Modeling the Formation of Price Expectations: A Bayesian Approach

By JOHN CASKEY*

Twice a year since 1947, Joseph Livingston, a financial columnist in Philadelphia, has recorded the inflation forecasts of professional economists. The surveyed economists generally underpredicted inflation from 1968 through 1979. This paper provides an empirical model of the formation of these economists' price expectations. The estimated model indicates that a convincing explanation for the Livingston inflation forecast series is that the economists had prior beliefs about the inflation process that they modified as they experienced the higher and more volatile inflation of the 1970's. This explanation is particularly appealing since it does not rely on statistically irrational behavior on the part of the forecasters.

A popular competing explanation for the underprediction of inflation during the 1970's argues that the Livingston forecasters either ignored available relevant information or processed that information poorly.[1] Many have noted that the Livingston survey participants had no monetary incentive to provide the best forecast possible.

While one cannot dismiss this alternative explanation, there are good grounds for seeking theories that do not rely upon either insufficient information sets or upon poor processing of available data. For example, commercial forecasters, with a monetary incentive to provide accurate forecasts and with large data banks, did not forecast significantly better than did the Livingston group. A comparison between the Livingston eight-month-ahead inflation forecasts and the comparable *CPI* inflation predictions of Data Resources, Incorporated (DRI) from 1973 to April, 1982 indicates the DRI's forecasts were no better than the mean forecast of the Livingston panel.[2] The mean absolute error of the DRI forecast was 3.22 percent while the mean absolute error of the Livingston forecasts was 3.2 percent. The DRI forecasts, the mean Livingston forecasts, and the actual

*Washington University, St. Louis, MO 63130. This paper was taken from research done for my dissertation at Stanford University. I am grateful for the advice that I received from the members of my dissertation committee: Robert E. Hall, Ben Bernanke, and Tom MaCurdy; as well as from a former fellow student, Tom Mroz. Many other people also improved this paper through their comments. I am particularly indebted to Don Cox, Paul Evans, Ed Greenberg, and two anonymous referees.

[1] For one example, see Douglas Pearce (1979).

[2] Jean Slamen, of the Federal Reserve Bank of Philadelphia, provided me with the Livingston data as well as with details on the methodology of the survey. In every survey, Livingston requests a forecast of the 6-month and 12-month-ahead *CPI* levels of a June or December starting date. On average, about 50 economists participate in each survey. They have diverse affiliations: the nonfinancial business sector, academic posts, financial institutions, and the Federal Reserve System. Livingston obtains a forecast by mailing the participants a one-page questionaire the month before the publication date. He publishes the survey results in June and December of each year. The questionaire includes the most current data available on the forecasts variables. In the case of the December publication of the *CPI* forecast, this is usually the September data but is sometimes the October data. John Carlson (1977) concludes that the participants base the forecasts on information that would be available one month before publication, i.e., in April or October. Before publication, Livingston sometimes adjusts the forecasts to take account of new information that has become available and that he thinks would have altered the forecasts of the participants. Rather than try to make similar adjustments or to use Livingston's published forecasts, I follow Carlson in working with the unadjusted forecasts and in treating them as 8 and 14-month forecasts.

My source of the DRI data is past issues of *The Data Resources Review of the U.S. Economy*, published from 1972 to the present. I am grateful to Katherine Kush of DRI for providing me with a number of these forecasts. Each issue of this monthly publication includes forecasts of the annual rates of change in the *CPI* for each quarter of the next year to year and a half. The DRI forecast that I used for comparison with the Livingston data was the forecast made at the end of April or October for the third and fourth quarters of the year, or first and second quarters of the next year, respectively. From these quarterly forecasts, I calculated the implicit 8-month DRI inflation forecast.

