

***Public Information Arrival, Exchange Rate Volatility,
and Quote Frequency***

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Abstract: The mixture of distributions model motivates the role of public information arrival in foreign exchange market dynamics. Public information arrival is measured using Reuters Money-Market Headline News. The exchange rates are high-frequency mark/dollar and yen/dollar quotes. Estimation results suggest that higher than normal public information brings more than the normal quoting activity and volatility. The results have implications for the debate over regulation of the foreign exchange market. Foreign exchange activity is not largely self-generating. Trading is likely providing the function it is meant to provide--adjusting prices and quantities to achieve an efficient allocation of resources.

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1. Introduction

Information as a determinant of asset prices plays a central role in many theoretical models. The recent literature on the microstructure of financial markets has produced models that treat the arrival of public information or “news” as an important factor with models differing in institutional characteristics such as the presence of informed and uninformed traders.¹ The empirical literature on the effect of public information arrival on exchange rates has generally focused on the effects of a limited number of announcements of key macroeconomic variables like money supply or trade balances.² Such studies focus on exchange rate changes or volatility around the time of announcements and so produce “snapshots” of the market over brief intervals every month (for most announcements) or week (for money supply announcements). Recently, papers have appeared that relate information arrival to stock market returns and activity in a spirit similar to ours but using different models and focusing on the U.S. stock market.³ We propose to examine the role of public information arrival as a determinant of exchange rate volatility and quote frequency in a continuous, high-frequency setting capturing the 24-hour nature of the market.

We start by describing the data available for measuring the rate of public information arrival to the market along with a discussion of the exchange rate data used for our empirical analysis. Next we provide a sketch of a mixture of distributions model for the foreign exchange market that links public information arrival with quote frequency and exchange rate volatility. Estimates of the effects of public information arrival on foreign exchange market volatility and quote frequency are provided in the following section. The last section offers a discussion of policy implications of our findings and a conclusion.

¹ See for example Admati and Pfleiderer (1989) or Glosten and Milgrom (1985) for stock market models. Bollerslev and Melvin (1994) provide an example for the foreign exchange market.

² Samples of this literature can be seen in Ederington and Lee (1993), Goodhart, Hall, Henry, and Pesaran (1993), Hakkio and Pearce (1985), Hogan and Melvin (1994), and Ito and Roley (1987). Studies closest in approach to ours but focusing on the impact of specific types of news are Andersen and Bollerslev (1998), DeGennaro and Shrieves (1997), and Payne (1996). Recently, we have received a paper by Eddelbüttel and McCurdy (1997) that uses a similar data set over a different time period and uses a different methodology to analyze the impact of news flow on exchange rate volatility.

³ Mitchell and Mulherin (1994) examine the link between Dow Jones news announcements and aggregate stock market returns. Berry and Howe (1994) relate the flow of news stories over Reuters’ North American Securities News wire to New York Stock Exchange volume and volatility.

The issue of the source of volatility in the foreign exchange market is not without controversy. Potential regulatory action to impose transaction taxes or other impediments to trade have been prefaced on a belief that the market is subject to periods of “excess volatility”, where market activity is unrelated to information regarding fundamentals and is being “self-generated” by noise traders. The last section of the paper draws the implications of our findings for this debate. We examine the evidence regarding the effect of news arrival on volatility and quote frequency. If volatility and the pace of activity in the market were independent of the flow of news, then this might provide support for regulatory action aimed at reducing trading volume and volatility. However, our evidence indicates that there is a systematic link between public information arrival, quotes, and volatility. Proponents of foreign exchange market regulation will find no support in our findings.

2. The Data and Seasonality

The exchange rate data are tick-by-tick observations on the Japanese yen and German mark price of the U.S. dollar as displayed on the Reuters FFX screen from December 1, 1993 to April 26, 1995.⁴ The arrival of public information is measured by the number of news headlines related to the United States, Germany, or Japan reported on the Reuters Money Market Headline News screen for the same period.⁵ The greater the number of news announcements, the more information received by participants. By using the flow of news in total rather than selecting only certain types of news (like money or employment announcements), we examine a more general concept of information flow than possible by only looking at shocks emanating from specific types of news. As Mitchell and Mulherin argue, “we avoid making arbitrary ex ante classifications of the type of news that moves markets and also avoid a bias toward emphasizing announcements that turn out, ex post, to influence the market in our sample (p. 925). There are 1,730,341 observations for the mark, 654,340 observations for the yen, and 60,693 observations on

⁴ The data were provided by Olsen and Associates, Research Institute for Applied Economics in Zurich.

⁵ While our original study encompassed all news reports, one referee correctly pointed out that news regarding the producer price index in Australia should not be as relevant for the mark/dollar and yen/dollar as news of direct relevance to the United States, Germany, and Japan. As a result, we removed all news not directly related to these 3 countries. We agree with the referee who stated that “far from being a data mining procedure, this is a necessary filtration of a very noisy series.”

the news. The basic unit of time we utilize in our analysis is hourly data (for instance, the number of quotes on the mark each hour). There are 8,784 business week hours in our sample period.⁶

It is now well known that the intradaily data contain strong seasonal patterns that must be addressed before attempting to make any statistical inference (see Andersen and Bollerslev (1994) and Dacorogna, et.al (1993)). Figs. 1 and 2 display the average hourly number of quotes entered on the Reuters screen for the mark and yen over the five-day business week measured in Greenwich Mean Time (GMT).⁷ The patterns are quite similar across all days of the week with discrete changes in quote activity marking the opening and closing of business hours in the different centers of foreign exchange trading in Asia, Europe, and America. For purposes of identifying the regional business hours in terms of (standard) GMT, the following hours may be used as indicative of 8am to 4pm: Tokyo, 2300-0700; London, 0800-1600; and New York, 1300-2100. Fig. 3 displays the average hourly number of reported news events on the Reuters screen for the business week. Here, also, we see a distinct intra-daily seasonality where news events climb to a daily peak in the European morning and when the European and North American markets overlap. Clearly, public information largely arrives during business hours in each region.

The need for seasonal adjustment is seen by the autocorrelation pattern for each series. Figs. 4 and 5 display the autocorrelations of the number of quotes on the mark and yen and Fig. 6 displays autocorrelations for the number of news reports. The autocorrelations are estimated out to 120 hours to show the strong pattern of peaks at 24, 48, 72, 96, and 120 hour lags. The figures illustrate the autocorrelations of the unadjusted data along with autocorrelations for a seasonally-adjusted (SA) series. The seasonal adjustment was done by dividing the data into subsamples representing standard time, daylight saving time (DST) in Europe only, DST in Europe and America, and DST in America only. Then each observation is divided by the mean number of quotes for each hour of the business week during that subsample. That is, we take the raw data for each subsample and construct a mean for each day and hour like Monday, 0-1; then Monday, 1-2; and so on through the 120 hours of the business week. We then use

⁶ In nine of these hours, the Reuters system was down. For these nine hours we replace the missing observations with the sample mean for each hour on each particular day. For instance, the observation for the number of quotes on the mark occurring on April 20, 1994 (a Wednesday) at 01:00 GMT is set equal to the sample mean for Wednesdays at 01:00.

these 120 averages over the business week to deflate the original hourly data.⁸ As seen in Figs. 4, 5 and 6, the autocorrelations of the seasonally-adjusted data indicate that the pronounced patterns over the business week are largely removed.

In addition, we also use the hourly returns for each currency, measured by the change in the log of the mid-price; and the associated volatility, measured as the absolute value of the hourly returns.⁹ Figs. 7 and 8 display the correlograms for the hourly returns. There is no apparent seasonality in these two series. Figs. 9 and 10 display the correlograms for the absolute hourly returns along with correlograms for the seasonally adjusted series for each. Clearly, the absolute returns display a seasonality calling for a seasonal adjustment in any model of return volatility. Using the seasonally-adjusted data allows us to examine how public information arrival that differs from the normal intradaily patterns affects the manner in which exchange rates differ from their normal intradaily patterns. The use of raw data would largely just demonstrate the fact that business hours open and close and public information and exchange rate dynamics differ between business hours and the rest of the day.

