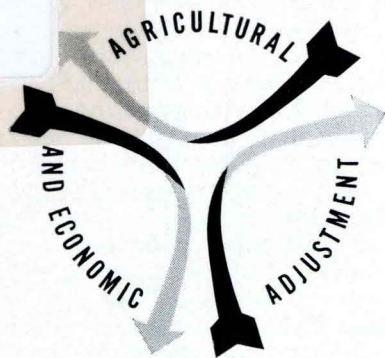


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Poultry Supply Functions (The Relation of Technical Change To Output of Eggs, Broilers and Turkeys)

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cooperating

**AGRICULTURAL AND HOME ECONOMICS EXPERIMENT STATION
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SUMMARY

Supply relations underlie the surplus, price and income problems of American agriculture. Yet specific knowledge of supply relations is still small. This study is part of a larger investigation directed toward increased knowledge of output response or supply in agriculture. It is concerned with a particular category of farm commodities; namely, poultry products. The objective of the study is to quantitatively identify variables which have been important in the response of poultry output over time. But methodological purposes also are important for the study, and considerable emphasis is placed on comparison of alternative models applicable to egg, broiler and turkey supply relations.

Technological change has been large in poultry production and evidently has had great effect on output. Hence, the first step in this study is that of quantifying technical change, as a substitute for time in the regression equations estimated. The number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate are selected as the output-input ratios which best indicate the levels of technology for the three poultry products. In extracting the net change in technology, by eliminating the effects of certain market conditions, a logistic function is fitted to data for each type of poultry. The values obtained from the estimated logistic functions are called the technology index of egg production, broiler production and turkey production. Poultry supply models are constructed with these technology indexes incorporated as variables.

An egg supply model was estimated for 1926-58. The results provide statistical evidence that the egg price of the hatching season is an important determinant for the number of pullets raised, and, hence affects the total output of eggs in the following year. This effect of the egg price on pullet-raising also is confirmed by the results of an equation estimated to show the effect of the egg-feed price ratio on farmers' demand for pullets. The egg supply function clearly indicates that technological progress has shifted egg supply to the right. The effects of competitive poultry enterprises on egg output could not be established at the national level of aggregation.

The technology index proved superior to a time trend in the egg supply function. The coefficient of determination was reduced from 0.9056 to 0.5770 by substituting time for the technology index in the egg supply function. Moreover, the influence of the egg price during hatching season is obscured by using time in the estimate of egg supply.

To see whether any change has occurred in supply elasticities, the egg supply model was estimated for two subperiods 1926-41 and 1947-58, and also for the smaller segments of periods 1926-33, 1934-40, 1941-46 and 1947-58. The results of estimation for these subperiods suggest that the price elasticity of egg supply has been reduced

among these periods. To test the hypothesis that the recent specialization tendency in egg production resulting from technological progress has caused the reduction, the elasticity of egg supply with respect to the egg-feed price ratio was formulated as a linear function of the technology index for statistical estimation. The results show that the elasticity is reduced by 0.0065 for a unit increase in the technology index. This value is statistically significant at the 5-percent level. The hypothesis is further confirmed by the result of estimation of farmers' demand for pullets. The demand elasticity for pullets with respect to the egg-feed price ratio is estimated also to decrease by 0.0155 for a unit increase in the technology index.

A broiler supply model was estimated first by least-squares methods for the period 1935-58. Broiler prices are shown to have a significant effect on the farmers' demand for broiler chicks in the analysis of monthly data. A model based on simultaneous equations for demand and supply of broilers also was estimated for annual data in the 1935-58 period. No improvement over the single-equation, least-squares estimate resulted from this model. The technology index also proved to be superior over a time trend variable in the analysis of broiler supply. By using time instead of the technology index with regression equation, the sign of the coefficient for the broiler-feed price ratio became negative.

To determine whether a change has occurred in price elasticity for broilers, a model was estimated for the two separate periods, 1935-46 and 1947-58. The supply elasticity with respect to the broiler-feed price ratio also was formulated in a model with the technology index expressed as a linear function. The estimates show that output elasticity with respect to price has been reduced by 0.1675 for a unit increase in the technology index.

The turkey supply model was estimated first for the period 1930-58. It showed that the turkey-feed price ratio of the previous fall significantly influences turkey output in the following year. The effects of competitive poultry enterprises on turkey output, at the national level of aggregation, could not be clearly established. The technology index again proved to be superior to a time variable. By substituting time for the technology index, the coefficient of determination was reduced by 10 percent, and the effect of the turkey price on the total output was obscured.

Separate supply functions were then estimated for the periods 1930-41 and 1942-58. The results indicate that the elasticity of output with respect to the turkey-feed price ratio has increased appreciably over time. To test the hypothesis that this increase in elasticity of turkey supply, with respect to the turkey-feed price ratio, has been caused by technical change, a linear function of the technology index was used. It indicated that the elasticity has increased by 0.0099 for a unit increase of the technology index.

The Koyck-Nerlove model of distributed lags provided a reasonable estimate of long-run supply elasticities for eggs and turkeys. But the results for a similar model applied to broilers provided

nonsensical results. Evidently, a Koyck-Nerlove model cannot be used successfully with data where the dependent variable has a trend of consistent increase or decrease.

Poultry Supply Functions (The Relation of Technical Change to Output of Eggs, Broilers and Turkeys)¹

BY EARL O. HEADY AND YUJIRO HAYAMI

This study includes a quantitative analysis of supply relations for poultry products in the United States. There are several stages in the supply of a farm commodity — the supply at producers' level, at the wholesale level and the retail level. This analysis is restricted to the supply of poultry products at the farm level. It is an attempt to predict the quantity of poultry products which farmers produce in response to the prices of these commodities, the prices of major cost items or inputs, and selected other variables.

The study is made as part of a larger analysis dealing with demand for or use of resources in agriculture and the supply of products. The surplus and income problems of agriculture revolve around problems of the magnitudes of inputs and outputs in the farming industry. Even now, little is known about the rate at which farmers' production responds to changes in price and other relevant phenomena. Accordingly, major debate still prevails over farm policy and the extent to which surplus problems might be solved under varying levels and policies of price.

The problems of supply are of particular importance in the feed grain-livestock sector of the agricultural economy. Greater knowledge is needed of the nature of supply response and the magnitude of outputs and prices which might exist under different degrees of controls over, or freedom in, the market mechanism. Accordingly, research has been initiated to estimate supply functions or response for major sectors of livestock and poultry and demand functions for feed grains. This study represents one phase of the over-all study and concentrates on supply functions for poultry products. Emphasis is placed on obtaining quantitative knowledge of the basic relations in poultry supply. Necessarily, then, the investigation involves methodology and the comparison of statistics and predictions obtained from alternative supply models.

THE POULTRY INDUSTRY

Poultry production provides about 20 percent of the combined livestock and poultry production

of the United States. The industry includes three major enterprises which are more or less distinct operations: (1) eggs with chicken meat as a by-product, (2) broilers and (3) turkeys.

Egg production primarily has been an enterprise of the family farm, though there is a tendency toward specialization in some sections of the nation. A distinct seasonality in egg production exists where farmers cause egg production to conform with operation of other enterprises.

Broiler production is the most specialized branch of the poultry industry. Geographically, broiler growers have become clustered in the South Atlantic region where production is highly commercialized and is continuous throughout the year.

Turkey production, originally a sideline in farm operations, is now highly specialized. Turkey production also is highly seasonal because of the seasonality of demand and egg production. Because of differences in final products and production patterns, each of the three major enterprises is treated separately in the following analysis, except that the empirical models employed involve certain interrelationships among enterprises.

Other poultry enterprises include ducks, geese, guineas, pigeons, quails and pheasants. These minor enterprises are negligible, however, in terms of their physical and value contribution to total poultry production. Therefore, analysis of them is not included in this study of poultry production.

Poultry production increased by 107 percent between the periods 1925-29 and 1953-59. In the same time span, total agricultural production increased by only 52 percent, and total livestock production, including poultry, increased by only 59 percent. The rapid growth of poultry production, relative to other meat products and aggregate farm output, is illustrated in fig. 1. The rates of growth in output differ considerably among poultry enterprises (fig. 2). Egg production, the most important component of poultry production, increased at about the same rate as total poultry production. The broiler enterprise has grown most rapidly. Starting at a negligible level of the mid-30's, the total output rose to more than 5 billion pounds of liveweight broilers in 1958. The increase in total output has been continuous, except

¹ Project 1406, Iowa Agricultural and Home Economics Experiment Station, Center for Agricultural and Economic Adjustment cooperating.

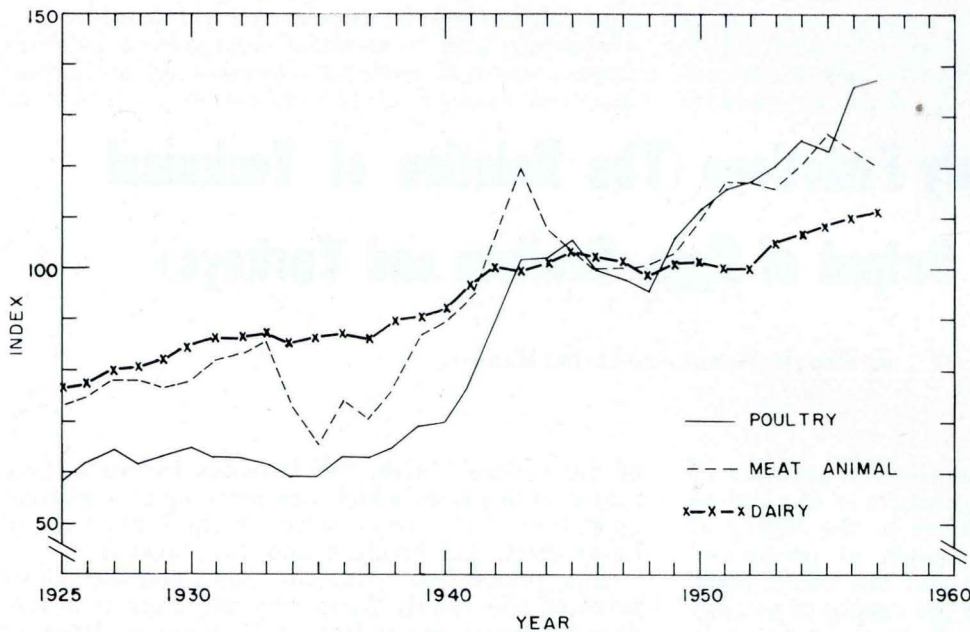
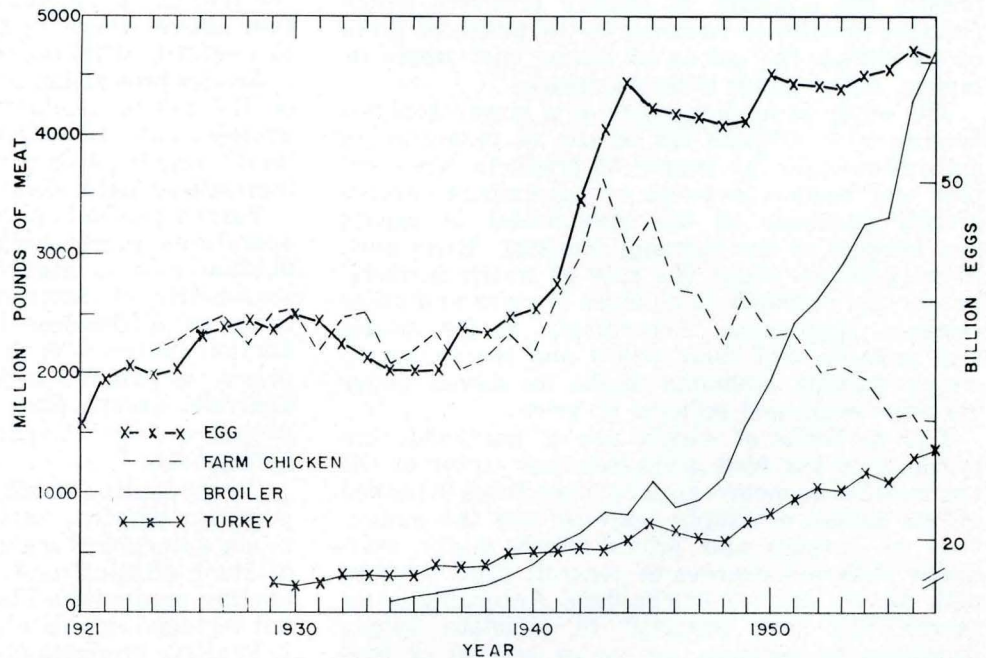


Fig. 1. Index numbers of livestock output — poultry, meat animal and dairy (1947-49=100).

Fig 2. Total poultry production, by products.



in 1944 and 1946 when small decreases occurred. Total broiler output doubled in each of the periods 1935-38, 1938-41, 1941-48, 1948-51 and 1951-58. The upward trend in turkey production generally has been steady, though accompanied by minor fluctuations. Output in the period 1953-57 was more than four times that of 1930-35. Among the major poultry products, only the output of farm chickens has shown a decline. The output of farm chickens was fairly stable before World War II, increased rapidly during the war and has been decreasing steadily since then.

The question arises: What caused these rapid developments in the poultry industry? The increase in output must have been caused by either

a rise in the relative price of poultry products or a reduction in production cost. Price movements of major poultry products are shown in fig. 3. The general price level of poultry products has not risen, except during the intrawar period. Poultry product prices have declined appreciably since 1948 and, over the past 15 years, have not been high relative to other types of livestock and relative to feed prices.

It is reasonable to assume from these price movements that the supply function for poultry products has shifted to the right more rapidly than has the demand function. The cost of production, one basis of the supply function, is determined by the prices of inputs and the technology of

Fig 3. Prices of poultry products, deflated by consumers' price index (cents per dozen eggs or pound of meat).

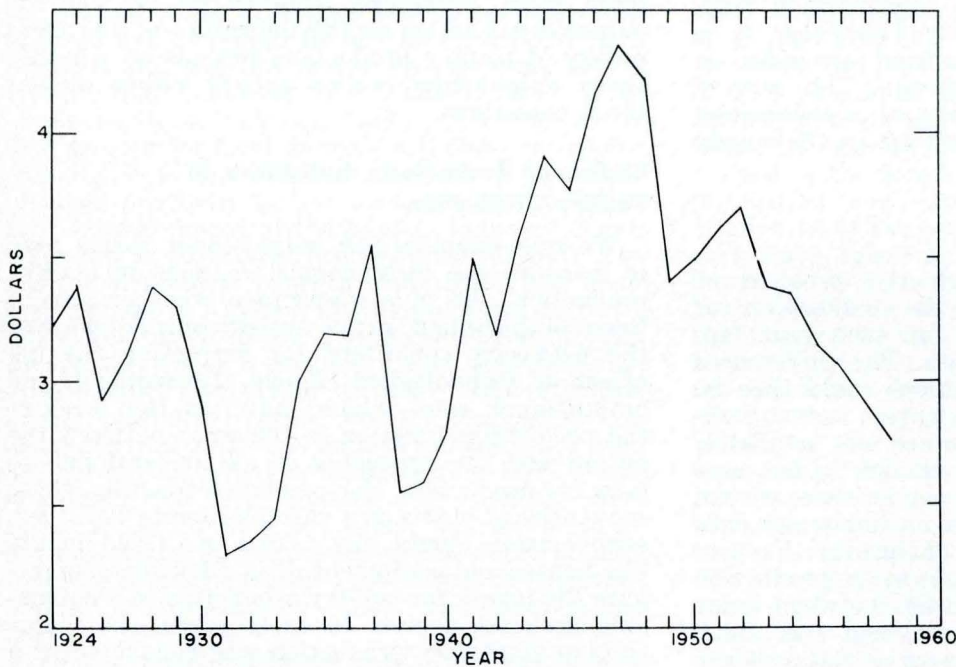
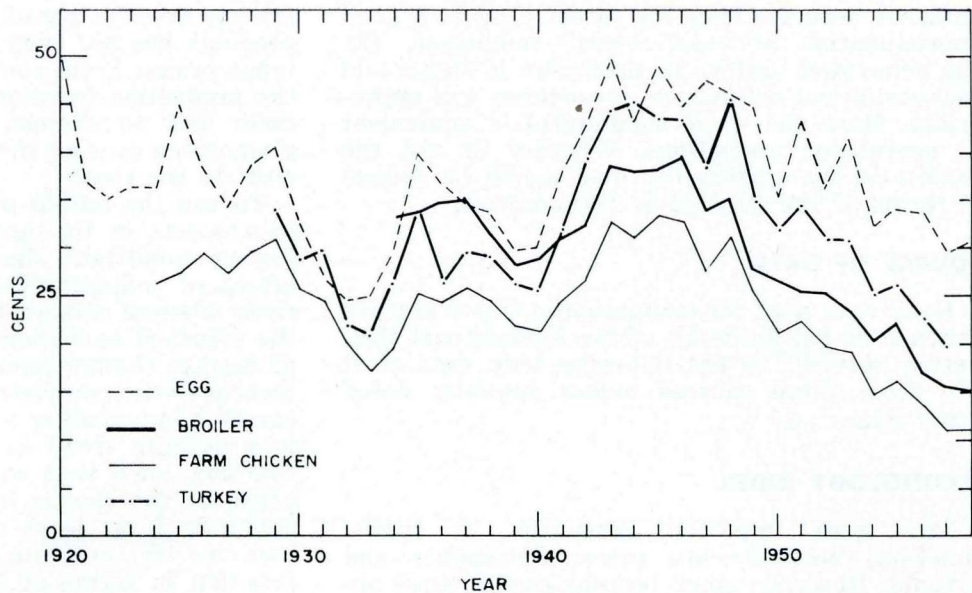


Fig. 4. Poultry ration cost, deflated by consumers' price index (dollars per 100 pounds of poultry feed).

production. It is likely, then, that the rapid rightward shift of the supply function must result from either a decline of input price or technological change which lowers the amount of inputs required per unit of output. However, the decline of input price is not the likely cause. Figure 4 shows that, though there have been considerable fluctuations, the price of poultry feed, the most important cost item, has been at about the same level in the recent decade as in earlier decades.