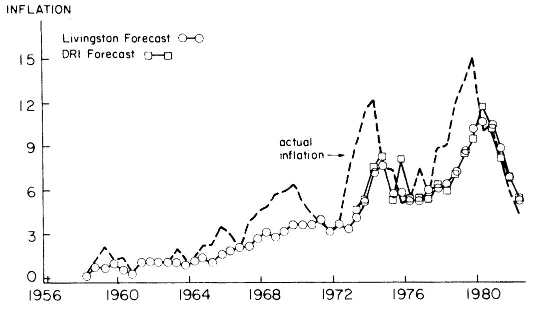

FIGURE 1. LIVINGSTON AND DRI FORECASTS

inflation rate are graphed in Figure 1. The similarity between the Livingston forecasts and those of DRI are remarkable. Since DRI is in the business of selling its forecasts, it has an obvious incentive to provide accurate forecasts. Furthermore, it had access to relevant data when making its forecasts. Moreover, these comparative observations about DRI's forecasts would apply equally well to the forecasts of the other major commercial forecasting establishments. Stephen McNees (1975; 1979; 1981) has done extensive comparisons of the performances of these forecasting services and has found that they all have similar records.

The model in this paper assumes that the Livingston forecasters processed new information in a statistically optimal manner given their beliefs about the inflation process. The statistical model is Bayesian since it represents the forecasters' subjective learning. Since I assume that the Livingston forecasts are the outcome of a specified forecasting and coefficient updating procedure, the missing element is the starting beliefs of the forecasters which would generate the observed series. I estimate the parameters of the Livingston economists' prior beliefs with maximum likelihood techniques.[3]

The results from this approach are very encouraging. I find that a credible set of 1958 prior beliefs about the inflation process combined with a Bayesian updating procedure accounts quite well for the Livingston forecasts. Moreover, the evolution of the coefficients over time agrees reasonably well with conventional ideas on the development of economists' beliefs about the determinants of inflation. For example, the estimated model indicates that the Livingston economists placed much more weight on recent inflation and monetary growth rates in predicting inflation at the close of the 1970's than they did in the early 1960's.

I. A Bayesian Learning Model of the Formation of Price Expectations

Before presenting a formal model of the formation of price expectations, it is helpful to first consider an informal description of the process. If asked to forecast the inflation rate in the United States over the next six months to a year, a group of economists might engage in the following thought process. From experience, reported research findings, and conventional wisdom, they believe that there is a set of variables, say, current inflation, monetary growth, fiscal policy, and aggregate demand that are good indicators of future inflation rates. They obtain information on the selected set of variables and on past correlations between these variables and subsequent inflation rates. The economists also ask themselves whether these observed past correlations should hold for

[3]This approach differs substantially from previous empirical studies of the formation of price expectations. I attempt to explain why the Livingston group forecast as it did. Previous research has focused on how the forecasts relate to other economic variables. Thus, while I explicitly model a learning and forecasting process, other researchers regress the Livingston price forecasts on variables that might influence price expectations. The estimated coefficients are then taken to identify the variables that the Livingston group used in forecasting prices and to indicate how much weight they placed on the variables. For example, see the papers by Stephen Turnovsky (1970), Jacob Frenkel (1975), K. Holden and D. A. Peel (1977), Kajal Lahari (1977), Rodney Jacobs and Robert Jones (1980), Donald Mullineaux (1980), David Resler (1980), Stephen Figlewski and Paul Wachtel (1981), and Edward Gramlich (1983). My comments on the methodology of this research must be qualified for three of these papers: Jacobs-Jones focus on the effect of changes in the price level, in the inflation rate, and in the acceleration of inflation; Mullineaux permits the coefficients to vary over time; and Figlewski-Wachtel obtain cross-sectional estimates over time.

the future. They might believe that the relationship between the selected variables and subsequent inflation rates has changed at a constant rate over time. If so, they give more weight to more recent correlations. They might think that sudden new economic policies, such as the imposition of sharp binding price controls, mean that old relationships contain no information relevant to future ones. In this case, they forecast on the basis of a best guess about future inflation without the benefit of observing correlations under this changed economic system. In all cases, the forecasters will not be bound by their initial beliefs. Rather, as they gain more experience with the economy, they may change their ideas about time-series relationships.

