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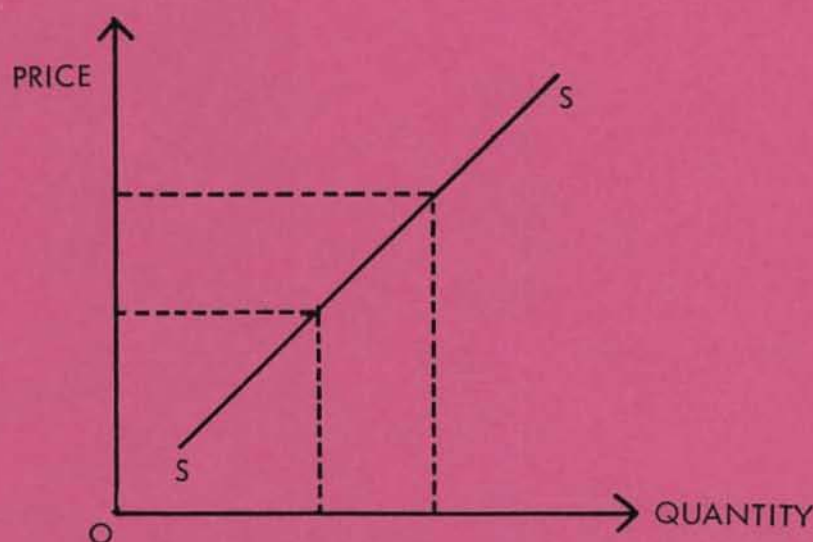
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MILK SUPPLY RESPONSE IN THE UNITED STATES AN AGGREGATE ANALYSIS

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"Some circumstantial evidence is very strong,
as when you find a trout in the milk."

Henry David Thoreau

Although U.S. milk production has increased only 5.6 percent since 1945, important year-to-year fluctuations in aggregate output have occurred. The purpose of this paper is (1) to identify the important economic factors influencing total milk output, (2) to estimate their impact by means of alternative statistical models, (3) to evaluate the results in a framework useful to dairy policy-makers.

Among other things, the models presented in this paper can be used to estimate how much the national average farm price of milk must be increased to obtain a given increase in output of milk when other things remain constant; what influence a given change in average feed grain or slaughter cow prices will have upon the output of milk; and what length of time is required for nearly-complete output adjustment to a given price change. In view of the 1965 and 1966 declines in milk production from the peak 1964 output, answers to these questions are timely. Recent changes in dairy price support levels and import quotas suggest that

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policy-makers are concerned about the current dairy situation.

Although the economic literature on milk and manufactured dairy products is almost unlimited, rather few attempts have been made to estimate an aggregate milk supply function. Three major studies are available--one by Willard W. Cochrane in 1958 and two by the late Harlow W. Halvorson in 1955 and 1958 [1, 2, 3].

Cochrane, in Farm Prices: Myth and Reality, attempted to measure a milk supply function with time series data for the 1947-56 period [1]. He concluded that the price elasticity of supply for milk is about +.03, but not statistically significant.

In his 1955 study, Halvorson was concerned with milk production response in the short-run (six months to one year) [3]. He concentrated on two components of total milk production, change in production per cow and change in cow numbers. Halvorson concluded that the short-run price elasticity of milk production is less than +.25 in the winter and probably less than +.10 in summer. Three years later, in 1958, Halvorson used a distributed lag procedure to derive short and long-run elasticity estimates for milk [2]. Data for two periods, 1927-57 and 1941-57, were fitted in identical fashion. He concluded that the short-run price elasticity of milk production was between +.15 and +.30 with indications that it was in the upper part of this range during the second period (1941-57). Similarly, the long-run supply elasticity appeared to range between +.35 and +.50 and was probably near the upper end of the range in the second period. Both Cochrane and Halvorson measured the influence of variables such as feed supplies and livestock prices on milk production.

About a decade has passed since these studies were published. Change has continued in the dairy sector. Hence, the analytical framework and the empirical estimates presented in this report may be more relevant to current dairy problems than the earlier efforts.

