

Information Aggregation, Inflation, and the Pricing of Indexed Bonds

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Using daily prices of indexed bonds between 1970 and 1979, we test whether announcements of the Israeli CPI contain information that is not already reflected in bond prices. The results indicate that bond prices reflect about 85 percent of the new information about inflation as it occurs (i.e., when the Central Bureau of Statistics samples prices). The announcement of the CPI 15 days after the end of the sampling period causes the remaining 15 percent adjustment in bond prices. This evidence raises questions about the empirical importance of misperceptions about inflation as a source of nonneutrality in monetary policy.

I. Introduction

This paper examines the timing of the reaction of indexed bond prices to the occurrence and subsequent announcement of inflation.

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Our data are from Israel and consist of a monthly time series of Consumer Price Index (CPI) announcements and a daily time series of prices of government-issued bonds that are indexed to the CPI. After estimating prediction models for the Israeli CPI, we examine the relations between bond returns and the expected and unexpected components of the CPI.

The Israeli CPI is announced approximately 2 weeks after the end of the month in which commodity prices are sampled. If bond traders are able to learn about inflation by observing the nominal commodity prices, there will be no reaction of bond prices when the CPI is announced. On the other hand, if the bond market cannot infer the behavior of inflation by observing individual commodity prices, the announcement of the CPI will be associated with a change in bond prices to reflect the previously unknown information about the CPI. In principle, traders in the bond market have access to all the information that is used to construct the CPI, although it is probably prohibitively expensive for any one trader to duplicate the data collection and assimilation activities of the Central Bureau of Statistics. Nevertheless, all traders have obvious pecuniary incentives to obtain information about the future behavior of the CPI, since the prices of indexed bonds are essentially the outcome of bets about the future level of the CPI.

This paper investigates the extent to which the market successfully aggregates information that individuals hold collectively but possibly no single individual possesses completely. Many attempts have been made to incorporate uncertainty and diverse information of traders into equilibrium models of capital markets, including Grossman (1976, 1978), Radner (1979), Grossman and Stiglitz (1980), Diamond and Verrecchia (1981), and Admati (1983). These papers investigate whether prices can aggregate investors' diverse information to the extent that they serve as a sufficient statistic for the aggregate information of traders, in which case the price is called "fully revealing." Suppose the announcement of the CPI merely aggregates information about commodity prices. This information was available to bond traders at least a fortnight prior to the announcement. If bond prices are fully revealing, then the market should not react to the announcement when it occurs, because the information contained in the announcement was impounded in prices 2 weeks earlier.

A related question arises in rational expectations models of business cycles, such as Lucas (1973, 1975) and Barro (1980). In these models there are several markets in the economy, and there are restrictions on the flow of traders and information across markets. Shocks are both economy-wide and local (i.e., vary across markets). Prices in each market reflect both local and economy-wide shocks, and

traders are unable to determine whether a nominal price change is due to a change in the relative price of the good or to overall inflation of all goods' prices. This confusion about inflation and relative price changes implies that monetary policy can have real effects.

The empirical tests in this paper suggest that about 85 percent of the reaction of bond prices to unexpected inflation occurs contemporaneously with the sampling of individual commodity prices, from 2 to 6 weeks prior to the announcement. The remaining 15 percent of the reaction to unexpected inflation occurs on the day following the announcement. Thus, while the evidence is inconsistent with the extreme hypothesis that indexed bond prices fully reflect the information about inflation as it occurs, the extent of confusion about inflation is not large.

Schwert (1981), Cornell (1983), and Ulrich and Wachtel (1984) study the empirical relations between announcements of the U.S. CPI or money supply and the prices of stocks and nominal bonds in the United States. The tests in this paper are more powerful for two reasons: (a) the payoffs to indexed bonds are directly linked to the CPI, and (b) the variance of the unexpected component of the CPI has been much higher in Israel than in the United States. Therefore, the results in this paper show a much stronger relation between unexpected inflation and daily bond price changes than has been found in previous studies.

Section II describes the inflation and bond price data and presents time-series models for the inflation rate in Israel. Given the estimates of expected and unexpected inflation from the time-series models, we examine the reaction of indexed bond prices to the unexpected component of the CPI. Using daily returns to a portfolio of indexed bonds, the tests in Section III estimate the speed of adjustment of indexed bond prices to information about inflation. Section IV discusses some alternative interpretations of the empirical results in Section III. Section V contains brief concluding remarks.

II. Inflation and Bond Price Data

A. The Consumer Price Index

The Consumer Price Index (CPI) for Israel is compiled by the Central Bureau of Statistics and is based on a broad sample of consumption goods (about 1,000 commodities and services in about 1,500 locations throughout Israel). The index for month t is announced after the close of trading on the Tel Aviv Stock Exchange on the first nonholiday after the fourteenth of the following month. Because there are so many financial contracts such as indexed bonds linked to the CPI, the

Central Bureau of Statistics tries to avoid leaks of information prior to the official announcement. Nevertheless, consumers observe the prices of individual commodities at the same time that the Central Bureau of Statistics collects the sample of prices that eventually aggregate into the CPI. Detailed information about the construction of the Israeli CPI is available in Israel Central Bureau of Statistics (1968).

To analyze the reaction of bond prices to information about inflation, it is important to determine the part of CPI inflation that is expected before the month when the inflation occurs. The difference between the actual inflation rate for January, announced on February 15, and the expected inflation rate based on information available on January 1 represents the information that could be learned about inflation between January 1 and February 15. Thus, it is the timing of the reaction of bond prices to unexpected inflation that is of primary interest.

One way to measure the expected and unexpected components of the CPI inflation rate is to use a statistical time-series model to predict future inflation based on past inflation rates. This approach has been used frequently with U.S. CPI inflation data, by Hess and Bicksler (1975), Nelson (1976), Nelson and Schwert (1977), and Schwert (1981), among others. Part A of table 1 contains means, standard deviations, and the first 12 autocorrelations of the monthly Israeli CPI inflation, p_t , from 1952 to 1981 and for several subperiods. Part B of table 1 contains summary statistics for the first differences of the CPI inflation rate, Δp_t . The autocorrelations of the inflation rate are large at all 12 lags for the overall 1952–81 sample period and for the 1972–81 subperiod. The autocorrelations of the changes in inflation in part B are generally small, except at lags 1, 2, 11, and 12. These results indicate that the stochastic process generating Israeli inflation is nonstationary. Moreover, the pattern of autocorrelations in part B suggests that the changes in inflation follow a second-order moving average process with a seasonal moving average component.¹

Table 2 contains estimates of this model for several sample periods along with some tests for the adequacy of the model. The estimates of the model parameters in table 2 are fairly stable across the three 10-year subperiods. However, the test statistics for constancy of the parameters within the 10-year subperiods are significant at the 5 percent level, except for the 1972–81 period. The Box-Pierce (1970) test statistics indicate that the autocorrelations of the residuals from these models are small. The Studentized Range test statistics, $S.R.(\hat{u})$, test the hypothesis that the distribution of residuals is normal with con-

¹ See Box and Jenkins (1976) for a discussion of nonstationary time-series processes such as this.

