Conditional Forecasting for the U.S. Dairy Price Complex with a Bayesian Vector Autoregressive Model

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Introduction

Historically, the U.S. dairy industry has been characterized by a managed price system that virtually eliminated the price risk that producers usually cope with in a competitive market environment. The U.S. government began to intervene in the milk marketplace in the 1930s. The current milk price support program was enacted with the Agricultural Act in 1949. Prices were supported by means of government purchases of "unlimited" quantities of surplus dairy products of a storable nature: cheese, butter, non-fat dry milk (NFDM), and evaporated milk.

From a practical point of view, a support price for milk can only be meaningfully implemented with purchases of manufactured dairy products because fresh milk is bulky and perishable. The government purchases were carried out by the Commodity Credit Corporation (CCC). With this program the CCC became an alternative wholesale market-level buyer of dairy products, thereby affecting the overall wholesale dairy demand.

By supporting the price of manufactured products and setting the processing margin or 'make allowance' to processors, the U.S. Federal government ensured that dairy manufacturers, competing for the common raw input, milk, would bid up the price to the USDA targeted level. Since bidding up the price of milk drove up the prices of all dairy products, this program effectively supported all of the prices throughout the entire dairy sector.

The operation of CCC had two crucial features with significant effects on the price variability of all dairy products. First, it stood ready to purchase unlimited quantities of given dairy products at the announced support prices. At those times of the year when there was excess supply of milk due to production seasonality, the CCC increased the demand for milk by actually purchasing manufactured products. This had the effect of establishing a *price floor* for all dairy products. It is important to note that CCC prices did not dictate what wholesale prices would be, but they provided a floor below which market prices were unlikely to fall to any great extent. If milk products were sold at lower prices, the implication was that either the seller had special preferences to sell to a commercial customer or the products sold did not meet the USDA/CCC standards.

Second, the CCC had the authorization to sell back purchased dairy products to the market whenever market prices were at least 110 percent of the support purchase prices. These "sellbacks" had the effect of establishing a *ceiling* price on dairy products. That is, any time a price went beyond the 110% level, it was more profitable for the processor/manufacturer to purchase the product from the CCC at the 110% level instead of producing it.

The operation of the Federal Price Support system could keep dairy prices within approximately a *narrow 10% band*. The band was not *exactly* 10% since the program was voluntary and businesses would occasionally honor pre-arranged contracts at prices outside the band. For the most part market participants were insulated and the program damped any significant price fluctuations.

Pre-1990's the U. S. dairy industry was characterized by public stock-holding and strongly managed prices. The early 1990s were characterized as a transition period with lower but fixed support price and rapidly declining public inventories of dairy products. The later part of the 1990's have been defined by a support price declining in real dollars and cash market prices determined by the forces of market demand and supply, Figure 1.

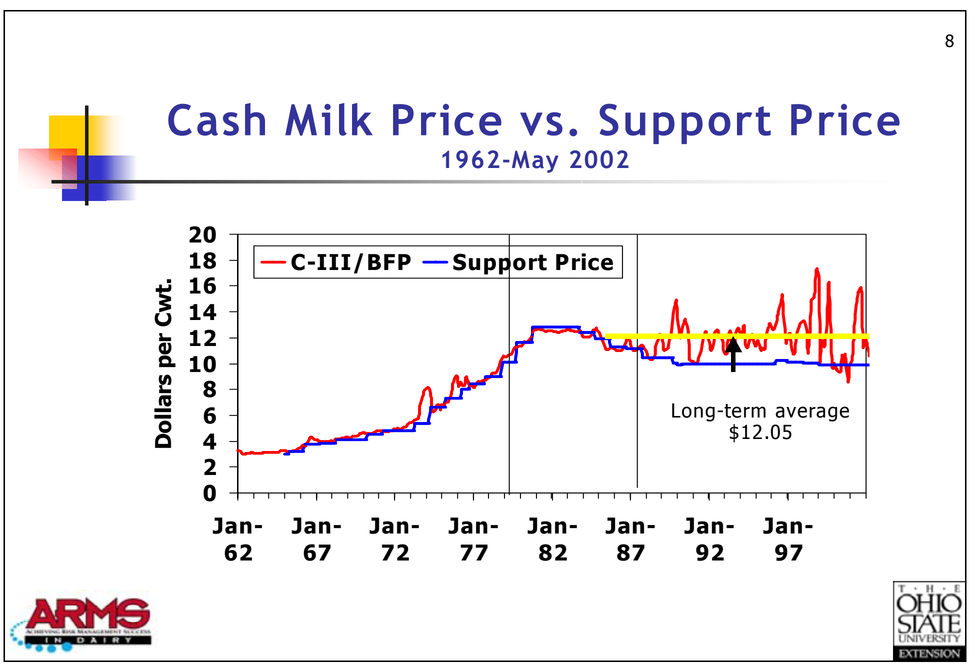

Figure 1. U.S. Milk Base Price vs Support Price.

