Technology and Price-Induced Effects on Aggregate Milk Supply in Washington State

by Don P. Blayney and Ron C. Mittelhammer
Blayney is an Agricultural Economist with the Economics Research Service, U.S. Department of Agriculture and Mittelhammer is a Professor in the Department of Agricultural Economics at Washington State University, Pullman, WA.

The authors gratefully acknowledge the editorial assistance of Gayle Willett of Washington State University Cooperative Extension Service in preparing this publication. We also thank Brenda Campbell for preparing the manuscript and tables, and Pete Cameron for his helpful final editorial review.
Introduction

The U.S. dairy industry periodically faces periods of heavy surplus milk production. These milk oversupply situations would seem to suggest that producers' production responses do not always match market (milk and input price) signals. Technological effects may be one contributing factor; the dairy industry has a long history of technological advances and innovation. Mechanical milking machines, bulk milk tanks, modern milking parlors, waste-handling equipment and feeding systems, artificial insemination, and improved animal management systems are some examples.

This analysis focused on the highly productive Washington state milk producers. In particular, it focused on the interaction of prices and technology in production decisions by Washington dairy farmers. The analysis is intended to provide dairymen, consumers, dairy industry leaders, and policy-makers in Washington with insights into the most important factors affecting observed production behavior and to quantify the degree to which technological advances contributed to the growth of the state's milk producing sector.

Dairying in Washington State

Washington is one of the top 10 milk producing states in the United States. For many years, the state's producers have had high output per cow, sometimes cited as a measure of productivity. The 1990 average milk production per cow was 18,557 pounds, ranking behind only New Mexico and almost 4,000 pounds above the U.S. average. Recent United States Department of Agriculture data reported 4.4 billion pounds of aggregate milk production in Washington for 1990, the ninth highest level of production in the country.

Washington's dairy industry is a mainstay of the state's agricultural economy. Milk is consistently ranked among the top-valued agricultural commodities produced. It accounted for about 14.4% of the total value of agricultural commodities produced in the state in 1989. Indigenous geographic and climatic conditions have played roles in developing the industry and its character. Major milk production areas in the state are west of the Cascade Range, near the Pacific Northwest's two major metropolitan areas: Seattle, Washington and Portland, Oregon. About 60% of Washington's milk production is in King, Pierce, Skagit, Snohomish, and Whatcom counties.

The mild climate of the state's west-side enhances production, as does the availability of high-quality forages from nearby sources, including alfalfa hay from the Columbia Basin Irrigation Project. The willingness of Washington milk producers to adopt technological advances also contributes to the character of the dairy industry. Adopting advanced milking and feeding systems, improved herd health care techniques, and genetic programs have been observed and analyzed. Effective and progressive management is also characteristic of a significant proportion of Washington milk producers.
This bulletin emphasizes results of a statistical analysis of Washington dairy data and their implications for milk production in Washington. The specific objectives of this bulletin are:

1. To discuss the analytical economic model underlying analysis of technological and economic effects on aggregate milk supply response in Washington.

2. To present estimates of aggregate milk supply response measures for the state and present a framework for separating the technology and the price effects on the supply response.

3. To use the results of the analysis to draw conclusions concerning the nature of milk supply response in Washington.

4. To summarize the implications of the analysis for Washington dairymen and for setting government dairy policy.

The Model

A statistical model of the aggregate milk supply and aggregate input demands for six inputs used by Washington's milk producers was developed. The six inputs analyzed were cows, concentrates, silage, hay, labor, and capital.

We developed the concept of an economically relevant aggregate production function (ERAPF) for this study. ERAPF represents the relationship between profit maximizing aggregate levels of output and inputs used by the state's milk producers and provides the basis for separating aggregate milk supply response in Washington into components involving technology effects and price effects (see Blayney, and Blayney and Mittelhammer for additional details concerning statistical aspects of the analysis).