TABLE 1

SUMMARY STATISTICS FOR ISRAELI INFLATION

| Period | Number of Months | Mean | Standard Deviation | A. Inflation Rate of Israeli CPI, ρ | | | | | | | | | | | | | |
|-------------------------------|------------------|-------|--------------------|--|----------|----------|----------|----------|----------|----------|----------|----------|-------------|-------------|-------------|-----------|-----|
| | | | | ρ_1 | ρ_2 | ρ_3 | ρ_4 | ρ_5 | ρ_6 | ρ_7 | ρ_8 | ρ_9 | ρ_{10} | ρ_{11} | ρ_{12} | $S(\rho)$ | |
| 1952-81 | 360 | .0169 | .0237 | .59 | .49 | .48 | .49 | .50 | .51 | .46 | .46 | .45 | .40 | .46 | .48 | .59 | .05 |
| 1952-61 | 120 | .0090 | .0222 | .24 | .17 | .14 | .23 | .15 | .12 | .15 | .15 | .15 | -.03 | .04 | -.02 | .30 | .09 |
| 1962-71 | 120 | .0051 | .0109 | .01 | .03 | -.17 | .01 | .00 | .19 | -.09 | .06 | .06 | -.19 | .07 | -.01 | .41 | .09 |
| 1972-81 | 120 | .0364 | .0282 | .58 | .38 | .39 | .33 | .42 | .41 | .33 | .30 | .30 | .33 | .35 | .45 | .49 | .09 |
| January 1970- January 1979 | 109 | .0215 | .0209 | .38 | .12 | .08 | .03 | .08 | .09 | .06 | .00 | .00 | .09 | .19 | .30 | .34 | .10 |
| | | | | B. Change in Inflation Rate of Israeli CPI, $\Delta\rho$ | | | | | | | | | | | | | |
| 1952-81 | 360 | .0001 | .0233 | -.39 | -.09 | -.03 | .00 | .01 | .06 | -.04 | .05 | .12 | -.12 | .04 | -.11 | .33 | .05 |
| 1952-61 | 120 | .0000 | .0271 | -.46 | -.03 | -.08 | .12 | -.03 | -.04 | .02 | .12 | -.17 | .09 | .09 | -.25 | .39 | .09 |
| 1962-71 | 120 | .0000 | .0152 | -.51 | .10 | -.19 | .11 | -.10 | .23 | -.22 | .21 | -.26 | .18 | .18 | -.26 | .45 | .09 |
| 1972-81 | 120 | .0003 | .0258 | -.28 | -.24 | .08 | -.17 | .11 | .09 | -.07 | -.07 | .02 | -.10 | .07 | .21 | .21 | .09 |
| January 1970- January 1979 | 109 | .0005 | .0228 | -.28 | -.19 | .00 | -.07 | .06 | .02 | .01 | -.10 | -.04 | .03 | .05 | .13 | .10 | .10 |

NOTE.— ρ_k is the sample autocorrelation coefficient for lag k , $k = 1$ to 12, and $S(\rho)$ is the large sample standard error of ρ_k under the hypothesis that all autocorrelations are zero.

TABLE 2
 ARIMA MODELS FOR THE ISRAELI INFLATION RATE, p
 $(1 - L)p_t = \mu + (1 - \theta_1 L - \theta_2 L^2)(1 - \nabla_1 L^2)u_t$

| Period | Sample Size, T | $\hat{\mu}$ | $\hat{\theta}_1$ | $\hat{\theta}_2$ | $\hat{\nabla}_1$ | $S(\hat{\theta})$ | S.R. ($\hat{\theta}$) | Box-Pierce | Stability Test |
|------------|------------------|-------------------|------------------|------------------|------------------|-------------------|-------------------------|------------|------------------|
| 1/52-12/81 | 360 | -.0001 (.0001) | .764 (.053) | .118 (.053) | -.291 (.053) | .0176 | 7.85* | 10.6 | 2.46* (8,348) |
| 1/52-12/61 | 120 | -.0003 (.0003) | .871 (.093) | .015 (.094) | -.336 (.099) | .0195 | 6.05* | 7.1 | 5.16* (4,112) |
| 1/62-12/71 | 120 | .0000 (.0001) | .822 (.091) | .166 (.091) | -.426 (.089) | .0102 | 6.96* | 19.4* | 2.52* (4,112) |
| 1/72-12/81 | 120 | .0001 (.0001) | .613 (.089) | .374 (.088) | -.284 (.100) | .0205 | 5.49 | 11.9 | 2.32 (4,112) |
| 1/70-1/79 | 109 | .0003 (.0001) | .619 (.093) | .374 (.092) | -.258 (.109) | .0181 | 6.75* | 7.3 | ... |

NOTE.—In the terminology of Box and Jenkins (1976), these are (0, 1, 2)(0, 0, 1)₁₂ multiplicative seasonal autoregressive-integrated moving average models. L is the lag operator. SAS was used to estimate the models. Large-sample standard errors are in parentheses under the coefficient estimates. $S(\hat{\theta})$ is the standard deviation of the residuals (i.e., of unexpected inflation). S.R. ($\hat{\theta}$) is the Studentized Range of the residuals, the ratio of the range to $S(\hat{\theta})$; see Fama (1976, chap. 1) for a discussion of this statistic. Box-Pierce is the portmanteau statistic for testing whether the residuals are not autocorrelated from lag 1 to lag 12 (see Box and Jenkins 1976, pp. 290-91), which would be distributed as χ^2_8 in this case. The stability test is a large-sample F -test of whether the parameters of the model (μ , θ_1 , θ_2 , and ∇_1) are constant over the period of estimation. From 1952 to 1981 the test is performed by comparing the fit for the overall sample with fits from the 1952-61, 1962-71, and 1972-81 subperiods. Within each of the subperiods the test is performed by reestimating the model on the first and last 5 years of data. The degrees of freedom are shown in parentheses under each F -statistic.