The Aggregate Supply of Milk

The Theory and the Models

Economic theory suggests that the aggregate U.S. output of milk is affected by the average farm price of milk, prices of variable inputs, and adopted technology. In this study it was hypothesized that farmers base their current production plans upon the previous year's average milk prices, either the current or a previous price of slaughter cows, and the current price or availability of feed inputs. These variables influence the number of milk cows kept in production by determining culling rates. The level of production also is related to feeding rates which are dependent upon feed prices, the quality of available feed, and breeding and managerial techniques used in production.

Production adjustments to price change may be different between the long-run and the short-run. Most dairy farmers are faced with high fixed costs and few good alternative uses for land, buildings, and equipment. In addition, a relatively long time period is required to raise calves and bring them into full production. On the other hand, a more rapid liquidation of dairy herds might occur when slaughter cattle prices are increasing relative to milk prices. In general, it was expected that the short-run supply elasticity for milk is quite low in the United States. As the time period under consideration becomes longer, the

supply response for milk is expected to become less inelastic. In this study it was hypothesized that short-run and long-run elasticities are different. Distributed lag techniques, developed by Nerlove, were used to test this hypothesis [5, 6, and 7].

Three basic milk supply response models were developed and are shown in Table 1. Each of these models are similar in the following ways: (1) the quantity of milk produced is the dependent variable in each model, (2) the price of milk, the price of slaughter cows, and measures of feed inputs are independent variables in each model. The feed inputs are represented by the price of feed grains, the amount of roughage feeds available, or both. The price of cows is either current slaughter prices or slaughter prices lagged one period. The ordinary least squares technique was used to estimate these models with data from the 1945-64 period.

Nerlove's distributed lag concept was employed in Model I. In this model, the supply adjustment can be shown as

$$(1) \quad Q_t - Q_{t-1} = \lambda (\bar{Q}_t - Q_{t-1})$$

where Q_t is current output of milk, \bar{Q}_t represents the long-run planned output of milk, and λ is a coefficient of adjustment. This equation says that the current quantity supplied will change in proportion to the difference between the long-run equilibrium quantity and the current quantity. Assuming that farmers adjust their planned output of milk in response to the previous year's price, the price of feed inputs, and the price of slaughter cows, one form of the long-run supply relation might be

$$(2) \quad \bar{Q}_t = a + bM_{t-1} + cG_t + dC_t$$

Table 1: Milk supply response models.

Models				
I. Quantity Milk	= f	(Milk prices,	Feed inputs,	Slaughter cow prices, Lagged dependent variable)
II. Quantity Milk	= f	(Milk prices,	Feed inputs,	Slaughter cow prices, Technology)
III. Quantity Milk	= f	(Milk prices,	Feed inputs,	Slaughter cow prices, Lagged dependent variable, Technology)

Variables^{a/}

(annual U.S. data for 1945-64)

Quantity Milk (Q_t)	=	Total U.S. production of milk, to the nearest ten million pounds.
Milk Prices (M_{t-1})	=	Average wholesale price of milk per cwt. received by farmers in the previous year, in dollars
Feed Inputs		
(G_t)	=	Index of prices received by farmers for feed grains (1957-59 = 100).
(R_t)	=	Roughage available; index number of hay, corn silage, sorghum forage, sorghum silage output (1957-59 = 100).
Slaughter Cow Prices (C_t)	=	Average price per cwt. at Chicago, commercial grade.
Lagged dependent variable (Q_{t-1})	=	Total milk production in the previous year.
Technology (T_t)	=	Milk production efficiency, see text.

^{a/} Data are from various issues of the following USDA publications: Agricultural Prices, Agricultural Statistics, Crop Production, Dairy Statistics, Grain, and Feed Statistics, and Milk Production. The data series used are presented in the appendix table to this report.

By substituting (2) into (1) an estimable short-run relationship is obtained

$$(3) \quad Q_t = \gamma a + \gamma b M_{t-1} + \gamma c G_t + \gamma d C_t + (1 - \gamma) Q_{t-1}$$

The variables can be in linear or logarithmic form.