Table 1 displays summary statistics of the data. The means for the seasonally-adjusted and unadjusted data are the same since we used a mean-preserving adjustment factor. In each case, the seasonal adjustment reduces the volatility of the data. While the autocorrelations appear in the figures mentioned above, the Box-Ljung statistics in Table 1 indicate significant serial correlation in all data. The serial correlation is severe in the quotes and news, and is even significant for the returns, which exhibit no seasonality. Of course, with over 8,000 observations, the estimated autocorrelations would have to be very close to zero for the Box-Ljung statistic to not register a significant value of chi-square.

3. Public Information Arrival and Exchange Rate Changes

⁷ Weekends are omitted from the sample due to the relative inactivity. The average number of quotes on the mark over the days of the week is: Monday, 4,502; Tuesday, 4,984; Wednesday, 4,941; Thursday, 4,778; Friday, 4,125; Saturday, 10; Sunday, 181. A similar pattern exists for the yen.

⁸ There are alternative seasonal adjustment techniques that could be employed here. Dacorogna, et. al (1993) and Andersen and Bollerslev (1994) provide good examples of different methods. We originally estimated a Fourier function as recommended by Andersen and Bollerslev to fit a nonlinear curve to represent the intradaily pattern. However, after much experimentation with alternative forms of this function, we found that no function removed the seasonality as effectively as the simpler method of using the 120 hourly average means of the business week estimated across all weeks.

The first empirical issue we address is the link between the arrival of information and exchange rate changes. While there exists an accepted theoretical literature linking public information, and the pricing and volatility of asset prices, the empirical evidence is still accumulating. Microstructure theories linking information arrival and market activity are reviewed in O'Hara (1995). The Mixture of Distributions Model (MODM) underlies statistical analyses and is associated with Clark (1973) and Tauchen and Pitts (1983). We follow this literature in deriving our model below. In recent years, GARCH models have dominated empirical work on time-series estimates of asset prices and volatility (see Bollerslev, et al. (1992)). Lamoureux and Lastrapes (1990) and Laux and Ng (1993) show how the mixture of distributions model provides an economic rationale for GARCH modelling of asset prices when the rate of information arrival is the mixing variable. We will, similarly, motivate our use of GARCH models via the mixture of distributions framework.

3.1. A Mixture of Distributions Model

Let there be N traders in the market who buy and sell currency. In every hour, the market arrives at a sequence of equilibria. Since we use hourly time intervals in our empirical work, we define a period as one hour. The movement from the previous equilibrium to the i th equilibrium is motivated by the arrival of new information to the market. The length of time from one equilibrium to the next varies, depending on the arrival of information. At the time of the i th within-period equilibrium, the desired position of the n th trader is given by:

$$P_{in} = \gamma(s_{in}^* - s_i) \quad (1)$$

where γ is a positive constant, s_{in}^* is the n th trader's reservation spot exchange rate given by this trader's perception of the "true" value of the currency, and s_i is the current spot rate. If the current spot rate is less than trader n 's reservation rate, then this trader holds a long position in the currency ($P_{in} > 0$). If the current spot rate is greater than trader n 's reservation rate, then trader n holds a short position ($P_{in} < 0$). Each trader's reservation rate will depend on expectations of future values and will differ with private

⁹ The absolute returns are used as a volatility proxy to illustrate the seasonality, they are not used in any model estimation.

information regarding customer order flows or the use of different models of the market. We ignore transaction costs like bid-ask spreads and brokers fees to simplify the analysis so that reservation prices describe differences across traders.

Equilibrium requires the market-clearing condition:

$$\sum_{n=1}^N P_{in} = 0 \quad (2)$$

and the market is cleared by the average of reservation spot rates so that the spot rate for the i th equilibrium is:

$$s_i = \frac{1}{N} \sum_{n=1}^N s_{in}^* \quad (3)$$

In order for the market to move from the previous to the i th within-hour equilibrium, public information must arrive and change traders' perceptions of the "true" value of the currency or exchange rate reservation prices. The resulting change in the market spot rate will be the average of the increments to all traders' reservation exchange rates. Assuming the within-hour increments to the market spot rate are normally distributed with mean zero and variance σ_i^2 , then:

$$ds_i = \frac{1}{N} \sum_{n=1}^N ds_{in}^*, \quad ds_i \sim N(0, \sigma_i^2) \quad (4)$$

The number of within-hour information events, I , which are associated with new equilibria is random. We sum the within-hour exchange rate changes to find the hourly change in the exchange rate. Since the hourly price change is a mixture of independent normals with mixing variable I , we have:

$$ds = \sum_{i=1}^I ds_i, \quad ds \sim N(0, \sigma_i^2 I) \quad (5)$$

Earlier empirical studies of the mixture of distributions hypothesis included a related equation for volume and inferred the value of the information mixing variable from volume data on stock markets or futures markets. We explicitly measure and estimate the effect of information arrival on exchange rate dynamics. In particular, the number of within-hour exchange-rate changes will be reflected in the number of within-hour quotes, so that quote frequency is a function of information arrival, or:

$$q_t = \alpha_0 + \alpha_1 I_t + \varepsilon_t \quad (6)$$

Beyond the obvious link between the MODM and quote frequency, one can readily see how equation 5) can lead to a justification for GARCH models of exchange rates. For GARCH effects to be present, there must be autocorrelation in I . While the autocorrelation might involve lags of any length, we use a first-order process for purposes of exposition. If we subscript I with a t denoting hour, then we can view the hourly time series of I_t , as measured by the Money Market Headline News crossing the Reuters screen, as a proxy for public information arrival. Fig. 3 shows how the pattern of news varies systematically over the day and indicates a clear pattern of time dependence. Assuming first-order autocorrelation of the news so that

$$I_t = a + bI_{t-1} + u_t, \quad (7)$$

then the variance of ds_t conditional on I_t ($h_t = \sigma^2 I_t$) is:

$$h_t = \sigma^2 a + bh_{t-1} + \sigma^2 u_t. \quad (8)$$

Equation 8) illustrates the sort of persistence in volatility that is captured in estimating GARCH models.

3.2. Public Information Arrival and Quote Frequency

The model presented in Section IIIa had the number of quote revisions in a period a function of the amount of information arriving in that period. In fact, this is a direct result of the theory while GARCH models of volatility persistence are implied by, but not directly derived from, the model. As a result, it is sensible to first empirically examine the link between quote frequency and information arrival. Past researchers have used the number of quotes as a useful observable measure of the level of trading activity in the market.¹⁰ A cursory examination of Figs. 1-3 reveals that quote frequency and information arrival follow similar intradaily patterns. For this reason, an exploration of the effects of information arrival on quote frequency must rely on seasonally-adjusted data. We are interested in examining the effects of information arrival on quote frequency when both have been standardized to eliminate the “normal” daily patterns, so we test whether information arrivals greater or less than the usual amount for a particular hour of a particular day of the week are associated with greater or less than the usual number of quotes on the mark and the yen.

¹⁰ Examples are Bollerslev and Domowitz (1993) or Goodhart and Figliuoli (1991).

Since the number of quotes per hour exhibits autoregressive heteroskedasticity, we estimate the following GARCH model for the number of quotes with information arrival in the mean equation:

$$\begin{aligned} q_t &= \alpha_0 + \alpha_1 I_t + \varepsilon_t \\ h_t &= b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2 \end{aligned} \quad (9)$$

Our empirical model uses one hour as the discrete interval of time and the 1993-95 data discussed earlier. There are 8,784 hourly observations in the sample period. Estimates are reported in Table 2. We see that public information arrival has a significantly positive effect on the number of quotes posted to the Reuters screen for both the yen and the mark. Periods with more than the usual amount of information hitting the market, are periods with a greater than usual number of price revisions. This is exactly as posited above in the mixture of distributions model where within-hour price revisions (ds_i) occur in response to new information.

An analysis of the residuals from the estimates of Table 2 indicates autocorrelation spikes at the first- and 24th lags, so the model is reestimated including first- and 24th-order lagged quotes in the mean equation. Results are reported in Table 3. The important qualitative finding is that even though the lagged quotes are statistically significant, information arrival still has a positive and significant effect on quote activity. These results suggest that there is an independent effect of information arrival apart from any temporal dependencies in the data.

It is interesting to note that the marginal effects of information arrival on quote changes appears to be of a relatively small magnitude. This indicates that there is much quote revision occurring apart from that related to public information arrival. A reasonable story here is the practice of traders altering quotes to manage positions and risk. Furthermore, while public information arrival is associated with quote frequency, we know that the interbank foreign exchange market is serving the needs of liquidity traders who trade for reasons apart from fundamentals that might be altered by news.