* Greater than the 90 fractile of the sampling distribution under the null hypothesis.

stant mean and variance. These statistics are large in many of the subperiods, indicating that there are outliers (i.e., large positive or negative unexpected inflation) or changes in the variance of unexpected inflation. The estimates of the residual standard deviation, $S(\hat{u})$, indicate that the variance of unexpected inflation was about four times higher in 1972–81 than in 1962–71, for example.

Based on the stability of the coefficient estimates in table 2, it seems reasonable to assume that the predictions and prediction errors from these models can be used to approximate the expected and unexpected components of the CPI inflation rate. In the subsequent tests using bond returns, expected inflation will be estimated as the prediction from a time-series model like those in table 2, where the model parameters are estimated using the most recent 60 months of inflation data. Our measure of unexpected inflation will be the prediction error from this time-series model.

B. Indexed Bonds

Indexed bonds are widely held and actively traded in Israel. In 1976 indexed bonds represented about 67 percent of the total market value of listed securities and about 30 percent of the trading volume on the Tel Aviv Stock Exchange. In addition, a large amount of bond trading occurs in the over-the-counter market in Israel. There is also a large volume of option bonds outstanding where the holder can choose to receive either a fixed payment or a partially indexed payoff when the bond matures.²

Daily prices of indexed bonds are collected from the *Tel Aviv Stock Exchange's Official Quotations* for 77 months between January 1970 and January 1979. Continuous data are available from January 1970 through August 1971 (402 observations), from January 1974 through June 1975 (329 observations), and from October 1975 through January 1979 (777 observations).³ We use an equally weighted portfolio of 12 actively traded indexed bonds to measure a daily holding period return, R_t . This portfolio represents a sample of the variety of indexed bonds issued by the Israeli government over this period. It contains coupon bonds with coupon rates ranging from 3 to 7 percent and maturities at issue of between 5 and 10 years. Once a bond enters the portfolio it stays until about 3 months prior to maturity, at which point it is replaced by another bond of between 5 and 10 years to maturity. The Tel Aviv Stock Exchange delists bonds that are within a

² Bank of Israel (1977, chap. 19) contains a detailed description of securities markets in Israel.

³ The data were collected from the library of Tel Aviv University's Recanati Graduate School of Business Administration. Because some of the quotations may be missing, there may be some days where trading occurred but for which we have no price data.

few months of maturity. Thus, the portfolio represents a mixture of maturities at any point in time. On maturity, the bondholder receives the par value multiplied by the change in the CPI since the bond was issued. Some bond issues have only partial indexation (80 or 90 percent). For an 80 percent indexed bond, the payoff at maturity is 20 percent of the par value plus 80 percent of the par value times the growth in the CPI since the bond was first issued. The coupon payments are not indexed.

There are several reasons the prices of indexed bonds might vary over time in addition to changes in the CPI. First, there is some probability of default, either as a result of wars or because the Israeli government changes the terms of the bond contract *ex post*.⁴ Second, the Bank of Israel apparently intervenes in the bond market with the intention of affecting bond prices.⁵ Finally, even if the principal and coupon payments were fully indexed and there was no default risk, the prices of long-term bonds would change if real discount rates varied over time. Thus we do not expect to find that all of the variation in bond prices is attributable to variation in expected or unexpected inflation.

In principle it would be better to incorporate data on coupon yield, maturity, and so forth into our analysis. Unfortunately, such data are not easily available. The data as we have them are good enough for our purpose since we are interested in the timing of the market response to unexpected inflation, not the absolute magnitude of the response. If we had data on more bonds and on the detailed characteristics on each bond, we could presumably construct a more powerful test of the timing of the market response to unexpected inflation.⁶

III. Information about the CPI and Bond Price Behavior

A. *Effects of Information Release on Bond Price Variability*

One way to analyze the effects of the CPI announcement on indexed bond prices is to examine the variability of bond returns on the days

⁴ See Bank of Israel (1977, pp. 442–43) for a discussion of government actions taken in December 1975 that affected payoffs to subsequently issued indexed bonds and the associated fear that previously issued bonds would also be affected. At this time the government also prohibited institutional investors from trading indexed bonds on the Tel Aviv Stock Exchange.

⁵ See Bank of Israel (1977, pp. 448–50) for a discussion of the trading activity by the Bank of Israel.

⁶ An unpublished appendix to this paper illustrates the effects of nonindexed coupons, partial indexation of principal, term to maturity, and varying real discount rates on the sensitivity of indexed bond prices to unexpected inflation. This appendix is available from the authors.

TABLE 3

ESTIMATES OF THE STANDARD DEVIATION OF INDEXED BOND RETURNS ON THE DAYS
AROUND CPI ANNOUNCEMENTS

| Day Relative to the CPI Announcement, i | Standard Deviation, σ_i |
|--|--------------------------------|
| -5 | .00773 |
| -4 | .00680 |
| -3 | .00700 |
| -2 | .00820 |
| -1 | .00501 |
| 0 | .00929 |
| 1 | .00803 |
| 2 | .00939 |
| 3 | .00603 |
| 4 | .00636 |
| 5 | .00689 |

NOTE.—These standard deviations for day i relative to the CPI announcement are computed using the daily data around each of the CPI announcements. The estimate of the standard deviation of bond returns (irrespective of CPI announcements) is .00744 based on all 1,508 daily bond returns.

surrounding the CPI announcement. If new information is released as a result of the announcement, variability should be higher on the day after the announcement.

Table 3 contains estimates of the standard deviation of bond returns for 11 trading days around the announcement day. For example, σ_0 represents the sample standard deviation of the bond returns on the first trading day after the CPI announcement (day 0) based on the 77 announcements in our sample. Table 3 also contains sample standard deviations for 5 trading days before (days -5 to -1) and 5 trading days after (days 1 to 5) the announcement day. The standard deviation of bond returns on the day following the announcement is the second highest among the 11 estimates in table 3. The standard deviation on day 0 is about 25 percent greater than the estimate of the standard deviation of bond returns for the entire sample.

This crude test suggests that there is information in the CPI announcement that was not previously available. However, since the evidence in tables 1 and 2 indicates that the CPI inflation rate was not stationary over this sample period, it is doubtful that the process generating bond returns was stationary. In this case the sample standard deviations in table 3 would have unknown statistical properties and statistical tests based on these estimates would be unreliable.