This decade long transition has been very rapid, by agricultural policy standards, and has had two implications. First, while the dairy industry still had its minimum prices guaranteed, the forces of market supply and demand most directly determine the actual market prices. Second, historical relationships between the different prices and other economic fundamentals may no longer be valid *because the institutional structure of the market has changed*: prices are no longer determined by managed purchases and sellbacks of Commodity Credit Corporation in an attempt to "stabilize" them, but by the free operation of the market.

This structural change can be interpreted in at least three different, though complementary ways. First, the power of the market participants has changed. The biggest market participant, the Government (represented by CCC), gradually lost its significance in the price determination process. Second, price shocks in one product market now affect quite directly the prices of other products and the farm price over time. Finally, with virtually not public inventory to damp price rises the potential for significant increases in price volatilities is real. In the post-public stock period, 1996-2001, market price has achieved record highs levels in 3 of the six years. For example, the volatility of cheese price, measured as the standard deviation of monthly prices, for 1981 was 0.74 cents, 1988—7.8 cents, 1996—13.4 and for 2001 – 23.2. Over a period of 20 years, the volatility of cheese has increased almost 30 times.

Despite the increasing price volatility and the associated risks with it, dairy producers, processors, and retailers must continue to operate in the newly developing environment and must continue to make economic decisions. Dairy producers must decide on the size of their herds: how much to cull and how much to invest in replacement heifers. They must decide whether to invest in new facilities, to improve their current ones, or to divest. They would like to be able to predict milk prices in order to make business decisions, as well as determine their expected profit margins. Likewise, dairy processors face complicated decisions. Processing facilities are rather expensive. They have high operating leverage—their fixed costs are relatively high compared to their operating costs—and small swings in prices result in huge swings in profits. With the increased volatilities of dairy prices, their ability to predict the prices of both their inputs and their outputs becomes crucial. They must further decide on inventories: expectations of high prices could help them profitably increase output inventories or prompt them to contract higher quantities of inputs. Finally, due to the high cost of facilities and difficulties in reorganizing production, they must decide well in advance on physical investments and labor policies. Thus, an ability to understand and predict prices can help processors make sound economic decisions. Dairy retailers and relatively large retail customers face substantial risks. Schools, for example, must operate under strict budgetary constraints and deliver pre-specified nutritional values. Therefore, it is important for them to forecast prices and contract well ahead of actual physical delivery.

Evolving price patterns and expectations of price increases and product shortages can help them, for example, increase their inventories or negotiate better prices. Pizzerias also purchase large quantities of cheese and butter. They cannot always pass the increasing dairy costs onto consumers, which means that unexpected price movements can hurt considerably their bottom line. Dairy retailers must contract in advance with dairy processors about their purchases and with retail customers about their sales. It is crucial for them to maintain their profit margins by proper matching of their purchase costs with sales revenues.

Thus, the structural change that forces dairy producers, processors, and retailers to operate in a new economic environment requires new research aimed at (1) developing price forecasting models of the dairy industry and (2) identifying the relationships between different dairy prices. The U.S. dairy price complex has been study in detail and a Bayesian Vector autoregressive modeling approach used to develop a price forecasting model (Petrov). In the work of Pretrov, the Litterman prior was used and the model developed to produce unconditional forecasts. The research reported on in this paper extends that model to incorporate a Normal-Wishart distribution for estimation of the model parameters along with Gibbs sampling procedure for generating conditional forecasts of the model variables (Gohout).

The conditional forecasting model developed and reported on in this paper is an application of a Bayesian Vector Autoregression (BVAR) with conditional forecasts and follows the approach set forth in the econometric literature (Gohout, Sims and Zha, Waggoner and Zha, Kadiyala and Karlsson). A BVAR is a Bayesian approach to multiple time series describing the dynamic relationships between a set of variables. The BVAR model works well when the underlying structure of the forces driving the variables is relatively stable. BVAR can appropriately account for cyclical economic behavior. Also the BVAR's appeal lies in our ability to provide conditional forecasts on the model variables.