The technology of production apparently is the major factor which has caused the poultry supply function to change.²

² The relative profitability of competing enterprises is another important factor affecting poultry production and supply. However, analysis suggests that, over much of the period analyzed, the absolute level of returns for other livestock enterprises had not declined. Technological change evidently has caused poultry production to increase in relative profitability, however.

OBJECTIVES AND EMPIRICAL APPROACH

The objective of this study is to estimate and interpret empirical supply functions for eggs, broilers and turkeys for the United States. In meeting these objectives, alternative regression techniques and models are applied to time series data. Most of the analysis is based on single-equation, least-squares methods. However, applicability of simultaneous models also is examined.

The basic approach used in this study is the statistical estimation of supply equations from nationally aggregated time-series data. This is the approach traditionally used in the analysis of demand and supply. The estimated parameters of the supply equations are meaningful if (1) the

data are accurate, (2) the model used is a good approximation of "real world" conditions, (3) the behavioral pattern of producers is stable and (4) statistical estimation procedures are appropriate. Here the word **meaningful** is equivalent to **useful for predictions**. Whether or not the conditions are sufficiently met should be judged in terms of the purpose of the analysis.

SOURCE OF DATA

Basic data used for estimation in this study are taken from the statistics of the Agricultural Marketing Service.³ In the following text, data cited are from these sources unless specially noted otherwise.

TECHNOLOGY INDEX

The most important variables in supply functions normally are prices for inputs and outputs. However, since technological change appears to have been extremely important in causing change in poultry supply functions, it is useful and necessary to construct an index or measurement of this phenomenon. The current section deals with construction of a technology index to serve with other variables in the supply models explained later.

Indicators of Technology

A direct way to approach the problem of changing technology would be estimation of poultry production functions for each year separately from farm-survey data. The differences between these estimated functions could then be measured. This procedure, however, is not practically feasible because data are not available. Since direct measurement of change in the production function over time is not feasible, we are forced to use some magnitudes in time-series data which indirectly reflect the change in the production function. The change in a production function is reflected in the ratios between input and output which have been realized over time. An output-input ratio in time-series data shows, at each point in time and for a given market situation, an average productivity for a certain input level. Not only the magnitudes of the production function but also the prices of output and input can affect the output-input ratio used by farmers. It is difficult to determine, from time series data, the extent to which a change in the output-input ratio is caused by a change in the production function or a change in the market situation. Obviously, however, from the data presented earlier, the supply function has changed

greatly even for periods when the price of poultry products has not been more favorable relative to input prices. From common knowledge, change in the production function, causing the input-output ratio also to change, has been the important phenomena causing the poultry supply function to shift to the right.

To use the output-input ratio as the indicator of changes in the production function, the following conditions should be satisfied: (1) the effect of market situation on the output-input ratio is small enough to be neglected, relative to the effect of technological change; (2) the effect of market change generally follows a similar pattern over the complete range of time, so that it can be eliminated by a certain scheme; (3) there is a definite trend in change of the production function, such that we can approximate the net effect of the change by fitting a certain type of function. If at least one of these conditions is met, we can evaluate the change in production function in terms of the change in the output-input ratio. Therefore, whether we can use the output-input ratios as the indicators of the technology of poultry production depends on whether these output-input ratios satisfy either one of these conditions.

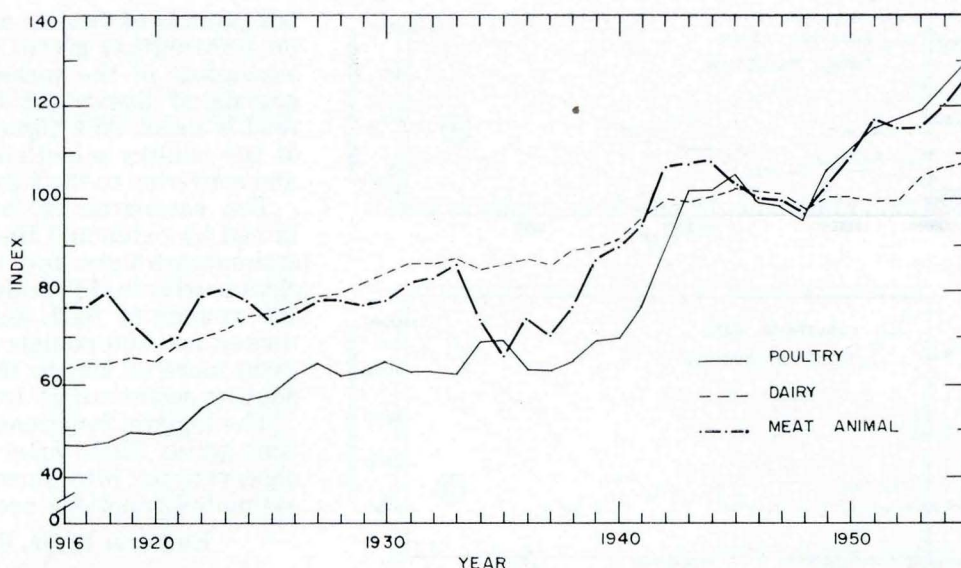
Choice of Technology Indicators in Poultry Production

We now examine the output-input ratios used to measure the technological changes in poultry production. We must determine whether any of these output-input ratios satisfy one or more of the necessary conditions for extracting the net effect of technological change. Theoretically, an output-input ratio which indicates the level of the production function is the ratio between the output and the aggregate of all **conventional** inputs for production. For poultry production, these conventional inputs are variable inputs like feed, semivariable inputs like flocks and fixed inputs like houses and equipment. It is difficult to aggregate the inputs for poultry production to a reasonably accurate degree. In early years, the major portion of poultry production was conducted as a sideline of the total farm operation. This situation still holds true for egg production. It is difficult to separate the labor devoted to poultry production from that used in other farm operations. National aggregative data are not available for the fixed capital of poultry. Under these limitations, the aggregation of all inputs would result in meaningless figures.

A more practical method is to choose a factor which has made the greatest contribution in the development of the industry. In poultry production, developments in breeding, nutrition, disease control and environmental control represent important biological innovations. New devices in ventilation, feeding and water systems, etc., represent important mechanical innovations. Mechanical innovations are reflected mainly in the average productivity of labor or the output-labor ratio.

³ U. S. Department of Agriculture. Egg and poultry statistics through 1957. U. S. Dept. Agr. Stat. Bul. 249. 1959; U. S. Department of Agriculture. The poultry and egg situation. PES 198-PES 257. 1958-1959; U. S. Department of Agriculture. Agricultural Marketing Service. Agricultural prices. (Mimeo.) 1958-1959; and U. S. Department of Agriculture. Chickens and eggs — farm production, disposition, cash receipts and gross income. U. S. Dept. Agr., Agr. Marketing Serv. POU 2-3 (59). 1959.

Fig. 5. Index numbers of livestock production per man-hour — poultry, meat animal and dairy (1947-49 = 100).



As is seen in fig. 5, poultry output per man-hour of labor has increased faster than other livestock products and was 76.3 percent larger in the period 1950-56 than in the period 1910-29. Between these two periods, output per man-hour increased by 21.6 percent for meat animals and 65.8 percent for dairying. It is doubtful, however, that the increase in labor productivity has been the major factor in the development of the poultry industry. First, labor cost is not a large proportion of all costs. The records of poultry farms in Iowa⁴ show that labor cost, though it varies widely from farm to farm, has rarely been above 30 percent of total cost throughout these 3 decades. Labor represents an even smaller proportion of total costs on large, highly specialized farms. Poultry production traditionally was a sideline enterprise, and labor used had an opportunity cost approaching zero. While no longer true for broilers and turkeys, farm flocks for egg production utilize mainly the labor of housewives. Hence, development of the poultry industry up to the middle 1930's must be explained mainly by innovations other than labor-saving devices.

This summary does not mean that mechanical innovations have been unimportant in the development of the poultry industry, but only that biological innovations have dominated. Labor increasingly is becoming an explicit cost for poultry farmers as specialization proceeds. Still, the main innovations which have encouraged development of the poultry industry in the past 3 decades are probably of a biological, rather than a mechanical, nature. Biological innovations have been represented by improvements in (1) nutrition, (2) breeding, (3) disease prevention and (4) environmental control. Those innovations alone have caused an enormous increase in poultry output per unit of feed input. USDA figures⁵ show that in

1935, 100 pounds of feed produced 18.9 pounds of broiler and 13.8 pounds of turkey. By 1957, 100 pounds of feed produced 33.9 pounds of broiler or 17.1 pounds of turkey. In the same period of time, egg production per layer increased similarly from 122 eggs to 198 eggs per year.

Feed is the largest single cost item in poultry production and currently comprises more than 50 percent of the total cost of production. (In the early days, feed was almost the sole item for cash expenditure in poultry production.) We assume that biological innovations, which are expressed in the change in the output-feed ratio, have had major importance in the development of the poultry industry during this century. Hence, we choose the output-feed ratios (feed-conversion rates) as the technology indicators in poultry production. Broiler-feed conversion rates and turkey-feed conversion rates are used in constructing the technology indexes of broilers and turkeys, respectively. For the egg functions, however, the number of eggs per layer is used for this purpose. Trends in the number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate are shown, in comparison to the total outputs, in fig. 6. The trends of these technology indicators are very similar to the trends in the total outputs.

Construction of Technological Variable

The number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate, by themselves, do not measure the net effects of technological change. However, they probably serve effectively enough to be used in constructing the technological variable to be used later. A logistic function is used in constructing the technological index.

There are several methods of estimating the parameters of the logistic function. A problem arises, however, in obtaining reasonable estimates of upper asymptotes, from the data on hand, by

⁴ Iowa State University of Science and Technology, Cooperative Extension Service. Annual reports of Iowa poultry demonstration flocks. (Mimeo.) 1930-59.

⁵ Jennings, R. D. Consumption of feed by livestock, 1909-56. U. S. Dept. Agr. Prod. Rpt. 21. 1958.

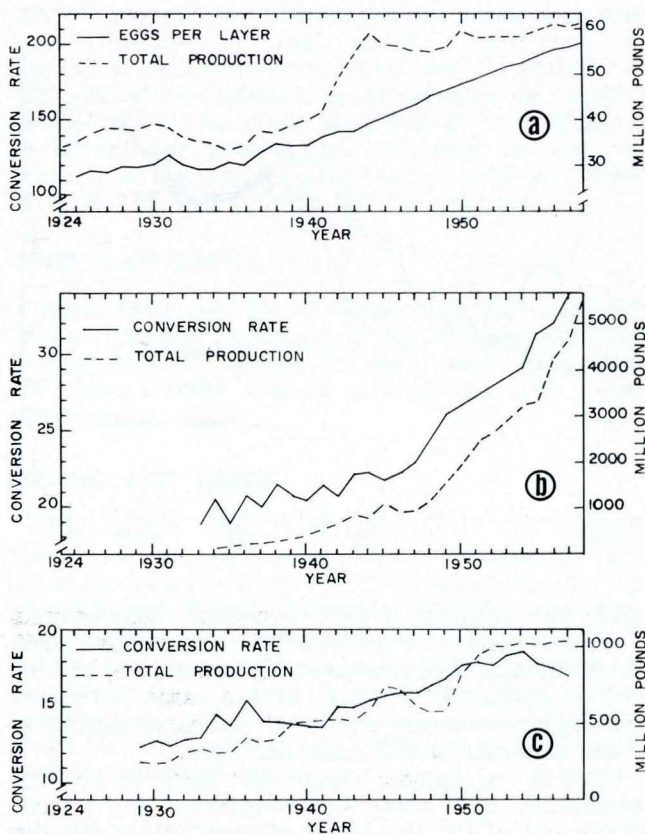


Fig. 6. (a) Number of eggs per layer and total output of eggs. (b) Broiler-feed conversion rate and total output of broilers, liveweight. (c) Turkey-feed conversion rate and total output of turkeys, liveweight.

any standard method. The broiler-feed conversion rate is still growing at an increasing rate. Though there is some sign of slowing down in the increase in number of eggs per layer, the deceleration tendency is not yet appreciable. The turkey-feed conversion rate has declined since 1955. But the efficiency of turkey production is still rising in an exponential fashion. From current time-series data, the estimates of upper asymptotes would be subject to great error. Therefore, the appropriate asymptote values must be established from *a priori* knowledge. The physical limit would be 365 eggs per layer and 1 pound of broiler or turkey meat per pound of feed. But it is generally believed that the national average figures will level off before reaching the physical limits.

For egg production, it is reported⁶ that the average production of hens in the Connecticut egg-laying contests appears to have leveled off at about 240 eggs per year. Records in other egg-laying contests indicate that egg production per year has attained a 250 level. Hence, 250 eggs is used for the upper asymptote value in national averages.

For the upper asymptote of the broiler-feed conversion rate, 67 pounds of liveweight broiler per

⁶ Bird, H. R. Fifty years of scrambling for more efficient egg production. *Feedstuffs* 31, No. 8:10-11. 1959.

100 pounds of feed is adopted. This ratio is based on information given by Combs.⁷ For the upper asymptote of the turkey-feed conversion rate, 33 pounds of liveweight turkey per 100 pounds of feed is used. This figure is based on the estimate of the poultry scientists at Iowa State University and conforms to the figure predicted by Scott.⁸

The estimates of lower asymptotes were obtained by extending the trend curves to 1900. The estimated values for lower asymptotes are 100 eggs per layer, 18 pounds of liveweight broiler per 100 pounds of feed, and 12 pounds of liveweight turkey per 100 pounds of feed. These values conform more or less to the knowledge expressed by poultry scientists at Iowa State University.

The logistic functions have been estimated from time-series data, after transforming the yearly observations into linear logarithmic form. The estimated functions are as follows:

Eggs per layer, R_e

$$(1) R_e = 100 + \frac{250}{1 + 19.72e^{-0.0777t}}$$

Broiler-feed conversion rate, R_b

$$(2) R_b = 18 + \frac{67}{1 + 55.67e^{-0.1116t}}$$

Turkey-feed conversion rate, R_T

$$(3) R_T = 12 + \frac{33}{1 + 42.07e^{-0.0899t}}$$

The original observations and the estimated values of the number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate are shown in table 1. Figure 7 indicates the conformance of the logistic function to the actual observations. The coefficients of correlation between the original observations and the estimated values are 0.993 for eggs, 0.988 for broilers and 0.911 for turkeys. Apparently, this function fits the data more effectively than other types of functions used.⁹

⁷ Combs, G. F., University of Maryland, Dept. of Poultry Husbandry, College Park, Maryland. Information on the upper asymptote for the broiler-feed conversion rate. (Private communication.) 1960. (Note: Dr. Combs used the words *feed conversion as broiler output divided by feed input*, which is the reverse of the feed conversion rate used in this study.)

⁸ Scott, M. L. Fifty years in turkey nutrition. *Feedstuffs* 31, No. 5:18-21. 1959.

⁹ For example, these are the results of the exponential function fitted to the same data:

Eggs per layer

$$(a) R_e = 105.2e^{0.0186t}$$

Broiler-feed conversion rate

$$(b) R_b = 17.8e^{0.0223t}$$

Turkey-feed conversion rate

$$(c) R_T = 12.4e^{0.0140t}$$

The correlation coefficients between the original observations and the exponential estimates are 0.983 for eggs, 0.959 for broilers and 0.941 for turkeys.

Table 1. Technology indicators of poultry production: values of actual observations and estimated values from logistic function.

Year	Number of eggs per layer		Broiler-feed conversion rate		Turkey-feed conversion rate	
	Actual ^a	Estimated	Actual ^a	Estimated	Actual ^a	Estimated
1925	112	113	.....	.....	.....	.....
1926	118	114	.....	.....	.....	.....
1927	117	115	.....	.....	.....	.....
1928	119	116	.....	.....	.....	.....
1929	119	117	.....	.....	12.4	12.8
1930	121	118	.....	.....	12.8	12.9
1931	127	119	.....	.....	12.5	13.0
1932	121	121	.....	.....	12.9	13.1
1933	118	123	18.9	19.3	13.0	13.2
1934	118	125	20.5	19.4	14.5	13.3
1935	122	127	18.9	19.5	13.8	13.4
1936	121	129	20.7	19.7	15.4	13.5
1937	130	131	20.0	19.9	14.1	13.6
1938	135	133	21.5	20.2	14.1	13.7
1939	134	135	20.8	20.5	13.9	13.9
1940	134	137	20.4	20.8	13.8	14.1
1941	139	140	21.5	21.1	13.8	14.3
1942	142	143	20.7	21.5	15.0	14.5
1943	142	146	22.2	21.9	15.0	14.7
1944	148	149	22.3	22.3	15.4	15.0
1945	152	152	21.8	22.8	15.8	15.3
1946	156	155	22.3	23.3	15.9	15.5
1947	160	158	23.0	23.9	15.9	15.8
1948	166	161	24.4	24.5	16.4	16.1
1949	170	165	26.2	25.2	16.9	16.5
1950	174	169	26.7	25.9	17.8	16.8
1951	177	173	27.3	26.7	18.0	17.2
1952	181	177	27.9	27.6	17.8	17.6
1953	185	182	28.5	28.6	18.4	18.1
1954	188	186	29.2	29.6	18.6	18.5
1955	192	190	31.5	30.7	17.9	19.0
1956	196	195	32.0	31.9	17.6	19.5
1957	198	200	33.9	33.2	17.1	20.0
1958	201	204	.....	.....	.....	.....

^a Source: Jennings, R. D. Consumption of feed by livestock, 1909-56. U. S. Dept. Agr. Prod. Rpt. 21. 1958.

