38)	(−0.77)
$\delta QM^{SG}/\delta QM^{DN}_{(\tau-2)}$ DN	0.19	0.21	0.04	−0.14	0.02	0.13	0.17	0.24	0.09	0.25*	0.03	0.002
	(1.79)	(1.52)	(0.35)	(−0.77)	(0.09)	(0.42)	(1.36)	(1.59)	(0.69)	(2.16)	(0.40)	(0.03)
$\delta QM^{SG}/\delta QM^{BH}_{(\tau-1)}$ BH	−0.13	0.03	−0.83	−0.51	0.13	0.14	−0.21	−0.17	−0.13	0.05	−0.28	−0.23
	(−0.56)	(0.12)	(−1.93)	(−1.04)	(0.37)	(0.48)	(−0.71)	(−0.59)	(−0.69)	(0.28)	(−1.80)	(−1.57)
$\delta QM^{SG}/\delta QM^{BH}_{(\tau-2)}$ BH	0.50	0.10	−1.09	−1.06	0.03	0.13	−0.30	−0.50	0.18	0.64	−0.32	−0.33
	(1.34)	(0.33)	(−0.84)	(−0.69)	(0.06)	(0.23)	(−0.61)	(−1.02)	(0.24)	(1.12)	(−0.77)	(−0.75)
$\delta QM^{SG}/\delta QM^{SG}_{(\tau-1)}$ SG	−0.18	−0.09*	−0.16**	−0.21*	−0.05	−0.39**	−0.21**	−0.18*	−0.19	−0.26**	−0.14**	−0.09**
	(−1.78)	(−1.96)	(−3.35)	(−2.24)	(−0.46)	(−2.94)	(−2.72)	(−2.70)	(−1.67)	(−2.60)	(−3.32)	(−2.61)
$\delta QM^{SG}/\delta QM^{SG}_{(\tau-2)}$ SG	−0.09	−0.20*	−0.06	−0.02	0.0003	−0.10	−0.05	−0.06	−0.06	−0.08	−0.03	−0.03
	(−0.77)	(−2.27)	(−1.10)	(−0.22)	(0.002)	(−0.70)	(−0.97)	(−1.29)	(−1.00)	(−0.76)	(−1.29)	(−1.01)
$\delta QM^{SG}/\delta QM^{SG}_{(\tau-3)}$ SG	0.04	0.08	−0.04	−0.04	0.03	−0.06	−0.20**	−0.18*	−0.09	−0.05	−0.07	−0.05
	(0.61)	(1.38)	(−0.61)	(−0.65)	(0.23)	(−0.54)	(−2.63)	(−2.44)	(−1.63)	(−0.85)	(−1.66)	(−1.48)
$\delta QM^{SG}/\delta QM^{SG}_{(\tau-4)}$ SG	−0.02	0.01	0.20*	0.09*	−0.09	−0.24**	0.10	0.12	0.03	−0.04	−0.08	−0.06
	(−0.51)	(0.27)	(−2.52)	(−2.48)	(−1.15)	(−2.66)	(1.26)	(1.68)	(−0.34)	(−0.72)	(−1.50)	(−1.42)
$\delta QM^{SG}/\delta QM^{SG}_{(\tau-5)}$ SG	0.008	0.04	−0.10	−0.06	0.01	−0.20*	0.20*	0.18	0.0007	0.03	−0.01	0.002
	(0.18)	(0.77)	(−1.40)	(−0.55)	(0.18)	(−1.96)	(2.16)	(1.87)	(0.01)	(0.42)	(−0.27)	(0.05)
N	230		192		127		131		167		617	
$\bar{R}^2$	0.08	0.11	0.02	0.10	0.02	0.22	0.07	0.15	0.03	0.14	0.02	0.07
DW	2.05	2.12	2.08	2.11	2.06	2.12	2.12	2.11	2.01	2.02	2.01	2.00

Beyond the specific bank interrelations, our results establish quite powerfully that the trader community learns about interventionary activity *before* the public is informed. Foreign exchange volatility increases until information is fully shared among traders, which occurs around 5 minutes *prior to* Reuters reports (see Fig. 1). Thereafter, volatility tapers off. This finding suggests that Reuters intervention reports are not actual "news" to market participants but constitute redundant information that has already been discounted through trading activity.

IX. Conclusion

This article investigates Goodhart's (1988) hypothesis that short-run information asymmetries establish certain bank traders as price leaders in the foreign exchange market. The focal news events here are Bundesbank intervention reports as recorded on the Reuters headline screen between 10/1/1992 and 9/30/1993. We create within-the-hour subsamples around these reports to examine tick-by-tick quote revisions for the six banks that input the most DM/US$ quotes on the Reuters screen.

The empirical methodology involves Granger-causality tests that are conducted in a time-varying framework to account for the age of past quote entries. It is shown that competitive traders treat Deutsche Bank as a price leader up to 60 minutes prior to intervention reports. As the market moves closer to the public announcement, strategic positioning becomes the prevalent driver of quote adjustment patterns. By the time of the Reuters announcement, attention to competitors' quote adjustments tapers off, and traders resume their preinterventionary trading interactions.

Our findings confirm the hypothesis that official Bundesbank intervention is associated with asymmetric information flows and transitory price leadership by Deutsche Bank. More broadly, the results support microstructure theories emphasizing news being disseminated through trading among heterogeneously informed agents. Furthermore, this article shows a distinct lead of actual trader reactions to interventions relative to their public announcement. The existence and duration of such informational leads should be an important empirical concern for studying other classes of news effects besides intervention in the foreign exchange market.

Appendix

Appendix Tables A.I and A.II present estimation results for a subset of banks based on the Granger causality model specified in equation (2) of the text. Specifically, results are reported for bank j = DB as the hypothesized price leader and for bank j = SG as a representative price follower. Six subsamples are defined around Bundesbank intervention reports: $-120/-60$ (preintervention period), $-60/-25$, $-25/0$, $0/+25$, $+25/+60$, and $-60/+60$ (aggregate intervention period). For each sample period, the marginal effects for both a constant coefficient model and one considering the age of regressor bank

quotes are reported. Estimates are based on robust standard errors with Newey-West (1987) serial correlation and heteroscedasticity correction.

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