The Bayesian VAR Model

A major advantage of the VAR approach is that it does not assume any specific structural relationships between the different variables but nonetheless identifies their relevant properties useful for prediction. A brief overview of the VAR model follows. For more complete exposition the reader should consult one of the many excellent textbooks in this area, e.g., Hamilton (1994).

A scalar time series y_t is represented in an autoregressive form in the following standard way:

$$y_t = c + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p} + \varepsilon_t$$

where $E(\varepsilon_t) = 0$

$$E(\varepsilon_t \varepsilon_k) = \sigma^2 \quad \text{for } t = k$$
$$= 0 \quad \text{otherwise.}$$

This vector autoregressive process describes the dynamic interactions among a set of variables collected in an (n by 1) vector $\mathbf{y}_t$. For example, the first element of $\mathbf{y}_t$, denoted by y_{1t}, may represent the price of cheese at time *t*, the second element (y_{2t})—the price of milk, and so forth.

A *pth-order vector autoregression*, denoted by VAR(p), is a vector generalization of the above three equations:

$$\mathbf{y}_t = \mathbf{c} + \phi_1 \mathbf{y}_{t-1} + \phi_2 \mathbf{y}_{t-2} + \ldots + \phi_p \mathbf{y}_{t-p} + \boldsymbol{\varepsilon}_t .$$

Here $\mathbf{c}$ denotes an (n by 1) vector of constants, and $\boldsymbol{\Phi}_j$ an (n by n) matrix of autoregressive coefficients for $j = 1, 2, \ldots, p$. The (n by 1) error term vector $\boldsymbol{\varepsilon}_t$ is a vector generalization of white noise:

$$E(\varepsilon_t) = \mathbf{0}$$

and

$$E(\varepsilon_t \varepsilon_k) = \boldsymbol{\Omega} \quad \text{for } t = k$$
$$= \mathbf{0} \quad \text{otherwise,}$$

with $\mathbf{\Omega}$ an (n by n) symmetric positive definite matrix.

Thus, the first element of the vector $\mathbf{y}_t$ depends on the first p lags of all components of $\mathbf{y}_t$, i.e., on all of its first p lags as well as the first p lags of all other variables. The Bayesian VAR statistical model, estimation, and conditional forecasting approach is set forth in detail in Gohout (2001) and will not be reviewed in this paper.

Data

The data set spans 14 years of monthly observations: 1988-2001. Data for the period of 1988-1994 have been obtained from the *Dairy Yearbook,* a publication of the Economic Research Service of the USDA, the 03/96 revised and updated edition. Data for 1995-2001 have been compiled from different sources to be accounted for below. *US Milk Production* is taken from the USDA / NASS Monthly Milk Production Report. *Cheese Production* is "All Cheese Production", which includes American, Italian, and other cheeses. *Non-Fat Dry Milk* is defined as "for human food". *Dry Whey* is defined as "for human food". *Cheese Prices* are obtained from a variety of sources. Prior to April 1997 these prices are for cheddar cheese 40# blocks as reported by the National Cheese Exchange at Greenbay, Wisconsin. After this date prices are taken as reported my the NASS / USDA. *Non-Fat Dry Milk Prices* are F.O.B. central states. *Whey Prices* are "for human food", central states. *Butter Prices* are obtained from the "WSP, Grade AA" at the Chicago Mercantile Exchange (CME) even though there is a reported price F.O.B. central states. The CME price is auction based, and therefore, preferred. *Nonfat Dry Milk Stocks* are reported separately for *government* owned and *manufacturer* owned and the total is used in this analysis. *Whey Stocks* are entirely manufacturer owned; the government does not hold any stocks of whey. Production and commercial storage quantities were obtained from the Agricultural Marketing Service yearly reports.

The Empirical Model

Our BVAR model treats all variables as endogenous. Mathematically, in this model the vector **y** includes all variables, not just the prices:

$\mathbf{y} \equiv$ [BFP, C_PR, B_PR, N_PR, W_PR, M_PR, M_PROD, C_SPR, B_SPR, N_SPR, W_SPR], where the variables are defined in Table 1 and 2.

Table 1. Descriptive statistics for model data.