The number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate estimated by the logistic function, as explained above, can be regarded as a measure of the "net effect" of technological progress in poultry production. These estimates will be termed the **technology index** of egg production, of broiler production and of turkey production. These indexes are used as the variables of technology in the following supply analysis of poultry products. In other words, the estimated quantities indicated in table 1 are used as the quantities representing the level of technology in each year for which observations are used in estimating regression equations. Hence, the observations for estimating $R_{e(t)}$ in equation 32 are the technology index quantities indicated for eggs in table 1.

SUPPLY MODELS

A linear equation or a system of linear equations is generally used in models for estimating economic relations from time-series data. By a linear equation, we refer to an equation of linear coefficients, but not necessarily of linear variables. Whatever transformations of original observations (e.g., logarithmic, quadratic, etc.) are used, the coefficients remain constant over the range of variables.

A linear equation is used as a first approximation of a real economic relationship so that the relations can be estimated statistically. Non-

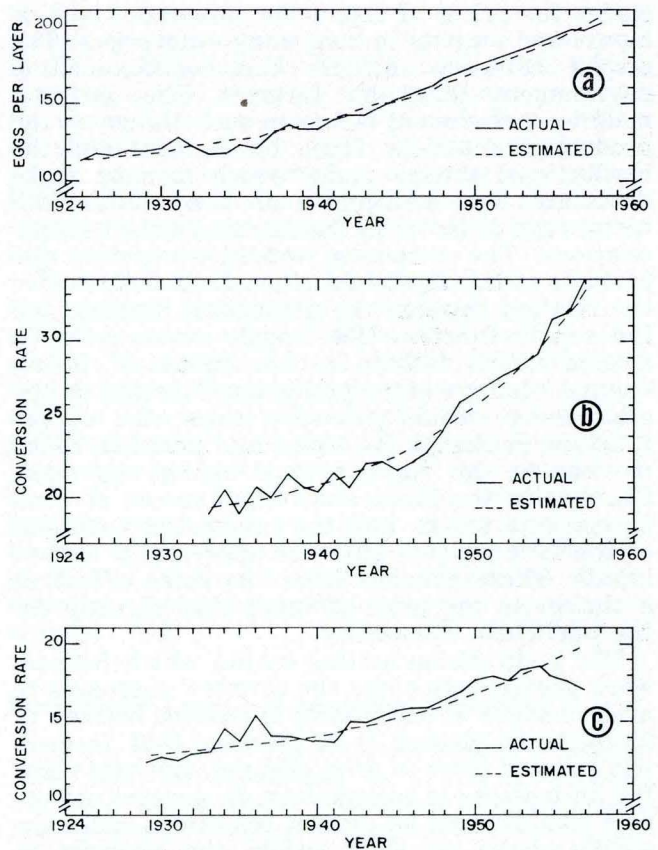


Fig. 7. (a) Number of eggs per layer, values of actual observations and estimated values from logistic function. (b) Broiler-feed conversion rate, values of actual observations and estimated values from logistic function. (c) Turkey-feed conversion rate, values of actual observations and estimated values from logistic function.

linear models are difficult to estimate, the difficulty multiplying as the number of variables increases.

A linear model is a necessary device for complex economic problems, but it has several limitations. For example, suppose a supply relation formulated in the general form

$$(4) F(X_1, X_2, X_3, \dots, X_n, \alpha_1, \alpha_2, \dots, \alpha_m, \epsilon) = 0,$$

where X_1 is commodity price, X_2 is quantity supplied, $X_3 \dots X_n$ are variables which affect supply, α 's are the parameters, and ϵ is a stochastic residual. The linear approximate of equation 4 is written as

$$(5) \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \eta = 0,$$

where the β 's are the parameters and η is a residual. The question arises: Is it valid to use equation 5 in analyzing the relation formulated in equation 4? Some deviations from equation 4 are inevitable in estimating equation 5. The problem is not whether there is deviation of equation 5 from the true relation, but how well it approximates equation 4.

The factors which affect supply can be classified into two categories: (1) market conditions and (2) structural conditions. The first category in-

cludes the prices of inputs for production and of inputs and outputs in competing enterprises. The second category includes the decision-making environment faced by farmers. The decision-making environment refers to such things as the production functions faced by farmers and the institutional setting under which farmers make decisions. Two categories of these influential factors are different in the way they affect supply relations. The structural conditions specify the position of the supply function, as is indicated in the relation between the production function and the supply function. The supply curve shifts in a geometrical fashion as the prices of inputs change. Changes in the production function, on the other hand, would generally cause the supply function to change its shape and position, likely moving to the right with a change in slope. Changes in the input and output prices of competing enterprises, and the production functions of the latter, would alter the opportunity cost of inputs. These changes have the same effect as a change in the price of input used directly for the particular commodity.

The institutional setting within which farmers work greatly influences the farmers' responses to price changes. If uncertainty is reduced because of institutional change, it is expected that farmers will respond more to price changes, and *vice versa* for an increase in uncertainty. In general, we expect that changes in market conditions cause the supply curve to shift, while the changes in structural conditions alter the shape, as well as the position, of the supply curve. A linear equation is a reasonable model for approximating the effects of market conditions on supply. The effects of market conditions on a linear supply function are readily adjusted by adding the variables of market conditions. On the other hand, a linear equation does not seem entirely adequate for expressing the effects of structural changes because the structural changes not only shift the supply function, but also affect the coefficient or elasticity of supply in the sense of changing the slope of the curve. However, any judgment as to whether or not these effects can be approximated by a linear equation must be relative and not absolute. Even the market conditions are not necessarily linear in their effects on supply.

Factors Affecting Supply

The next step in the supply analysis of poultry products is the determination of the specific variables to be included in the model. Selection, while based on theory and logic, is necessarily restrained by data available in time-series forms. Variables for the market conditions are readily available in official statistics. We use the price of poultry feed to represent the price of this main input in poultry production. Feed comprises the major portion of variable cost, and farmers are likely to respond importantly to the change in its cost.

Hogs and broilers are selected as enterprises

which compete with egg production. Eggs are selected *a priori* as a main enterprise competing with broiler production. Eggs and broilers are selected as the main enterprises competing with turkey production. These enterprises are the ones which are most likely to affect the relative profitability of the poultry industry, in a nationally appreciable magnitude. Hogs are the most important enterprise which may compete against eggs for nonspecialized family farms. Broilers and eggs are competitive among specialized broiler growers. Eggs and turkeys or broilers and turkeys are in a competitive relation. Turkey production, however, is a relatively minor enterprise in the poultry industry. Turkeys do not have a nationally important effect on broilers and eggs, although turkeys may be affected by eggs or broilers. Possibly, other enterprises such as milk cows and cattle feeding may compete directly against poultry. However, because of the small degree of competition and because of problems of multicollinearity in number of variables possible, variables for the latter enterprises are not included in the supply models. The competitive relations outlined above are selected *a priori* as hypotheses to be tested. These tests are accomplished in regression models presented in later sections of the study. We wish to determine whether these hypotheses are accepted or rejected on the basis of the aggregate time-series data available.

Data for variables for the structural conditions are generally difficult to obtain. However, we use the technology indexes mentioned earlier for this purpose. It should be remembered that the technology indexes are constructed from the data of the number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate. Increases in these ratios are fairly uniform over a wide range in size of enterprise.

Structural Changes in Poultry Supply Relations

The dominant effects of technological progress in poultry production probably are those which cause the supply function to shift. However, we cannot neglect its effect on the coefficients or elasticities of supply. Other structural conditions, such as the institutional setting, also affect the supply coefficients. The technological indexes may partly reflect change in the institutional settings, since technological progress has been a primary factor in changing the institutional environment. The tendency toward specialization, increased flock size and concentration in the poultry industry has been brought about by technological progress. As the number of poultry farms decreases, and as their size increases, remaining farmers are those better able to obtain information and to improve their bargaining power. Changes such as these reduce market uncertainty and alter the response of production to price. Technological progress thus may affect supply coefficients or elasticities (a) directly by changing the production functions and (b) indirectly

through altering the institutional and decision-making setting. Hence, it is necessary to incorporate the technology indexes into the supply models in such a way that they allow reflection of change in both supply coefficients and structure.

Forms of Equations and Variables

The main variables affecting poultry supply have already been specified. It is theoretically possible to include all these factors (prices of inputs and outputs, technology indexes, prices of inputs and outputs in competing enterprises) as independent terms in the regression equations. Since the number of observations is limited for time-series data (and problems of multicollinearity arise), it is necessary to use a limited number of variables. Because of these considerations, feed price is introduced in the model through a ratio of output price divided by input price, instead of including feed price as an independent term. The effects of a competing enterprise are synthesized into one variable called a profitability index. The profitability index is the output-input price ratio (multiplied by the technology index in the case of poultry). By the deflation and the synthesis of variables, the information which otherwise might be obtained by using each variable as an independent term in an equation is lost. But these transformations are justified in terms of the empirical difficulties mentioned previously.

The original observations for all variables are transformed into logarithmic forms. The logarithmic transformation is used because of logical bases and because the coefficients of a logarithmic function are directly the coefficients of elasticity. One of the limitations of a logarithmic function, however, is its constant elasticity over the entire range of estimates. Other algebraic functions provide mathematical restraints which may be equally realistic or unrealistic.

Methods of Estimation

The question arises as to whether a single equation or simultaneous equations should be used for estimating the supply relations of poultry products. Market price and quantity of a product are simultaneously determined at an equilibrium of demand and supply. The simultaneous-equation method might seem appropriate for estimating supply relations. It has been shown, however, that the single-equation least-squares method is generally appropriate for the analysis of supply for agricultural products.¹⁰ A seasonality in production and a time lag between a production plan and its outcome are characteristic of agricultural production. As a result of seasonality and time lag, prices by which farmers determine their out-

puts are generally the prices of the previous period, or expectations linked to their experience in the previous periods. In this sense, prices of the previous period serve as predetermined variables for the output in the present period. Some degree of simultaneity may exist in the adjustments which can be made during a production period. But usually the amount of adjustment possible is relatively small and should not produce appreciable bias in the least-squares estimates.

Possible simultaneity in demand and supply of the poultry products is considered in the empirical analysis which follows. However, we find distinct seasonalities in all poultry production except broilers. The seasonal nature of production and the time lag between farmers' plans and their outcomes make the traditional single-equation least-squares method appear appropriate in analysis of eggs and turkeys. The simultaneous-equation method is restricted to the analysis of broiler supply, where the simultaneity in the production is expected to be so great that the single-equation estimation could provide meaningless results.

Distributed Lags and Long-Run Elasticity

In the time-series analysis of supply relations, time must be considered as a crucial element. Farmers make their production decisions, not instantaneously, but over a period of time. Supply elasticities can be classified on the basis of length of time needed for adjusting inputs. A supply elasticity over a period long enough for farmers to adjust all inputs is called a long-run elasticity. If the length of time is such that some of the inputs are regarded as fixed, the elasticity is short run. The elasticity is zero for a time period so short that no inputs can be altered. Elasticities may range from zero to a much larger long-run magnitude, depending on the number and kind of inputs which are fixed.

The supply elasticities estimated from the time-series data in this study are of a short-run nature. Long-run elasticities cannot be measured directly from time-series data, but can be estimated indirectly by use of distributed lag models, which assume a particular path in farmers' adjustment of production.

Koyck¹¹ suggests a model of distributed lags for statistical estimation of economic time series adjustment. His method is as follows: Suppose a general model of supply as

$$(6) \quad Q_t = a + b_0P_t + b_1P_{t-1} + b_2P_{t-2} + \dots + b_nP_{t-n}$$

where Q_t and P_t are output and price at a period t . If the variables in equation 6 are logarithmic, the long-run price elasticity of supply is

$$(7) \quad E_1 = \sum_{i=0}^{\infty} b_i$$

¹⁰ For example see: Fox, K. A. The analysis of demand for farm products. U. S. Dept. Agr. Tech. Bul. 1081. 1953; and Earl O. Heady. Economics of agricultural production and resource use. Prentice-Hall, New York. 1952. Ch. 15-17 on expectations and decisions.

¹¹ Koyck, L. M. Distributed lags and investment analysis. North-Holland Publishing Company, Amsterdam, Netherlands. 1954.

The effect of price converges geometrically as time passes, so that

$$(8) \quad b_t = \partial b_{t-1} \quad 0 \leq \partial < 1.$$

It follows from equations 6 and 8 that

$$(9) \quad Q_t = a + b_0 P_t + b_0 \partial P_{t-1} + b_0 \partial^2 P_{t-2} + \dots + b_0 \partial^n P_{t-n}.$$

If we lag equation 9 by one period, and multiply it by ∂ , we get

$$(10) \quad \partial Q_{t-1} = a\partial + b_0 \partial P_{t-1} + b_0 \partial^2 P_{t-2} + \dots$$

By subtracting equation 10 from equation 9 we obtain

$$(11) \quad Q_t = a(1 - \partial) + b_0 P_t + \partial Q_{t-1}.$$

Equation 11 is readily estimated statistically, and the long-run price elasticity of supply is given by

$$(12) \quad E_1 = \sum_{i=0}^{\infty} \partial^i b_0 = \frac{b_0}{1 - \partial}.$$

Koyck derives the model for estimating distributed lags and long-run elasticities from a general form of distributed lags. Nerlove¹² arrives at the same basis from a dynamic model of producers' behavior (or consumers' behavior in case of demand), assuming a static expectation.

Nerlove's dynamic model is formulated as

$$(13) \quad Q_t - Q_{t-1} = \gamma (Q_t^* - Q_{t-1}),$$

where Q_t and Q_t^* are an actual output and a long-run equilibrium output at period t and γ is the coefficient of adjustment. Equation 13 supposes that, in each period, producers adjust output in proportion to the difference between the actual output and the long-run equilibrium output. Assuming static expectations of producers, a long-run supply function is written as

$$(14) \quad Q_t^* = a + bP_t$$

where b is the long-run elasticity of supply. By substituting equation 14 into 13, we obtain

$$(15) \quad Q_t = a\gamma + b\gamma P_t + (1 - \gamma)Q_{t-1}.$$

Equation 15 has exactly the same form as equation 11, if we replace $(1 - \partial)$ with γ and b_0 with $b\gamma$. If the variables are in logarithmic form, the long-run elasticity of supply is given by

$$(16) \quad E_1 = \frac{b\gamma}{1 - (1 - \gamma)} = b.$$

The Koyck-Nerlove method of estimating the long-run elasticity is based on the assumption of a static expectation. The long-run elasticities for poultry products are estimated in this study, assuming static expectations by farmers.

EMPIRICAL ANALYSIS: EGGS AND FARM CHICKENS

The model used for the empirical analysis of eggs and farm chickens can be deduced from the

¹² Nerlove, M. Statistical estimation of long-run elasticities of supply and demand. *Jour. Farm Econ.* 40:861-880. 1958.

relations shown in fig. 8. The figure includes the relations which are crucial in understanding the supply of eggs and farm chickens at the farm level. These graphic relations are presented in a fashion such that the diagrammatical presentation can be converted directly to mathematical models for estimation.

Two models for the different empirical approaches are constructed from the relations presented in fig. 8, a model for a single-step analysis of egg supply and one for a multistep analysis. Several relations are involved in the total production process for the multistep model, as suggested in fig. 8. Where the relations, indicated by small Arabic letters, are not self-evident for the multistep model, they will be explained following the designation of variables. The two models are as follows:

I. Model for single-step analysis of egg supply

$$(17) \quad Q_e = f \left[\left(\frac{P_e}{P_f} \right)', \left(\frac{P_e}{P_f} \right)'_{t-1}, \left(\frac{P_e}{P_f} \right), \left(\frac{P_c}{P_f} \right), \right.$$

$E_{h(t-1)}, E_{b(t-1)}, R_e$

II. Model for multistep analysis of egg and farm chicken supply

(a) Pullet-raising

$$(18) \quad X_p = f \left[\left(\frac{P_e}{P_f} \right)', E_h, E_b, R_e \right]$$

(b) Cockerel-raising

$$(19) \quad X_k = \gamma X_p$$

(c) Hen-culling

$$(20) \quad X_{h,c} = f \left[\left(\frac{P_e}{P_f} \right), \left(\frac{P_c}{P_f} \right), X_h \right]$$

(d) Pullet-culling

$$(21) \quad X_{p,c} = f \left[\left(\frac{P_e}{P_f} \right), \left(\frac{P_c}{P_f} \right), X_p \right]$$