In Model II, a special trend variable was used to represent milk production efficiency. Milk production per man-hour, a plausible indicator of efficiency, increases smoothly at a decreasing rate from 1945 to 1950 and then increases at an increasing rate from 1951-1964. However, this variable cannot be used directly since it contains the dependent variable in the numerator. Therefore an S-shaped time trend was used. This function was formed as follows: the year 1950 was set equal to zero, then the previous years (1945-1949) were represented by the negative square of time measured backwards from 1950, the subsequent years (1951-64) were represented by the positive square of time measured forward from 1950.

Model III combines the features of Models I and II. In each of the three models, a mean-zero, random error term was included to account for the influence of unspecified independent variables.

The Equation Forms

Economic theory says little about the appropriate algebraic form of the supply relation. As Hildreth and Jarrett point out, "...in most studies of economic relations, economic considerations do not give the investigator strong grounds for choosing a particular form. Within fairly wide limits, the choice is made on grounds of simplicity or convention, and must be regarded as to some extent arbitrary" [4, p. 12].

Two common approaches are to express the supply relation (1) as a linear function in actual numbers or (2) as a linear function in logarithms. A supply function expressed as linear in actual numbers has constant slope coefficients and variable elasticities. On the other hand, a logarithmic function has variable slopes and constant elasticities. Since there seems to be little a priori knowledge on the equation forms for milk, these two forms of the supply relation were investigated for each model.

The Empirical Results

There appears to be little solid basis for choosing between empirical results given by the linear and the logarithmic forms of the three models. Table 2 shows the statistical results of these two algebraic forms for three versions of Model I. These three versions differ in the way in which prices and quantities of feedstuffs are specified. It was found that the same coefficients were significant (or nonsignificant) under either form, and the coefficients of determination were similar. Furthermore, in the linear case, the supply elasticities do not vary much over the range of the data. Similar results also were obtained with Models II and III. Thus it appears that either equation form is an acceptable means of expressing the milk supply relation, but perhaps the logarithmic form may be preferable since supply elasticities can be computed directly.

Some additional results are presented in Table 3. The first three equations are versions of Models I, II, and III, which involve differing specifications of slaughter cow price, the lagged dependent variable, and the efficiency variable. The latter three equations in the table are

Table 2. Comparison of linear and logarithmic equation results for model (I)^a.

Equation	Milk Price M_{t-1}	Grain Prices G_t	Roughage Available R_t	Slaughter Price C_t	Lagged Dependent Variable Q_{t-1}	R^2	γ^b	N^c	Supply Elasticity ^d	
									Short Run	Long Run
(I.1) Linear	192.8 (55.41)	-5.313 (1.156)		-36.01 (6.419)	.591 (.070)	.960	.409	5.70	.078	.191
									.066	.161
									.053	.130
(I.1) Log	.068 (.016)	-.062 (.011)		-.062 (.008)	.539 (.062)	.970	.461	4.85	-.68	.148
(I.2) Linear	113.4 (62.59)		26.24 (6.473)	-44.00 (6.637)	.342 (.121)	.954	.658	2.79	.046	.070
									.038	.058
									.027	.041
(I.2) Log	.044 (.020)		.200 (.049)	-.069 (.010)	.349 (.115)	.955	.651	2.84	.044	.068
(I.3) Linear	145.5 (51.45)	-3.643 (1.202)	15.59 (6.282)	-38.58 (5.632)	.396 (.099)	.972	.604	3.23	.059	.098
									.049	.081
									.040	.066
(I.3) Log	.055 (.014)	-.046 (.011)	.104 (.042)	-.063 (.007)	.386 (.081)	.979	.614	3.15	.055	.090

^aThe estimated short-run coefficients are shown in this table; the long-run coefficients can be obtained by dividing the short-run coefficients by γ . Standard errors are in parentheses. Strict interpretation of the usual tests of statistical significance is not appropriate for distributed lag models. Serial correlation in residuals is not substantial in any of these equations.

