# MILK SUPPLY RESPONSE IN DELAWARE

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**Abstract.** Milk supply response by dairy farmers in Delaware was analyzed employing distributed lag price structures for number of milk cows and milk production per cow. A polynominal distributed lag model is fitted to quarterly data with deflated prices for the period 1966 to 1978. The variations in the number of milk cows is explained by about 98 percent. Farmers react positively to milk prices after 1-2 years, while wages and feed prices have a negative impact on cow numbers. Milk production per cow shows positive adjustments to milk prices after 6 to 15 months. Technology and feed prices influence also milk production ($\bar{R}^2$ =.87). While the short-run price elasticity of milk production is only .2, the long-run aggregate elasticity grows to 2.8 percent. Intermediate-run projections of milk supply were also performed with the model.

## INTRODUCTION

This paper addresses the supply side of changing supply-demand relationships in milk. Since balancing demand and supply of milk is a delicate matter involving producers, consumers and institutions, knowledge of the dynamics of supply, elasticities over the intermediate run, and projections are useful to decision makers in such institutions, so that proper signals can be sent to dairy farmers.

Various approaches have been employed to analyze supply of agricultural commodities, especially milk. They can be summarized and classified as follows: There are single and multiple equation (recursive or simultaneous systems) supply functions in which econometric relationships attempt to capture behavioral relationships of producers to changing profitability of milk production (Alicbusan and Elterich, 1977; Elterich and Johnson, 1970; Wipf and Houck, 1967; and Halvorson, 1958). Another group of models uses mathematical programming (static, parametric, quadratic, spatial and dynamic) to determine the normative solutions (supply functions) for producers and processors under various scenarios (Hallberg et al. 1978; Kottke, 1970; Sundquist et al., 1963; Northeast Dairy Adjustments Study Committee, 1968). A third group of models uses simulations to arrive at equilibrium solutions or reactions of producers to different price-cost relationships (Hallberg and Fallert, 1976; Ruane and Hallberg, 1972). Another group may employ a blend of methodologies, e.g. linear programming and simulation to answer the questions posed (Novakovic, 1979). Studies involving producer panels attempt to capture the microeconomic dynamics, providing a data base for Markov chains (Conneman, 1967). This very brief review does not permit delving fully into the existing wealth of studies (Colyer, 1970).

The purpose of this study was to estimate a milk supply response function for Delaware for the short and intermediate run using two single equations with distributed lags. The study used aggregate data to reflect behavioral relationships of milk producers. Previous studies by Wilson and Thompson, Chen, Courtney and Schmitz, Jackson, Hammond and Milligan used distributed lag models to estimate milk supply response. The justification for the approach taken was the behavior of farmers, who, depending upon their socio-demographic characteristics, react with varying time lags to profit or price-cost stimuli in milk production.

The output response to changes in the profitability of producing milk was hypothesized to be rather slow and gradual due to the length of the production cycle of the dairy animal and the large amount of capital needed in dairy farming, most of which is fixed. Thus, the impacts of milk price, feed costs, and wage rates on milk production were hypothesized to be distributed over time. On relatively short notice, farmers can make adjustments in feeding management strategies, but need much more time to increase cow numbers, since building up a herd is either time- or capital-consuming and, therefore, a decision with intermediate consequences.

## MODEL SPECIFICATION

The milk supply model for Delaware consisted of an identity of aggregate milk production which combines the two behavioral components: the number of milk cows and milk production per cow. These two components were multiplied together to determine the aggregate production of milk in the state. The *number of milk cows* was considered a function of lagged prices of milk cows (–), beef cattle (+), farm labor (–) and distributed lag price of milk (+).[1] The variables expected to influence *milk production per cow* were technology (time +), seasonality of milk production (+ or –) and lagged prices for 16 percent dairy ration (–), alfalfa hay (–) and milk (+). The number of milk cows did not produce a significant coefficient and hence was omitted.[2]

A number of distributed lag models have been used to estimate the supply response of agricultural production. The most popular form is the partial adjustment, distributed lag model formulated by Nerlove. One problem with this formulation is that the adjustment process to a price change for the estimated value of the "adjustment coefficient" is restricted by the geometrically declining specification which does not represent behavioral reality in the case of milk. An alternative to the Nerlovian geometrically declining lag model is the polynomial distributed lag model. The coefficients of this model are restricted to lie on a polynomial of low order. In the chosen formulation, the coefficients of the lag distribution first rise and then decline after reaching a maximum.[3]

To capture both the short-run and intermediate-run effects of the prices of milk and concentrates on milk supply, a second-degree polynomial distributed lag of these variables was use.[4] For some variables, such as prices of milk cows and alfalfa hay, only single

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[1]Since milk cows produce milk, heifers and bulls (meat), it was hypothesized that beef prices will have a positive relationship to the number of milk cows. + or – indicates the hypothesized sign of the estimated parameters.