Quantity and price data for estimating the model were collected from several secondary sources for 1966-1985, the analysis period for this study. Aggregate quantity data relating to milk production and input usage were derived by multiplying per cow data by the number of cows in the state. The cow number was the annual average total number of cows in the state, excluding heifers not yet fresh reported in Agricultural Statistics and Washington Agricultural Statistics. Milk production per cow and concentrates fed per cow data were obtained from various issues of Agricultural Statistics. Hay and silage feeding information came from annual summaries of Dairy Herd Improvement Association (DHIA) records. Labor requirements were derived from national annual average labor per cow data published in Economic Indicators of the Farm Sector: Production and Efficiency Statistics, 1984. The labor data does not differentiate between hired and owner-operator labor. Washington State University (WSU) Cooperative Extension enterprise budgets were used to calculate per cow capital input levels in dollar expenditure terms, where capital referred to operating capital not inclusive of land and building costs.

Price data was obtained from many of the same sources as the quantity data. The milk price was defined as the annual average return per hundredweight of milk. The concentrate feed price was defined by the annual average value per hundredweight fed to milk cows. Both the milk price and the concentrate feed price were obtained from various issues of Agricultural Statistics. The annual DHIA summaries provided delivered costs per ton of hay and silage which were used as the prices of these two feed inputs. The costs represent the prices paid by dairy farmers, not the prices received by producers of hay and silage. WSU Cooperative Extension enterprise budgets provided the labor price, defined as the hourly hired labor wage rate on dairy farms. Prices for cows and capital were calculated to capture the stock and flow characteristics (current and salvage values) of the two inputs. The cow price and capital data were collected from various issues of Agricultural Statistics and Washington Agricultural Statistics, and from the WSU Cooperative Extension enterprise budgets.

As an average measure of the relative importance of the various categories of inputs to overall milk production costs, the average percentage contribution to aggregate production costs represented by each input category was calculated for the 1966-1985 period. The results were as follows: concentrates -27.03%, hay - 15.98%, silage - 7.86%, labor - 21.94%, cows - 13.54%, and capital - 13.65%. 

Objectives
The statistical model referred to in the preceding section provided empirical estimates of: 1) price elasticities and, 2) technology- and price-induced effects on aggregate milk production in Washington’s dairy economy. The concept of elasticity is simple: it is a measure of the percentage change in one variable induced by a 1% change in a second variable. Of particular interest are price elasticities, which measure the percentage change in milk production or input usage due to a one percent change in the milk price or some input price. There are two categories of price elasticities. One is called an own-price elasticity, which measures the percentage change in milk production or usage of an input due to a 1% change in the (own) milk or input price, respectively. Other price elasticities are called cross-price elasticities, which measures the percentage change in milk production or in the usage of a particular input that occurs when a 1% change occurs in a price other than the price of the milk or input, respectively.

The estimates of the average (over the entire period of analysis) own-price and cross-price elasticities for the aggregate Washington milk supply and the aggregate cow, concentrates, hay, silage, labor, and capital demands for the state are shown in Table 1. The main diagonal elements of the price elasticity array, shown in bold type, are the own-price elasticity estimates and the off-diagonal elements are the cross-price elasticity estimates.

Table 1. Matrix of Own-Price and Cross-Price Elasticity Estimates and Technological Rates of Change*

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Milk</th>
<th>Cows</th>
<th>Concentrates</th>
<th>Hay</th>
<th>Silage</th>
<th>Labor</th>
<th>Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk</td>
<td>.8932</td>
<td>-1.128</td>
<td>-1.1946</td>
<td>-1.124</td>
<td>-.0675</td>
<td>-.3174</td>
<td>-.0885</td>
</tr>
<tr>
<td>Cows</td>
<td>1.1446</td>
<td>-1.134</td>
<td>-2.250</td>
<td>-1.962</td>
<td>.0003</td>
<td>.3988</td>
<td>-.209</td>
</tr>
<tr>
<td>Concentrates</td>
<td>.9551</td>
<td>-1.137</td>
<td>-.4434</td>
<td>-.0835</td>
<td>-.0841</td>
<td>-.1655</td>
<td>-.0652</td>
</tr>
<tr>
<td>Hay</td>
<td>.9653</td>
<td>-1.161</td>
<td>-.1481</td>
<td>-.4145</td>
<td>-.0252</td>
<td>-.3660</td>
<td>.1526</td>
</tr>
<tr>
<td>Silage</td>
<td>1.3039</td>
<td>.0003</td>
<td>-.3306</td>
<td>-.0566</td>
<td>-1.156</td>
<td>-.7682</td>
<td>-.0333</td>
</tr>
<tr>
<td>Labor</td>
<td>2.1611</td>
<td>-.2676</td>
<td>-.2294</td>
<td>-.2901</td>
<td>-.2708</td>
<td>-.8692</td>
<td>-.2339</td>
</tr>
<tr>
<td>Capital</td>
<td>.6844</td>
<td>-.1532</td>
<td>-.1027</td>
<td>.1375</td>
<td>-.0134</td>
<td>-.2658</td>
<td>-.2868</td>
</tr>
</tbody>
</table>