An outside observer trying to model the formation of expectations over time must then capture the major elements of above process. The Bayesian model in this paper takes an important step in that direction. It explicitly recognizes that the economists began forecasting with specific prior beliefs about the inflation process. It also permits the forecasters to learn over time and to modify their initial beliefs. In this implementation of the Bayesian learning mode, however, I impose an important restriction. I assume that the forecasters believed the relationship between the variables in the information set and subsequent inflation rates to be stable over the relevant period. While the validity of this assumption may be challenged, it is nevertheless worthwhile to begin with this restricted model and to see how well it can explain the observed price expectations on its own.[4]

The Bayesian model of the formation of Livingston price expectations has four elements: the inflation process in which the group believed, the group's prior beliefs about the parameters of that process, the statistical rule that the group used in updating its beliefs about the coefficients, and the group's forecasting rule. In this section, these elements are specified. In the next section, from the observed Livingston forecasts and based on an assumed information set, I estimate the parameters of the Livingston group's prior beliefs about the coefficients in the inflation process.

The model of the formation of price expectations assumes that the Livingston group believed that the one-period-ahead inflation rate had the time-series representation

$$(1) \qquad y_t = X_{t-1}B + e_t \qquad e \sim N(0,\sigma^2)$$

where y is the actual inflation rate, X is the k element row vector of observations on the right-hand side variables which includes lagged dependent variables, and e is the disturbance term.[5] The y_0 is assumed to be fixed. The time subscript, $t-1$, indicates that these are variables that could have been known in the earlier period. Thus X_{t-1} could also include variables from two periods before or more.

A multivariate normal distribution for the coefficients in equation (1) represents the initial beliefs of the Livingston forecasters about the inflation process. It is convenient to write the prior distribution for B as

$$(2) \qquad B \sim N\left(B_0, \sigma^2 V_0^{-1}\right),$$

and $\sigma^2 V_0^{-1} \equiv Q^{-1}$. In what follows, V_0^{-1} is referred to as the prior covariance matrix, although it should be remembered that it is actually merely proportional to the true co-

[4]A completely general model with unrestricted parameter variation cannot be estimated. One could, however, somewhat relax the stability assumption. In my dissertation, I modify the model presented here in order to permit one abrupt change in the Livingston group's prior as a consequence of new information from outside of the information set. I used this modified model in a study of the impact on the group's price expectations of the Fed's October 1979 announcement. However, with semiannual price forecast observations and with an event so near the end of the sample period, it was necessary to impose severe and probably distorting restrictions on the parameters in order to obtain enough degrees of freedom to estimate them. Alternatively, one could permit a smooth discounting of the information content of old data. One cannot, however, estimate both this rate of discount as well as the prior covariance matrix for the parameter B without imposing arbitrary restrictions.

[5]The presence of lagged dependent variables in the information set justifies serial independence. One could, however, estimate the model with a serially correlated error term, though this would add several parameters.

variance matrix, Q^{-1}. The B_0 is the Livingston group's prior beliefs about the value of B. The matrix V_0^{-1} is a measure of their uncertainty in their prior beliefs relative to σ^2.

I assume that the Livingston group forecast inflation on the basis of their evolving beliefs about B. The Kalman filter, which in its usual formulations assumes σ is known, is the recursive statistical rule that represents the updating of beliefs about B. As Richard Meinhold and Nozer Singpurwalla (1983) and others have explained, if σ is known, the Kalman filter is a convenient method for obtaining the parameters of the normally distributed posterior distribution on B conditional on new y and X observations.

As is shown generally in Arnold Zellner (1971) (or, for this specific case, in my dissertation), although σ is not known, one can employ the Kalman filter to represent the Livingston group's updating of their beliefs about B. If σ is unknown, one models a Bayesian learning rule by specifying a prior distribution for σ and deriving a joint posterior distribution for B and σ conditional on the new y and X observations. Assuming that σ has an inverted *gamma* distribution, the marginal posterior distribution for B will be multivariate t-statistic. The mean, B_m, of this posterior distribution represents the Livingston group's new beliefs about B. This mean is equal to the mean of the normal distribution on B conditional on a known σ.