[2]Other variables such as different technology proxies (artificial insemination, bulk handling, labor productivity in dairy production), manufacturing wage rates, the price of utility cows, steers, heifers, and calves were initially assumed to affect the two functions. Early results did not indicate a strong or satisfactory relationship of these variables.

[3]For details see Chen, Courtney and Schmitz, Johnston and Kmenta.

[4]A third degree polynominal distributed lag formulation proved to be less satisfactory with respect to statistical measures in test runs.

lagged values were used. In both cases, the primary criterion for variable lag periods was the time it took for the price-cost relationship to influence the actual decision of farmers. Additional criteria in determining lag periods were the sign and the statistical level of significance of the coefficients. Preliminary investigations were undertaken for all lagged variables before deciding on the final lag form.

Both behavioral equations were initially estimated with ordinary least squares. Preliminary regression results of the milk supply model showed that the data were characterized by autocorrelated residuals. As a result, equations for both the number of milk cows and milk production per cow were estimated using the Cochrane-Orcutt iterative procedure (Kmenta, pp. 287-288).[5]

Quarterly data for the 13-year period, 1966-78 were used to estimate the structural parameters of the milk supply model. During this period, inflation rates were at times over 10 percent per year; thus, the expected production response was based on changes in real prices as opposed to nominal prices. Recently Bell, Roop and Willis indicated some statistical or econometric reasons for deflating time series data. Specifically, deflating yields efficient, unbiased estimators when the undeflated residuals are heteroscedastic. Another advantage is that extreme observations will have less effect on the estimation. Deflating may also remedy a severe multicollinearity problem. Hence, all prices were deflated by the 1967 index of prices paid (for commodities, interest, taxes and wages) by farmers.[6] The time series data were collected and adapted from various publications and unpublished series of the United States Department of Agriculture and Maryland-Delaware Crop Reporting Board.

## RESULTS

Equations for both the number of milk cows and milk production per cow contain the variables specified above. In general, the criteria used for including variables in a particular equation were the statistical level of significance, expected signs of the estimated coefficients, and usefulness of the variables for both forecasting and tracing through the differential impacts of alternative policy options. In some cases, logic demanded that a variable, although not highly significant, be included to obtain overall superior results.

### Discussion of Equations

Lagged milk prices (up to 11 quarters), prices of milk cows and feed concentrate, and changing average farm wage rates explain 98 percent of the variation in *cow numbers.* All the signs for (opportunity) cost and price coefficients are as expected and usually significant at the five percent probability level or better. The Durbin-Watson Statistic indicates no problem with autocorrelation (Table 1, equation 1).

Milk prices—especially during 12 to 24 months prior to the current quarter—exerted a positive and very significant influence on cow numbers. A deflated 10 cents per 100 lbs. higher milk price is associated with an increase of 40 to 50 cows per quarter. While these numbers are small, the aggregate effects of a sustained 10 cents per 100 lbs. price change (over 11 quarters) amount to over 380 cows. Current quarter prices have insignificant coefficients, implying that price expectations play a minor role in production decisions.

To account for the fixity of labor, a four-quarter average for changing wages is used, which relates inversely to a change of cow numbers. A one cent increase in the farm wage leads to a decrease of 35 cows per quarter, *ceteris paribus.* Wage rates are correlated to technological change (partial correlation coefficient of .85), thereby emerging as a proxy for that variable. Other statistical analyses indicate that technology is responsible for a reduction of 166 cows per quarter. The remaining cows produce sufficiently more milk per cow for total supply to remain approximately constant. Seasonal effects are not significant at the 20 percent probability level and hence, are omitted from the equation presented.

A price increase of one dollar for replacement cows leads farmers to reduce their herds by four cows after three quarters, when the effect is largest. Negative adjustments to increased concentrate prices are largest and most significant after six quarters, and amount to 15 cows per one dollar/ton increase.

The statistical results suggest that diary farmers in Delaware react strongly to milk price changes, labor costs (technological advance) and concentrate prices in expanding or contracting their herds, but are less influenced by such factors as costs for replacement cows.

Eighty-seven percent of the variation in *milk production per cow* is explained by technology, feed and milk prices and, to an insignificant extent, by seasonality (equation 2). The significant coefficients carry the expected positive signs for technology, spring season and lagged milk prices and the expected negative signs for lagged concentrate and alfalfa hay prices. The Durbin-Watson statistic indicates no problem with positive serial correlation at the one percent probability level.