Variable Label	Description	Mean Value	Standard Deviation	Range {Min – Max)
BFP	Price for Class III milk per hundredweight	12.08	1.654	8.57 – 17.34
C_PR	Cheese price per pound	1.328	0.17	1.06 – 1.90
B_PR	Butter price per pound	1.134	0.364	0.648 – 2.76
N_PR	Nonfat dry milk price per pound	1.042	0.129	0.73 – 1.58
W_PR	Whey price per pound	0.202	0.046	0.116 – 0.33
M_PR	U.S. All Milk price per hundredweight	13.47	1.417	11.3 – 18.1
M_PROD	U.S. milk production per month (1,000)	12,860	767	11,310 – 14,791

Table 2. Dairy product stocks to production ratios

C_SPR	Cheese stocks to cheese production Ratio	0.908	0.117	0.666 – 1.256
B_SPR	Butter stocks to butter production ratio	0.002	0.002	0.0001 – 0.008
N_SPR	Nonfat dry milk stocks to Nonfat dry milk ratio	2.257	1.956	0.63 – 9.71
W_SPR	Whey stocks to whey production ratio	0.432	0.087	0.28 – 0.74

Table 3 reports the simple correlations between these model variables over the 1988 – 2001 time period.

Table 3. Correlations between model variables.

	BFP	*C_PR*	*B_PR*	*N_PR*	*W_PR*	*M_PR*	*M_PROD*	*C_SPR*	*B_SPR*	*N_SPR*	*W_SPR*
BFP	1.00										
C_PR	0.94	1.00									
B_PR	0.43	0.53	1.00								
N_PR	0.45	0.45	-0.14	1.00							
W_PR	0.46	0.46	0.45	0.25	1.00						
M_PR	0.70	0.65	0.41	0.34	0.40	1.00					
M_PROD	-0.10	-0.02	0.13	0.03	0.22	0.07	1.00				
C_SPR	-0.27	-0.14	0.31	-0.34	-0.07	-0.20	0.38	1.00			
B_SPR	-0.16	-0.19	-0.29	-0.13	-0.42	-0.39	-0.45	0.03	1.00		
N_SPR	-0.02	0.06	0.42	-0.22	0.30	0.07	0.34	0.62	0.01	1.00	
W_SPR	-0.07	-0.04	-0.07	-0.14	-0.59	-0.02	-0.19	0.17	0.28	-0.09	1.00

An examination of the contemporaneous correlations in table 3 shows that certain variables in this model are much more closely correlated than are others. For example, the base milk price BFP is closely correlated with the cheese price C_PR and the All Milk price M_PR and not as closely correlated with contemporaneous milk production M_PROD or the stocks to product production ratios. This is as to be expected as we would expect these variables to be much more important only in a lagged relationship or an autoregressive model.

The Conditional Bayesian VAR Forecasts

The estimated model is a Normal-Wishart distribution (Gohout) which contains all of the parameters. The Normal – Wishart model for the U.S. dairy price complex involves a very large number of parameters: [m * {(m*p)+1}] = 1584 where m = number of endogenous variables (11) and p = selected autoregressive length (13). A complete description of the Normal – Wishart distribution for this model includes posterior estimates of the covariance matrix of the disturbances which is 144 x 144, (ii) conditional expectations of the model parameters (1584), (iii) the conditional covariance matrix of all parameters (1584 x 1584). These details are available from the authors on request. Figures 2 and 3 show the actual data plus the conditional forecasts for two key variables in the model – the base milk value and the cheese price. These cheese value variable is a key driver in the U.S. dairy economy and the link between these two variables is clearly evident in the two figures.