Each period the Livingston group obtains new information on inflation and on other variables in its information set. They use this new information to update their beliefs about B according to the three recursive equations of the Kalman filter:

$$(3) \qquad \hat{B}_t = \hat{B}_{t-1} + K_t(y_t - X_{t-1}\hat{B}_{t-1})$$

$$(4) \qquad \hat{V}_t^{-1} = \hat{V}_{t-1}^{-1} - K_t X_{t-1}\hat{V}_{t-1}^{-1}$$

$$(5) \qquad K_t = \sigma^2\hat{V}_{t-1}^{-1}X'_{t-1} \times \left[X_{t-1}\sigma^2\hat{V}_{t-1}^{-1}X'_{t-1} + \sigma^2\right]^{-1} = \hat{V}_{t-1}^{-1}X'_{t-1}\left[X_{t-1}\hat{V}_{t-1}^{-1}X'_{t-1} + 1\right]^{-1},$$

where $\hat{B}_{t-1}$ and $\hat{V}_{t-1}$ are the Livingston group's beliefs in period $t-1$ about B and a measure of its uncertainty relative to σ^2. The $\hat{B}$ is a k element column vector. The $\hat{V}$ is a $k \times k$ matrix and K is the k element column vector known as the Kalman gain.

Assuming that the Livingston group has a quadratic loss function, its inflation forecast is

$$(6) \qquad yp_{t+1} = X_t\hat{B}_t.$$

One observes the Livingston predictions, yp. If it is assumed that the predictions are the outcome of the Bayesian coefficient updating procedure specified in equations (3)–(5), the only missing elements behind the formation of the group's expectations are the group's information set, X, and the group's starting beliefs about B. If one makes reasonable assumptions about the components of X, one can then estimate the starting beliefs of the Livingston group about the inflation process.[6]

In empirically implementing this model of the formation of the Livingston group's price expectations, the individual's thought processes cannot, of course, be fully replicated. First, I will likely omit some of the minor variables used in their forecasting process. Second, I estimate the model using the revised data that is now available, not the data that was available to the Livingston panel at the time of each forecast. Third, the model assumes that the Livingston group believed B in equation (1) to be constant. In sum, these factors introduce an error term into the equality between the observed Livingston forecasts and the forecasts that my replication of their expectation process produces.

[6]As discussed in my dissertation, one cannot estimate the parameters of a prior distribution on σ since one does not observe the variance of the distribution on the y forecasts. One could, however, hypothesize that the variance across the survey respondents in each period bears a particular relation to the variance on the posterior distribution of y, where y_t is distributed $N(X_{t-1}\hat{B}_{t-1}, X'_{t-1}V_t^{-1}X_{t-1} + w^2)$. Unfortunately, it is unclear what the particular relation would be. Moreover, such an approach is philosophically at odds with my implicit treatment of the Livingston forecasters as a homogeneous group.

Therefore, I rewrite (6) as

$$(7)\qquad yl_t = yp_t + u_t \qquad\qquad u \sim N(0, \sigma_u^2),$$

where yl is the observed Livingston inflation forecast. The error term is assumed to be normally distributed and serially uncorrelated: we expect that the impact of omitted elements would be roughly constant over time, and the imperfect modeling introduces no clear bias into the error.

The estimation procedure seeks the B_0 and V_0^{-1} that maximize the likelihood of the log-likelihood function based on (7), which is

$$(8)\quad \operatorname{Log} L = (-n/2)\log(\sigma_u^2) - (1/2\sigma_u^2)(yl - yp)'(yl - yp) + \text{constant}.$$

With four variables in X, however, this involves estimating fifteen parameters. Consequently, to gain a few additional degrees of freedom without unduly restricting the model, I assume that the precision matrix, V_0, can be parameterized by a one-factor scheme. That is, I rewrite the symmetric precision matrix V_0 in the following manner:

$$\begin{bmatrix} V_{11} & V_{12} & V_{13} & V_{14} \\ & V_{22} & V_{23} & V_{24} \\ & & V_{33} & V_{34} \\ & & & V_{44} \end{bmatrix} = f'f + D$$

where $\quad f = (f_1, f_2, f_3, f_4)$

and $\quad D = \begin{bmatrix} d_1 & & & \\ & d_2 & & \\ & & d_3 & \\ & & & d_4 \end{bmatrix}$

The restriction permits a full covariance matrix, yet reduces the number of parameters in the model by two.[7] With four right-hand side variables composing X, there are thirteen parameters to estimate: the four prior means, the four elements of the diagonal matrix, the four factor loadings, and the variance σ_u^2.