(e) Counting of young farm chickens produced

$$(22) \quad X_{y,c} = X_k + X_h - X_d + X_{p,c}$$

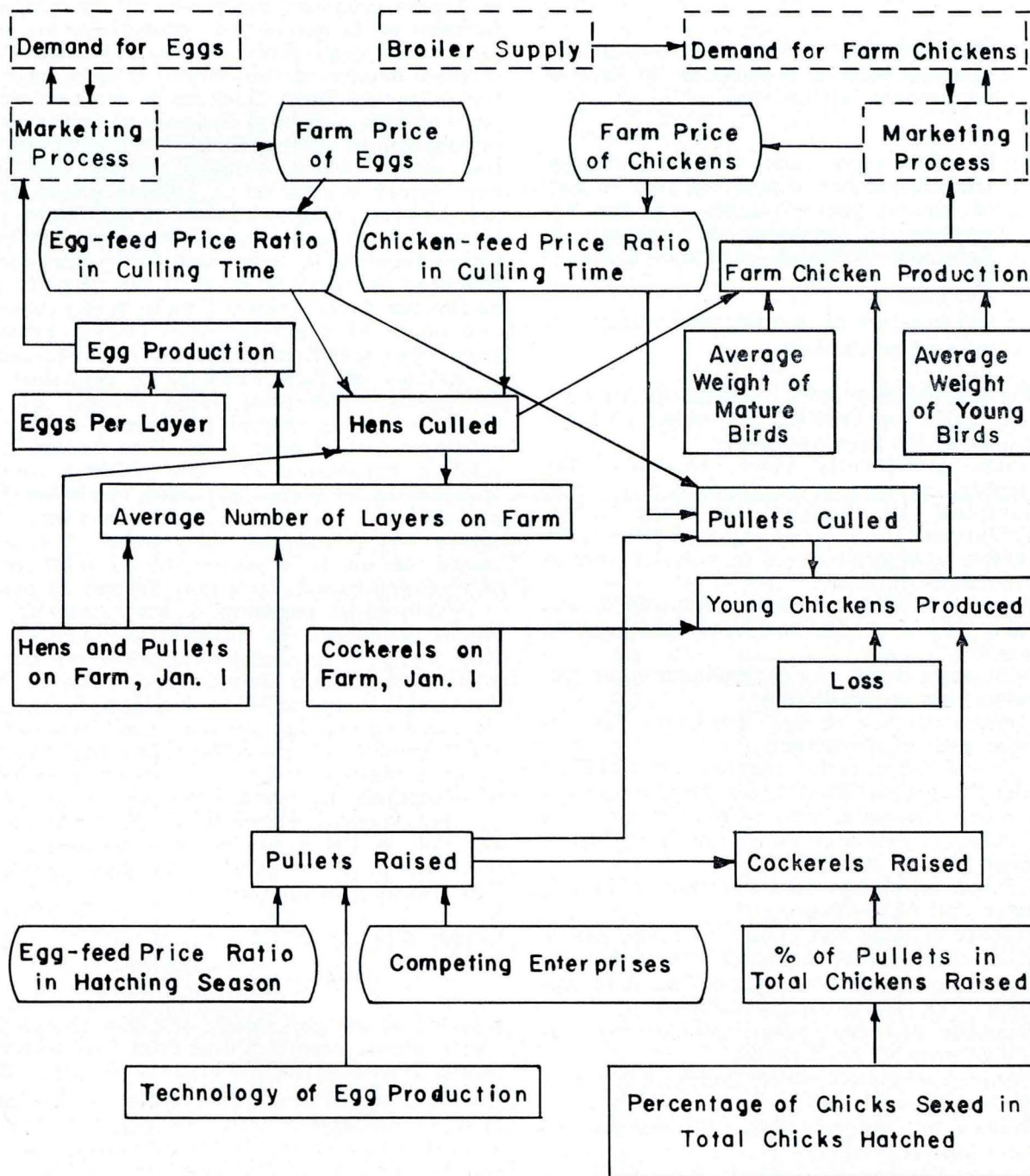
(f) Output of farm chickens

$$(23) \quad Q_c = W_m \cdot X_{h,c} + W_y \cdot X_{y,c}$$

(g) Counting of average number of layers on farm

$$(24) \quad X_l = X_h + X_p - X_{h,c} - X_{p,c} - X_r$$

Fig. 8. Relations in egg supply.



Prices are enclosed inside of semicircular rectangles and quantities are enclosed inside of squares. Arrows show direction of influence. Demand and marketing relations are enclosed inside of dashed squares.

(h) Output of eggs

$$(25) Q_e = R \cdot X_1$$

The following variables, computed from data of the sources mentioned previously, are:

$\left(\frac{P_e}{P_f}\right)$: Egg-feed price ratio, year average for calendar year of predictions, to express adjustment within year.

$\left(\frac{P_e}{P_f}\right)'$: Egg-feed price ratio, weighted average from November of previous year to May of current year. Weights are: for November—1, December—2, January—3, February—4, March—5, April—3, May—1.

$\left(\frac{P_c}{P_f}\right)$: Chicken-feed price ratio, year average for year of predictions.

E_h : Hog profitability index, average of hog-corn price ratio for October, November and December in the previous year.

E_b : Broiler profitability index, November-May weighted average of broiler-feed price ratio multiplied by broiler technology index. Weights are the same as egg-feed price ratio.

Q_c : Number of eggs produced in calendar year of predictions (billion).

Q_e : Quantity of farm chickens produced in calendar year of predictions, liveweight (million pounds).

R_c : Technology index of egg production for calendar year of predictions.

R : Average number of eggs per layer for calendar year of predictions.

γ : Cockerel-pullet ratio, number of cockerels raised in proportion to the number of pullets raised for calendar year of predictions.

X_k : Number of cockerels raised (million) in calendar year of predictions.

X_p : Number of pullets raised (million) in calendar year of predictions.

X_h : Number of hens and pullets on farm, Jan. 1 of calendar year of predictions (million).

X_n : Number of cockerels on farm, Jan. 1 of calendar year of predictions (million).

$X_{h,c}$: Number of hens culled (million) in calendar year of predictions.

$X_{p,c}$: Number of pullets culled (million) in calendar year of predictions.

X_d : Number of cockerels lost (million) in calendar year of predictions.

X_l : Average number of layers on farm (million) in calendar year of predictions.

X_r : Residual in counting the number of layers (million).

W_m : Average weight of mature chickens, liveweight (pounds) in calendar year of predictions.

W_y : Average weight of young chickens, liveweight (pounds) in calendar year of predictions.

Composition of the Enterprise

This section outlines the logic employed in constructing the models: We suppose for the single-step model that farm chickens, but not broilers or fryers produced independently by specialized farmers or in specialized enterprises, are a by-product of eggs. This assumption implies that farmers determine the output of eggs, and thus the output of farm chickens in response to the price of eggs — but not the price of farm chickens in response to other prices. We do, however, later test models which suppose chicken, and hence egg, output is affected by chicken prices. We do not, however, employ models of simultaneous relationships in egg and chicken price response. Characteristically, eggs and farm chickens are produced as joint products. Cash receipts from marketing farm chickens have rarely exceeded one-fourth of the total cash income generated from eggs and farm chickens. And the relative importance of farm chickens to eggs has been decreasing. The total value product of farm chickens now is around 10 percent of the total value product of eggs alone. The decline in the relative importance of farm chickens to eggs stems from changes in poultry technology, especially the practice of chicken-sexing. Until sexing was introduced, the number of cockerels raised was about 50 percent of the total number of chickens raised. It is now around 20 percent.

Pullet chicks sexed as a percentage of total chicks purchased by farmers are plotted over time in fig. 9. Available data series are not long enough to show a logistic trend. But it seems reasonable to approximate this trend by the logistic function. Sexing practice was introduced at the beginning of the 1930's, has been accepted at an increasing rate, and it is likely that the rate of acceptance will slow down as the percentage of chicks sexed approaches 100. The logistic function is fitted to the data with zero as a lower asymptote and 100 as an upper asymptote. The resulting estimation is

$$(26) S = \frac{100}{1 + 54.14e^{-0.1285t}}$$

where S is the percentage of pullet chicks sexed and t is time with $t = 0$ at 1929. The trend estimated by the logistic function is plotted in fig. 9.

Estimation of the chicks sexed by the logistic function is important for the purpose of prediction. It is also necessary for estimating, from the reported data of total chickens raised, the number of cockerels and the number of pullets raised in the past years. The procedures and the results of estimating the number of pullets and cockerels raised are summarized in table 2.

Some Relations in the Multistep Model

We now detail some of the relations indicated under the multistep model.

Fig. 9. Sexed pullets as percentage of farmers' chicks purchased, values of actual observations and estimated values from logistic function.

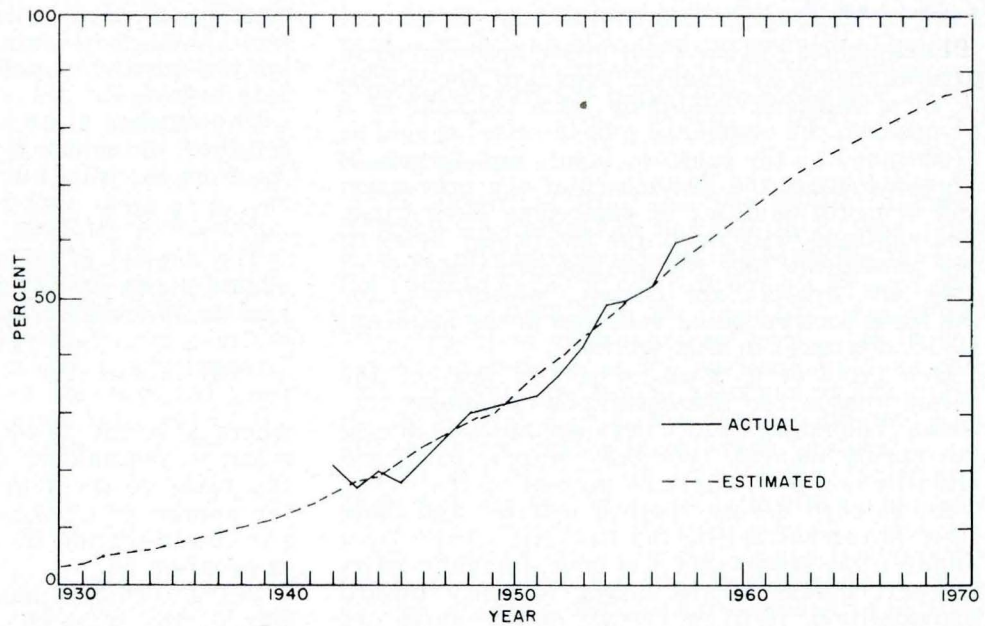


Table 2. Numbers of pullets and cockerels raised: estimation procedures from reported data on farm chickens raised, 1925-58.

Year	Number of chickens raised (million) (1)	Sexed pullets as a percentage of chicks purchased (2)a	Sexed cockerels as a percentage of chicks purchased (3)b	Straight-run chicks as a percentage of chicks raised (4)c	Sexed pullets (million) (5)d	Straight-run pullets (million) (6)e	Estimated number of pullets raised (million) (7)f	Estimated number of cockerels raised (million) (8)g
1925	678.7	2.1	0.4	97.5	14.3	330.9	345.2	333.5
1926	718.3	2.3	0.5	97.2	16.5	349.1	365.6	352.7
1927	750.4	2.6	0.5	96.9	19.5	368.6	383.1	367.3
1928	700.0	3.0	0.6	96.4	21.0	337.4	358.4	341.6
1929	751.1	3.4	0.7	95.9	25.5	360.2	385.7	365.4
1930	777.0	3.8	0.8	95.4	29.5	370.7	400.2	376.8
1931	709.4	4.3	0.9	94.8	30.5	336.3	366.8	342.6
1932	735.5	4.9	1.0	94.1	36.0	346.1	382.1	358.4
1933	750.1	5.6	1.1	93.3	42.0	349.9	391.9	358.2
1934	644.4	6.3	1.3	92.4	40.6	297.7	388.3	306.1
1935	658.3	7.1	1.4	91.5	46.7	301.2	347.9	310.4
1936	715.0	7.9	1.6	90.5	56.5	323.6	380.1	334.9
1937	601.1	8.9	1.8	89.3	63.6	268.4	332.0	269.1
1938	650.7	10.0	2.0	88.0	65.1	286.3	351.4	299.3
1939	696.7	11.3	2.3	86.4	78.7	301.0	379.7	317.0
1940	683.7	12.6	2.5	84.9	79.8	269.0	348.8	284.9
1941	745.0	14.1	2.8	83.1	105.0	309.6	414.6	330.4
1942	844.3	20.9	4.2	74.9	176.5	316.2	492.7	351.6
1943	1,001.4	17.2	5.4	77.4	172.2	387.6	559.8	441.6
1944	832.1	20.3	4.9	74.8	168.9	311.2	480.1	352.0
1945	890.4	18.5	4.8	76.7	164.7	341.5	506.2	384.2
1946	737.6	22.3	4.4	73.3	169.5	270.4	434.9	302.7
1947	719.4	26.0	4.5	69.5	187.0	250.0	437.0	282.4
1948	615.1	30.0	4.5	65.5	184.5	201.5	386.0	229.1
1949	705.1	31.0	4.0	65.0	218.6	229.2	487.8	257.3
1950	619.8	32.0	5.0	63.0	198.3	195.3	393.6	226.2
1951	622.9	33.0	5.0	62.0	205.6	193.1	398.7	224.2
1952	561.0	37.0	5.0	58.0	207.6	162.7	370.3	190.7
1953	547.5	42.0	5.0	53.0	230.0	145.1	375.1	172.4
1954	539.9	49.0	6.0	45.0	264.6	121.5	386.1	153.8
1955	461.9	50.0	7.0	43.0	231.0	99.3	330.3	131.6
1956	478.6	53.0	7.0	40.0	253.7	95.7	349.4	129.2
1957	394.3	61.0	6.0	33.0	240.5	65.1	305.6	88.7
1958	435.8	61.0	6.0	33.0	265.8	71.9	337.7	98.1

a Data available for 1942-58, and estimated for 1925-41 by logistic trend.

b Data available for 1943-58, and estimated for 1925-41 by multiplying column (2) by one-fifth. One-fifth is the 5-year average for 1943-47 of ratios of sexed cockerels to sexed pullets as percentage of total chicks purchased by farmers.

c Column (4) = 100 - column (2) - column (3).

d Column (5) = [column (1) × column (2)] ÷ 100.

e Column (6) = [½ column (1) × column (4)] ÷ 100.

f Column (7) = column (5) + column (6).

g Column (8) = column (1) - column (7).

Relations of Raising Pullets and Cockerels

Pullet-raising is the most important relation in determining the output of eggs and the output of farm chickens. Assuming farm chickens as a by-product, the number of pullets raised should be determined by the prices of inputs and outputs in egg production, the technology of egg production and the profitabilities of competing enterprises. The egg-feed price ratio, the technology index of egg production and the profitability indexes of hogs and broilers are chosen, respectively, for the three corresponding variables in the empirical model discussed in this section.

One problem in measurement is that of the period chosen for the observation of these variables. The majority of chicks are hatched during the spring months, especially March, April and May. Before 1940, about 80 percent of the chicks were hatched during these 3 months, and more than 90 percent during the first half of the year. Though this seasonality has been gradually leveling off because of the recent tendency toward specialization, 70 to 80 percent of the chicks are still being hatched during the first 6 months of the year.

Considering the seasonality in hatching and the time lag between farm planning and its outcome, the egg-feed price ratios of 7 months — November of the previous year through May of the present year — are averaged with the weights explained later. The same period is chosen for the broiler profitability index. But before 1953, when monthly broiler data were not available, the average of the present year's price and the previous year's price is used as a substitute for the 7-month weighted average. October, November and December are chosen for the period of observation for the hog profitability index. These 3 months constitute the period in which the winter farrowing of sows largely is determined.

The seasonality in pullet-raising and egg production and the resulting specification of the observation periods have very important implications for the estimation method. The majority of pullets hatched during the spring months start laying eggs in the fall. Pullets hatched in early spring lay some eggs before summer. But the rate of lay is low for the first 2 or 3 months, and the quantity of eggs produced by the spring-hatched pullets is small in magnitude. The egg-feed price ratio and the profitabilities of the competing enterprises in the hatching season affect the output of eggs in the fall, but do not affect, or have only a weak effect on, the output in the hatching season itself. The relation between the number of pullets raised and the prices in spring thus is generally unilateral rather than simultaneous. For this reason, the single-equation least-squares method is deemed sufficient for estimating the pullet-raising relation.

The number of cockerels raised is determined directly from the number of pullets raised, assuming farm chickens as the by-product of eggs. Mathematically, this relationship is formulated in

equation 19. The cockerel-pullet ratio, γ , in equation 19 was used from the procedures in estimating the number of pullets and cockerels from the data in table 2.

The number of cockerels, X_k , is, by definition, obtained by subtracting the number of pullets, X_p , from the total number of chickens raised, X_c .

$$(27) X_k = X_c - X_p$$

The number of pullets raised is determined by adding the number of sexed pullets and half of the number of straight-run chicks. This is given by

$$(28) X_p = s \cdot X_c + \frac{1 - s - k}{2} X_c$$

where s is the ratio of the number of pullets sexed to the number of chickens raised and k is the ratio of the number of sexed cockerels to the number of chickens raised. The magnitude of s is obtained from the logistic function estimated in equation 26.

Sexed cockerels have composed a small fraction of the total chicks purchased by farmers. These sexed cockerels are mainly for home consumption and will be reduced to a negligible amount as the commercialization of the enterprise proceeds. For a predictive purpose, the average of the number of sexed cockerels in proportion to the number of sexed pullets in the preceding 5 years can be extrapolated as a rough approximation.

Equation 28 can be transformed into

$$(29) X_p = \frac{1 + s - k}{2} X_c$$

Solving equation 29 for X_c ,

$$(30) X_c = \frac{2}{1 + s - k} X_p$$

and by substituting equation 30 into equation 27, we obtain

$$(31) X_k = \left[\frac{2}{1 + s - k} - 1 \right] X_p = \gamma X_p$$

The cockerel-pullet ratio is thus derived from the percentage of chicks sexed.

Relations of Culling Hens and Pullets

The culling of hens is an important determinant in the output of eggs and the output of farm chickens. Pullets start laying eggs within about 4 months after being hatched, and the rate of lay increases until it reaches a peak at about 12 months. The rate of lay then declines gradually. Whether to continue keeping hens or to cull them becomes a problem for farmers generally after hens are kept for one year or longer.

The number of hens culled in a year is restrained by the number of hens and pullets on the farm at the beginning of the year. The data are reported for the number of hens and pullets on the

farm, Jan. 1. Other variables which may affect the number of hens culled are the prices of eggs, farm chickens and poultry feed. If the market is favorable for eggs, farmers will keep hens longer, reducing the number of hens culled. On the other hand, if the market is favorable for farm chickens, farmers will tend to cull more hens. The annual averages of egg-feed price ratio and chicken-feed price ratio are included in the equation of hen-culling.

Among these three variables in the equation which affect hen-culling, the number of hens and pullets on farms Jan. 1, is predetermined, but the two other variables are not exactly predetermined. The annual averages of both the egg-feed price ratio and the chicken-feed price ratio affect the number of hens culled, and consequently the output of eggs and of farm chickens. These outputs, in turn, affect the prices of eggs and farm chickens. Here is a simultaneous determination of prices and outputs.