3.3. Public Information Arrival and Exchange Rate Volatility

Aside from the direct MODM link between information arrival and quotes, one can also derive a link between information arrival and volatility, as done in Section 3.1. To explore the evidence regarding volatility, we first estimate a baseline GARCH(1,1) model with no information variable included:

$$\begin{aligned} ds_t &= \alpha + \varepsilon_t \\ h_t &= b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2 \end{aligned} \quad (10)$$

Since Figs. 9 and 10 show that there is an intradaily seasonal pattern in the volatility of the hourly change in the exchange rate, we scaled the hourly returns by the mean absolute return for each hour to measure ds in the mean equation and adjust for the intradaily seasonality. Table 4a reports the estimates of this model for the mark and the yen and we see that there are significant GARCH effects in the data. The standard errors reported in this and other tables are Bollerslev-Wooldridge robust standard errors that take into account the nonnormality of the residuals. This persistence of volatility in high-frequency exchange rate changes has been documented by others and is an established stylized fact of the data.¹¹ We might be able to shed some light on the source of this volatility persistence by considering the model outlined above. The mixture of distributions model specified the conditional variance at time t as a function of information arriving in the market. As a result, we can examine whether the addition of the information variable to the model accounts for the persistence of volatility.

In order to estimate the model, the deseasonalized rate of information arrival, I_t , is entered in the conditional variance equation and the following model is estimated:

$$\begin{aligned} ds_t &= \alpha + \varepsilon_t \\ h_t &= b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2 + b_3 I_t \end{aligned} \quad (11)$$

Table 4b reports these results. The information variable does not enter significantly in the conditional variance equation.¹² In both cases strong GARCH effects remain. Lamoureux and Lastrapes found that when they included a daily volume proxy for the information arrival mixing variable in the conditional variance equation for daily stock returns, volatility persistence disappeared. They inferred that ARCH and GARCH effects in financial asset price time series reflect time dependence in the rate of information arrival to the market that may disappear if one explicitly models the information process. This result does not appear to hold for our sample of high-frequency exchange rates where the regular intradaily seasonality

¹¹ Other papers which recently document long-memory in intradaily volatility include Andersen and Bollerslev (1998) and Henry and Payne (1997).

¹² The likelihood ratio statistic for testing the significance of adding I_t is less than 3.5 in both the yen and mark cases. This is an insignificant value of Chi-square with 1 degree of freedom.

has been removed. When there is more than the normal amount of information arriving in an hour, there does not appear to be more than the normal amount of volatility in that hour.

The importance of adjusting for the regular pattern of intradaily seasonality to infer the effects of information arrival on volatility can be shown by estimating the model of Table 4b using the unadjusted data. Table 5 reports such results. In this case, we see that information arrival has a positive and significant effect on volatility. Comparing Table 4b and Table 5, it is clear that we make incorrect inferences regarding the effect of information arrival on volatility if we do not adjust for the regular pattern of intradaily seasonality. It appears that Table 5 is reflecting the regular daily cycle of exchange rate volatility and news flow that occurs with the normal ebb and flow of business activity as the business day moves through the world. Once this seasonality is removed, the systematic relationship between information flow and exchange rate volatility disappears, as in Table 4b.

3.4. Joint Estimation

Given the potential correlations between quotes and returns, a bivariate GARCH model is estimated to exploit the potential greater efficiency from combining both models. The explicit model used is a version of the *BEKK* model discussed in Kroner and Ng (1998). The mean equations are as given in equations (9) and (10). The variance model is given as:

$$H_t = C_0' C_0 + G \circ A' \varepsilon_{t-1} \varepsilon_{t-1}' A + N' I_t N + B \circ H_{t-1} \quad (12)$$

where C_0 , G , and B are symmetric 2x2 parameter matrices and A and N are general 2x2 parameter matrices. N has off diagonal elements equal to zero and our estimation also fixes N_{11} equal to zero as information is an explanatory variable for return variance. I_t is the product of the information flow variable used earlier in the single equation models and a 2x2 identity matrix. The diagonals of G are equal to one and the symbol \circ denotes element-by-element multiplication.¹³

Estimates of the bivariate model are presented in Table 6. Focusing on the public information effects, we now see that public information arrival enters significantly in the quote mean equations for both

¹³ See Kroner and Ng for details regarding theory and estimation.

the yen and mark. In addition, the conditional variance of returns now has public information arrival as a significant variable. The efficiency gains of the bivariate model results in revealing return volatility to be a significant function of information arrival even with seasonally-adjusted data.

4. Implications of Results and Conclusions

We have presented evidence regarding the effect of public information arrival on quote frequency and exchange rate volatility as motivated by the mixture of distributions model. The evidence suggests that quote frequency and volatility of the mark/dollar and yen/dollar exchange rate are both affected by the rate of public information arrival to the market. The link between public information and market activity runs counter to the implications of some research that suggests that private information largely determines asset price movements with public information arrival largely irrelevant. However, the empirical estimates clearly indicate that there are more quote revisions than can be explained solely by public information. Clearly private information and noise trading must be a part of the explanation.

Our results also have implications for the debate over regulation of the foreign exchange market and proposals to “throw sand in the wheels of international finance.” Supporters of such regulation seek to permit “normal functioning” of the foreign exchange market but want to limit opportunities for noise trading and “self-fulfilling speculative movements.”¹⁴ The goal is to eliminate “excess volatility” of the foreign exchange market that results from noise traders trading on other than information regarding fundamentals. Proposals for transaction taxes or non-interest-bearing deposit requirements to trade currencies are supposed to reduce the activity of such noise traders and provide a more stable market. Regardless of whether noise traders are necessarily good or bad, it is difficult to prove the existence of “excess volatility” without being able to clearly identify and measure the fundamentals that change expectations and prices in the market. In this paper, we derive a simple mixture of distributions model that links price revisions to information arrival. Without identifying the nature of the information flow in terms of specific fundamentals, we examine the arrival of information over the business week for the 1993-1995

period and document that the number of price revisions (quotes) and the conditional volatility of returns for the yen and mark are functions of the rate of information arrival. Our findings do not support the hypothesis that foreign exchange market activity is largely self-generating and unrelated to new information. This suggests that trading is providing the function it is meant to provide--adjusting prices and quantities to achieve an efficient allocation of resources. While the results of one study are hardly the basis for setting public policy and additional research in this area is needed (and surely forthcoming), the empirical case for throwing sand in the wheels of international finance must rest on more than casual anecdotal evidence. Until such time that robust evidence exists supporting claims of 'self-generating trading' or 'excess volatility' unrelated to fundamentals that can be reduced by raising costs of trading, one must cautiously consider proposals for imposing such costs.

¹⁴ A summary of the debate with an emphasis on EMS problems is provided in the January 1995 issue of the Economic Journal with papers by Eichengreen, Tobin, and Wyplosz; Garber and Taylor; and Kenen. A good summary with a stock market perspective is Schwert and Seguin (1993).