II. Estimates of the Parameters of the Model

In estimating the model, I assume that the Livingston panel bases its prediction of the eight-month-ahead annual inflation rate on the following information set: a constant, the past ten-month's annual inflation rate (*INFL*), the annual rate of change in the past six-month money stock (*DM1L*), and the past quarter's federal budget surplus as a percentage of *GNP* (*SURL*).[8] I also experimented with several alternative specifications of the information set. I replaced the fourth variable, *SURL*, with the full-employment federal budget surplus as a percentage of potential *GNP* (*FSURL*) and with the unemployment rate (*UNL*). I also estimated the model with five variables in the information set: the original four along with the unemployment rate.

I might summarize the estimation technique by stating that the maximum likelihood procedure chooses values for the parameters of the Livingston group's prior distribution on B such that, when this prior is updated each period by the Kalman filter and used to forecast, the forecast series resembles the Livingston series.

I estimate the model using data from 1959 through 1982. Thus, the estimated parameters are for the prior distribution that the Livingston group placed on B in the second half of 1958. This prior distribution represents the starting beliefs of the Livingston panel as to the time-series relationship between the four selected right-hand side variables and the future inflation rate. Since the model specifies the manner in which the forecasters would update their beliefs, the estimates tell us both their starting beliefs and the evolution of those beliefs over time. As the forecasters obtain additional observations on the inflation process, they "learn," or, equivalently, update their beliefs about B.

[7]This restriction is particularly important when I estimate the model with 5 right-hand side variables. In this case it reduces the number of parameters from 21 to 16. With 48 observations this reduction can be important. Moreover, the restriction is minimal in that it still permits each element of the covariance matrix to be different.

[8]See the Appendix for details on the variables.

TABLE 1—ESTIMATES OF THE BAYESIAN LEARNING MODEL: 1958:2

	Constant	*INFL*	*DM1L*	*SURL*	*FSURL*	*UNL*
Prior Means[a]	0.283	0.093	−0.17	−0.572		
	(.042)	(.0086)	(.019)	(.067)		
Prior Covariance Matrix[b]						
Constant	.312	.00005	.0413	−.0132		
INFL		.00277	−.00006	.000018		
DM1L			.00702	.0144		
FSURL				.169		
Error Variance Estimate − σ_u^2	.075	(.0022)				
Likelihood Function Value −38.15						
Alternative Specifications of the Information Set						
Prior Means	.876	.135	−.092		−.37	
	(.083)	(.0093)	(.0275)		(.073)	
Likelihood Function Value −26.73						
Prior Means	.33	.042	−.10			−.028
	(.185)	(.0127)	(.0148)			(.035)
Likelihood Function Value −27.96						
Prior Means	.92	.052	−.176	−.49		−.105
	(.16)	(.016)	(.028)	(1.89)		(.17)
Likelihood Function Value −39.40						

[a]Standard errors of the estimates are shown in parentheses.

[b]This covariance matrix is constructed from the estimated factor loadings and the elements of the diagonal matrix: f_1 −54.1 (42.5); f_2 20.8 (19.6); f_3 384.4 (300.6); f_4 −40.3 (31.9); d_1 2.34 (0.47); d_2 350.1 (11.1); d_3 42.3 (26.6); d_4 4.9 (1.08)

Employing a program for estimating the parameters of nonlinear equations, I obtained the maximum likelihood estimates presented in Table 1. The estimated prior means are those that the Livingston group placed on the coefficients of the reduced-form inflation model (1) in late 1958. The prior covariance matrix is estimated up to an unknown scale term σ^2, and indicates the relative confidence that the forecasters had in their beliefs about the respective coefficients and in their beliefs about the interaction among these coefficients. Finally, the standard errors indicate the econometrician's uncertainty about the estimates and are unrelated to the Livingston panel's beliefs.

How should one interpret these estimates? The estimated prior mean for the coefficient on *INFL* indicates that, had the inflation rate previous to the 1959:1 Livingston forecast been 1.14 percent instead of the actual 0.14 percent, the group would have increased its inflation forecast from 0.61 to 0.62 percent. In other words, prior to seeing the 1959 data, the Livingston panel thought that changes in the previous period's inflation rate contained little information relevant to the next period's inflation rate.