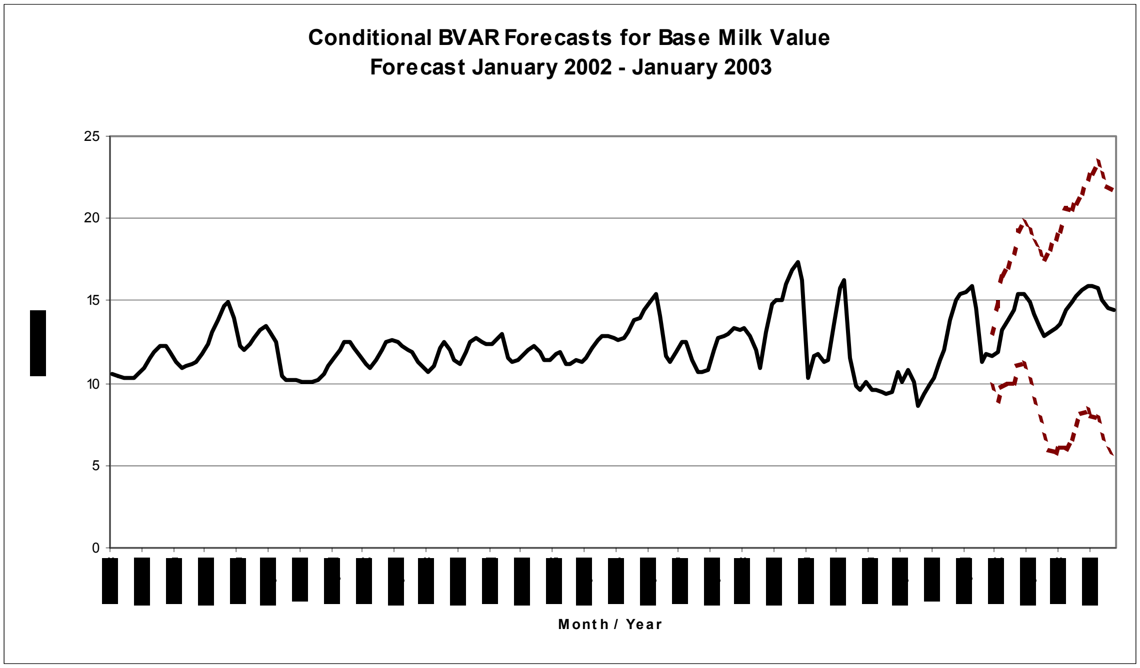

Figure 2. Conditional BVAR Forecasts for Base Milk Value.

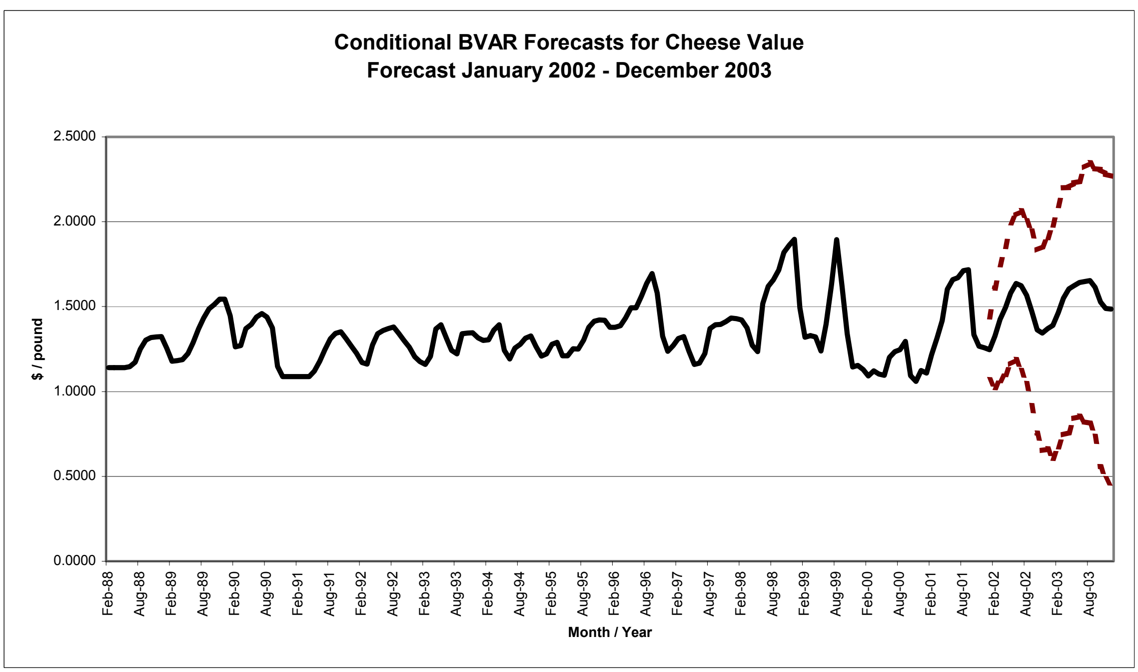

Figure 3. Conditional BVAR Forecast for Cheese Value.

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