*All elasticities and rates are evaluated at the means of the data points. A dot placed above Q or X_i refers to the rate of change in the variable with respect to technology change over time. Entries in the price elasticity matrix measure the percentage change in the quantity of milk supplied, or quantity of input demanded (the quantity indicated by the row names under the "Quantity" label), given a one percent change in the price of milk or the price of an input (the price indicated by the column names under the "Price Elasticities" label).
Cross-price elasticities measure the response of input demand or output supply to changes in prices other than the respective own-prices. Economic theory states that cross-price elasticities may be either positive or negative. The sign of a cross-price elasticity relating two inputs indicates whether the inputs are substitutes (positive sign) or complements (negative sign) in the production process. Inputs are never overall substitutes when firms are behaving as profit-maximizing economic units and all input/output adjustments to price changes are accounted for.

Again using hay as an example, a cross-price elasticity is the percentage change in the quantity of hay demanded due to a 1% change in the price of either the output, milk, or some other input such as cows. The hay quantity demanded changes by about -0.17% for a 1% change in the price of cows, all other prices held constant. Since the cross-price elasticity estimate is negative, the implication is that higher cow prices lead to a reduced demand for hay, when all other prices hold constant.

The effect of input price changes on aggregate milk supply are expected to be negative. That is, the higher the price of production inputs, the less output will be produced (which would be indicated by negative cross-price elasticity estimates between the output and each input). The empirical estimates of the milk cross-price elasticities support the theoretical expectation. A 1% rise in cow prices implies a 0.11% decrease in aggregate milk production; production falls by 0.19% for a 1% rise in concentrate feeds prices. Price rises of 1% in silage and hay lead to declines in production of 0.11% and 0.06%, respectively. Labor price changes have the largest effect on milk production; a 1% increase in the price of labor implies a 0.32% decline in aggregate milk production. Finally, production declines about 0.09% when the capital price rises by 1%. All of the estimated milk supply cross-price elasticities are in the inelastic range.

The inelasticity of the aggregate milk supply response to changes in milk and input prices is one contributing factor to the perceived periodic oversupply problem identified by dairy industry analysts and policy-makers. Inducing changes in the milk price, which is a policy option in the United States for affecting milk supply, does not necessarily bring about the desired level of production response. The following example illustrates the inelasticity of quantity supplied.

Suppose that aggregate milk supply in Washington is determined to be 10% above its desired level. Even a 10% reduction in milk price would only result in a 8.9% decrease in supply given the aggregate supply response estimated by the supply-response model, all other prices held constant. To achieve the desired 10% reduction in milk production using only milk price as the incentive would require a price reduction of 11.2%.

An alternative option for affecting milk supply in the state would be to use input prices as the policy instrument. However, the input cross-price elasticity estimates for Washington are more inelastic than the supply own-price elasticity estimate. All of the absolute values of the supply cross-price elasticities are less than 0.8932. Reducing milk supply 10% would require an even more drastic individual input price increase, in percentage terms, than the aforementioned milk price decrease, all else held constant.

As the estimated elasticities in Table 1 suggest, Washington’s milk producing sector is affected by an interrelated set of economic factors that may, at times, work at cross purposes. For example, decreasing feed prices would increase aggregate milk supply while decreasing milk prices would decrease supply. The net impact of the two price effects depends on the relative magnitudes of the change in prices and the value of the cross-price and own-price elasticities. The opposing nature of these economic incentives provides one explanation of why it is possible to observe increasing milk supplies during periods of decreasing milk prices. Changes in input prices can compensate for the declining milk price.