This simultaneity, however, is not expected to be strong. Most hens are culled because they are old and have a low rate of lay. A market situation is a relatively minor consideration in farmers' decision-making relative to culling hens. Moreover, the effect of culling on the output of eggs should be discounted because the hens culled are low-laying.

Baker¹³ reports that the output of eggs in a crop year can be accurately predicted on the basis of the number of potential layers on a farm and the number of eggs per layer at the beginning of the crop year. These two factors explain 98.7 percent of the variance in the total output of eggs for the years 1930-31 through 1947-48. Baker's study shows that the adjustment of egg production is very small within a crop year. If so, factors which determine the output of eggs can be regarded as predetermined. Though the seasonality of egg production has been leveling off since 1948, the production adjustment within a crop year should be much smaller than the adjustment made prior to the decision year.

Hence, even if prices within the year affect the hen-culling, it is doubtful that the effect of culling on the output can be so large as to cause an appreciable bias on the least-squares estimates. The least-squares method also seems sufficient for analyzing the hen-culling relation.

Culling becomes a problem usually after hens are kept for 1 year or longer. Every year, however, a small fraction of pullets raised is culled for home consumption, or, because of sickness, physical deformity, etc. The number of pullets culled is largely determined by the number of pullets raised. There is some possibility that pullets are culled more heavily when the market situation is unfavorable for eggs or favorable for chickens. To test whether market situations affect pullet-culling, an equation is estimated which

includes the annual averages of the egg-feed price ratio and the chicken-feed price ratio. The discussion about simultaneity in the hen-culling applies equally to the pullet-culling relation.

Counting Relations

The output of eggs and the output of farm chickens are primarily determined by the relations of raising and culling chickens. To connect the outputs to the number of chickens raised and culled, we formulate the counting equations. These counting equations are formulated in the process of estimating the numbers of hens and pullets raised. The data of hens and pullets culled can be estimated from the data of chickens sold and consumed on the farm where produced.

Data are reported for the number of young birds and the number of mature birds sold from farms. We assume that, for chickens sold from farms, mature birds are hens culled and young birds are cockerels raised and pullets culled. The number of young birds and the number of mature birds consumed on the farm where produced are estimated by multiplying the reported total number of chickens consumed on the farm where produced by the percentage of young birds and mature birds in the total number sold. This estimation procedure is based on the assumption that the composition of chickens consumed on the farm where produced is the same as that of the chickens sold.

Mature chickens sold and consumed on the farm where produced add up to the number of mature birds produced, or the number of hens culled. Young chickens sold and consumed on the farm where produced add up to the number of young chickens produced for sale. Quantities arising from these estimations are summarized in table 3.

The number of pullets culled can be estimated as a residual in counting the total number of young chickens produced. Young chickens are composed of cockerels raised, cockerels on the farm at the beginning of a year and pullets culled. The number of young chickens produced, estimated in table 3, should equal the sum of the numbers of cockerels raised, cockerels on the farm on Jan. 1 and pullets culled minus the number of cockerels lost by death. Cockerels lost during the year are estimated in table 4. The data from procedures for estimating the number of pullets culled are shown in table 5.

In the process of estimating the number of hens culled and of pullets culled, the number of young chickens produced and of mature chickens produced are obtained. The output of farm chickens is given by summing (a) the number of young chickens produced multiplied by the average weight of young chickens and (b) the number of mature chickens produced multiplied by the average weight of mature chickens.

The output of eggs is also counted from various sources. The output of eggs is, by definition, the average number of layers on the farm multiplied by the average number of eggs per layer. The

¹³ Baker, R. L. Some factors affecting the quantity and quality of eggs marketed by certain producers. Unpublished Ph.D. thesis. Iowa State University Library, Ames, Iowa, 1949.

Table 3. Numbers of young and mature chickens produced: estimation procedures from reported data on chickens sold and consumed on farms where produced, 1931-58.

Year	Number chickens sold		Percent chickens sold		Chickens consumed on farm where produced			Estimated number of chickens produced	
	Young (1)	Mature (2)	Young (3)a	Mature (4)b	Total (5)	Young (6)c	Mature (7)d	Young (8)e	Mature (hens culled) (9)f
	(million)				(million)	(million)	(million)	(million)	(million)
1931	245.1	183.5	57.2	42.8	231.0	132.1	98.9	377.2	282.3
1932	248.0	170.3	59.3	40.7	246.6	146.2	100.4	394.2	270.6
1933	260.7	180.4	59.1	40.9	254.4	150.4	104.0	411.1	284.4
1934	220.0	183.3	54.5	45.5	219.0	119.4	99.6	339.4	283.0
1935	217.9	147.6	59.6	40.4	218.8	130.4	88.4	348.3	236.0
1936	235.4	159.6	59.5	40.5	235.1	139.9	95.2	375.3	254.9
1937	178.0	173.8	50.6	49.4	215.1	108.9	106.2	286.9	280.0
1938	185.1	141.3	56.7	43.3	227.8	129.2	98.6	314.3	240.0
1939	217.2	159.4	57.7	42.3	224.8	129.7	95.1	346.9	254.4
1940	191.4	178.5	51.7	48.3	201.2	104.0	97.2	295.5	275.6
1941	259.8	152.5	63.0	37.0	197.7	124.6	73.1	384.4	225.7
1942	317.5	175.5	64.4	35.6	193.7	124.7	69.0	442.2	244.5
1943	440.9	242.1	64.6	35.4	190.6	123.1	67.5	564.0	309.6
1944	345.3	266.6	56.4	43.6	178.7	100.8	77.9	446.1	344.5
1945	371.7	237.6	61.0	39.0	183.1	111.7	71.4	483.4	309.0
1946	282.7	246.8	53.4	46.6	173.1	92.5	80.6	375.2	327.4
1947	279.9	211.6	56.9	43.1	161.9	92.1	69.8	372.0	281.3
1948	202.7	198.7	50.5	49.5	153.3	77.4	75.9	280.1	274.8
1949	260.3	180.6	59.0	41.0	156.2	92.2	64.0	352.5	244.7
1950	208.2	200.6	50.9	49.1	152.1	77.4	74.7	285.6	275.2
1951	215.1	182.8	54.1	45.9	146.0	79.0	67.0	294.1	249.8
1952	187.4	176.1	51.6	48.4	138.3	71.4	66.9	258.8	243.0
1953	164.6	172.0	48.9	51.1	128.6	62.9	65.7	227.5	237.8
1954	162.1	169.5	48.9	51.1	129.3	63.2	66.1	225.3	235.6
1955	108.7	155.6	41.2	58.8	121.4	49.9	71.5	158.6	226.9
1956	112.7	148.5	43.1	56.9	124.0	53.4	70.6	166.1	219.1
1957	67.9	144.5	32.0	68.0	115.4	36.9	78.5	104.8	223.0
1958	85.6	139.6	38.0	62.0	114.6	43.5	71.1	129.1	210.7

a Column (3) = $\frac{\text{Column (1)}}{\text{Column (1) + Column (2)}} \times 100$.

b Column (4) = $\frac{\text{Column (2)}}{\text{Column (1) + Column (2)}} \times 100$.

c Column (6) = $[\text{Column (3)} \times \text{Column (5)}] \div 100$.

d Column (7) = $[\text{Column (4)} \times \text{Column (5)}] \div 100$.

e Column (8) = $\text{Column (1)} + \text{Column (6)}$.

f Column (9) = $\text{Column (2)} + \text{Column (7)}$.

Table 4. Number of cockerels lost during a year: estimation procedures from reported data of total chickens raised and lost during a year for 1931-58.

Year	Chickens raised (1)	Chickens lost (2)	Rate of loss (3)a %	Cockerels raised (4)b	Cockerels on farm Jan. 1 (5)	Estimated loss of cockerels (6)c %
1931	709.4	62.8	8.9	342.6	48.0	34.6
1932	735.5	62.9	8.6	353.4	51.0	34.6
1933	750.1	65.2	8.3	358.2	53.8	34.3
1934	644.4	66.1	10.3	306.1	48.6	36.4
1935	658.3	60.6	9.2	310.4	39.6	32.2
1936	715.0	64.4	9.0	334.9	40.8	33.9
1937	601.1	68.6	11.4	269.1	44.2	35.7
1938	650.7	67.5	10.4	299.3	36.7	34.8
1939	696.7	75.6	10.9	317.0	42.5	39.0
1940	633.7	78.1	12.3	284.9	45.6	40.7
1941	745.0	80.8	10.9	330.4	41.5	40.4
1942	844.3	92.4	10.9	351.6	49.0	43.8
1943	1,001.4	87.7	8.8	441.6	53.1	43.3
1944	832.1	107.2	12.9	352.0	58.6	52.9
1945	890.4	91.3	10.3	384.2	42.6	43.7
1946	737.6	91.1	12.4	302.7	50.4	43.6
1947	719.4	83.7	11.6	282.4	35.8	37.0
1948	615.8	79.0	12.8	229.1	32.1	33.5
1949	705.1	82.3	11.7	257.3	31.5	33.7
1950	619.8	84.5	13.6	226.2	32.8	35.3
1951	622.9	83.4	13.4	224.2	31.7	34.3
1952	561.0	87.6	15.6	190.7	29.3	34.3
1953	547.5	83.6	15.3	172.4	25.1	30.2
1954	534.9	85.1	15.8	153.8	25.8	28.3
1955	461.9	84.2	18.2	131.6	22.1	28.0
1956	478.6	86.0	18.0	129.2	22.5	27.3
1957	394.6	86.8	22.0	88.7	21.3	24.2
1958	433.0	80.8	18.7	98.1	18.4	21.7

a Column (3) = $\frac{\text{column (2)}}{\text{column (1)}} \times 100$.

b Estimated in table 2.

c Column (6) = $[\text{column (3)} \times [\text{column (4)} + \text{column (5)}]] \div 100$.

Table 5. Number of pullets culled: estimated as residuals in counting young chickens produced, 1931-58.

Year	Young chickens produced (1)a	Cockerels raised (2)b	Cockerels on farm Jan. 1 (3)	Loss of cockerels (4)c	Estimated number of pullets culled as residual (5)d
1931	377.2	342.6	48.0	34.6	21.2
1932	394.2	353.4	51.0	34.6	24.4
1933	411.1	358.2	53.8	34.3	33.4
1934	339.4	306.1	98.6	36.4	21.1
1935	348.3	310.4	39.6	32.2	30.5
1936	375.3	334.9	40.8	33.9	33.5
1937	286.9	269.1	44.2	35.7	9.8
1938	314.3	299.3	36.7	34.8	13.1
1939	346.9	317.0	42.5	39.0	26.4
1940	295.5	284.9	45.6	40.7	5.7
1941	384.4	330.4	41.5	40.4	52.9
1942	442.2	351.6	49.0	43.8	85.4
1943	564.0	441.6	53.1	43.3	112.6
1944	446.1	352.0	58.6	52.9	88.4
1945	483.4	384.2	42.6	43.7	100.3
1946	375.2	302.7	50.4	43.6	65.7
1947	372.0	382.4	35.8	37.0	90.8
1948	280.1	229.1	32.1	33.5	52.4
1949	352.5	257.3	31.5	33.7	97.4
1950	285.6	226.2	32.8	35.3	61.9
1951	294.1	224.2	31.7	34.3	72.5
1952	258.8	190.7	29.3	34.3	73.1
1953	227.5	172.4	25.1	30.2	60.2
1954	225.3	153.8	25.8	28.3	74.0
1955	158.6	131.6	22.1	28.0	32.9
1956	166.1	129.2	22.5	27.3	41.7
1957	104.8	88.7	21.3	24.2	19.0
1958	129.1	98.1	18.4	21.7	34.3

a Estimated in table 3.

b Estimated in table 2.

c Estimated in table 4.

d Column (5) = $\text{column (1)} - [\text{column (2)} + \text{column (3)} - \text{column (4)}]$.

average number of eggs per layer is reported, and its trend is estimated in constructing the technology index of egg production. The average number of layers on the farm is determined by (1) hens and pullets on the farm, Jan. 1, (2) pullets raised and (3) hens and pullets culled. The values of these items are already given. Residual in counting the average number of layers consists of such items as the loss by death, the pullets which do not reach the age of laying and the errors in estimation. Figures resulting from the layer-counting relation are shown in table 6.

Model for Single-Step Analysis

The preceding discussion explains the logic in constructing the model for the multistep analysis. The model for the single-step analysis of egg supply is constructed by combining the intermediate relations into one equation.

The most important factor which affects the output of eggs in a year is the number of pullets raised in the previous year. The lagged values of the independent variables in the equation of pullet-raising are included in the equation for the single-step analysis. These lagged values are the variables which determine the number of pullets raised in the previous year. The second factor which affects the output of eggs is the number of pullets raised in the year. The November-May weighted average of the egg-feed price ratio is selected as a variable which determines the number of pullets raised in the present year. The other

variables which affect the number of pullets raised in the present year are excluded from the equation to avoid multicollinearity with the lagged values. The third factor which affects the output of eggs is the relation of culling hens and pullets. For the variables which may affect culling, the annual averages of egg-feed price ratio and of chicken-feed price ratio are included in the equation.

Single-step analysis is conducted only for the supply of eggs. In the supply of farm chickens, the change over time in the intermediate relations due to sexing practice has been great. Hence, it is quite meaningless to attempt a simple association between the output of farm chickens and the price of eggs, or even of farm chickens and chicken price.

Empirical Estimation and Modification of Models

Models have been presented so far in terms of a priori knowledge and logic. In actual empirical estimation of these models, some variables may be found to be insignificant, or to have large multicollinearity with other variables. The results of estimation may suggest that some additional variables are needed. The models are first estimated within the framework outlined above, then are modified on the basis of the results of estimation. We present the models as outlined above, then modify them on the basis of initial empirical results. The single-step supply function will be presented first.

Single-Step Analysis of Egg Supply

The result of estimation of equation 17, the single-step equation for egg supply for 1926-58, is:

$$(32) \log Q_e = -3.5179 + 0.2052 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.4879 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.1133 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.3257 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.0507 \log E_{h(t-1)} + 0.1934 \log E_{b(t-1)} + 1.6534 \log R_{c(t)}$$

(0.0718) (0.0712) (0.1232) (0.0726) (0.0348) (0.0620) (0.0970)

$$R^2 = 0.9779$$

In this regression equation, the coefficients of $\log (P_e/P_f)'$ and $\log (P_e/P_f)'_{t-1}$ are significant at the 1-percent level. The values of these coefficients show the positive effects of the egg-feed price ratios in the hatching season of the previous year, and of the present year on the output of eggs. The coefficient of the lagged value of $(P_e/P_f)'$ which expresses the ratio in the previous year and therefore the premium on adding pullets to the flock, is estimated to be larger than that of the present value of the same variable, the latter indicating whether existing hens should be culled or retained.

Table 6. Counting of average number of layers on farms during a year, 1931-58.

Year	Layers on farm during a year (1)	Hens and pullets on farm Jan. 1 (2)	Pullets raised during a year (3)a	Hens culled (4)b	Pullets culled (5)c	Residual (6)d
			(million)			
1931	303.0	243.6	366.8	282.3	21.2	3.7
1932	299.1	229.6	382.1	270.6	24.4	17.6
1933	299.7	236.7	391.9	284.4	33.4	11.1
1934	290.7	238.3	338.3	283.0	21.1	-18.2
1935	276.4	211.8	347.9	236.0	30.5	16.8
1936	284.9	226.4	380.1	254.9	33.5	33.2
1937	288.0	249.3	332.0	280.0	9.3	4.0
1938	275.9	215.0	351.4	240.0	18.1	37.4
1939	289.6	241.8	379.7	254.4	26.4	51.1
1940	296.6	253.6	348.8	275.6	5.7	24.5
1941	300.9	239.9	414.6	225.7	52.9	75.0
1942	341.6	277.7	492.7	244.5	85.4	98.9
1943	383.0	318.6	559.8	309.6	112.6	73.2
1944	395.8	349.6	480.1	344.5	88.4	1.0
1945	369.4	301.5	506.2	309.0	100.3	29.0
1946	357.6	322.1	434.9	327.4	65.7	6.3
1947	345.1	281.0	437.0	281.3	90.8	0.8
1948	331.6	278.0	386.0	274.8	52.4	5.2
1949	330.7	258.3	447.8	244.7	97.4	33.3
1950	339.5	286.8	393.6	275.2	61.9	3.8
1951	327.8	258.2	398.7	249.8	72.5	6.8
1952	320.5	261.4	370.3	243.0	73.1	-4.9
1953	312.1	237.6	375.1	237.8	60.2	2.6
1954	314.2	255.1	386.1	235.6	74.0	17.4
1955	309.1	257.2	330.3	226.9	32.9	18.6
1956	309.9	238.6	349.4	219.1	41.7	17.3
1957	304.8	250.0	305.6	223.0	19.0	8.8
1958	301.3	224.6	337.7	210.7	34.3	16.0

a Estimated in table 2.

b Estimated in table 3.

c Estimated in table 5.

d Column (6) = [column (2) + column (3) - column (4) - column (5)] - column (1).

The coefficient of $\log (P_e/P_f)$ is considerably smaller than of $\log (P_e/P_f)'_{t-1}$ and is significant at a probability level of 30 percent. This suggests that the effect of relative egg price on egg supply is much smaller through hen-culling than through pullet-raising. The coefficient of $\log R_e$ is large in value and also highly significant, indicating that farmers have responded strongly to technological progress in eggs in expanding their production.