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Table 1
Descriptive Statistics

	<u>Data Series:</u>							
	<u>DM Quotes</u>		<u>¥ Quotes</u>		<u>News</u>		<u>DM Returns</u>	<u>¥ Returns</u>
	<u>nsa</u>	<u>sa</u>	<u>nsa</u>	<u>sa</u>	<u>nsa</u>	<u>sa</u>	<u>nsa</u>	<u>nsa</u>
Mean:	195.6	195.6	74.2	74.2	6.8	6.8	-.00003	-.00003
Std. Dev.	157.2	84.3	50.48	37.1	4.35	3.27	.0013	.0015
Box-Ljung (12)	26939	9661	5537	8870	4020	1875	33.72	36.96
Box-Ljung (24)	56487	15006	13072	14571	8215	2985	82.24	61.35

Table 2

Estimates of Quote Frequency With Information Arrival

$$q_t = \alpha_0 + \alpha_1 I_t + \varepsilon_t$$

$$h_t = b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2$$

	Yen: <u>Coefficient</u>	<u>Std. Error</u>	Mark: <u>Coefficient</u>	<u>Std. Error</u>
<u>Mean equation</u>				
Constant	62.59	0.975*	180.18	2.619*
I _t	1.351	0.127*	2.000	0.299*
<u>Conditional Variance equation</u>				
Constant	769.0	62.04*	2011	446.7*
h _{t-1}	0.417	0.034*	0.620	0.044*
ε ² _{t-1}	0.050	0.047	0.210	0.072*
Q ² (12)	8.5		14.1	
Q ² (24)	63.4		65.6	
log likelihood	-43498		-50108	

* (**) denotes significance at the 1% (5%) level

Table 3

Estimates of Quote Frequency With Information Arrival and Lagged Quotes

$$q_t = \alpha_0 + \alpha_1 I_t + \alpha_2 q_{t-1} + \alpha_3 q_{t-24} + \varepsilon_t$$

$$h_t = b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2$$

	Yen: <u>Coefficient</u>	<u>Std. Error</u>	Mark: <u>Coefficient</u>	<u>Std. Error</u>
<u>Mean equation</u>				
Constant	15.74	1.314*	41.22	3.599*
I _t	0.930	0.146*	1.259	0.165*
q _{t-1}	0.524	0.013*	0.592	0.018*
q _{t-24}	0.173	0.012*	0.149	0.019*
<u>Conditional variance equation</u>				
Constant	879.2	151.9*	893.1	126.6*
h _{t-1}	0.189	0.078*	0.512	0.046*
ε ² _{t-1}	-0.11	0.093	0.419	0.040*
Q ² (12)	17.4		21.2	
Q ² (24)	69.3		85.7	
log likelihood	-42022		-48488	

(**) denotes significance at the 1% (5%) level

Table 4a

**Estimates of Exchange Rate Returns
Baseline Model Estimates - No Information Proxy**

$$ds_t = \alpha + \varepsilon_t$$

$$h_t = b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2$$

	Yen: <u>Coefficient</u>	<u>Std. Error</u>	Mark: <u>Coefficient</u>	<u>Std. Error</u>
<u>Mean equation</u>				
Constant	0.016	0.013	-0.150	0.148
<u>Conditional Variance equation</u>				
Constant	2.076	2.231	2.477	2.101
h_{t-1}	0.929	0.051*	0.923	0.047*
ε_{t-1}^2	0.061	0.041	0.059	0.032*
Q ² (12)	25.1		29.6	
Q ² (24)	34.9		40.9	
log likelihood	-34337		-33191	

* (**) denotes statistical significance at the 1% (5%) level

Table 4b

**Estimates of Exchange Rate Returns
Including Information Arrival Proxy in Conditional Variance Equation**

$$ds_t = \alpha + \varepsilon_t$$

$$h_t = b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2 + b_3 I_t$$

	Yen: <u>Coefficient</u>	<u>Std. Error</u>	Mark: <u>Coefficient</u>	<u>Std. Error</u>
<u>Mean equation</u>				
Constant	0.015	0.014	-0.145	0.074**
<u>Conditional Variance equation</u>				
Constant	1.247	0.936	1.734	2.104
h_{t-1}	0.924	0.038*	0.915	0.032*
ε_{t-1}^2	0.063	0.027*	0.063	0.022*
I_t	0.189	0.221	0.180	0.152
$Q^2(12)$	24.2		28.5	
$Q^2(24)$	33.5		40.2	
log likelihood	-34335		-33190	

* (**) denotes statistical significance at the 1% (5%) level

Table 5

**Estimates of Exchange Rate Returns Including Information Arrival Proxy
No Adjustment for Intradaily Seasonality**

$$ds_t = \alpha + \varepsilon_t$$

$$h_t = b_0 + b_1 h_{t-1} + b_2 \varepsilon_{t-1}^2 + b_3 I_t$$

	Yen: <u>Coefficient</u>	<u>Std. Error</u>	Mark: <u>Coefficient</u>	<u>Std. Error</u>
<u>Mean equation</u>				
Constant	-0.018	0.047	0.074	0.039**
<u>Conditional Variance equation</u>				
Constant	-1.899	5.091	-4.709	2.894*
h_{t-1}	0.738	0.047*	0.506	0.061*
ε_{t-1}^2	0.160	0.033*	0.385	0.113*
I_t	3.547	0.864*	5.513	0.553*
$Q^2(12)$	8.5		3.6	
$Q^2(24)$	16.7		8.1	
log likelihood	-34841		-33684	

* (**) denotes statistical significance at the 1% (5%) level

Table 6

Bivariate GARCH Estimates of Information Effects on Quote Frequency and Volatility

$$Y_t = \beta X_t + \varepsilon_t$$

$$H_t = C_0' C_0 + G \circ A' \varepsilon_{t-1} \varepsilon_{t-1}' A + N' I_t N + B \circ H_{t-1}$$

		Yen		Mark	
		<u>Coefficient</u>	<u>Std. Error</u>	<u>Coefficient</u>	<u>Std. Error</u>
<u>Mean equation</u>					
<u>Quotes</u>					
Constant	63.07	0.686*	180.08	1.137*	
I _t	1.335	0.089*	1.887	0.153*	
<u>Returns</u>					
Constant	0.062	0.121	0.136	0.111	
<u>Conditional variance equation</u>					
<u>Quotes</u>					
Constant	95.36	6.453*	1062.03	26.338*	
ε ² _{t-1}	0.440	0.008*	0.803	0.010*	
h _{t-1}	0.740	0.010*	0.363	0.007*	
<u>Returns</u>					
Constant	0.968	0.295*	2.397	0.326*	
ε ² _{t-1}	0.246	0.006*	0.286	0.006*	
h _{t-1}	0.925	0.004*	0.886	0.005*	
I _t	0.474	0.057*	0.543	0.056*	
<u>Covariance</u>					
Constant	0.448	0.393	-0.895	3.780	
ε ² _{12,t-1}	-0.011	0.003*	-0.002	0.001	
ε ² _{21,t-1}	-0.269	0.012*	-0.142	0.039*	
h _{12,t-1}	0.901	0.042*	0.413	0.191*	
G ₁₂	0.077	0.036*	0.225	0.053*	
log likelihood	-77973		-83247		