The analysis of the own- and cross-price elasticity estimates shown in Table 1 provides one perspective on changes in aggregate milk supply and aggregate input demand in Washington’s dairy industry. Also included in the table (the last column) are broad indicators of the effect of technological change on aggregate Washington milk supply and aggregate Washington input demands for cows, concentrates, hay, silage, labor, and capital.

The annual growth rate in milk supply attributed solely to technological advance, evaluated at average levels of output and input prices, over the 20-year period of analysis is about 5.6%. This growth rate is a measure of the annual rate of change in output estimated to be obtainable from technological advance assuming: 1) prices that are average for the period of analysis, 2) a base-level of technology equal to that existing at the midpoint of the analysis period, and 3) no changes in market prices that would act to
mitigate the technology-induced expansion of the milk supply. The corresponding rate of growth in input demands induced by technological expansion are positive, ranging from 2.8% to just over 8%.

These positive growth rates suggest that advances in dairy industry technology in the state are input-using. That is, to varying degrees, adopting technological advances in the industry requires additional input usage. Feed use, particularly concentrate feeding, appears the most effected by technological change while labor and capital demands are less affected.

An analysis of year-to-year changes in Washington’s aggregate milk supply offers another perspective on the supply response issue. The economically relevant aggregate production function (ERAPF) mentioned previously is the basis for the analysis. Three components of changing milk supply were identified: 1) the constant input technology component, 2) the constant price input adjustment component, and 3) the input adjustment to price change component (see table 2). The meaning of each component is described as follows:

**Constant Input Technology Component**
The constant input technology component is the change in year-to-year milk output attributed to a situation where the level of input usage is held constant at the earlier year’s level while technology is advanced to the later (next) year’s level. This component is a measure of the change in milk supply from year-to-year that can be attributed solely to technological advance using unchanged quantities of the various categories of inputs. Thus, this component is an indicator of the increased level of efficiency with which a given level of inputs

### Table 2. Year to Year Milk Production Decomposition Using Profit Function Analysis

<table>
<thead>
<tr>
<th>Year</th>
<th>Milk Production (million cwts)</th>
<th>Constant Input Technology Increment (million cwts) (%change)</th>
<th>Constant Price Input Adjustment (million cwts) (%change)</th>
<th>Input Adjustment to Price Change (million cwts) (%change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>22.073</td>
<td>.277 (1.257)</td>
<td>.378 (1.712)</td>
<td>-.272 (-1.234)</td>
</tr>
<tr>
<td>1967</td>
<td>22.456</td>
<td>.314 (1.396)</td>
<td>.387 (1.722)</td>
<td>-.507 (-2.558)</td>
</tr>
<tr>
<td>1968</td>
<td>22.649</td>
<td>.349 (1.539)</td>
<td>.412 (1.817)</td>
<td>-.631 (-2.787)</td>
</tr>
<tr>
<td>1969</td>
<td>22.778</td>
<td>.376 (1.652)</td>
<td>.456 (2.001)</td>
<td>-.931 (-4.088)</td>
</tr>
<tr>
<td>1970</td>
<td>22.679</td>
<td>.387 (1.704)</td>
<td>.512 (2.258)</td>
<td>-.343 (-1.512)</td>
</tr>
<tr>
<td>1971</td>
<td>23.235</td>
<td>.417 (1.795)</td>
<td>.542 (2.334)</td>
<td>-.629 (-2.706)</td>
</tr>
<tr>
<td>1972</td>
<td>23.566</td>
<td>.434 (1.843)</td>
<td>.608 (2.580)</td>
<td>-.673 (-2.854)</td>
</tr>
<tr>
<td>1973</td>
<td>23.936</td>
<td>.388 (1.620)</td>
<td>.619 (2.585)</td>
<td>-1.655 (-6.916)</td>
</tr>
<tr>
<td>1974</td>
<td>23.287</td>
<td>.324 (1.393)</td>
<td>.730 (3.133)</td>
<td>.603 (2.590)</td>
</tr>
<tr>
<td>1975</td>
<td>24.944</td>
<td>.382 (1.530)</td>
<td>.775 (3.107)</td>
<td>.853 (3.419)</td>
</tr>
<tr>
<td>1976</td>
<td>26.953</td>
<td>.467 (1.734)</td>
<td>.809 (3.000)</td>
<td>-1.173 (-4.351)</td>
</tr>
<tr>
<td>1977</td>
<td>27.056</td>
<td>.458 (1.683)</td>
<td>.968 (3.576)</td>
<td>.067 (.247)</td>
</tr>
<tr>
<td>1978</td>
<td>28.549</td>
<td>.531 (1.859)</td>
<td>1.000 (3.503)</td>
<td>-2.353 (-8.240)</td>
</tr>
<tr>
<td>1979</td>
<td>27.727</td>
<td>.418 (1.508)</td>
<td>1.230 (4.436)</td>
<td>-1.528 (-5.512)</td>
</tr>
<tr>
<td>1980</td>
<td>27.847</td>
<td>.352 (1.262)</td>
<td>1.370 (4.920)</td>
<td>-.503 (-1.808)</td>
</tr>
<tr>
<td>1981</td>
<td>29.065</td>
<td>.350 (1.205)</td>
<td>1.507 (5.186)</td>
<td>.487 (1.674)</td>
</tr>
<tr>
<td>1982</td>
<td>31.409</td>
<td>.419 (1.335)</td>
<td>1.699 (5.411)</td>
<td>.357 (1.135)</td>
</tr>
<tr>
<td>1983</td>
<td>33.884</td>
<td>.474 (1.399)</td>
<td>1.897 (5.599)</td>
<td>-1.410 (-4.162)</td>
</tr>
<tr>
<td>1984</td>
<td>34.845</td>
<td>.430 (1.233)</td>
<td>2.118 (6.078)</td>
<td>-1.650 (-4.736)</td>
</tr>
</tbody>
</table>