Table 4 contains nonparametric tests based on ranks of the daily returns within each month. These nonparametric tests should correct for nonstationarity in the process generating bond returns due to the

TABLE 4
EFFECTS OF CPI ANNOUNCEMENTS ON THE DISPERSION OF BOND PRICES: NONPARAMETRIC TESTS BASED ON RANKS

$$Y_{it} = \mu + \sum_{j=-5}^3 \delta_j D_{it} + u_{it} \quad (1)$$

| Sample Period | Sample Size, T | μ | δ_{-5} | δ_{-4} | δ_{-3} | δ_{-2} | δ_{-1} | δ_0 | δ_1 | δ_2 | δ_3 | δ_4 | δ_5 |
|-----------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1/4/70-1/31/79 | 1,508 | .531 (.012) | -.023 (.036) | -.021 (.036) | -.045 (.036) | -.011 (.036) | -.075 (.036) | .073 (.036) | .004 (.036) | .050 (.036) | -.002 (.036) | -.022 (.036) | -.033 (.037) |
| 1/4/70-8/31/71 | 402 | .551 (.023) | -.106 (.072) | -.002 (.072) | -.024 (.072) | -.049 (.072) | -.154 (.072) | -.009 (.072) | -.053 (.072) | .057 (.072) | -.005 (.072) | -.101 (.072) | -.071 (.072) |
| 1/3/74-6/30/75 | 329 | .515 (.027) | -.047 (.077) | -.062 (.077) | -.088 (.077) | .030 (.077) | .021 (.077) | .115 (.077) | .031 (.077) | -.027 (.077) | .072 (.077) | .126 (.077) | .082 (.079) |
| 10/2/75-1/31/79 | 777 | .527 (.017) | .031 (.051) | -.010 (.051) | -.033 (.051) | -.009 (.051) | -.076 (.051) | .097 (.051) | .022 (.051) | .082 (.051) | -.031 (.051) | -.047 (.051) | -.063 (.051) |

NOTE.—Standard errors in parentheses under the coefficients.

nonstationary inflation rate. We rank the daily bond returns within a month from lowest to highest, 1 to N_t , where N_t is the number of trading days in month t . The days are labeled relative to the announcement day, so $i = 0$ is the day after the announcement, $i = -1$ is the day of the announcement, $i = 1$ is the second day after the announcement, and so forth. Thus, for each day i relative to the CPI announcement within month t there is a ranking M_{it} , where $1 \leq M_{it} \leq N_t$. To normalize the rankings with respect to the number of observations per month, we define the variable $X_{it} = (M_{it} - 1)/(N_t - 1)$, which varies between zero and one. Finally, since we are interested in either very high or very low returns associated with the announcement of the CPI, we create the variable $Y_{it} = 2|X_{it} - .5|$, which also varies between zero and one. Under the null hypothesis that bond returns are unaffected by the CPI announcement, both X_{it} and Y_{it} should be approximately uniformly distributed across months t for a given day i . Unless we know whether inflation is unexpectedly high or low when it is announced, we have no hypothesis about X_{0t} , but Y_{0t} should be large if bond returns are either high or very low after the announcement. To test this hypothesis we regress Y_{it} against the set of dummy variables D_{it} ,

$$Y_{it} = \mu + \sum_{i=-5}^5 \delta_i D_{it} + u_{it}, \quad (1)$$

where $D_{it} = 1$ when the observation occurs on day i relative to the announcement, and $D_{it} = 0$ otherwise. For example, $D_{0t} = 1$ on the day after the CPI announcement (day 0). The coefficient δ_i measures the differential dispersion in bond return rankings on day i relative to the CPI announcement.

The results in table 4 show that bond returns are more variable on the day following CPI announcements. In all but the 1970–71 sub-period, the estimates of δ_0 are positive, and for the total sample they are more than two standard errors above zero. There is no indication that any of the other dummy variable coefficients are different from zero, so it seems that the announcement day has more price variability than the other 10 trading days around the announcement. This crude test indicates that there is at least some information in the announcement that is not available prior to the announcement. The tests that follow give a more detailed picture of this phenomenon.

B. Effects of Inflation on Daily Bond Returns

To measure the reaction of indexed bond prices to new information about inflation, we are most interested in the relation between bond

returns and unexpected inflation, \hat{u}_t . The current unexpected inflation rate has two effects on the price of an indexed bond. The predicted future level of the CPI is changed by the amount of current unexpected inflation. In addition, the future levels of expected inflation are increased (decreased) as a result of positive (negative) unexpected inflation.⁷ Thus, the predicted redemption payoff is increased by current unexpected inflation. The increase in future expected inflation will probably increase nominal interest rates, which decreases the value of future cash flows.

One way to determine the time when the bond market first becomes aware of the unexpected inflation rate is to analyze daily bond returns around the announcement of the CPI. To test whether the announcement conveys information that is not already reflected in bond prices, we could regress the bond return for the first trading day after the announcement on the unexpected inflation rate corresponding to the announced CPI,

$$R_t = \alpha + \gamma_0 \hat{u}_t + \epsilon_t \quad (2)$$

For example, if the January CPI is announced on February 15, R_t is the bond return on February 16 and \hat{u}_t is the unexpected inflation for January. Since we have 77 months of bond return data, the regression in (2) would use 77 day 0 bond returns to estimate the coefficient of unexpected inflation γ_0 . If the announcement of the CPI affects bond prices, γ_0 should be positive. If the bond market is able to use sources other than the official announcement to find out about the inflation that occurred in January, there should be no adjustment of bond prices as a result of the official announcement on February 15, and γ_0 should equal zero.

As a conventional test of capital market efficiency, we could estimate the reaction, if any, of bond prices on the days following the CPI announcement. Defining R_{t+k} as the bond return on the $(k + 1)$ st day following the announcement of the CPI and \hat{u}_t as the unexpected component of the corresponding CPI, the regression

$$R_{t+k} = \alpha + \gamma_k \hat{u}_t + \epsilon_{t+k} \quad (3)$$

can be used to estimate any reaction of bond prices that occurs after day 0. If the coefficients γ_k are nonzero, it implies that bond prices are slow to react to the CPI announcement.