The positive sign for the coefficient of $\log (P_e/P_f)$ seems to reject the hypothesis that farmers cull more hens when the chicken price is favorable. (Egg output would be smaller under this condition.) However, the positive magnitude may be partly caused by the positive correlation between the output of eggs and the price of farm chickens over business cycles in the national economy. Both the hog profitability index and the broiler profitability index have positive coefficients. At the national level of supply, it would appear that hogs and broilers are not the main products competing with eggs. Again, these positive coefficients may also be explained by positive correlation between their associated variables and the output of eggs over the business cycle and between other time trends at the national level. The upward trend over time in both the broiler profitability index and the output of eggs evidently causes a high correlation between them, resulting in the positive coefficient.

To determine whether the effects of competing enterprises might be reflected by removing possible multicollinearity, the model is estimated after (P_e/P_f) and (P_c/P_f) are dropped. The resulting equation is:

$$(33) \log Q_e = -2.2270 + 0.3242 \log \left(\frac{P_c}{P_f} \right)' \\ (0.1109) \\ + 0.3750 \log \left(\frac{P_c}{P_f} \right)'_{t-1} \\ (0.1187) \\ + 0.0772 \log E_{1t} + 0.2201 \log E_{2t} + 1.2011 \log R_e \\ (0.0584) \quad (0.1001) \quad (0.1110)$$

$$R^2 = 0.9264$$

The coefficients of $\log E_{1t}$ and $\log E_{2t}$ remain positive in equation 33. Judging from the resulting statistics, the competitive relation between eggs and broilers is not strong at the national level of aggregation, at least not strong enough to overcome the positive correlation resulting from business cycle or trend.

Baker indicated that a competitive relation between eggs and hogs cannot be found statistically in Iowa. The competitive relation between these two enterprises would be expected to be prominent in Iowa. If a competitive statistical relation cannot be found in Iowa, it is unlikely that it can be established in an aggregative egg supply function for the United States. A competitive relation between eggs and broilers is becoming important as the broiler industry develops and as broiler growers consider egg-laying hens as a substitute for

broilers. However, this relation between eggs and broilers is of recent development. Therefore, it is reasonable that the competitive relation cannot be found statistically in nationally aggregated time-series data for the period 1926-58.

It is expected *a priori* that the effect on the output of eggs resulting from culling hens is much smaller than that resulting from raising pullets. To test whether the culling of hens has affected the total output of eggs in an appreciable magnitude, the model is estimated after the variables of the competing enterprises are dropped. The following equation results:

$$(34) \log Q_e = -3.5171 + 0.2836 \log \left(\frac{P_e}{P_f} \right)' \\ (0.0779) \\ + 0.5219 \log \left(\frac{P_e}{P_f} \right)'_{t-1} - 0.0842 \log \left(\frac{P_e}{P_f} \right) \\ (0.0793) \quad (0.1273) \\ + 0.4369 \log \left(\frac{P_c}{P_f} \right) + 1.8658 \log R_e \\ (0.0756) \quad (0.0879)$$

$$R^2 = 0.9674.$$

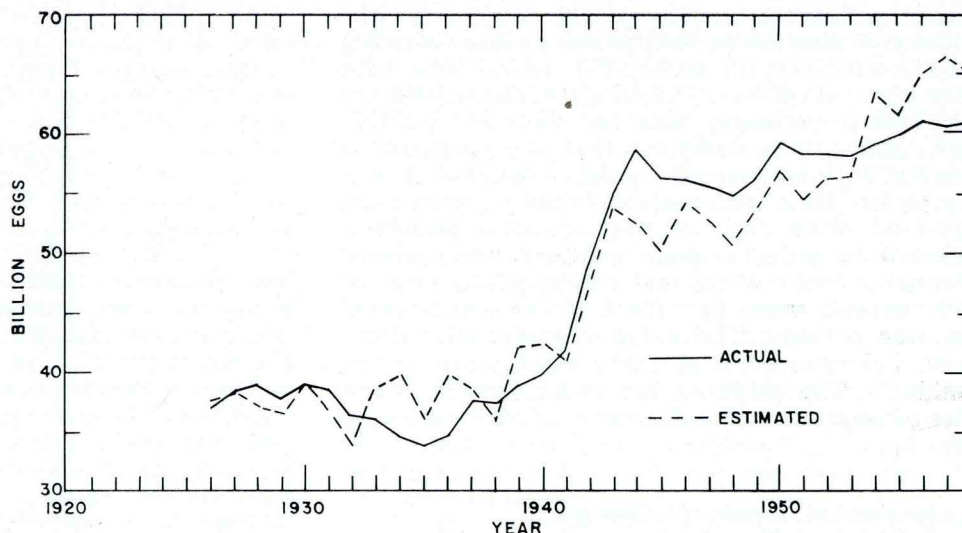
In this estimate, the coefficient of $\log (P_e/P_f)$ is negative, and statistically significant only at the 50-percent level. The coefficient of $\log (P_c/P_f)$ still has a significant positive value. It may be contended that chickens are not a by-product and the positive coefficient shows the effect of chicken price on pullet-raising and egg production more than on the culling of hens. It is more plausible however, that the significant positive value of the coefficient is due to the correlation between chicken price and the output of eggs through the business cycle. Another possibility is that simultaneity causes the bias in the least-squares estimates. But it is not likely that the simultaneity in the relation of culling can cause such a large bias.

Since the effects of competing enterprises and of culling hens and pullets on the output of eggs are not found statistically in a meaningful way, the variables which represent those effects are dropped from the model. The result of estimation of the simplified model is:

$$(35) \log Q_e = -2.2430 + 0.3637 \log \left(\frac{P_e}{P_f} \right)' \\ (0.1154) \\ + 0.4824 \log \left(\frac{P_c}{P_f} \right)'_{t-1} + 1.3898 \log R_e \\ (0.1175) \quad (0.0939) \\ R^2 = 0.9056 \quad d = 0.76$$

In this estimate, the coefficients of all three variables are significant at the 1-percent level and have signs which do not contradict theory. The value of the Durbin-Watson d-statistic shows a positive serial correlation of residuals at the 5-percent level. The positive serial correlation is caused by the change in the price elasticity of supply during the war years. As shown in fig. 10, equation 35 consistently underestimates the output of eggs for the years from 1941 through 1953, and con-

Fig. 10. Total number of eggs produced, values of actual observations and estimated values from equation 35.



sistently overestimates it for the years after 1954. The consistent underestimation and overestimation for particular periods cause the positive serial correlation in the residuals. This underestimation and overestimation of the output must be due to the underestimation of the price elasticity of supply for 1941-53 and the overestimation of price elasticity of supply for 1954-58. During the war, especially in the early years, the farmers' expectation for egg price was very optimistic. And farmers responded to the price rise in this period more than in other periods, resulting in a dramatic increase in the output of eggs. During the price decline in the early postwar years, output did not fall at the same rate as it rose during the war. This is consistent with the hypothesis of the irreversible supply curve by Cassels.¹⁴ The adoption of technology and the investment of fixed capital during the boom of the war could not be reversed quickly when the war was over.

Estimates With Time and Elasticity Differentials

Hence, the price elasticity of egg supply was inflated in the booming period of the war and early postwar years and was reduced when the egg price started to fall. However, it is the limitation of a linear equation that the coefficients remain constant over the range of observations. The elasticity with respect to $(P_e/P_f)'$ in equation 35 is an average of the elasticities for different periods. The serial correlation of residuals is expected to decrease if we estimate the model for each of the subperiods in which the price expectation of farmers is relatively homogeneous.

For the sake of comparison and to examine the efficiency of the technology variable, a model which substitutes time, t , with $t = 1$ at 1926, for the technology index is estimated as follows:

$$(36) \log Q_e = 1.1405 + 0.1090 \log \left[\frac{P_e}{P_f} \right]' + 0.1604 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.2151 \log t$$

(0.2430) (0.2425) (0.0419)

$$R^2 = 0.5770 \quad d = 0.12$$

The value of R^2 is markedly reduced, compared with equation 35, and the coefficients of $\log (P_e/P_f)'$ and $\log (P_e/P_f)'_{t-1}$ are not significant at the 5-percent level. Serial correlation is extremely high. On this basis, equation 36 is inferior to equation 35.

Time is traditionally used as a substitute for the technology variable for the time-series analysis of supply. The intrinsic weakness of using time to represent technological progress was discussed in a previous section. The statistics found in comparing equations 35 and 36 support the advantage of using the technology index as a variable, rather than time.

To obtain the long-run elasticities of egg supply, a Koyck-Nerlove type of model was estimated as follows:

$$(37) \log Q_e = -0.9094 + 0.1839 \log \left[\frac{P_e}{P_f} \right]' + 0.2290 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.4104 \log R_e + 0.7520 \log Q_{e(t-1)}$$

(0.0635) (0.0677) (0.0677) (0.0849)

$$R^2 = 0.9752 \quad d = 0.85$$

In this equation, the coefficients have signs consistent with theory and values significant at the 5-percent level. The long-run elasticities obtained from equation 37 are: 0.7414 with respect to $(P_e/P_f)'$ and 0.9234 with respect to $(P_e/P_f)'_{(t-1)}$

14 Cassels, J. M. The nature of statistical supply curve. Jour. Farm Econ. 15:378-383. 1933.

These values are reasonable, compared with the short-run elasticities estimated in equation 35: 0.3637 with respect to $(P_e/P_f)'$ and 0.4824 with respect to $(P_e/P_f)'_{t-1}$. The long-run elasticities are expected to be larger than the short-run elasticities. Again, it is indicated that the elasticity is greater with respect to buying chickens and raising pullets than with respect to hen-culling. (The egg-feed price ratio of the previous year was selected to reflect effects on flock management through pullet-raising and the egg-feed ratio of the current year to affect flock management through culling.) The value of d-statistics, however, indicates positive serial correlation in the residuals. The cause of the serial correlations in this estimate must be the same as that for equation 35.

Evaluation of Structural Change in Single-Step Model

Previous discussion suggested that technological change not only causes a shift in the supply function, but also generally alters the elasticities of supply. Hence, we now evaluate the structural change in egg supply as it is caused by technological progress.

As a first step, we estimate the supply functions and elasticities for two or more subperiods omitting variables representing competing enterprises. The data series from 1926 to 1958 are divided into two subperiods — 1926-41 and 1947-58 — with the intrawar years excluded.

The estimates of the egg supply function for these two periods are:

1926-41

$$(38) \log Q_e = 0.1972 + 0.0981 \log \left(\frac{P_e}{P_f} \right)' + 0.1674 \log \left(\frac{P_e}{P_f} \right)'_{t-1} + 0.5199 \log R_e$$

(0.1640) (0.1675) (0.3751)

$$R^2 = 0.3803 \quad d = 0.48$$

1947-58

$$(39) \log Q_e = 0.6367 + 0.0529 \log \left(\frac{P_e}{P_f} \right)' + 0.0819 \log \left(\frac{P_e}{P_f} \right)'_{t-1} + 0.4386 \log R_e$$

(0.0617) (0.0642) (0.0640)

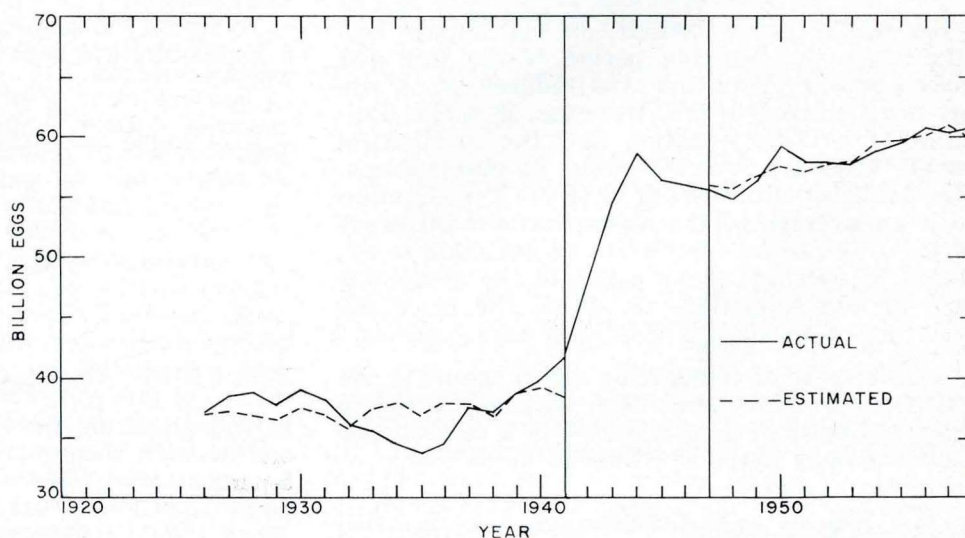
$$R^2 = 0.8726 \quad d = 1.37$$

The elasticities with respect to $(P_e/P_f)'$ and $(P_e/P_f)'_{t-1}$ in these estimates for the divided periods are much smaller than those in the estimate for the whole period. The reduction of the elasticities in these estimates is caused by excluding the observations of the intrawar years from the analysis. As a result of the exclusion of intrawar years, the estimate for each subperiod is exempted from the influence of the unusually high price elasticities during the war, which inflate the elasticities with respect to $(P_e/P_f)'$ and $(P_e/P_f)'_{t-1}$ in the estimate for the whole period.

As was expected, the serial correlation of residuals is reduced in the estimate for 1947-58. The value of the d-statistic of equation 39 falls in the inconclusive region. But the serial correlation of residuals in the estimate for 1926-41 seems still to exist, judging from the value of the d-statistic of equation 38. As suggested in fig. 11, this serial correlation is caused by the overestimation of the outputs in the years of the great depression when the farmers' expectations became unusually pessimistic and output of eggs was reduced more than the usual amount relative to the decline in egg price. This change in the price expectation causes the overestimation of the price elasticity and the resulting overestimation of the output for the period of the depression.

Comparing the estimates for 1926-41 and 1947-58, the marked difference is: The elasticities of supply with respect to $(P_e/P_f)'$ and $(P_e/P_f)'_{t-1}$ for the former period are twice as large as those for the latter period. Considering the advances of technology between these two periods, the differ-

Fig 11. Total number of eggs produced, values of actual observations and estimated values from equations 38 and 39.



ence in these elasticities would suggest that technological progress caused the decrease in the price elasticity of egg supply.

Technological progress in egg production has been accompanied by an increase in the amount of fixed capital used for production. Before the middle of the 1930's, a relatively small amount of fixed capital investment was required for raising farm flocks. Chickens were raised in the yard, range or corner of the barn, salvaging waste grains, weeds and insects. Today, most chickens are confined in poultry houses with devices of environmental control. Investment for building, ventilation, feeding equipment and water systems has been increasing. As the portion of fixed capital increases, it becomes more difficult for farmers to adjust the production for price change — at least in the short run.

Obviously, technological progress has caused the tendency toward specialization of egg production. As an enterprise is specialized, it becomes more difficult for farmers to enter or quit the enterprise on a short-term basis. When egg production is one of the branches of a multienterprise farm, the farmer can easily shift the resources of production from eggs to other enterprises or from other enterprises to eggs. Once the farmer specializes in eggs, he cannot raise anything but chickens, at least in the short run, however unfavorable the egg price is relative to the prices of other commodities. Real differences in the magnitude of supply elasticity between equation 38 and equation 39 might thus be explained by the technological progress of egg production.

Again, to compare short-run and long-run elasticities, the Koyck-Nerlove model is estimated for each subperiod. The equations follow:

1926-41

$$(40) \log Q_e = -1.0973 + 0.1060 \log \left[\frac{P_e}{P_f} \right]' + 0.1857 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.4944 \log R_e + 0.8414 \log Q_{e(t-1)}$$

(0.1002) (0.1024) (0.2292) (0.1829)

$$R^2 = 0.7074 \quad d = 0.98$$

1947-58

$$(41) \log Q = 0.4598 + 0.0620 \log \left[\frac{P_e}{P_f} \right]' + 0.0886 \log \left[\frac{P_e}{P_f} \right]'_{t-1} + 0.3779 \log R_e + 0.1689 \log Q_{e(t-1)}$$

(0.0672) (0.0687) (0.1365) (0.3308)

$$R^2 = 0.9366 \quad d = 1.42$$

The long-run elasticities obtained from equations 40 and 41 are: 0.6683 with respect to $(P_e/P_f)'$ and 1.1709 with respect to $(P_e/P_f)'_{t-1}$ for the period 1926-41, and 0.0746 with respect to $(P_e/P_f)'$ and 0.1066 with respect to $(P_e/P_f)'_{t-1}$ for the period of 1947-58. The long-run elasticities are larger than their corresponding short-run elasticities in both equations 40 and 41.

The long-run elasticities for the period of 1926-41 seem unreasonably large. This may be due to the underestimation of the coefficient of adjustment. The coefficient of adjustment is underestimated because the consistent increase in the output of eggs causes the high positive correlation between Q_e and $Q_{e(t-1)}$. The difficulty in applying the Koyck-Nerlove model to the case in which the dependent variable has a trend of consistent increase or decrease is discussed later in the analysis of broiler supply.

Though the estimates of the long-run elasticities for the period 1926-41 seem too large, it seems reasonable to suppose that the long-run supply elasticities are at least larger in the prewar years than in the postwar years. The decline in the long-run elasticities again might be explained by the difficulty of entry and exit resulting from specialization. From these statistical estimates, however, we cannot say definitely that the elasticity of supply has been reduced because in either estimate, long-run or short-run, the coefficients are nonsignificant at the 5-percent level.

For further investigation, regression equations are estimated for the two periods: 1926-33 and 1934-40. The former period is prior to the rapid progress in technology, while in the latter period recent technology had been initiated and was proceeding rapidly. To examine supply structure for the war period, equations also are estimated for the period 1941-46.

Since the number of observations in each period is small and because the egg-feed price ratio in the hatching season of the present year is of relatively minor importance in relation to the output of eggs in the present year, the term $(P_e/P_f)'$ is dropped from the equation. Finally, the technology index is dropped from the equation of 1926-33, because technical changes were small before 1933.