The estimated prior mean for the coefficient on the rate of change in the money stock indicates that, had *M*1 grown at 1.72 percent a year in late 1958 instead of the actual 0.72 percent growth rate, the Livingston panel would have reduced its 1959:1 inflation forecast from 0.61 to 0.44 percent. Moreover, the negative sign on this coefficient remained when *SURL* was replaced with unemployment, *UNL*, or the full-employment deficit measure, *FSURL*. However, in both of these cases the estimated prior mean increased from −.17 to about −.10. Although most economists today would place a positive coefficient on *DM1L*, there is evidence that these estimates of the beliefs of economists in 1959 may be reasonable. Benjamin Klein (1975, 1978), for example, has argued that the United States was at that time on an unofficial gold standard. Thus, money supply increases were likely to be reversed in later periods and did not signal a relaxed monetary policy. Nevertheless, while a zero coefficient would not be surprising for forecasters of 1959, a negative one is surprising.

Finally, the prior coefficient on *SURL* indicates that, had this measure of the budget surplus as a percentage of *GNP* been 1.6 percent instead of the actual .6 percent in the third quarter of 1958, the Livingston group would have changed their inflation forecast from .61 to .04 percent. Thus, the panel of 1959 believed that changes in this variable contained substantial information about the next period's inflation rate. This finding supports the general notion that economists in 1959 placed much weight on fiscal policy as a determinant of aggregate demand and, consequently, of inflation. Further support for this interpretation lies in the estimated prior mean of $-.37$ if *SURL* is replaced by *FSURL*, the full-employment surplus as a percentage of potential *GNP*. Similarly, when the model was reestimated with a fifth right-hand side variable, unemployment (*UNL*), the estimated prior mean on *SURL* was $-.48$, indicating that the finding is fairly robust, even after controlling for the state of aggregate demand.

The estimates of the 1958:2 prior covariance matrix shown in Table 1 reveal the relative confidence that the Livingston group placed in their beliefs about the value of the coefficients. Since σ^2 is unknown, the absolute size of the estimated coefficients is indeterminate.[9] The relatively loose prior variance on the constant suggests the panel's willingness to quickly revise their beliefs about the value of this coefficient. To a lesser extent, the same holds true for the coefficient on the federal budget surplus. The prior variances on the other two variables are of about the same magnitude and are much tighter than that on the constant or on the *SURL* coefficient. Thus, the panel would be much slower to revise its beliefs about these coefficients in the face of data that indicates a different time-series relationship between these variables and future inflation.

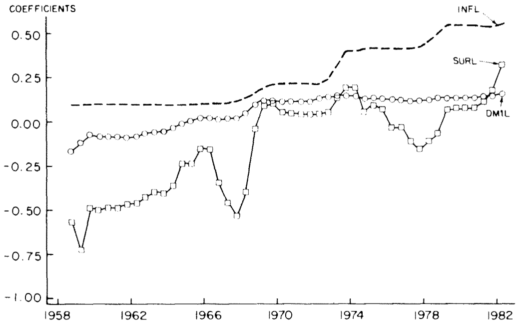

FIGURE 2. EVOLUTION OF THE COEFFICIENTS

The strength of the Bayesian learning approach lies not only in its ability to estimate the starting beliefs of the Livingston panel, but also in its ability to capture the evolution of those beliefs over time. Figure 2 shows the evolving beliefs of the Livingston panel about the time-series relationship among the variables in their information set and future inflation. Examination of the graph shows that the panel learned to place more and more weight on the previous period's inflation rate in forecasting future prices. A second striking pattern is the change in importance given to money growth: panel members steadily increased the weight that they placed on past changes in money in forecasting prices.[10]

Particularly interesting is the evolution of the coefficient on *SURL*. The smooth decline in the weight that the group placed on this variable agrees with the popular notion that as economists began to place more weight on monetary growth in forecasting inflation, they

[9]One possible estimate of a ball park figure for the panel's 1958:2 σ^2 is obtained by regressing y_t on X_{t-1} from 1953:1 through 1958:1 and using the residuals to construct a $\hat{\sigma}^2$. This approach yields a $\hat{\sigma}^2$ of approximately 0.4.