Similarly, by looking at the regression of bond returns for the $(k - 1)$ st day prior to the CPI announcement R_{t-k} we could estimate the

⁷ The persistent positive autocorrelations of the inflation rates in table I indicate that current unexpected inflation increases expectations of inflation for many future periods.

reaction of bond prices to unexpected inflation *prior* to the announcement:

$$R_{t-k} = \alpha + \gamma_{-k}\hat{u}_t + \epsilon_{t-k}. \quad (4)$$

For example, if there are about 20 trading days per month and about 10 trading days between the end of the month and the subsequent CPI announcement, there are about 30 trading days between the beginning of January and the announcement of the January CPI. Therefore, we could estimate up to 30 different regression coefficients γ_{-k} to measure the timing of the reaction of bond prices to the unexpected inflation rate. If bond traders can infer some of the new information about inflation before the announcement, some of the coefficients γ_{-k} should be positive. For example, suppose that inflation occurs throughout January that is not predictable from the information available at the end of December. Bond prices might increase at the same time that the unexpected inflation occurs, because bond traders can observe the simultaneous unexpected increases in the prices of a variety of consumption goods (i.e., there is little confusion about changes in relative prices versus overall inflation). If this scenario is typical, the coefficients representing the days when the inflation occurs, γ_{-30} to γ_{-11} , should be positive. If bond traders can infer the inflation rate as it occurs, the subsequent announcement by the Central Bureau of Statistics is redundant and the coefficients γ_{-10} to γ_5 should be zero.

The regressions in (2), (3), and (4) focus on the effect of unexpected inflation on daily bond returns. It is likely that expected inflation also affects bond returns, since the expected real return to holding the bond is the expected nominal return minus the expected inflation rate. The autocorrelations in table I indicate that the expected CPI inflation rate varied substantially during the 1970–79 period. Therefore, we include a measure of the daily expected inflation rate (the prediction of monthly inflation based on the 60 most recent months of CPI data divided by the number of trading days in the month) in the regressions to reflect the fact that expected bond returns should be higher when expected inflation rises. For example, for the announcement day returns, equation (2) would be modified by including a measure of expected inflation, \hat{p}_t ,

$$R_t = \alpha + \beta\hat{p}_t + \alpha_0\hat{u}_t + \epsilon_t. \quad (5)$$

Since expected and unexpected inflation are uncorrelated, the estimate of the coefficient of unexpected inflation γ_0 should be unaffected. However, to the extent that bond returns are higher when expected inflation is high (so that β is positive), adding the expected inflation variable in (5) will decrease the variance of the errors and

improve the precision of our estimates of the effects of unexpected inflation. In effect, we are modeling the nonstationarity of inflation that was discussed in Section IIIA above.

If expected nominal returns are positively related to expected inflation (which is presumably the motivation for buying an indexed bond), the coefficient of expected inflation should be positive, $\beta > 0$. If the expected real returns to indexed bonds are constant over time, the coefficient of expected inflation should equal unity, $\beta = 1.0$.

Instead of estimating many separate regressions of the type illustrated by (2), (3), (4), and (5), we combine all of these coefficients into a multiple regression:

$$R_t = \alpha + \beta \hat{p}_t + \sum_{k=30}^{-5} \gamma_{-k} \hat{u}_{t+k} + \epsilon_t. \quad (6)$$

The variable \hat{p}_t is used to measure the effect of expected inflation on daily bond returns. Two values of the expected inflation variable are used each month. For the trading days after the CPI announcement, \hat{p}_t is equal to the one-step-ahead forecast from a time-series model like those estimated in table 2. The model is estimated using the 60 most recent monthly inflation rates, and the prediction of monthly inflation is divided by the number of trading days in the month. For the trading days to and including the CPI announcement, \hat{p}_t is equal to the two-step-ahead forecast based on 60 months of data not including the current value of the CPI. This prediction of monthly inflation is also divided by the number of trading days in the month.⁸

For example, the December CPI is not announced until January 15; therefore, until January 16 we base our prediction of January's inflation on the 60 months of data up through November. If this two-step-ahead prediction of inflation is .04 (4 percent per month) and there are 20 trading days in January, $\hat{p}_t = .04/20 = .0020$ for each of the trading days from January 1 through January 15. As of January 16 the December CPI is known, so we use the new one-step-ahead forecast of inflation. Suppose the new forecast is .03 (3 percent per month); then $\hat{p}_t = .03/20 = .0015$ for each of the trading days from January 16 through January 31. The expected inflation variable is transformed into units of trading days to be comparable with the bond returns.

The variable \hat{u}_t equals the unexpected component of the CPI on the day after the announcement and zero otherwise. Thus, on February

⁸ We also considered regression specifications that allowed the expected bond return to vary by the day of the week or by the number of days since the last trade. We also allowed the variability of bond returns to be related to the number of days since the last trade. None of these specifications improved the statistical properties of the regressions reported in the text.

$16 \hat{u}_t$ equals the unexpected inflation rate for January based on the one-step-ahead forecast of inflation using 60 months of data including December's CPI. The multiple regression in (6) is a convenient way to estimate unexpected inflation coefficients for up to 30 trading days prior to the announcement (γ_{-30}) and up to 5 trading days after the announcement (γ_5). For the days between the beginning of January and the announcement of December's CPI on January 15, we use a measure of unexpected January inflation based on the two-step-ahead prediction from November. Thus, for days -30 to -20 , the expected inflation variable does not use information about the previous month's CPI (which is not yet announced).

Since there are approximately 20 trading days per month, the coefficients γ_{-30} to γ_{-11} represent daily responses to unexpected inflation during the period when the inflation occurs, the coefficients γ_{-10} to γ_{-1} represent responses of bond prices between the end of the month when the inflation occurs and the subsequent announcement, the coefficient γ_0 measures the response of bond prices on the day after the announcement, and the coefficients γ_1 to γ_5 represent any response of bond prices during the next 5 trading days after the announcement. The total effect of unexpected inflation on bond prices is measured by adding up the coefficients γ_{-30} to γ_5 .

C. The Speed of Reaction of Bond Prices to Unexpected Inflation

Table 5 contains estimates of regressions similar to (6) for the 1970–79 sample period and the three subsamples, 1970–71, 1974–75, and 1975–79. To economize on the number of parameters to be estimated, the results in table 5 impose the constraint that the coefficients of unexpected inflation are equal within each 5-day interval from -30 to -26 , -25 to -21 , and so forth. The coefficient for the announcement day, γ_0 , is estimated separately.