A real milk price increase of one cent leads farmers to produce .6 to 1.2 pounds more per cow per quarter, with the highest values after a lag of three to four quarters. The aggregated adjustment to a sustained price rise would increase milk per cow by less than six pounds over six quarters. The current quarter coefficient is not significant, indicating that reactions to price expectations are weak.

A change in technology (proxy time which is closely related, $r = .98$, to labor productivity in dairy production) increases milk output by 22 pounds/cow. A one dollar increase of the concentrate price/ton results in a decline of .9 to 3.4 pounds of milk production per cow, depending upon the lag considered. The aggregate impact over four quarters of a sustained one dollar concentrate real price change amounts to about 12 pounds/cow of milk output in the opposite direction. For a one dollar increase per ton of alfalfa hay, milk output declines by about 11 pounds/cow after four quarters. During the second calendar quarter the cows tend to give 20 pounds more milk than during the last calendar quarter, but seasonality coefficients are not significant.

### Supply Elasticities

Elasticities are reported for the number of milk cows, milk production per cow, and the total supply of milk with respect to changes in the price of milk. For each function, elasticities were calculated for each lag period as well as the aggregate elasticity which encompasses the total length of the lag period considered. The elasticities were computed at the respective means of the variables considering the 1966-78 time period.

The results indicate that for a one percent sustained change in the price of milk at time t, the elasticities of the number of milk cows and milk production per cow are 0.1 and 0.23, respectively in $t+2$ (Table 2). For the number of milk cows, elasticity values for a particular quarter reach their maximum at $t + 6$ (.2) and then gradually decline. On the other hand, for milk production per cow, the elasticity reaches a maximum of 0.27 at $t + 3$.

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[5]The Time Series Processor (TSP) computer program was utilized to estimate the polynominal distributed lag model.

[6]Furthermore, the statistical significance of the parameters and the tightness of fit of the two equations were greatly improved by changing from nominal to deflated prices.

**Table 1**
Estimated Regression Coefficients of Milk Production Model, Delaware, 1966-1978

| | Equation 1 Number of Cows | | Equation 2 Milk Production Per Cow (lbs.) | |
|---|---|---|---|---|
| Variable | Coefficient | Standard Error | Coefficient | Standard Error |
| Constant | -884.020 | | -13.552 | |
| Price Milk Cows | | | | |
| ($/head) t-3 | -4.287† | 1.651 | | |
| Farm Wage (Mov. avg.) | | | | |
| (¢/hour) t-4 | -35.449‡ | 8.729 | | |
| Price Concentrates ($/ton) | | | | |
| t | | | - .852 | 1.903 |
| t-1 | | | -2.581‡ | .784 |
| t-2 | | | -3.361‡ | .882 |
| t-3 | | | -3.191‡ | 1.075 |
| t-4 | | | -2.070† | .803 |
| t-6 | -15.143† | 5.921 | | |
| Price Alfalfa Hay | | | | |
| ($/ton) t-4 | | | -11.347‡ | 3.144 |
| Technology (trend) | | | 22.319‡ | 3.778 |
| Milk Price (¢/100 lbs.) | | | | |
| t | -.488 | .802 | .051 | .461 |
| t-1 | 1.121* | .702 | .638** | .343 |
| t-2 | 2.445‡ | .733 | 1.028‡ | .309 |
| t-3 | 3.484‡ | .823 | 1.219‡ | .310 |
| t-4 | 4.237‡ | .914 | 1.211‡ | .297 |
| t-5 | 4.705‡ | .976 | 1.006‡ | .247 |
| t-6 | 4.888‡ | .995 | .602‡ | .149 |
| t-7 | 4.787‡ | .965 | | |
| t-8 | 4.400‡ | .883 | | |
| t-9 | 3.727‡ | .746 | | |
| t-10 | 2.770‡ | .554 | | |
| t-11 | 1.528‡ | .305 | | |
| Season | | | | |
| Winter | | | -28.59 | 30.28 |
| Spring | | | 20.33 | 33.90 |
| Summer | | | -8.91 | 33.17 |
| $\overline{R}^2$ | .997 | | .871 | |
| Durbin-Watson Stat. | 1.871 | | 1.993 | |
| F-Value | 300.7 | | 34.041 | |

*Indicates significance at the 20 percent probability level.
**Indicates significance at the 10 percent probability level.
†Indicates significance at the 5 percent probability level.
‡Indicates significance at the 1 percent probability level.