The results for the four subperiods are summarized in table 7. The elasticity of supply with respect to $(P_e/P_f)'_{t-1}$ is indicated to have decreased except for the war years. The elasticity estimated for 1934-40 seems too small, compared with the elasticity for 1926-33. Probably the elasticity with respect to $(P_e/P_f)'_{t-1}$ is underestimated for the period 1934-40 because of the multicollinearity between $(P_e/P_f)'_{t-1}$ and R_e . The trend in the technology index takes over the upward trend in the egg price during the period of recovery from the 1930's depression. The real response of farmers to price and cost would have been larger for the period 1934-40 than the statistical estimate shows.

The elasticity with respect to $(P_e/P_f)'_{t-1}$ is largest for the period 1941-46. The causes for this large price elasticity of supply during the war

Table 8. Supply elasticity of eggs with respect to $(P_e/P_f)'_{t-1}$ for subperiods.

Subperiod	Average of the technology index for the period	Supply elasticity of eggs with respect to $(P_e/P_f)'_{t-1}$	
		Computed from equation 43	Estimated separately for each period
1926-33	118.34	0.5566	0.3106
1934-40	129.45	0.4844	0.0704
1941-46	147.41	0.3676	0.5017
1947-58	181.61	0.1453	0.0886
1926-58	148.99	0.3573	0.3752

$P_f)'_{t-1}$. There is another weakness of the model for predictive purposes. The nonlinear coefficient is assumed to be a linear function of the technology index. There is a tendency to overestimate the elasticity for the earlier periods and to underestimate the elasticity for the later periods. As R_e increases, the coefficient will eventually become negative. Equation 43 thus cannot be extrapolated over a wide range.

The estimate of the nonlinear coefficient of $\log (P_e/P_f)'_{t-1}$ provides little information about what the elasticity was in a certain period of the past or what it will be in the future. But it again provides empirical suggestion that a decline in price elasticity of egg supply occurs as technology advances.¹⁵

Multistep Analysis of Egg Supply

The preceding empirical analysis has been based on a single equation, to estimate the egg supply function in a single-step manner. In this analysis, the various processes, steps or enterprises involved in raising pullets, culling chickens and related activities were combined into a single estimating equation. We now turn to the multistep model discussed earlier and estimate separate regression equations for separate or distinct operations in the egg-farming process. As explained previously, the supply of eggs and farm chickens consists of four major steps in the poultry enterprise: (1) the raising of pullets, (2) the raising of cockerels, (3) the culling of hens and (4) the culling of pullets. Each of these four relations is now analyzed separately. Once the number of pullets raised, the number of cockerels raised, the number of hens culled and the number of pullets culled are estimated, the total output is automatically given for eggs through counting equations 22 and 23, and for farm chickens through counting equations 24 and 25.

Relation of Raising Pullets

The relation of pullet-raising is formulated in equation 18. This equation also might be termed "the farmer demand function for pullets." In the single-step analysis, it was apparent that the effects of competing enterprises on the supply of

eggs are not large enough to be statistically isolated in nationally aggregated data. Hence, we start our analysis in estimating the empirical counterpart of equation 18 with E_{1t} and E_{2t} dropped. The resulting equation is as follows for the period 1926-58:

$$(44) \log X_p = 1.2317 + 0.7194 \log \left(\frac{P_e}{P_f} \right)' + 0.2732 \log R_e$$

(0.1659) (0.1161)

$$R^2 = 0.3869 \quad d = 0.42$$

In this estimate, the coefficient of $\log (P_e/P_f)'$ is positive in sign and significant at the 1-percent level. This indicates a positive response in pullet-raising to the egg-feed price ratio in the hatching season. The coefficient of $\log R_e$ has a significant positive value at the 5-percent level, also showing a positive response in number of pullets raised as the efficiency of egg production has advanced. In other words, the technological progress has shifted the farmers' demand for pullets upward.

The values of estimates for both coefficients are statistically significant at the 5-percent level and have signs consistent with theory. However, the value of R^2 is 0.3869, indicating a small degree of association between values of observations for the number of pullets raised and the estimated values from equation 44. Also, the value of the d-statistic shows that the residuals in the equation are serially correlated. We now examine the causes of this serial correlation.

Figure 13 indicates that equation 44 consistently underestimates the number of pullets raised for the period 1941-50, and overestimates for the period 1953-58. The underestimation for the former period again might be explained by the optimistic price expectation of farmers during the war years. This optimistic expectation increased the elasticity of farmers' demand for pullets, as well as the elasticity of egg supply with respect to egg price.

The overestimation for the number of pullets raised in the latter period results partly through the compensation process in the least-squares estimation — compensation for the underestimation of the former period. But the more important

¹⁵ By the estimate, we can evaluate the effect of technological progress on the elasticity with respect to $(P_e/P_f)'_{t-1}$.

Table 9. Number of cockerels raised: estimation procedures from the number of pullets raised estimated by equation 45.

Year	s Ratio of the number of sexed pullets to the number of chickens raised (1) ^a	k Ratio of the number of sexed cockerels to the number of chickens raised (2) ^b	γ Pullet-chicken ratio (3) ^c	X_p Estimated number of pullets raised (million) (4) ^d	X_k Estimated number of cockerels raised (million) (5) ^e
1926	0.023	0.005	0.965	400	386
1927	0.026	0.005	0.959	398	382
1928	0.030	0.006	0.953	358	341
1929	0.034	0.007	0.947	391	370
1930	0.038	0.008	0.942	419	395
1931	0.043	0.009	0.934	313	292
1932	0.049	0.010	0.925	352	326
1933	0.056	0.011	0.914	449	410
1934	0.063	0.013	0.905	339	307
1935	0.071	0.014	0.812	362	323
1936	0.079	0.016	0.881	424	374
1937	0.089	0.018	0.867	310	269
1938	0.100	0.020	0.852	382	325
1939	0.113	0.023	0.835	425	355
1940	0.126	0.025	0.817	364	297
1941	0.141	0.028	0.797	403	321
1942	0.209	0.042	0.714	455	325
1943	0.172	0.054	0.789	493	389
1944	0.203	0.049	0.733	408	299
1945	0.185	0.048	0.759	447	339
1946	0.223	0.044	0.696	427	297
1947	0.260	0.045	0.646	414	267
1948	0.300	0.045	0.594	387	230
1949	0.310	0.040	0.575	428	246
1950	0.320	0.050	0.575	384	221
1951	0.330	0.050	0.563	400	225
1952	0.370	0.050	0.515	376	194
1953	0.420	0.050	0.460	384	177
1954	0.490	0.060	0.399	374	149
1955	0.500	0.070	0.399	365	146
1956	0.530	0.070	0.370	354	131
1957	0.610	0.060	0.290	353	102
1958	0.610	0.060	0.290	332	96

^a Column (2) of table 2.

^b Column (3) of table 2.

^c $\gamma = \frac{2}{1 + s - k} - 1$.

^d Estimated from equation 45.

^e Column (5) = column (3) \times column (4).

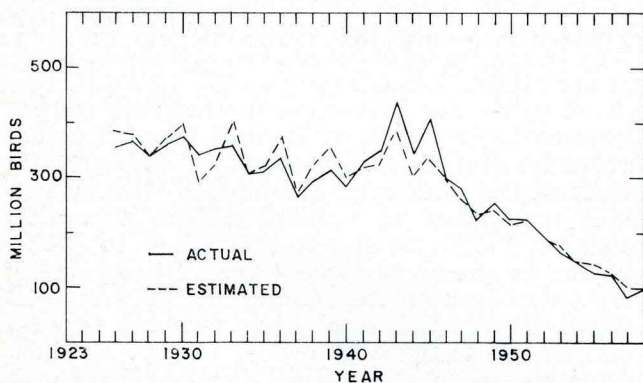


Fig. 15. Number of cockerels raised, values of actual observations and values obtained through equation 19 from numbers of pullets raised estimated by equation 45.

equation 19. If we estimate the number of pullets raised from equation 45, then the estimate of the number of cockerels raised is provided by multiplying the pullet estimate by the cockerel-pullet ratio γ obtained from the percentage of pullet chicks sexed. The process of estimation is summarized in table 9, and the estimated values are plotted in fig. 15.

Relation of Culling Hens

The effect of prices on egg production, through culling hens and pullets, is not indicated specifically and statistically in the single-step analysis. This is true since, in the more "gross" procedure of the single-step analysis, culling relations are minor in their effects on egg output relative to the effects of pullet-raising.

To test whether the prices of eggs and farm chickens influence the number of hens culled, the hen-culling relation formulated in equation 20 is estimated for 1931-58 as follows:

$$(47) \log X_{h,c} = 1.1876 - 0.5242 \log \left(\frac{P_c}{P_f} \right) + 0.3391 \log \left(\frac{P_c}{P_f} \right) + 0.6210 \log X_h$$

(0.1119) (0.0443) (0.0811)

$$R^2 = 0.8522 \quad d = 1.52$$

The coefficients of all three independent variables have values significant at the 1-percent level. The d-statistic rejects the hypothesis of the serial correlation in the residuals at the 5-percent level. The negative sign in the coefficient of $\log (P_c/P_f)$ indicates that farmers continue keeping hens for a favorable price ratio and cull them for an unfavorable ratio. The positive sign in the coefficient of $\log (P_c/P_f)$ indicates that farmers cull more hens when the market situation is favorable for chickens and cull fewer when the market situation is unfavorable.

The number of hens culled is largely associated with the number of hens and pullets on the farm at the beginning of a year. But the results in equation 47 indicate that farmers also use culling, in response to the prices of eggs and farm chickens during a year, to adjust the number of hens. Predicted values for number of hens culled from equation 47 are compared with actual observations in fig. 16. This feature of estimation and decisions could not be uncovered in the single-step analysis.

Relation of Culling Pullets

The next step is to see whether the prices of eggs and farm chickens have any effect on the number of pullets culled. The relation of pullet-raising, as formulated in equation 21, is estimated as follows:

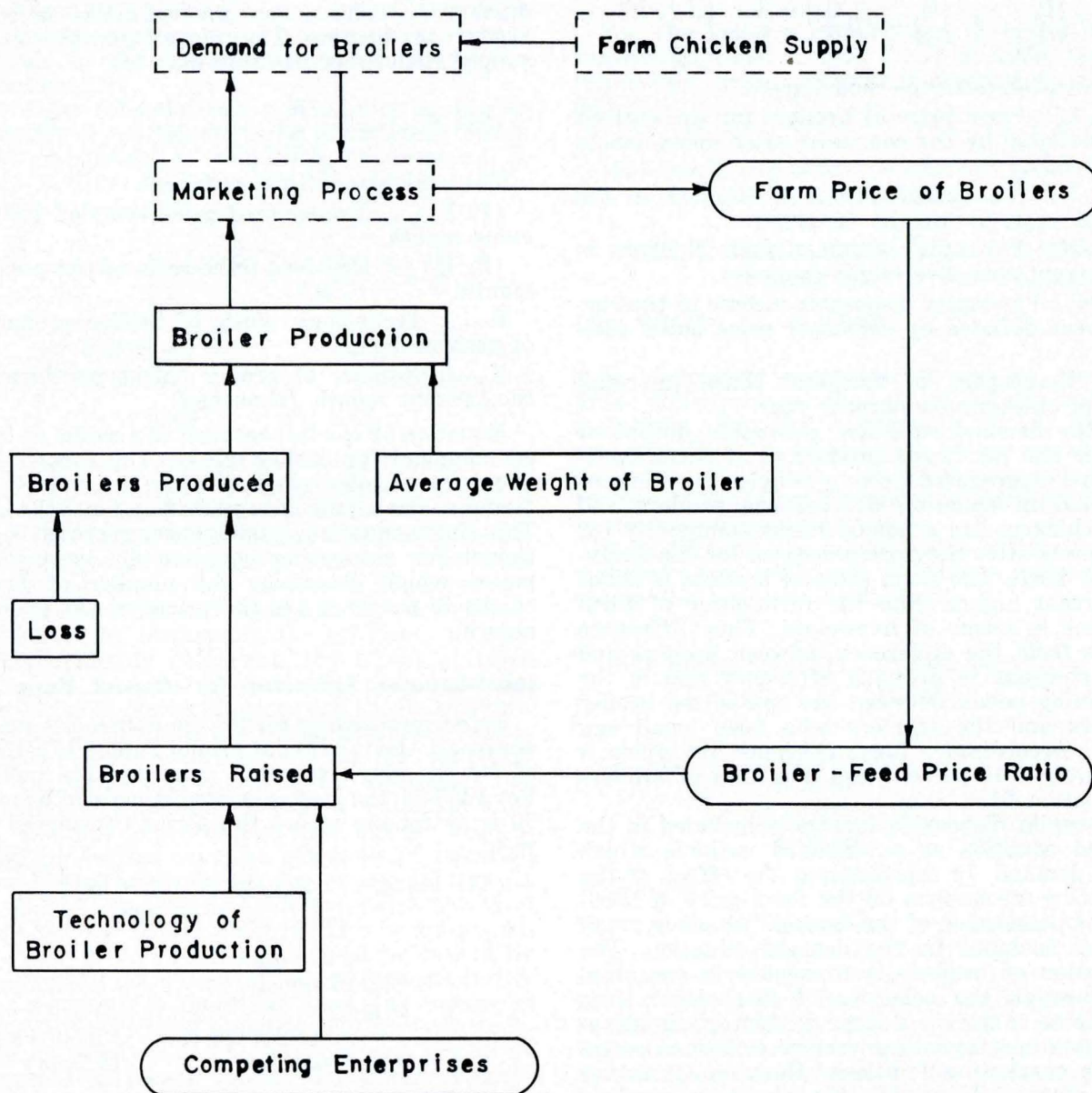
$$(48) \log X_{p,c} = -10.9533 + 1.1079 \log \left(\frac{P_c}{P_f} \right) - 1.5237 \log \left(\frac{P_c}{P_f} \right) + 4.8976 \log X_p$$

(1.0617) (0.3972) (0.7352)

$$R^2 = 0.7104$$

Only the coefficient of $\log X_p$ has a value that is statistically significant. Moreover, the signs of coefficients for $\log (P_c/P_f)$ and $\log (P_c/P_f)$ contradict the hypothesis that farmers cull fewer hens when prices are favorable for eggs or unfavorable for chickens.

Fig. 18. Relations in broiler supply.



Prices are enclosed inside of semicircular rectangles and quantities are enclosed inside of squares. Arrows show direction of influence. Demand and marketing relations are enclosed inside of dashed squares.

One characteristic feature of broiler production is its continuous nature. Over the past 3 decades, technological advance has allowed the production period to be reduced from about 100 days to less than 70 days. Broiler growers now produce three to six broods per year. The number of broilers can be adjusted to price change even within a year. If the calendar year is used as the production period, price and output would appear to be simultaneously determined. Hence, a simultan-

eous-equation approach seems appropriate in estimating broiler supply functions from annual data. (If time-series data were available for specific intrayear production periods, single-equation, least-squares methods would be appropriate.) To appropriately express simultaneity, the over-all model necessarily includes a demand equation.

An equation of consumers' demand for broilers, to be used for the simultaneous-equation approach, is as follows:

$$(51) \left[\frac{P_b}{L} \right] = f \left[\left[\frac{Q_b}{N} + 0.9 \frac{Q_c}{N} \right], \frac{I}{N}, F_c \right]$$

The variables in the model are:

(P_b/L) : Farm price of broilers for the current year deflated by the consumer price index (cents per pound).

(Q_b/N) : Per-capita output of broilers in the current year, liveweight (pounds).

(Q_c/N) : Per-capita output of farm chickens in the current year, liveweight (pounds).

(I/N) : Per-capita disposable income in the current year deflated by consumer price index (dollars).

F_c : Percentage of farmers' share in retail price of chickens for current year.

In the demand equation, per-capita output of broilers and per-capita production of farm chickens are aggregated into a single variable, as indicated in equation 51, because broilers and farm chickens are a homogeneous commodity for consumers after they are processed for the ready-to-cook meat. The farm price of broilers is about 10 percent higher than the farm price of farm chickens in terms of liveweight. This difference results from the difference between broilers and farm chickens in dressing efficiency and in the bargaining power between the specialized broiler growers and the farmers who keep small egg flocks. Accordingly, farm chickens are given a price weight 10 percent less than that of broilers in equation 51.

Per-capita disposable income is included in the demand equation as a standard variable which shifts demand. In representing the effect of the marketing mechanism on the farm price of broilers, the percentage of the farmers' share in retail price is included in the demand equation. The production of broilers is connected to consumption through the relations of marketing. It is possible to construct a large system of simultaneous equations, including various equations representing marketing relations. However, it is not the primary object of this study to analyze marketing relations. The formulation of a complex system of market relations not only increases the computational burden, but also usually results in estimates confounded by multicollinearity. Hence, the relation of demand and supply for broilers is formulated as a simple two-equation system represented in equations 50 and 51.

Model for Monthly Data

The model just presented is for analysis of annual data. The short period of broiler production, however, requires analysis of monthly data. Monthly data of broiler chicks purchased by farmers have been reported since 1954. About 3 weeks are required for chicks to be delivered after a farmer orders them from hatcheries. Considering this time lag, the broiler-feed price ratio, the egg-feed price ratio of the previous

month and the technology index of broiler production are chosen as the variables affecting broiler production. The model for the broiler supply analysis of monthly data is:

$$(52) X_{b(m)} = f \left[\left[\frac{P_b}{P_f} \right]_{m-1}, \left[\frac{P_e}{P_f} \right]_{m-1}, R_{b(m)} \right]$$

The variables in this model are:

$(P_b/P_f)_{m-1}$: Broiler-feed price ratio of the previous month.

$(P_e/P_f)_{m-1}$: Egg-feed price ratio of the previous month.

$R_{b(m)}$: Technology index of broiler production of present month.

$X_{b(m)}$: Number of broiler chicks purchased in the present month (thousand).