* denotes statistical significance at the 1% level

Fig. 1: Average Hourly Quotes: Mark/Dollar

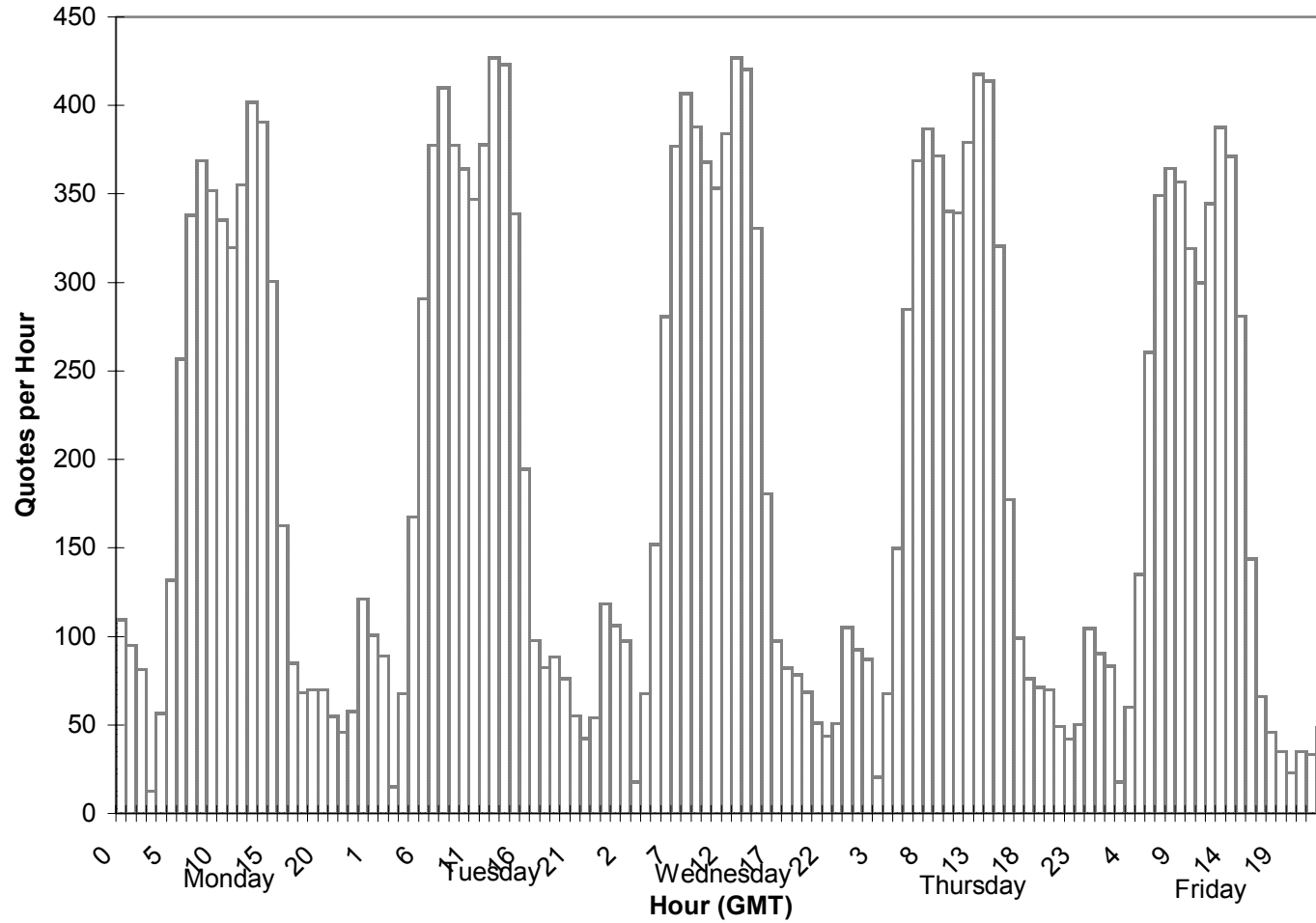


Fig. 2: Average Hourly Quotes: Yen/Dollar

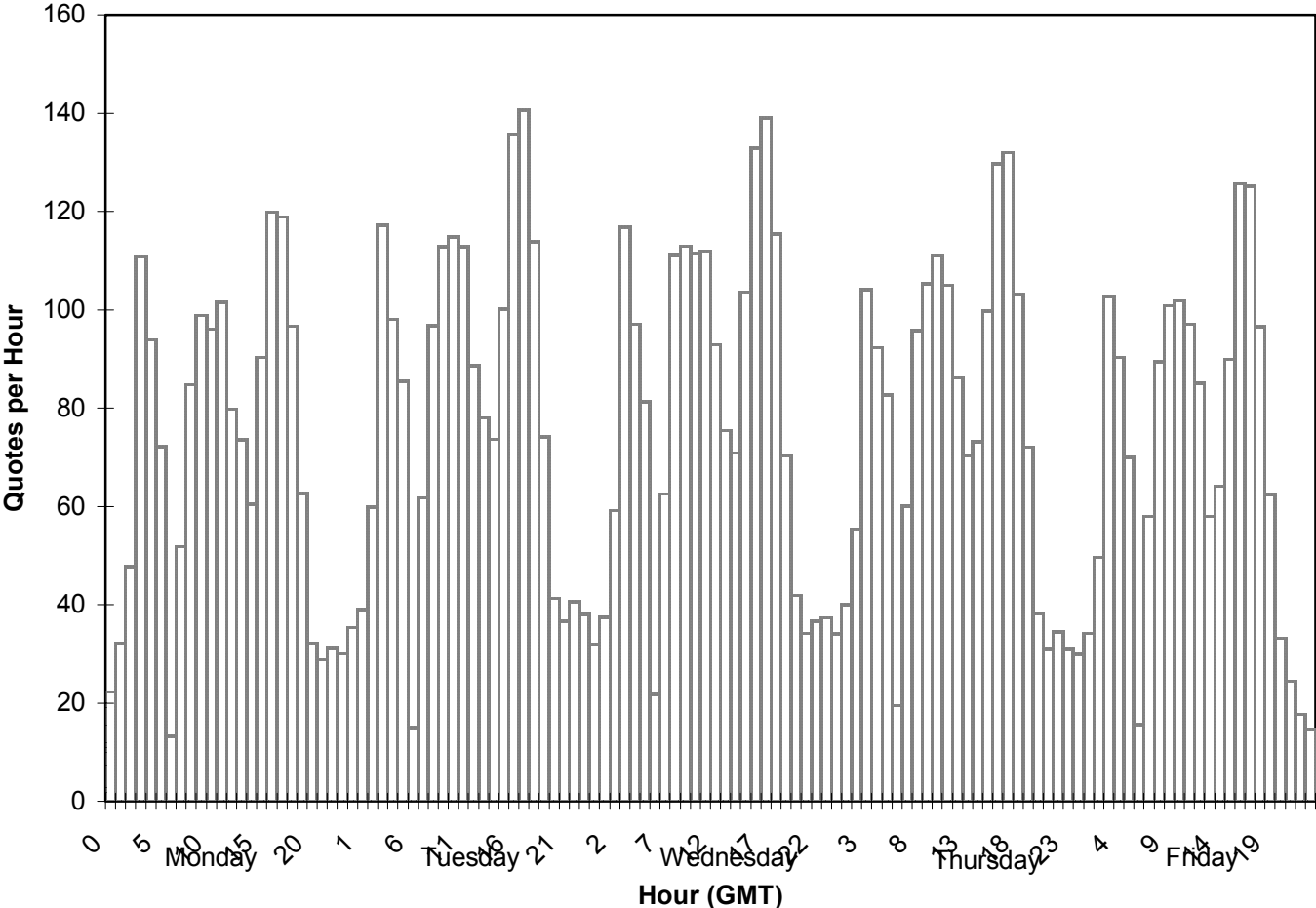