The elasticity of milk supply at any point in time t is found by adding the elasticities of the number of milk cows and milk production per cow for that particular period. Hence, the elasticity of milk supply for t + 2 is 0.33.

The results indicate that short-run elasticities of cow numbers, milk production per cow and milk supply are inelastic. For a one percent sustained increase in milk price, dairy farmers will react by increasing milk production per cow first, cow numbers eventually, and hence the total supply of milk to bolster their returns. The results further indicate that with the passage of each quarter, milk supply continues to become less inelastic, from 0.19 at t + 1 to 0.44 at t + 4 and decreases to 0.06 in t + 11.

The aggregate or cumulative price elasticity is obtained from the arithmetic sum of the entire time period considered. The elasticities of cow numbers, milk production per cow, and milk supply are 1.27, 1.56 and 2.83, respectively. These long-run elasticities are considerable and larger than estimates from previous studies for other regions and models. Since the model presented is based on behavioral relationships of producers, the results may indeed reflect the nature and reaction of Delaware dairy farmers.

**Forecasting Milk Supply Response by Quarters for 1979 to 1983**

One important application of an econometric model is in forecasting endogenous variables. Estimates of the polynomial lag

[7]Before any forecasts were made, the prediction efficiency of the model was evaluated by using, for the time period studies, the Mean Absolute Percentage Error (MAPE) which is .69 and 2.1 percent for the cow number and milk production equation, respectively.

**Table 2**
Estimated Price Elasticities of Cow Numbers, Milk Production Per Cow and Milk Supply for Delaware, Polynomial Distributed Lag Model in Real Prices, 1966-1978

| Time Period | Elasticity of Cow Numbers EMC | Elasticity of Milk Production Per Cow, EY | Elasticity of Milk Supply Es = EMC + EY |
|---|---|---|---|
| t | -0.020 | 0.011 | -0.009 |
| t + 1 | 0.046 | 0.141 | 0.187 |
| t + 2 | 0.102 | 0.227 | 0.329 |
| t + 3 | 0.144 | 0.270 | 0.414 |
| t + 4 | 0.176 | 0.268 | 0.444 |
| t + 5 | 0.195 | 0.223 | 0.418 |
| t + 6 | 0.203 | 0.133 | 0.336 |
| t + 7 | 0.199 | | 0.199 |
| t + 8 | 0.182 | | 0.182 |
| t + 9 | 0.155 | | 0.155 |
| t + 10 | 0.115 | | 0.115 |
| t + 11 | 0.063 | | 0.063 |
| Aggregate Elasticity | 1.56 | 1.27 | 2.83 |

model were used to make forecasts of the number of milk cows and milk production per cow in Delaware for 1979 to 1983. These forecasts were based on the extrapolation by linear trends of the independent variables during the 1974-1978 period and fitted with structural coefficients of the two equations. This method should cover the most recent structural changes that have occurred in the dairy sector.

The forecasted values of the number of cows, milk production per cow and in the aggregate are presented in Table 3. The forecasts for cow numbers deviate from the observed values in the first two quarters of 1979, approximately by -2.1 to -3.3 percent, for milk production per cow by -1.8 to +4.7 percent, and for total production by -5.3 and 1.5 percent, respectively. Results of the forecast indicate that the number of cows in 1983 will decline by about 10 percent from 1978, while at the same time, milk production per cow will increase by 10 percent. Thus, the resulting milk production is expected to remain unchanged.

## SUMMARY AND CONCLUSIONS

The objective of the study was to estimate a milk response function for Delaware using distributed lag price structures.

The model consisted of one relationship for the number of milk cows and another relationship for milk production per cow. Total supply of milk was determined by the identity that multiplied the

**Table 3**
Forecasts From 1979-1983 of Number of Milk Cows, Milk Production Per Cow and Aggregate Production, and Relative Changes From 1978, Delaware