^b γ is referred to as the coefficient of adjustment if the equation is linear in natural numbers and is the elasticity of adjustment if the equation is in log form.

^c N is the estimated number of years required for 95 percent output adjustment to a given price change. As formulated by Nerlove if N is the number of periods for adjustment to within 5 percent of the long-run equilibrium level, N may be determined by the equation $(1 - \gamma)N \leq .05$ where γ is the coefficient of adjustment [7].

^dThe estimated elasticities for linear equations are given at three points along the function: two standard deviations of price above the mean, the mean, and two standard deviations of price below.

Table 3. Comparison of three basic milk supply models, with and without the Korean War influence.^a

Equation	Milk Price M_{t-1}	Grain Prices G_t	Slaughter Price C_t	Slaughter Price C_{t-1}	Lagged Dependent Variable Q_{t-1}	Efficiency T	Dummy Variable K	R^2	γ^b	N^c	Supply Elasticity	
											Short Run	Long Run
(I.1) Log	.068 (.016)	-.062 (.011)	-.062 (.008)		.539 (.062)			.970	.461	4.85	.068	.148
(II.1) Log	.110 (.035)	-.083 (.020)		-.089 (.016)		.020 (.006)		.911			.110	
(III.1) Linear	318.2 (102.5)	-7.075 (1.703)		-39.72 (13.86)	.338 (.189)	109.1 (105.5)		.922	.662	2.76	.127 .108	.192 .163
(I.1) _k Log	.058 (.014)	-.066 (.009)	-.065 (.007)		.579 (.054)		.012 (.005)	.980	.421	5.48	.058	.138
(II.1) _k Log	.122 (.025)	-.098 (.014)		-.124 (.014)		.020 (.032)	.032 (.008)	.959			.122	
(III.1) _k Linear	350.1 (78.30)	-8.015 (1.321)		-65.24 (12.96)	.265 (.145)	151.6 (81.02)	341.1 (101.3)	.959	.735	2.26	.140 .119	.190 .162
											.098	.133

^aLong-run coefficients can be computed for equations (I.1), (III.1), (I.1)_k and (III.1)_k by dividing the short-run coefficients by γ . Standard errors are in parentheses. Serial correlation in the residuals is substantial only in equation (III.1).

^b γ is referred to as the coefficient of adjustment if the equation is linear in natural numbers and is the elasticity of adjustment if the equation is in log form.

^cN is the estimated number of years required for 95 percent output adjustment to a given price change. As formulated by Nerlove, if N is the number of periods for adjustment, to within 5 percent of the long-run equilibrium level, N may be determined by the formula $(1 - \gamma)^N = .05$ where γ is the coefficient of adjustment [7].

^dThe estimated elasticities for linear equations are given at three points: two standard deviations of price above the mean, the mean, and two standard deviations of price below.

similar to the first three but include the additional effect of a zero-one variable for the Korean War years, 1951-54. The empirical results shown in these tables are suggestive of a variety of models and versions which were examined.

Consider, for example, equation (I.1). All coefficients are of the expected sign and large relative to their estimated standard errors. The four independent variables account for 97 percent of the variation in the output of milk over the 1945-64 period. Both short-run and long-run supply elasticities are estimated in equation (I.1); the estimated short-run elasticity is about +.07 while the long-run elasticity is about +.15. These elasticity estimates and most of those obtained in other versions of this analysis are lower than were obtained by Halvorson [2]. This seems reasonable since recent changes in the dairy sector, such as fewer and larger dairy herds, probably have made supply response to price more inelastic. The estimated elasticity of adjustment and the length of the adjustment period also are obtained from equation (I.1). According to this equation, about 45 percent of the adjustment to a price change occurs in the first year, then four more years are required for almost complete adjustment to take place, all other things held unchanged. One interpretation of these results is that if milk prices increase, farmers probably will make a short-term adjustment in the first year by increasing feeding rates and culling herds less closely. In the longer period of time (5 years) the farmers are able to respond to price increases by raising more calves and increasing their herd size. Differing adjustment periods are given by other equations, but none are much less than three years.