[10]Mullineaux obtained a similar result using a varying parameter regression technique over the period from 1966 to 1977. There is, however, a major difference between our two approaches. Mullineaux regresses the Livingston forecasts on variables that one might reasonably assume to enter the Livingston group's information set. He permits the coefficient to vary over time in a restricted manner. While this technique does show that the relation between the Livingston forecasts and the assumed set of information variables shifted over time, it does not provide any grounds, such as a learning process, for why the shift occurred. Consequently, one should not construe Mullineaux's noteworthy study of expectations to be a model of the formation of expectations in the sense of explaining why people forecast as they did.

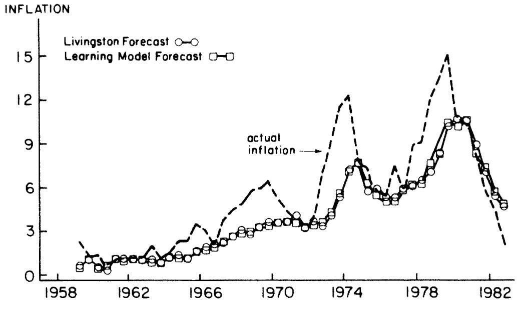

FIGURE 3. LIVINGSTON AND LEARNING MODEL FORECASTS

placed less importance on fiscal policy. The post-1969 positive coefficient on *SURL* is, however, a puzzle. One thought is that since part of fiscal policy is an automatic response to business cycle conditions, *SURL* may proxy both discretionary fiscal policy as well as aggregate demand conditions. When, however, *SURL* is replaced with *FSURL*, the forecasting coefficient still becomes positive post-1977.

As Figure 3 shows, the Bayesian learning model explains quite well the Livingston group's forecasts. The forecasts from the estimated prior and the updated coefficients coincide with the Livingston group's forecasts to an impressive degree. The mean squared difference between the two forecast series is 0.075. This settles one issue conclusively: a specific set of 1958:2 prior beliefs for the Livingston panel exists that, when combined with a Bayesian model of learning, accounts quite well for the Livingston forecasts.

III. Conclusion

This paper demonstrates that one can explain the Livingston inflation forecasts as the product of a learning process. Two underlying assumptions should, however, be emphasized. It is assumed, not tested, that the panel followed Bayes' Rule in updating their beliefs. It is also assumed that the panel believed the underlying parameters of the inflation process were constant over the estimation period. Further research could perhaps adopt a more general learning model that permits either a continuous or discontinuous discounting of the information content of older data.

We should not interpret the findings presented in this paper as proof that the Livingston forecasts were the most accurate forecasts possible given available information. The estimates do show, however, that the Livingston forecasts are consistent with optimal forecasting behavior. This is because I find that plausible initial beliefs combined with an updating procedure that follows the laws of conditional probability account for the observed forecasts. We do not need to appeal to statistical irrationality in explaining the Livingston price expectations.

APPENDIX

INFLV: The mean of the inflation forecasts (*CPI*) of the participants in the Livingston survey.

INF: The *CPI*-based annual inflation rate over the eight-month period that coincides with the horizon of the Livingston forecast (i.e., April/December or October/June). The *CPI* monthly series was obtained from the U.S. Department of Commerce *Business Conditions Digest*. The index is the All Items index. The inflation rate is calculated according to the following formula:

$$INF = 100\left(\exp\left(\frac{12}{8}\log\frac{CPI_t}{CPI_{t-8}}\right)-1\right).$$

INFL: A similarly calculated *CPI* annual inflation rate over the ten-month period just prior to the date of the Livingston forecasts (i.e., June/April or December/October).