The last column in table 5 measures the total response of bond returns to unexpected inflation by summing the weekly coefficients, multiplying this sum by 5.0, and adding the announcement day coefficient, γ_0 . This estimate of the total response of bond returns to unexpected inflation helps put the magnitude of the announcement day coefficient in perspective. Even though there is a statistically significant announcement day effect in table 5, the announcement day reaction of bond prices is only a small part of the reaction to unexpected inflation.

Several things are notable about the results in table 5. First, the results for the January 1970 to August 1971 subperiod are weak compared with the other two subperiods, or with the overall sample,

TABLE 5

DAILY INDEXED BOND RETURNS AND UNEXPECTED INFLATION: BY WEEKS, FROM THE BEGINNING OF THE SAMPLING PERIOD THROUGH THE ANNOUNCEMENT OF THE CPI

(Expected and Unexpected Inflation Based on the Last Announced CPI)

$$R_t = \alpha + \beta \hat{\pi}_t + \sum_{k=30}^{-5} \gamma_{-k} \hat{u}_{t+k} + \epsilon_t \quad (6)$$

| PERIOD | SAMPLE SIZE, T | UNEXPECTED INFLATION COEFFICIENTS, γ_{-k} FOR k DAYS BEFORE THE CPI ANNOUNCEMENT | | | | | | | | | | | ESTIMATES OF THE TOTAL RESPONSE OF BOND RETURNS TO UNEXPECTED INFLATION* | |
|-----------------|----------------|---|-----------------|-----------------|----------------|-----------------|-----------------|----------------|-----------------|-----------------|-----------------|-----------------|--|----------------|
| | | $\alpha \cdot 10^3$ | β | -5 to -1 | 0 | 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | 26-30 | S(ϵ) | R ² | |
| 1/4/70-1/31/79 | 1,508 | .605 (.339) | .424 (.208) | -.010 (.015) | .081 (.033) | .020 (.015) | .015 (.015) | .042 (.015) | .027 (.016) | .033 (.015) | -.024 (.019) | .0074 | .017 | .600 (.211) |
| 1/4/70-8/31/71 | 402 | .529 (.105) | -.309 (.250) | .012 (.013) | .045 (.029) | .006 (.013) | .011 (.013) | .023 (.013) | -.009 (.014) | -.015 (.014) | -.013 (.016) | .0016 | .027 | .090 (.185) |
| 1/3/74-6/30/75 | 329 | 2.333 (1.303) | -.582 (.606) | -.029 (.024) | .040 (.050) | -.006 (.025) | .012 (.027) | .019 (.024) | -.039 (.024) | -.084 (.027) | -.022 (.065) | -.0075 | .058 | .528 (.450) |
| 10/2/75-1/31/79 | 777 | .907 (.828) | .423 (.467) | -.004 (.026) | .101 (.058) | .024 (.027) | -.009 (.027) | .057 (.027) | .020 (.027) | .014 (.024) | -.024 (.026) | .0090 | .013 | .496 (.353) |

NOTE.—Standard errors are in parentheses. S(ϵ) is the standard deviation of the residuals. R² is the coefficient of determination. $\hat{\pi}_t$ is the forecast of the CPI inflation rate from an ARIMA model estimated using the most recent 60 months of data. $\hat{\pi}_t$ is divided by the number of trading days in the month. \hat{u}_t is equal to the unexpected inflation rate on the day the CPI is announced and zero otherwise. Except for the announcement day coefficient, γ_{-k} , the 30 lead coefficients and five lag coefficients are estimated subject to the constraint that the coefficients in each 5-day interval ("week") are equal. The expected inflation variable $\hat{\pi}_t$ is based on the last announced value of the CPI. From January 1 to January 15, $\hat{\pi}_t$ is based on the two-step-ahead prediction using November's CPI. After January 15, the December CPI is known, so $\hat{\pi}_t$ is based on the one-step-ahead prediction using December's CPI.

* The total effect of unexpected inflation on bond returns is calculated by summing the "weekly" coefficients, multiplying this sum by 5, and adding the announcement day coefficient. For the total sample the estimate is $.5(1) = .010 + .020 + .015 + .042 + .027 + .083 + .024 + .081 = .482$.

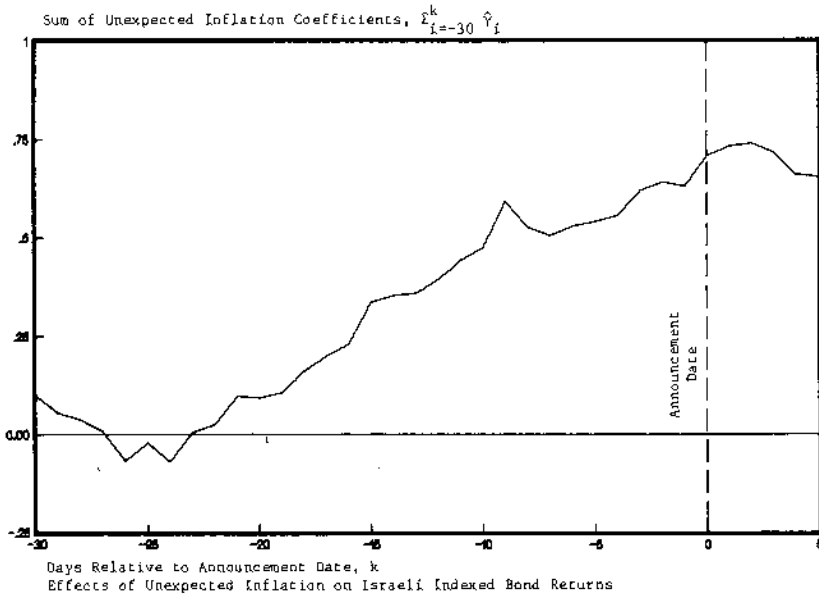


FIG. 1.—Cumulative effects of unexpected inflation, January 1970–January 1979

so most of the subsequent remarks do not apply to the first subperiod. Second, the effect of expected inflation on nominal bond returns is positive for the total sample period. More important, the coefficients for the unexpected inflation variables in table 5 are generally positive, and some are several standard errors above zero. For example, for the total sample of 1,508 daily observations, the announcement day coefficient is .081 with a standard error of .033, and the estimates of γ_{-11} to γ_{-15} and γ_{-21} to γ_{-25} are more than two standard errors above zero. These estimates suggest that about 14 percent of the total effect of unexpected inflation on bond returns occurs on the day the CPI is announced, while about 86 percent of the effect occurs during the 11–25 days prior to the announcement. In other words, most of the adjustment occurs within the month the inflation actually occurs, but there is still a substantial additional adjustment on the announcement day. This pattern is similar for the subperiods.