Fig. 3: Average Hourly News Headlines

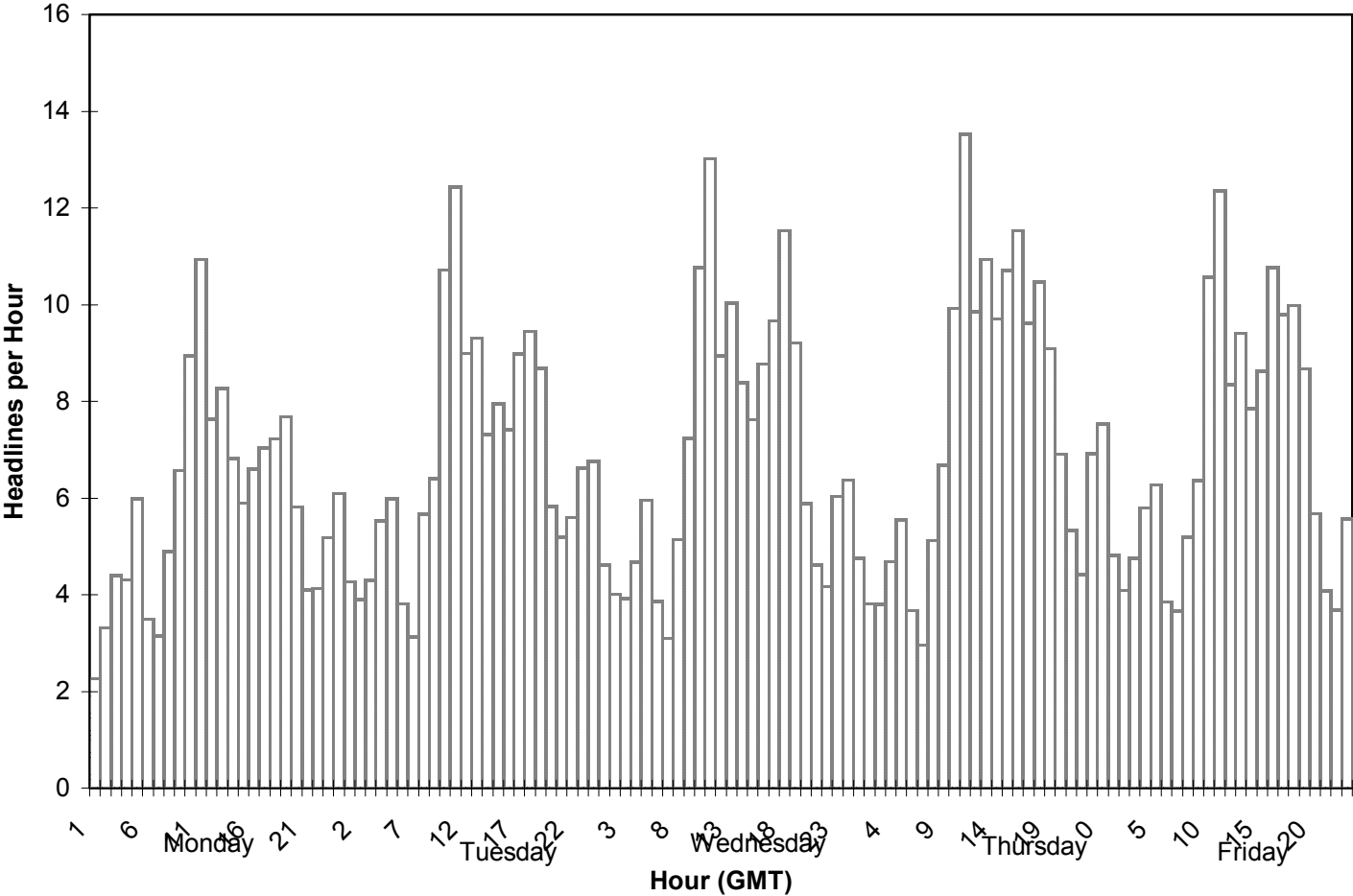


Fig. 4: Correlogram: Mark/Dollar Quotes

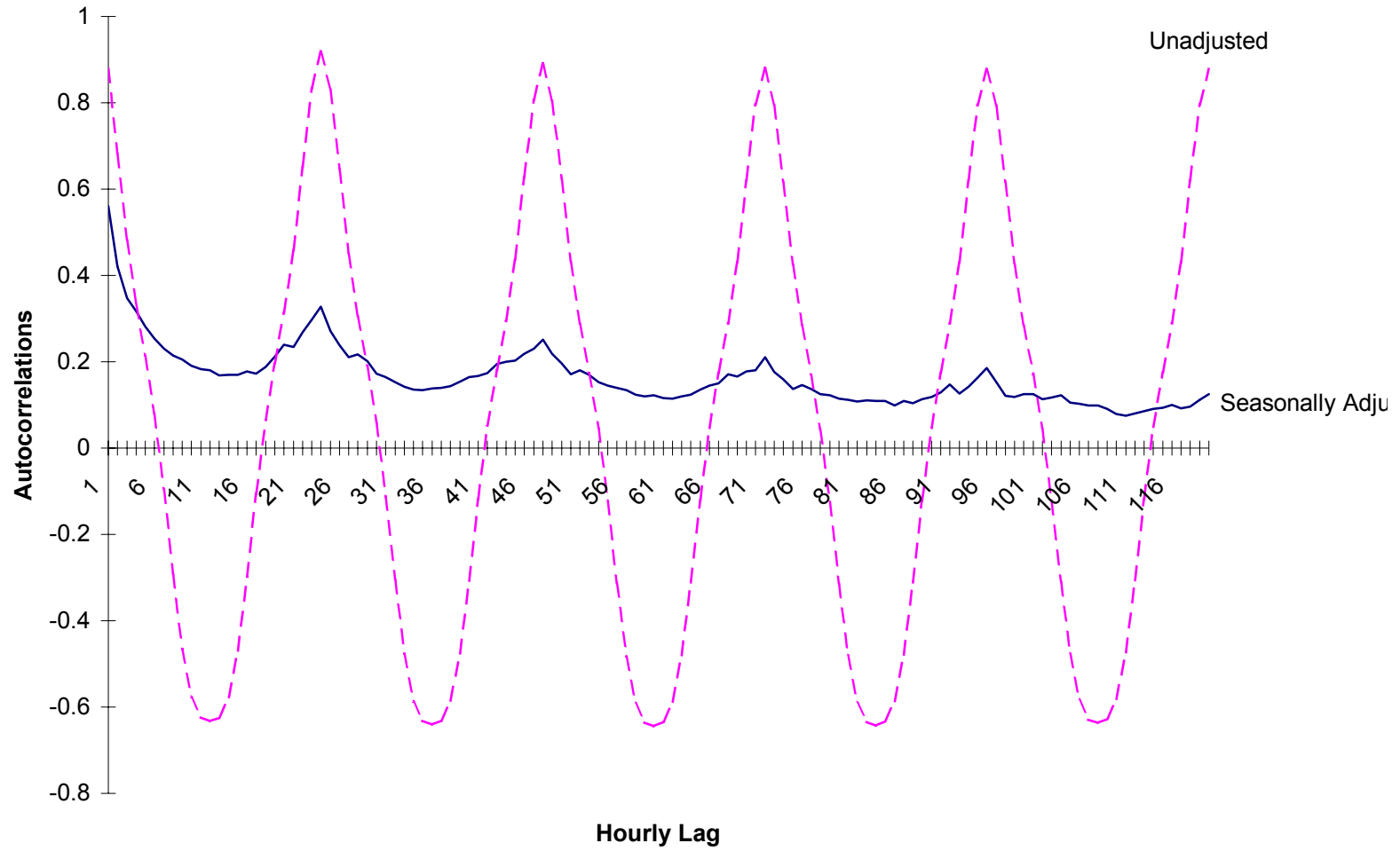


Fig. 5: Correlogram: Yen/Dollar Quotes