Some results from Model II are shown in equation (II.1) of table 3. All estimated coefficients in this equation exhibit the expected sign and are large relative to their standard errors. A lower R^2 is obtained in Model II than in Model I, and the estimated short-run supply elasticity is higher than in Model I. The efficiency variable, T , displays a significant coefficient although its precise interpretation is elusive.

Equation (III.1) shows the results of combining models I and II. The relative size of the standard errors of the lagged dependent variable and the technology variable coefficients is larger than in previous models. This is attributed to intercorrelation among the independent variables, especially Q_{t-1} and T . Here also the variation of price elasticity along the function is not large within the range of most of the price data. The final three equations of table 3 show that the dummy variable for the Korean War period is itself significant and improved the overall fit. The inclusion of this variable also increased the ratio of most other estimated coefficients to their standard errors. In addition, the estimated supply elasticities do not differ very much from those obtained in equations which did not include the dummy variable. The inclusion of a shift variable for this war-time period is justified on the basis of an assumed upward shift in price expectations of dairy farmers.

Since the equations were fitted with 1945-64 data, the computed value of milk production for 1965 represents an independent "test" of the models. The data in table 4 are predicted values of output for the equations in table 3 and the percentage error of each compared to the actual 1965 output of 125.1 billion pounds. Equations (I.1) and $(I.1)_k$ out-perform the others

in this test mainly because they include the effect of current slaughter cow prices which were rather high in 1965.

The actual vs. estimated values of the dependent variable for equation (I.1) are shown in figure 1 for the 1945-64 sample period and the independent "test" year of 1965. This illustration is similar to those obtained with the other versions, although the fit here is slightly better than with most other equations.

Conclusions

The empirical results indicate that either the linear or logarithmic equation form can be used in estimating the milk supply relation. Model I which utilizes Nerlove's distributed lag concept, resulted in the closest estimated values of the actual U.S. output of milk and is probably the best overall expression of the supply function. According to this model, the short-run supply elasticity appears to be about +.07 while the long-run supply elasticity is about +.15. Other models indicate slightly higher supply elasticities, but none higher than +.12 in the short-run and +.16 in the long-run, at the means of Model III. Including a dummy variable in Model I for the Korean War years resulted in slightly lower price elasticity estimates. Although it increased the R^2 and the significance levels of the other coefficients, its predictive value was poorer in 1965. About five years are required for nearly complete adjustment to a given price change. The short-run cross elasticities of supply with respect to slaughter cow prices and grain prices are both about -.06.