The timing of the reaction of bond prices to unexpected inflation is illustrated in figure 1. This graph is based on an unconstrained estimate of equation (6) using 1,508 daily observations between January 1970 and January 1979. Figure 1 shows how the effects of unexpected inflation on bond prices accumulate during the 6 weeks from the beginning of the month up through the announcement of the CPI. This plot is the cumulative sum of the coefficient estimates in

equation (6), $\sum_{i=k}^k \hat{\gamma}_i$, where $k = -30, \dots, 5$. The cumulative sum rises smoothly from day -23 up to day -9 , where it is approximately .59. There is no additional change until the announcement day, when it rises to about .71. Thus, an unexpected 1.0 percent increase (decrease) in the CPI is associated with a 0.71 percent increase (decrease) in bond prices during this period of 30 trading days. It appears that about 85 percent of the adjustment of bond prices occurs between days -23 and -9 , when the inflation occurs, and the remaining 15 percent adjustment occurs immediately after the CPI is announced. The two standard error range around the cumulative sum at day 0 is from 0.33 to 1.09.

IV. Effects of Measurement Error in Expected and Unexpected Inflation

Our measure of unexpected inflation is a proxy for the new information that becomes available to the bond market between the beginning of a month and the announcement of that month's CPI. The unexpected inflation measure is merely a proxy because the time-series prediction model may not fully capture the bond market's information at the beginning of each month. Several types of errors could affect the estimates in figure 1 and in table 5. Some extreme cases help put the previous results in perspective.

First, suppose that the bond market has perfect foresight, so that the actual inflation rate is perfectly predictable from information available to bond traders, although it is not perfectly predictable from past inflation rates. In this case, the distinction between expected and unexpected inflation is meaningless, and the statistical model used to measure unexpected inflation would be a poor proxy for the new information that becomes available to the bond market. There should be no reaction of bond prices to the announcement of the CPI. Thus, the fact that bond prices seem to be positively related to our measure of unexpected inflation on the day after the announcement indicates that our statistical model does proxy for the unexpected component of the CPI.

Another question that arises concerns the effects of random or systematic measurement errors in the calculation of the CPI. Suppose that the level of the CPI contains a serially random measurement error each month (possibly due to sampling error in collecting a sample of consumer goods prices). Since the payoff on indexed bonds is linked to the level of the CPI in the month of maturity, random sampling errors in the current month should not affect bond traders' expectations of the future level of the CPI. In this case, any measure of unexpected inflation would contain two parts, one that represents

new information about current inflation and future expected inflation and a second part that is pure measurement error. The larger the variance of the measurement error relative to the variance of the underlying unexpected inflation rate, the lower will be all of the estimates of the unexpected inflation coefficients. In effect, this is a form of the errors-in-variables problem. In this case, all of the unexpected inflation coefficients will be biased toward zero, but the relative magnitudes should not be affected. Therefore, the timing of the response of bond prices to unexpected inflation would be correctly measured by the coefficients in figure 1, for example, but the overall magnitude of the effect would be underestimated. Given that the estimates of many of the unexpected inflation coefficients in table 5 are more than two standard errors greater than zero, it seems that the problem of random measurement errors in the CPI is not serious.

It is possible that current errors in the CPI could have a permanent effect on future levels of the CPI.⁹ A large number of commodity and service prices are controlled by the government and are automatically adjusted to reflect the current level of the CPI. Also, many labor and rental contracts are indexed to the CPI or to the U.S. dollar. Thus, it is possible that random sampling error could cause a permanent change in the CPI. Since the terminal payoff on indexed bonds is linked to the CPI, it is possible that bond prices would react to the CPI announcement, even if "unexpected inflation" were due to sampling errors by the Central Bureau of Statistics. Thus, it is possible that bond prices fully reflect the "true" inflation rate at the time when the inflation occurs, and the subsequent reaction of bond prices when the CPI is announced merely reflects the sampling error of the government agency. From this perspective, the proportion of the reaction of bond prices to unexpected inflation that occurs after the announcement is an upper bound on the extent to which bond prices fail to reflect the "true" inflation rate.

Another source of error in our estimates of expected and unexpected inflation concerns the time at which estimates of expected inflation are revised. Recall that in table 5 two different estimates of expected inflation are used within each month. For the days from January 1 through January 15, the two-step-ahead forecast of inflation based on the November CPI is used. Since the December CPI is available on January 16, the remaining days in the month use the one-step-ahead forecast. This procedure is conservative in the sense that it assumes that bond traders know nothing about the December CPI until it is announced on January 15. Based on the estimates of the

⁹ We would like to thank Michael Mussa for this argument.

response of indexed bond prices to unexpected inflation in table 5, it seems that bond traders know most of the information about the December CPI by January 1. Therefore, the estimates of expected and unexpected inflation from January 1 through January 15 in table 5 probably use less information than the market.

To illustrate a different assumption about the information available to bond traders, table 6 contains estimates equivalent to those in table 5, except that the one-step-ahead forecast of January's inflation is used for each day in the month. In other words, the regressions in table 6 assume that bond traders know the December CPI as of January 1. Interestingly, the estimates of the coefficients of both expected and unexpected inflation are larger in table 6 than the corresponding estimates in table 5. For example, for the total sample period January 1970 through January 1979 the estimate of the coefficient for expected inflation increases from .424 to .648 and the estimate of the total effect of unexpected inflation increases from .600 to .720. Although the magnitude of these estimates increases, the pattern of timing of the effect of unexpected inflation on bond returns is virtually the same as in table 5. Approximately 84 percent of the response occurs from 11 to 25 trading days prior to the announcement, and about 11 percent occurs on the day after the announcement.