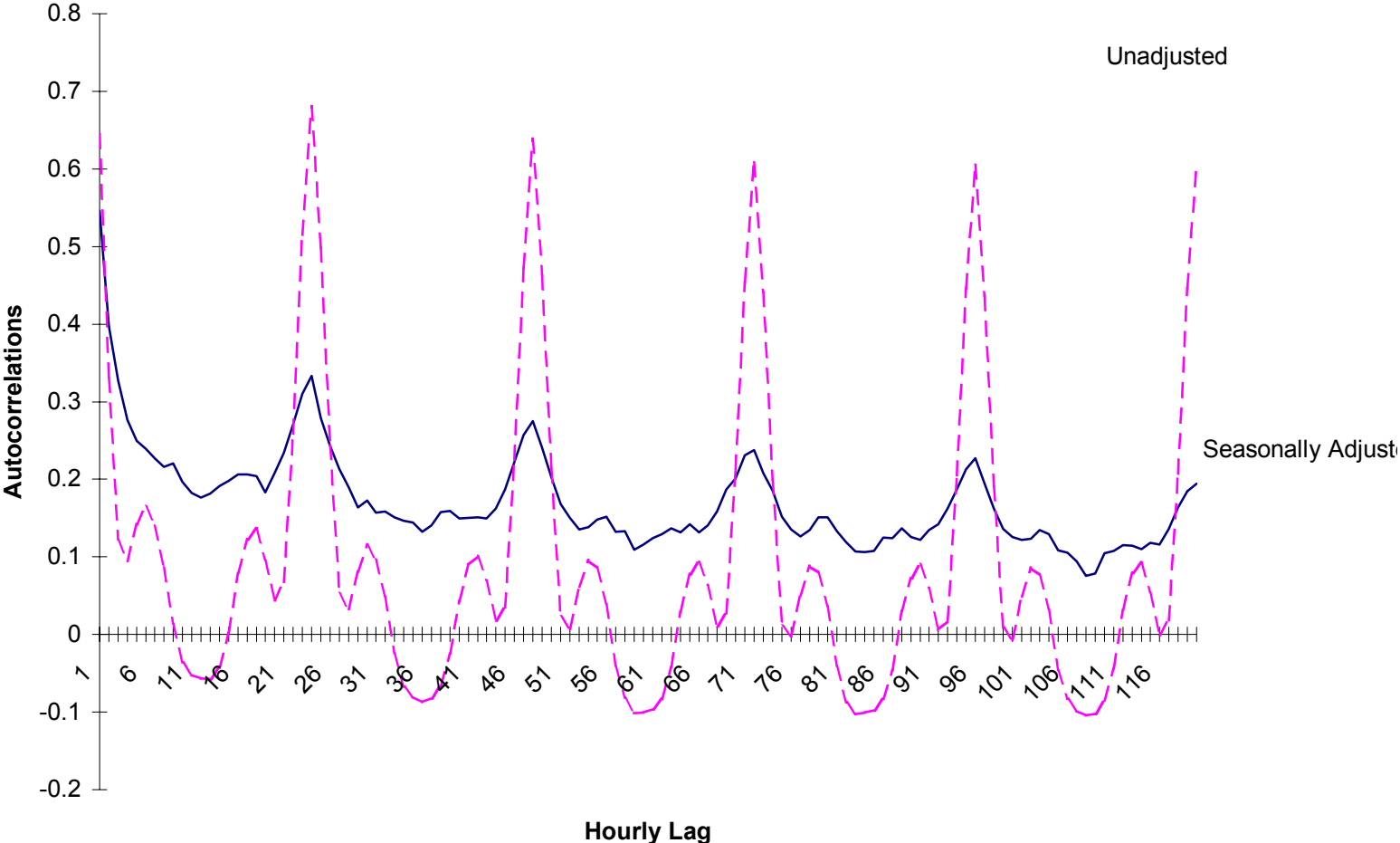


Fig. 6: Correlogram: News Headlines

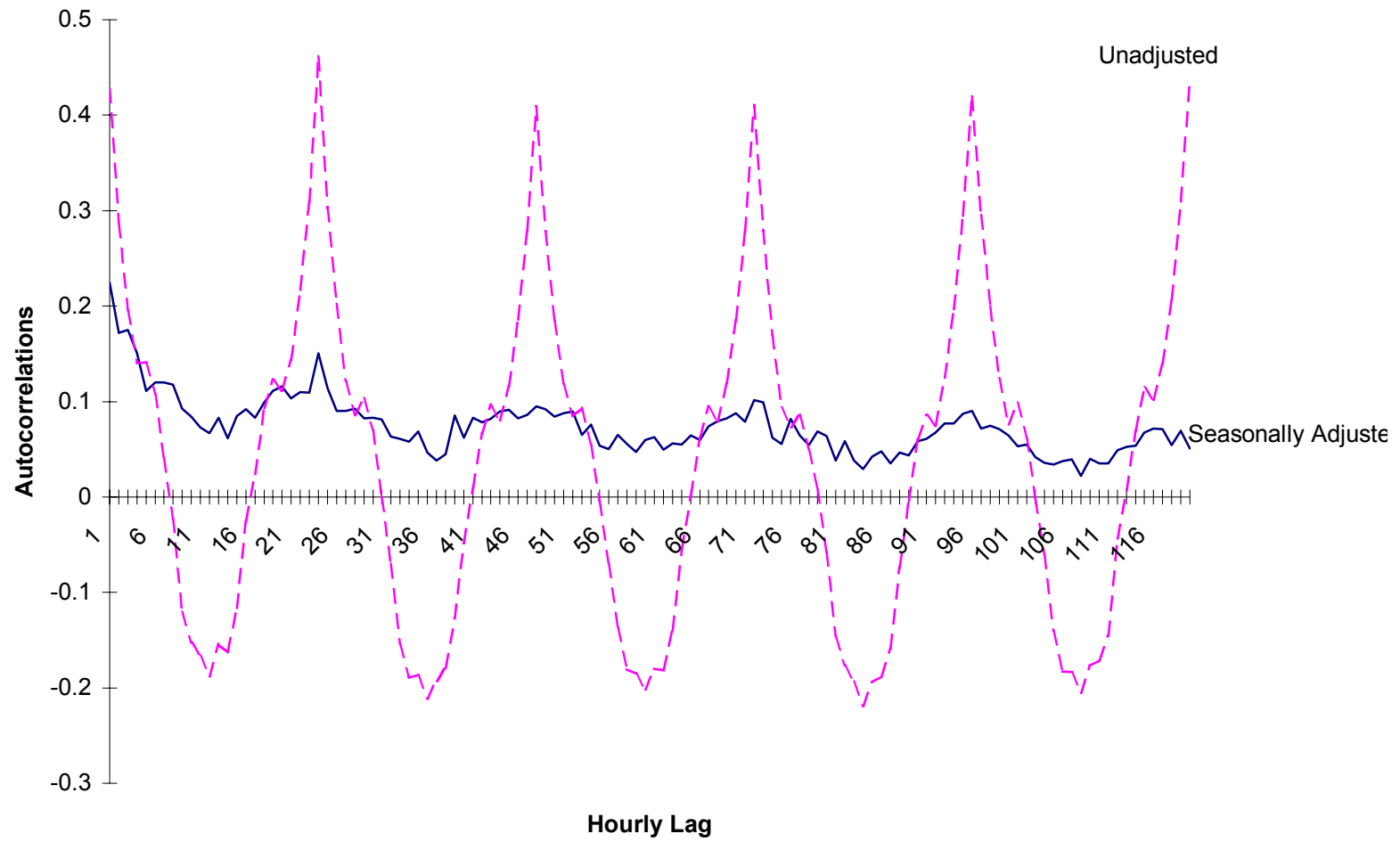


Fig. 7: Correlogram: Mark/Dollar Returns

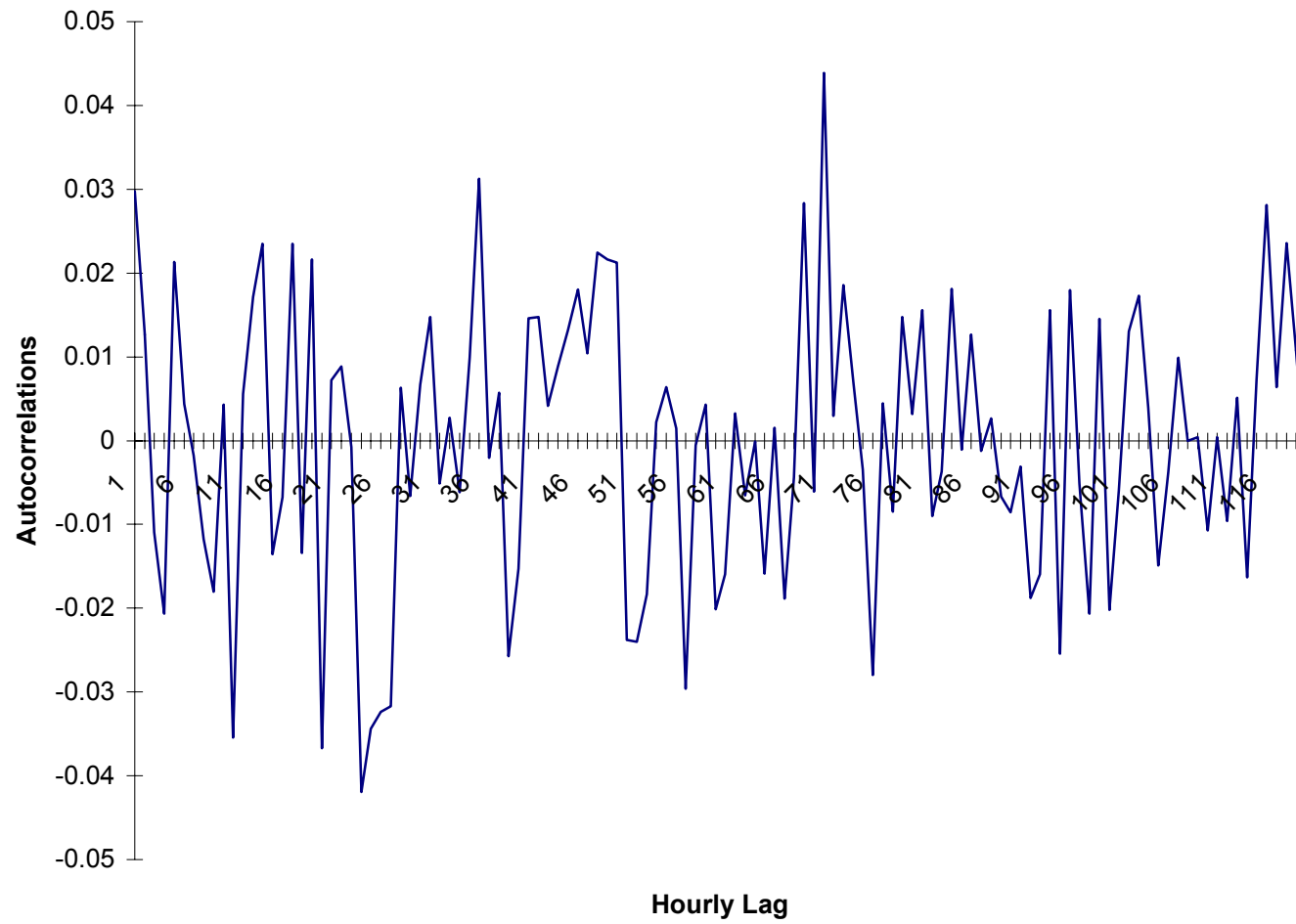