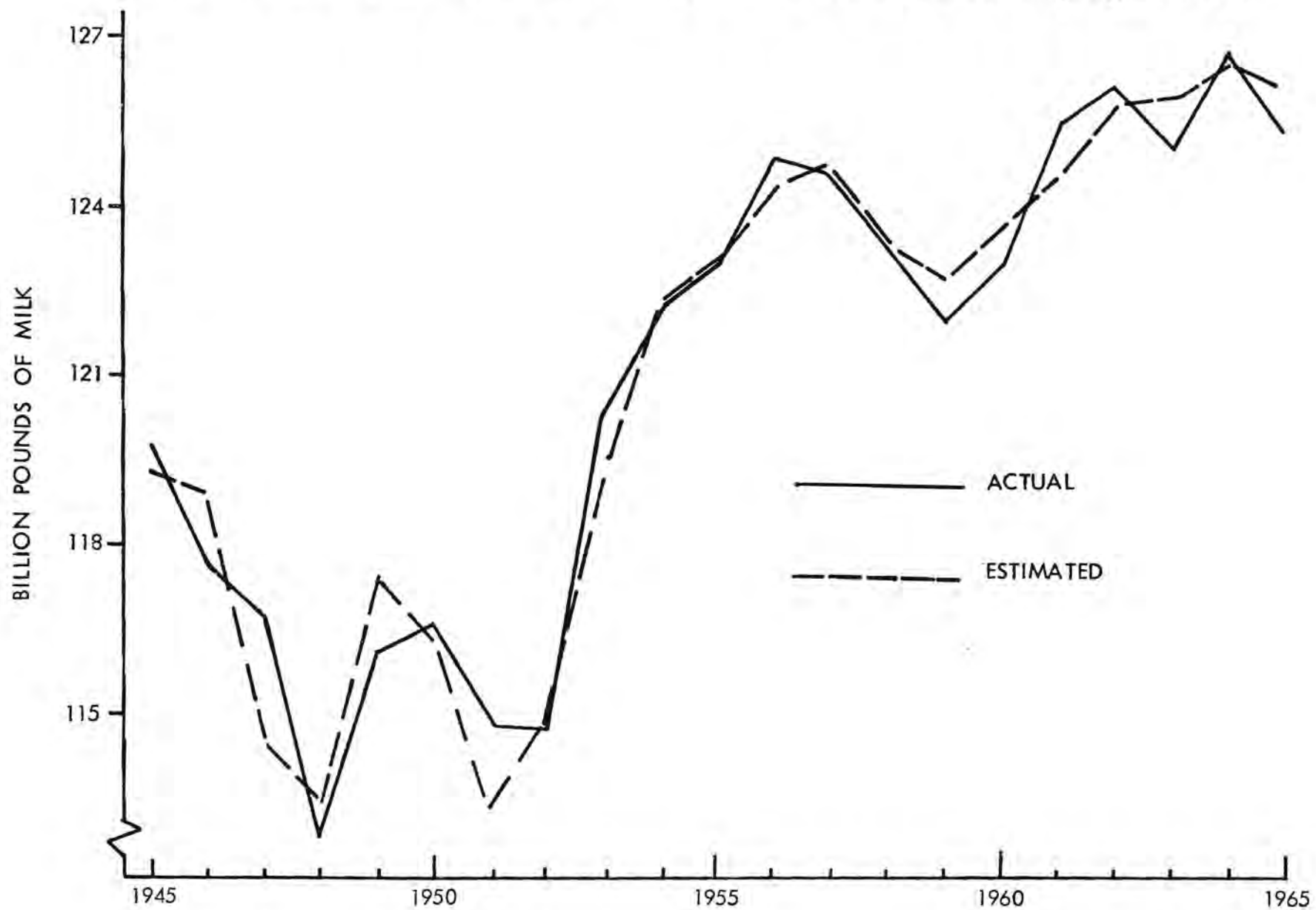
Table 4 Predicted milk production; 1965.

Equation	Predicted Milk production	Percentage error (based on actual 1965 output of 125.1 billion lbs.)
	billion lbs.	percent
(I.1) Log	125.9	0.64
(II.1) Log	127.5	1.92
(III.1) Linear	127.1	1.60
(I.1) _k Log	126.0	0.72
(II.1) _k Log	127.8	2.16
(III.1) _k Linear	127.9	2.24

The drop in milk production in both 1965 and 1966 has concerned dairy analysts. Milk cow numbers declined sharply in both years, but per-cow production increases were only 2-3 percent per year. In the past, increases in production per cow were large enough to off-set the long-run decreases in cow numbers. However, in 1965 and 1966 this was not true, and the aggregate output of milk fell a total of 5.5 billion pounds from the record 1964 level. This decrease may be attributed to extremely favorable slaughter cow prices and poorer quality feeds in certain sections of the United States. Most of the 1965 output decrease predicted by Model I, figure 1, is the result of higher slaughter prices.

Perhaps an increasing number of farmers, having decided that dairying is not paying an acceptable return for their labor and invested capital,

ESTIMATED VS. ACTUAL U.S. MILK PRODUCTION EQUATION (I .1), 1945-65



are now liquidating their dairy investments and directing their efforts to other farm enterprises or to attractive off-farm employment. If this is the case, then we may expect a decline in aggregate milk production for some time unless substantially higher milk prices relative to slaughter prices are forthcoming. Considering only price adjustments and using a long-run supply elasticity of $+0.15$, the 1964 level of milk production could be restored in about 1971 by a sustained 30 percent increase in average milk prices. Quicker adjustment would require a larger price increase.