We interpret the differences in the results between tables 5 and 6 as an illustration of the effects of measurement errors in our proxies for expected and unexpected inflation. Recall that the only differences in the regressions concern the proxies for expected and unexpected inflation during the first half of each month. In table 5 we assume that the previous month's CPI is completely unknown until it is announced. In table 6 we assume that the market knows the previous month's CPI by the end of the month when the prices are measured. The estimates of expected and unexpected inflation that are used in table 6 contain more current information than the estimates in table 5. If the bond market really does have such current information about inflation, the proxies used in table 5 contain measurement errors, and it is not surprising that the coefficient estimates for both expected and unexpected inflation are closer to zero. Of course, it is well to reiterate that the pattern of timing of the response of bond prices to unexpected inflation is unaffected.¹⁰

¹⁰ Given that most of the reaction of bond prices to unexpected inflation occurs between days -20 and -10 , we also considered the possibility that the period between CPI announcements was the relevant period of analysis. This would be from day -20 to day 0. The results from estimating this specification, constraining the coefficients for days -30 to -21 to equal zero, are very similar to the results in tables 5 and 6 and fig. 1.

TABLE 6

DAILY INDEXED BOND RETURNS AND UNEXPECTED INFLATION: BY WEEKS, FROM THE BEGINNING OF THE SAMPLING PERIOD THROUGH THE ANNOUNCEMENT OF THE CPI

(Expected and Unexpected Inflation Based on the Previous Month's CPI)

$$R_t = \alpha + \beta \hat{\pi}_t + \sum_{k=1}^3 \gamma_k \hat{\pi}_{t+k} + \epsilon_t \quad (6)$$

| PERIOD | SAMPLE SIZE, T | α (t) ^a | β | UNEXPECTED INFLATION COEFFICIENTS, γ_{k-1} FOR k DAYS BEFORE THE CPI ANNOUNCEMENT | | | | | | | | | | | R ² | S(ϵ) | ESTIMATES OF THE TOTAL RESPONSE OF BOND RETURNS TO UNEXPECTED INFLATION* |
|----------|----------------|---------------------------|----------------|--|----------------|-----------------|-----------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|------|----------------|-----------------|--|
| | | | | -5 to -1 | 0 | 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | 26-30 | | | | | | |
| 1/4/70- | 1,508 | .328 (.339) | .648 (.216) | -.009 (.015) | .082 (.033) | .014 (.015) | .016 (.015) | .046 (.015) | .031 (.015) | .044 (.016) | -.015 (.020) | -.015 (.020) | -.015 (.020) | .021 | .0074 | .720 (.218) | |
| 1/31/70- | 402 | .368 (.108) | .331 (.272) | .006 (.013) | .041 (.029) | -.006 (.013) | .008 (.013) | .032 (.013) | .002 (.014) | -.016 (.014) | -.007 (.015) | -.007 (.015) | -.007 (.015) | .032 | .0016 | .145 (.181) | |
| 8/31/71- | 929 | .647 (1.407) | .266 (.691) | -.019 (.025) | .034 (.050) | -.002 (.025) | .019 (.026) | .029 (.024) | .045 (.024) | -.007 (.024) | .007 (.024) | .007 (.024) | .007 (.024) | .053 | .0075 | .797 (.381) | |
| 8/30/75- | 777 | .492 (.773) | .707 (.449) | -.002 (.026) | .102 (.058) | .020 (.026) | -.002 (.026) | .062 (.027) | .023 (.027) | .023 (.028) | -.022 (.028) | -.022 (.028) | -.022 (.028) | .015 | .0090 | .612 (.364) | |

NOTE.—Standard errors are in parentheses. S(ϵ) is the standard deviation of the residuals. R² is the coefficient of determination. $\hat{\pi}_t$ is the forecast of the CPI inflation rate from an ARIMA model estimated using the most recent 60 months of data. $\hat{\pi}_t$ is divided by the number of trading days in the month. $\hat{\pi}_t$ is equal to the unexpected inflation rate on the day the CPI is announced and zero otherwise. Except for the announcement day coefficient, γ_{k-1} , the 30-lag coefficients and five-lag coefficients are estimated subject to the constraint that the coefficients in each 5-day interval ("week") are equal. The expected inflation variable $\hat{\pi}_t$ is based on the CPI for the previous month. For each of the days in January, ϵ_{t-k} is based on the one-step-ahead prediction using December's CPI. In contrast with table 5, the estimates in this table assume that December's CPI is known on January 1 even though it is not officially announced until January 15.

* The total effect of unexpected inflation on bond returns is calculated by summing the "weekly" coefficients, multiplying this sum by 5, and adding the announcement day coefficient. For the total sample the estimate is $0.38 + .009 + .034 + .016 + .046 + .031 + .044 + .033 + .082 = .720$.

V. Summary and Conclusions

The market for consumer-price-indexed bonds provides an opportunity to study the extent to which available information is reflected in security prices. We examine the timing of the reaction of bond prices to the occurrence and subsequent announcement of inflation in the CPI. Most of the reaction (about 85 percent) occurs from 2 to 5 weeks before the announcement, which is the period when the inflation occurs. There is no discernible reaction of bond prices during the 2 weeks from the end of the month when commodity prices are measured until the announcement of the price index. There is a significant reaction of bond prices on the day after the CPI is announced (about 15 percent of the total reaction). Thus, it seems that bond prices reflect most of the information about inflation at the same time that the inflation occurs, but bond prices do not fully reflect the behavior of inflation, since there is a reaction to the formal announcement of the CPI.

The evidence in this paper has implications for the theoretical literature on asset pricing. Some models (most notably Grossman [1976]) show the existence of equilibrium prices that reflect all traders' private information, even when information varies across traders and no trader collects information already available to others. To the extent that the CPI is just an aggregation of individual commodity prices, the announcement of the CPI does not add to the set of information available to all investors. Since bond prices react to the CPI announcement, they do not fully reflect the aggregate information available to all investors.

Nevertheless, the evidence in this paper indicates that about 85 percent of the reaction of bond prices occurs during the month when consumer goods prices are changing. Interestingly, there seems to be no additional reaction between the end of the month and the announcement of the CPI 2 weeks later. Thus, even though bond prices do not completely reflect inflation as it occurs, it seems that most of the information about inflation is reflected in bond prices very quickly. This finding has implications for the monetarist rational expectations business-cycle models, such as Lucas (1973, 1975) and Barro (1980). In these models, current economy-wide data (such as the inflation rate) are not available to individuals, so their decisions are based on inferences about economy-wide data from observations in local markets (such as individual commodity prices). Consequently, people confuse relative price changes with overall inflation. Our findings suggest that this confusion is minimal, as most of the learning about unexpected inflation takes place as soon as inflation occurs. At the least, the results in this paper raise questions about whether mis-

perceptions of inflation are large enough to explain substantial fluctuations in real activity.

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