Fig. 8: Correlogram: Yen/Dollar Returns

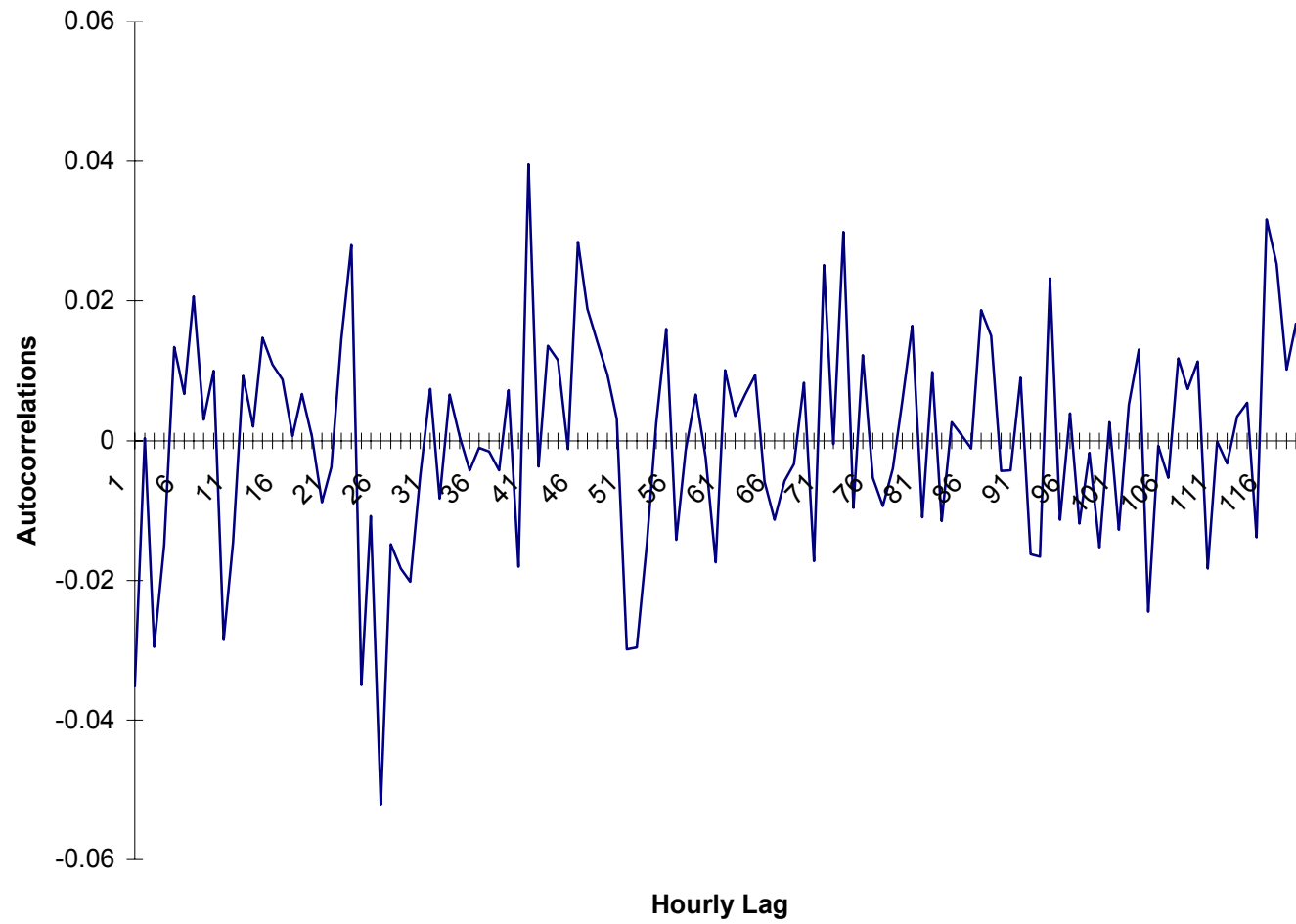


Fig. 9: Correlogram: Mark/Dollar Absolute Returns

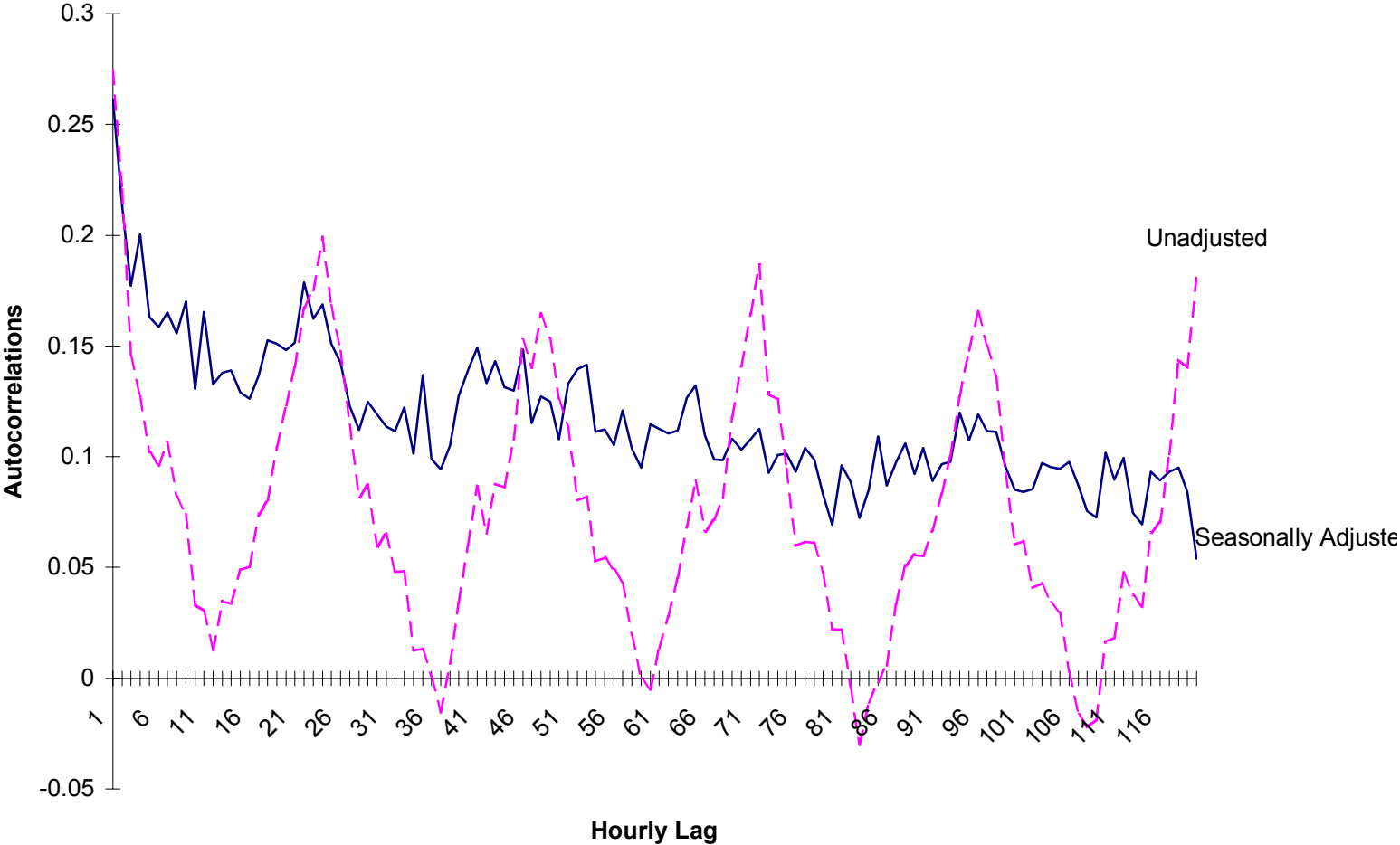


Fig. 10: Correlogram: Yen/Dollar Absolute Returns