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7. Nerlove, Marc and William Addison, "Statistical Estimation of Long-Run Elasticities of Supply and Demand," J. Farm Econ. 40:861-880, Nov. 1958.

Appendix table: Data used for estimation of milk supply functions

Year	Q_t Total U.S. milk production (1) (ten million lbs)	M_{t-1} Wholesale price of milk (2) (\$/cwt)	G_t Grain price index (3) (1957-59 = 100)	R_t Roughage index (4) (1957-59 = 100)	C_t Slaughter cattle price (5) (\$/cwt)	T_t Efficiency indicator (6) (1950=0)	K_t Dummy variable Korean War
1945	11,983	3.21	103	93	13.65	-.25	0
1946	11,770	3.19	125	87	14.62	-.16	0
1947	11,681	3.99	152	84	17.84	-.09	0
1948	11,267	4.27	191	84	22.64	-.04	0
1949	11,610	4.88	113	83	18.41	-.01	0
1950	11,660	3.95	117	89	21.48	0	0
1951	11,468	3.89	142	92	27.76	.01	1
1952	11,467	4.58	152	90	21.74	.04	1
1953	12,022	4.85	136	92	13.92	.09	1
1954	12,209	4.32	129	92	13.28	.16	0
1955	12,295	3.97	122	98	12.98	.25	0
1956	12,486	4.01	113	94	12.72	.36	0
1957	12,463	4.14	110	101	14.83	.49	0
1958	12,322	4.21	97	102	19.76	.64	0
1959	12,199	4.13	98	97	19.11	.81	0
1960	12,295	4.16	95	103	16.21	1.00	0
1961	12,544	4.21	92	102	16.07	1.21	0
1962	12,602	4.22	95	105	15.89	1.44	0
1963	12,501	4.10	99	105	15.11	1.69	0
1964	12,660	4.11	101	105	13.57	1.96	0

Appendix table (continued)

Data Sources

- (1) Q_t = Total U.S. Production of Milk
(1944-59) USDA, Dairy Statistics through 1960, ERS, Statistical Bulletin No. 303, Table 152, p. 152.
(1960-61) USDA, Supplement for 1962 to Dairy Statistics through 1960, ERS, Table 152, p. 26.
(1962-present) USDA, Milk Production, SRS (a monthly publication).
- (2) M_{t-1} = Average wholesale price of milk
(1944-59) USDA, Dairy Statistics through 1960, ERS, Statistical Bulletin No. 303, Table 249, p. 262.
(1960-present) USDA, Milk Production, SRS (a monthly publication).
- (3) G_t = Prices received for feed grains.
(1944-60) USDA, Grain and Feed Statistics through 1961, ERS, Statistical Bulletin No. 159, Revised June 1962, Table 39, p. 40.
(1961-64) USDA, Supplement for 1964 to Grain and Feed Statistics, ERS, Table 30, p. 20.
(1965-present) USDA, Agricultural Prices, SRS (a monthly publication).
- (4) R_t = Roughage Feed - Total Output
(1945-60) USDA, Agricultural Statistics 1962, Table 663, p. 540.
(1961-64) USDA, Agricultural Statistics 1964, Table 659, p. 454.
(1964-1965) USDA, Crop Production: 1965 Annual Summary, SRS, December 20, 1965, p. 51.
- (5) C_t = Price of slaughter cows.
(1944-53) USDA, Agricultural Statistics 1962, Table 474, p. 381.
(1954-63) USDA, Agricultural Statistics 1964, Table 469, p. 321.
(1964) USDA, Agricultural Statistics 1965, Table 465.
- (6) T_t = Efficiency indicator (see text)
- (7) K_t = Dummy variable for Korean War (1951, 1952, 1953 = 1) (all other years are zero).