*a*Adding the values of adjustments/increments listed in the right-most three columns to the milk production values in a given year results in the milk production value in the next year.

*b*Represents the increment to output attainable if input usage were held constant at the level used in a given year, t, but technology were advanced to the level existing in the next year, t+1.

*c*Represents the difference between the level of output that is profit-maximizing at year t price levels and year t+1 technology, and the level of output attainable using year t input levels and year t+1 technology.

*d*Using year t+1 technology, this represents the difference between profit maximizing output levels at price levels existing in year t+1 and year t.
A change in technology often held constant at 1984 levels but advances in technology. For logical advance since input usage levels used prior to the technology input usage to make optimum use in Washington in 1984 is measure the full production requires a change in the level of input usage to hold constant and equal to the previous prices at 1984 levels. This component is a measure of the total year-to-year change in milk production in the state. The separation of the year-to-year supply changes in Washington shown in Table 2 suggests that advancing technology played a major role in expanding the state's aggregate milk supply. Technological advance accounted for an average yearly increase in milk supply of 4.9%. Of this 1.5% is attributed to the pure effect of technological advance at constant input use levels while the remaining 3.4% is attributed to readjustments of input levels to make optimal use of the advancing technology. The significant input adjustment component of the effect of technological advance is consistent with the earlier observation that technological advancements are largely input-using on Washington dairy farms.

The output-enhancing effects of technological advance were mitigated by adjustments to changing output and input prices. On average, these price adjustments resulted in a yearly reduction in aggregate milk production of 2.3%. The net effect of the technology and price adjustments is a 2.6% yearly average increase in milk production in the state.

The period 1983-85 graphically illustrates how the combination of technological advance and changing market prices for milk and inputs can result in aggregate milk production responses that would be unexpected if only changing market prices for milk and inputs were considered. Milk prices and input prices were much less favorable during 1983-85 than at the beginning of the decade. In Washington, milk prices declined 6.7% during the period. All input costs increased (except for concentrate feeds); hay by 1.3%, silage by 2.9%, labor by 13.5%, and capital services by 7%. The decline in concentrate feed prices was 5.5%.

The effects of the unfavorable milk and input price changes during the period are reflected by the last two row entries in column 4 of Table 2. Estimated milk production changes due to input

### Constant Price Input Adjustment

A change in technology often requires a change in the level of input usage to make optimum use of the new technology. Thus, the previous "constant input technology component" does not necessarily measure the full production opportunities provided by technological change since input usage is held constant and equal to the previous levels used prior to the technology change. The constant price input adjustment is the additional change (over and above the constant input technology component) in milk output that can be attained by allowing the level of input usage to adjust to profit maximizing opportunities made available from adopting the new technology, given milk and input prices held constant and equal to the price levels existing prior to the technology change. This component is a measure of the increment to production available from an efficient reallocation of input levels that makes optimal use of the new technology. Note that the effects of input level reallocations induced by changing market conditions are not included in the measure since prices are held constant at the levels existing prior to the technological advance.