| | | Number of Cows | | Milk Production | | | |
|---|---|---|---|---|---|---|---|
| | | | | Per Cow | | Aggregate | |
| | | thousands | % change from 78 | pounds | % change from 78 | milk lbs. | % change from 78 |
| Observed | | | | | | | |
| 1978 | 1. Quarter | 11.800 | — | 2860 | — | 33.81 | — |
| | 2. Quarter | 11.600 | — | 2740 | — | 32.10 | — |
| | 3. Quarter | 11.600 | — | 2650 | — | 31.41 | — |
| | 4. Quarter | 11.500 | — | 2750 | — | 31.71 | — |
| Forecasted | | | | | | | |
| 1979 | 1. Quarter | 11.406 | -3.34 | 2808 | -1.81 | 32.03 | -5.26 |
| | 2. Quarter | 11.355 | -2.11 | 2868 | +4.67 | 32.57 | +1.46 |
| | 3. Quarter | 11.304 | -2.55 | 2850 | +7.54 | 32.21 | +2.55 |
| | 4. Quarter | 11.253 | -2.15 | 2870 | +4.35 | 32.29 | +1.83 |
| 1980 | 1. Quarter | 11.202 | -5.07 | 2852 | -0.28 | 31.95 | -5.50 |
| | 2. Quarter | 11.151 | -3.87 | 2912 | +6.27 | 32.47 | +1.15 |
| | 3. Quarter | 11.100 | -4.31 | 2893 | +9.18 | 32.12 | +2.26 |
| | 4. Quarter | 11.049 | -3.92 | 2913 | +5.94 | 32.19 | +1.51 |
| 1981 | 1. Quarter | 10.997 | -6.80 | 2896 | +1.25 | 31.84 | -5.83 |
| | 2. Quarter | 10.946 | -5.63 | 2956 | +7.87 | 32.35 | +0.78 |
| | 3. Quarter | 10.895 | -6.80 | 2937 | +10.84 | 32.00 | +1.88 |
| | 4. Quarter | 10.844 | -5.70 | 2957 | +7.53 | 32.07 | +1.14 |
| 1982 | 1. Quarter | 10.793 | -8.54 | 2939 | +2.78 | 31.72 | -6.18 |
| | 2. Quarter | 10.742 | -7.40 | 2999 | +9.46 | 32.22 | +0.37 |
| | 3. Quarter | 10.691 | -7.84 | 2981 | +12.48 | 31.87 | +1.46 |
| | 4. Quarter | 10.640 | -7.48 | 3001 | +9.11 | 31.93 | +0.69 |
| 1983 | 1. Quarter | 10.588 | -10.27 | 2983 | +4.30 | 31.58 | -6.60 |
| | 2. Quarter | 10.537 | -9.16 | 3043 | +11.05 | 32.06 | -0.12 |
| | 3. Quarter | 10.486 | -9.60 | 3024 | +14.13 | 31.71 | +0.96 |
| | 4. Quarter | 10.435 | -9.26 | 3044 | +10.70 | 31.77 | +0.19 |

number of milk cows by the milk production per cow. A polynominal distributed lag model was fitted to quarterly data—prices being deflated—for the period 1966 to 1978, to estimate the relevant equations. The estimated coefficients were, in general, statistically highly significant, having signs agreeing with theoretical and empirical expectations.

Approximately 98 percent of the variation in the number of cows was explained by the equation which indicated that farmers reacted significantly and positively to milk price changes after one to two years lead time. The number of cows was reduced in response to higher wage rates, but in a shorter time lag. Concentrate prices also conversely influenced cow numbers.

Milk production per cow $\overline{R}^2 = .87$) showed positive adjustments to milk price changes primarily between six to 15 months. Technology played an important role in milk output, while feed prices (hay and concentrates) had a small but very significant negative influence on milk production.

For analytical purposes, price elasticities for each lag period were computed. Estimated supply elasticities can be useful for bargaining associations, government and industry leaders during price negotiations. The estimated aggregate elasticity was 2.8, indicating that—while inelastic (.2) in the short-run, dairy farmers will increase milk supply by a considerable 2.8 percent for each one percent increase in the price of milk after three years. Apparently, Delaware dairy farmers react rather quickly to changing real price signals, since the fewer dairy farmers have larger herds and are more specialized. This estimate might be used to analyze the effect of changing milk price on milk supplies. For example, the estimate could be helpful in arriving at a price that would stimulate the desired milk supply in the absence of structural changes during the period considered. It is realized that with technological progress, approximately the same milk production could be forthcoming from a reduced cow herd.

Estimated supply elasticities can also be used to measure public costs of price supports for manufactured dairy products. The government sets higher price supports for manufactured dairy products to support a higher manufacturing price for milk. This in turn causes the fluid price of milk to rise since it is tied directly to the manufacturing price by a fixed differential in most federal and state milk market orders. The whole process will eventually affect the price received by dairy farmers and, hence, the level of milk output. While higher price supports may increase producer revenues, they may also reduce consumption of manufactured dairy products and raise the government costs associated with purchasing surplus output. How much government costs will change depends on the elasticities of supply and demand.

Forecasts of cow numbers and milk production for 1979 were close to observed values. The 1983 projections indicate that cow numbers will decline while milk production per cow will increase, leaving aggregate milk production unchanged.

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