DM1L: The annual growth rate in the money stock ($M1$) over the six-month period just prior to the date of the Livingston forecast (i.e., October/April or April/October). The monthly data on $M1$ was provided by the Federal Reserve Board. The annual rate of growth was calculated according to the following formula:

$$DM1 = 100\left(\exp\left(\frac{12}{6}\log\frac{M1_t}{M1_{t-6}}\right)-1\right).$$

SURL: The federal government's seasonally adjusted quarterly budget surplus at an annual rate divided by the seasonally adjusted quarterly measure of *GNP* at an annual rate. This ratio was then multiplied by 100 in order to scale it similarly to the other variables. The data is for the quarter just prior to the Livingston forecast date (i.e., the first and third quarters). The source of both measures is the U.S. Department of Commerce, *National Income and Product Account of the United States*.

FSURL: This variable is constructed similarly to *SURL* but using the full-employment federal surplus and potential *GNP*. The Federal Reserve Bank of St. Louis provided me with this data.

UNL: Unemployment as a percentage of all workers in the months of April or October. The data source is the Bureau of Labor Statistics.

REFERENCES

Carlson, John A., "A Study of Price Forecasts," *Annals of Economic and Social Measurement*, 1977, *6*, 27–56.

______, "Perceptions (or Misperceptions) of Inflation," in William Gale, ed., *Inflation: Causes, Consequences, and Control*, Cambridge: Oelgeschlager, Gunn, and Hain, 1981.

Caskey, John, "Modeling the Formation of Price Expectations," unpublished doctoral dissertation, Stanford University, 1983.

Figlewski, Stephen and Wachtel, Paul, "The Formation of Inflationary Expectations," *Review of Economics and Statistics*, February 1981, *63*, 1–10.

Frenkel, Jacob A., "Inflation and the Formation of Expectations," *Journal of Monetary Economics*, June 1975, *1*, 403–21.

Gramlich, Edward M., "Models of Inflation Expectations Formation: A Comparison of Household and Economist Forecasts," *Journal of Money, Credit and Banking*, May 1983, *15*, 155–73.

Holden, K. and Peel, D. A., "An Empirical Investigation of Inflationary Expectations," *Oxford Bulletin of Economics and Statistics*, November 1977, *39*, 291–99.

Jacobs, Rodney L. and Jones Robert A., "Price Expectations in the United States: 1947–75," *American Economic Review*, June 1980, *70*, 269–77.

Klein, Benjamin, "Our New Monetary Standard: The Measurement and Effects of Price Uncertainty, 1880–1973," *Economic Inquiry*, December 1975, *13*, 461–84.

______, "The Measurement of Long- and Short-term Price Uncertainty: A Moving Regression Time Series Analysis," *Economic Inquiry*, July 1978, *16*, 438–52.

Lahari, Kajal, "A Joint Study of Expectations Formation and the Shifting Phillips Curve," *Journal of Monetary Economics*, July 1977, *3*, 347–57.

McNees, Stephen K., "An Evaluation of Economic Forecasts," *New England Economic Review*, November/December 1975, 3–39.

______, "The Forecasting Record for the 1970s," *New England Economic Review*, September/October 1979, 33–53.

______, "The Recent Record of Thirteen Forecasters," *New England Economic Review*, September/October 1981, 5–21.

Meinhold, Richard and Singpurwalla, Nozer, "Understanding the Kalman Filter," *American Statistician*, May 1983, *37*, 123–27.

Mullineaux, Donald J., "Inflation Expectations and Money Growth in the United States," *American Economic Review*, March 1980, *70*, 149–61.

Pearce, Douglas K., "Comparing Survey and Rational Measures of Expected Inflation," *Journal of Money, Credit and Banking*, November 1979, *11*, 447–56.

Resler, David H., "The Formation of Inflation Expectations," *Federal Reserve Bank of St. Louis Review*, April 1980, *62*, 2–12.

Turnovsky, Stephen J., "Empirical Evidence on the Formation of Price Expectations" *Journal of the American Statistical Association*, December 1970, *65*, 1441–54.

Zellner, Arnold, *An Introduction to Bayesian Inference in Econometrics*, New York: Wiley & Sons, 1971.

Data Resources, Incorporated, *The Data Resources Review of the U.S. Economy*, Lexington: DRI, various months.

U.S. Department of Commerce, *Business Conditions Digest*, Washington: USGPO, various months.

______, *National Income and Product Account of the United States, 1929–1776*, Washington: USGPO, 1981.

______, *Survey of Current Business*, Washington: USGPO, various months.