The sum of the constant input technology component and the constant price input adjustment is a measure of the total year-to-year change in production attributable to technological advance. Using 1984 and 1985 again for illustration, an additional 2,118 hundred million pounds of milk is obtainable (over and above the constant input technology component) from technological advance if input level allocations were made efficiently under 1985 technology while holding milk and input prices at 1984 levels.

### Input Adjustment to Price Change

Once the effect of technological advance on milk output is isolated, the final incremental change to milk output concerns adjustments to changing market conditions, i.e. the effects of changing milk and input prices on profit maximizing levels of milk supply and input usage. The "input adjustment to price change" is the additional change in output supply (positive or negative), from the previous technology-efficient level, induced by modifying input usage to maximize profits under changed market price levels. For example, the change in milk and input prices between 1984 and 1985 is estimated to have incrementally decreased milk production by 1.65 hundred million pounds from the level of milk production that would be technologically efficient at 1984 prices.

The sum of the first two components represents the total effect of technological advance at constant prices, e.g. a total of an additional 2,548 hundred million pounds between 1984 and 1985. Adding the three estimated production increments to the estimated value of aggregate milk production in a given year results in the estimated aggregate milk production for the following year.

The effects of the unfavorable milk and input price changes during the period are reflected by the last two row entries in column 4 of Table 2.
adjustments in response to changing milk and input prices were negative in 1983 and 1984, equalling 1.4 and 1.65 hundred million pounds, respectively. However, the effects of technological advance, about 2.3 and 2.5 hundred million pounds in 1983 and 1984, more than offset the production decreases associated with price changes so that aggregate milk supply continued to expand.

The dairy farmer’s decision to produce milk is influenced by both the technology of dairying and the market prices of milk and inputs required to produce milk. The aggregate supply response of Washington dairymen can have significant impacts on both the state and the national dairy industry, and have a bearing on the success or failure of government dairy policy. A statistical model incorporating both technology and price effects was developed and used to estimate aggregate milk supply and aggregate input demand price elasticities. It was also used to separate the aggregate milk supply response for Washington State into components representing the effects of pure technological advance, technologically efficient input level allocation, and profit-maximizing input level reallocations due to milk and input price changes.

The own- and cross-price elasticity estimates for the state were, in the main, as economic theory postulates. The own-price elasticity of supply was positive and the six input demand own-price elasticities were negative. All of the own-price elasticities were inelastic, which is consistent with analyses of the dairy industry in other parts of the United States. The cross-price elasticities between inputs were mostly negative, a result indicative of gross complementarity between inputs in the dairy industry.

Broad indicators of technological advance derived from the model suggested that dairy industry technologies in Washington are input-using and affect feed inputs to a greater extent than labor and capital inputs. The inelasticity of milk supply response to price changes suggested that rather severe milk price decreases would be required if government policy mandated that aggregate milk supply should be reduced via economic incentives.

Separating sources of aggregate milk supply response in Washington indicated that prices had the expected effects on aggregate supply—rising input costs and decreasing milk prices exerted downward pressure on milk production in the state. However, the effects of technological advance overwhelmed the negative effects of changing market prices. As a result, aggregate milk supply in the state increased by about 2.6% per year during a period when milk and input price signals suggested a reduction in milk production was warranted.

Conclusions

The Dairy Termination Program of 1986, (program effects not included in the analysis) was an effort to reduce the productive capacity of the U.S. dairy industry by slaughtering or exporting dairy cows and removing production for at least 5 years. The dairy herd in Washington was reduced by about 14% but producers not enrolled in the program expanded herds and offset the loss. The aggregate dairy herd declined by 6.3% between 1985 and 1987 while aggregate milk production expanded slightly (from 3.75 to 3.76 billion pounds). Apart from such direct efforts to reduce the size of the dairy herd, the expansionary effects of technology on the state’s aggregate milk production can be slowed, or reversed, only by substantial decreases in milk prices and/or substantial increases in input prices.
References