Equation 52 can be regarded as a model of farmers' demand for broiler chicks. The farmers' demand for broiler chicks almost exclusively determines the supply of broilers 2 or 3 months later. The single-equation least-squares method is sufficient for estimating equation 52, because the prices which determine the number of broiler chicks to purchase are the prices of the previous month.

Least-Squares Estimates for Annual Data

Before proceeding to the simultaneous-equation approach, the relation of broiler supply is estimated by the single-equation, least-squares method. For 1935-58, the least-squares estimate of equation 50 is as follows where the period considered is a year:

$$(53) \log Q_b = -11.0858 + 0.9396 \log \left[\frac{P_b}{P_f} \right] \\ (0.7932) \\ + 0.2115 \log \left[\frac{P_b}{P_f} \right]_{t-1} + 1.1580 \log E_e \\ (0.8052) \quad (0.5992) \\ + 1.3217 \log E_{e(t-1)} + 5.5065 \log R_b \\ (0.5460) \quad (0.7033)$$

$$R^2 = 0.9527$$

The coefficients of $\log (P_b/P_f)$ and $\log (P_b/P_f)_{t-1}$ have signs consistent with theory but are significant only at low probability levels. The coefficient of $\log (P_b/P_f)$ has a positive value larger than that of $\log (P_b/P_f)_{t-1}$, suggesting that farmers adjust broiler production more in response to the price of the present year than to the price of the previous year. The statistical evidence is not strong, however, considering the low value of the regression coefficients relative to their standard errors.

The coefficients of $\log E_e$ and $\log E_{e(t-1)}$ have positive values, contradicting the hypothesis that the egg enterprise competes strongly with broilers. The positive signs in these coefficients must be caused by the positive correlation between the output of eggs and the egg profitability index throughout the business cycle. The coefficient of

$\log R_b$, has a large positive value which is highly significant. This confirms our *a priori* knowledge that technological progress is a major factor contributing to the miraculous growth of broiler production.

Since the effect of egg profitability on broiler production is not proved to be statistically meaningful, the model is simplified by dropping E_e and $E_{e(t-1)}$ from the equation. The results for the simplified model are:

$$(54) \log Q_b = -8.2756 + 1.4925 \log \left(\frac{P_b}{P_f} \right) + 0.3802 \log \left(\frac{P_b}{P_f} \right)_{t-1} + 7.1406 \log R_b$$

(0.8515) (0.5516)

$R^2 = 0.9268 \quad d = 0.45$

In this equation, all coefficients are consistent in sign with theory, but the coefficient of $\log (P_b/P_f)_{(t-1)}$ is extremely small relative to its standard error. The relative production costs of broilers have been reduced consistently as the technology of broiler production has advanced. The total output of broilers has increased almost continuously since 1934, the increase in the efficiency of production evidently offsetting the effect of price declines in the years of unfavorable markets. Other possible causes of price coefficients with low statistical significance are the simultaneous bias in the least-squares estimates and the bias resulting from the serial correlation in the residuals. The possibility of simultaneous bias is examined later with the simultaneous-equation model. The d-statistic indicates that the residuals of equation 54 are serially correlated. As we see in fig. 19, equation 54 consistently underestimates the total output for the period 1939-45. This underestimation of the total output again must be caused by the optimistic price expectations of farmers during the war years. On the other hand, the change in the price elasticity of supply resulting from technological progress might have caused the overestimation in recent years. The effect of tech-

nological progress on the elasticity is examined in the following section.

For the sake of comparison, a model which substitutes time, t , with $t=1$ at 1935, for the technology index of broiler production is estimated.

$$(55) \log Q_b = 3.0342 - 0.8898 \log \left(\frac{P_b}{P_f} \right) - 0.7447 \log \left(\frac{P_b}{P_f} \right)_{t-1} + 1.1860 \log t$$

(0.5963) (0.6579) (0.0679)

$R^2 = 0.9171 \quad d = 0.64$

In comparing equations 55 and 54, there is little difference in the values of R^2 and the d-statistic. But the coefficients of $\log (P_b/P_f)$ and $\log (P_b/P_f)_{t-1}$ in equation 55 are negative in sign and inconsistent with theory. On this basis, the use of the technology index appears preferable to the use of the time variable.

A model with the lagged value of total output included as an additional variable is estimated to obtain the long-run elasticities:

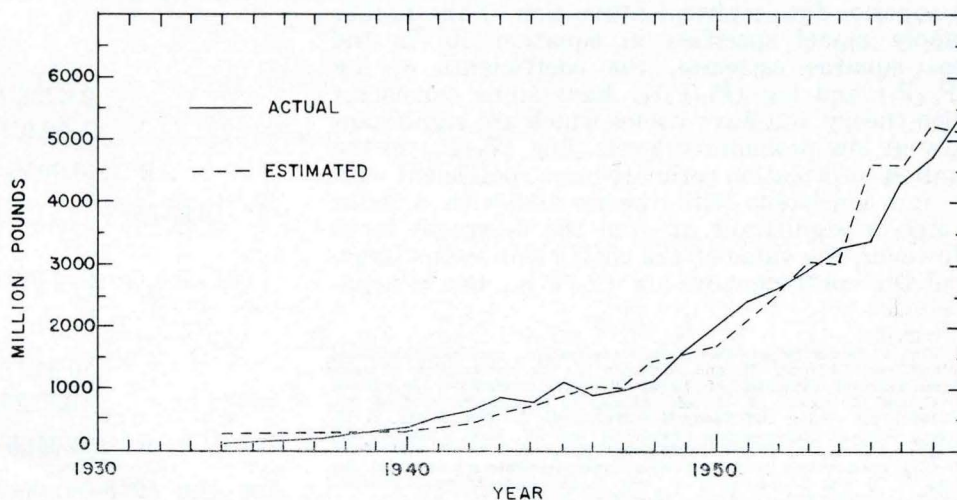
$$(56) \log Q_b = 0.7145 - 0.3914 \log \left(\frac{P_b}{P_f} \right) + 0.0440 \log \left(\frac{P_b}{P_f} \right)_{t-1} - 0.1991 \log R_b + 0.9619 \log Q_{b(t-1)}$$

(0.3521) (0.3181) (0.6728) (0.0841)

$R^2 = 0.9907 \quad d = 2.31$

The results of estimation in equation 56 seem meaningless because the coefficient of $\log R_b$ has a negative value. Technological progress is a basic factor which has caused rapid growth of broiler production. A negative coefficient for $\log R_b$ would indicate that total output has decreased as technology has advanced. The nonsensical esti-

Fig. 19. Quantity of broilers produced (liveweight), values of actual observations and estimated values from equation 54.



mate for the technology index shows the inapplicability of the Koyck-Nerlove model to the case in which a dependent variable is increasing or decreasing consistently. In the case of broiler supply, the total output has increased consistently, except for minor setbacks in 1944 and 1946. The positive correlation between the total output of broilers and its lagged value is so high that the lagged value of the total output takes over the upward trend in the technology index in the statistical estimation.

Simultaneous-Equation Estimates for Annual Data

Simultaneous-equation estimation of broiler supply from annual data is suggested, since the price and output of broilers can be simultaneously determined within a year. The model to be used is the system of two equations: equation 50 with E_c and $E_{c(t-1)}$ dropped for supply and equation 51 for demand. The limited-information, maximum-likelihood method¹⁶ is used for estimating these two equations.

The results of estimation for 1935-58 annual data are these:

Supply Equation

$$(57) \log Q_b = -11.7960 + 7.3182 \log \left(\frac{P_b}{P_f} \right) - 3.8503 \log \left(\frac{P_b}{P_f} \right)_{t-1} + 8.8600 \log R_b$$

(2.9219) (2.3939) (1.2429)

Demand Equation

$$(58) \log \left(\frac{P_b}{L} \right) = 4.2331 - 0.2848 \log \left(\frac{Q_b}{N} + 0.9 \frac{Q_c}{N} \right) - 1.6295 \log \left(\frac{I}{N} \right) + 1.5453 \log F_c$$

(0.0964) (0.4122) (0.1655)

In comparing the results of estimation in equation 57 with the results in equation 54, it is difficult to determine whether the least-squares or the limited-information, maximum-likelihood method is superior for empirical estimation of the broiler supply model specified in equation 50. In the least-squares estimate, the coefficients of $\log (P_b/P_f)$ and $\log (P_b/P_f)_{t-1}$ have signs consistent with theory, but have values which are significant only at low probability levels. $\log (P_b/P_f)$ in the limited-information estimate has a coefficient with a sign consistent with theory and with a value which is significant at even the 5-percent level. However, the value of the coefficient seems large, and the coefficient of $\log (P_b/P_f)_{t-1}$ has a nega-

tive sign which contradicts theory. It is hard to determine why the coefficient of the latter becomes negative in the limited-information estimate. Multicollinearity between the exogenous variables in the system likely is the cause. Evidently estimation by the simultaneous-equation approach does not contribute appreciably to knowledge of broiler supply functions.

For the sake of comparison, the least-squares estimate of the demand equation is shown in equation 59.

$$(59) \log \left(\frac{P_b}{L} \right) = 0.0301 - 0.0238 \log \left(\frac{Q_b}{N} + 0.9 \frac{Q_c}{N} \right) - 0.3792 \log \left(\frac{I}{N} \right) + 1.447 \log F_c$$

(0.1061) (0.4432) (0.1414)

$$R^2 = 0.8880$$

In comparing the empirical estimates in equation 58 with the results in equation 59, the limited-information method seems superior for the analysis of broiler demand. In both equations, the coefficients of per-capita output of chickens and of farmers' share of the retail price of farm chickens have signs consistent with theory, but the coefficients of per-capita income have negative signs which contradict theory. In limited-information estimation, however, the coefficient for per-capita output of chickens is statistically significant at the 1-percent level.

Evaluation of Structural Change With Annual Data

To evaluate possible change in broiler supply structure, supply analysis is conducted separately for two divided periods: 1935-46 and 1947-58. Considering the short series of data, the war years are not excluded.

The least-squares estimates of broiler supply functions for these two periods are:

1935-46

$$(60) \log Q_b = -16.8371 - 0.2080 \log \left(\frac{P_b}{P_f} \right) - 2.6733 \log \left(\frac{P_b}{P_f} \right)_{t-1} + 16.3584 \log R_b$$

(1.4519) (1.4046) (2.3508)

$$R^2 = 0.9055 \quad d = 0.95$$

1947-58

$$(61) \log Q_b = -3.7252 - 0.0684 \log \left(\frac{P_b}{P_f} \right) + 0.3127 \log \left(\frac{P_b}{P_f} \right)_{t-1} + 4.7807 \log R_b$$

(0.8251) (0.3127) (1.9297)

$$R^2 = 0.9505 \quad d = 0.49$$

For the 1935-46 period, the coefficients of log

¹⁶ For a discussion of the limited-information, maximum-likelihood method, see: Chernoff, H. and Divinsky, N. The computation of maximum-likelihood estimates of linear structural equations. In: Hood, W. C. and Koopmans, T. C., eds. Studies in econometric method. pp. 112-199. John Wiley and Sons, New York, N. Y. 1953; Klein, L. R. A text book of econometrics. Chaps. III and IV. Row, Peterson and Company, Evanston, Illinois. 1956; and Koopmans, T. C. and Hood, W. C. The estimation of simultaneous linear economic relationships. In: Hood, W. C. and Koopmans, T. C., eds. Studies in econometric method. pp. 112-199. John Wiley and Sons, New York, N. Y. 1953.

(P_b/P_f) and $\log (P_b/P_f)_{t-1}$ are negative in sign. During this period, growth of broiler production increased rapidly, by 800 percent. The upward trend in the total output resulting from technological improvement is so great that it dominates the effects of prices. Consequently, the regression of output on the broiler-feed price ratio is negative.

The same explanation undoubtedly applies for the negative coefficient of $\log (P_b/P_f)$ in the 1947-58 estimate. Too, multicollinearity between $\log (P_b/P_f)$ and $\log (P_b/P_f)_{t-1}$, brought about by the downward trend in broiler price since 1950 while output has continued to increase because of technical improvement, is another cause for the negative sign. From the estimates for 1935-46 and 1947-58 separately, it is difficult to determine whether the supply elasticity because of price had changed; the price coefficients are meaningless in sign and statistically nonsignificant.

To test separately whether technological progress has had important influence on the farmers' response to price, a model with nonlinear coefficients is estimated for 1935-58:

$$(62) \log Q_b = -17.2010 + 5.7630 \log \left(\frac{P_b}{P_f} \right) \\ (4.0800) \\ + 13.6848 \log R_b - 0.1675 \left[R_b \log \left(\frac{P_b}{P_f} \right) \right] \\ (6.6383) \quad (0.1689) \\ R^2 = 0.9296 \quad d = 0.44$$

In this estimate, the coefficients are nonsignificant at the 5-percent level except for the coefficient of $\log R_b$. Judging from the d-statistic, equation 62 gives no improvement in serial correlation of residuals over equation 54. Technological change apparently is not the major factor causing the serial correlation of residuals in equation 54. Outputs estimated from equation 62 are plotted in fig. 20 for comparison with fig. 19 and equation 54.

We now transform equation 62 into the form with a nonlinear coefficient for $\log (P_b/P_f)$:

$$(63) \log Q_b = -17.2010 + (5.7630 \\ - 0.1675 R_b) \log \left(\frac{P_b}{P_f} \right) + 13.6848 \log R_b$$

The nonlinear coefficient in equation 63 indicates that elasticity of broiler output with respect to (P_b/P_f) decreased by 0.1675 for a unit increase in the technology index of broiler production. However, the coefficient for the interaction term in equation 62 is not large relative to the magnitude of its standard error.

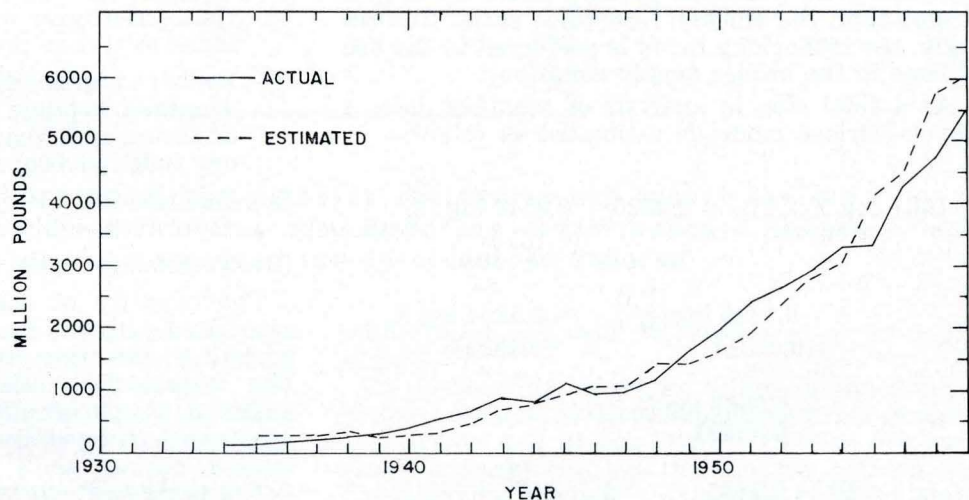
From the statistical estimates analyzed, we are only able to say that technological progress has shifted the broiler supply function upward. Any effect which it has had on the elasticity of supply must be weak. Technological progress might have increased or decreased the price elasticity of broiler supply. But the effect of the change on elasticity is relatively small so that it is overshadowed by the shift *per se* in the supply curve.

Least-Squares Analysis of Monthly Data for Broilers

We now turn to estimation of broiler supply from monthly data. The model of equation 52 is estimated by least-squares from the data of 56 months from January 1955, through August 1959:

$$(64) \log X_{b(m)} = -3.2683 + 0.3998 \log \left(\frac{P_b}{P_f} \right)_{m-1} \\ (0.1412) \\ - 0.1121 \log \left(\frac{P_e}{P_f} \right)_{m-1} + 3.4241 \log R_{b(m)} \\ (0.0961) \quad (0.3789) \\ R^2 = 0.7109 \quad d = 0.58$$

Fig. 20. Quantity of broilers produced (liveweight), values of actual observations and estimated values from equation 62.



The coefficients of $\log (P_b/P_f)_{m-1}$ and $\log R_{b(m)}$ are significant at the 1-percent level and have signs consistent with theory. The coefficient of $\log (P_c/P_f)_{m-1}$, significant at the 30-percent level of probability, is negative in sign, indicating a competitive relation between eggs and broilers. The value of the d-statistic shows the positive serial correlation of residuals. Equation 64 tends to underestimate the output of broilers in the first half of the period and to overestimate it in the second half of the period. The price of broilers has been declining quite consistently since 1955, and the rate of increase in the output has slowed down but is still positive.

The effect of the broiler-feed price ratio on total output is statistically significant in regression for monthly data. (The effect of price on the output was overshadowed by the upward trend in the total output for the regression of annual data.) Equation 64 indicates that farmers adjust broiler output to price, although some bias in estimates is expected because of serial correlation in residuals.

To determine any advantage or disadvantage in use of the technology index, in the model using monthly data, time designated as m , with $m=1$ for January 1955, is substituted for the technology variable in the following regression equation:

$$(65) \log X_{b(m)} = 2.0533 + 0.1842 \log \left(\frac{P_b}{P_f} \right)_{m-1} \\ (0.1336) \\ -0.3096 \log \left(\frac{P_c}{P_f} \right)_{m-1} + 0.1962 \log m \\ (0.1015) \quad (0.0239) \\ R^2 = 0.6764 \quad d = 0.49$$

The R^2 value is lowered slightly by substituting time for the technology index. The coefficient of $\log (P_b/P_f)_{m-1}$ and its t value are reduced. On the other hand, the coefficient of $\log (P_c/P_f)_{m-1}$ becomes larger and statistically significant. However, it contradicts *a priori* knowledge that the egg-feed price ratio has greater effect on broiler output than the chicken-feed price ratio. Accordingly, the technology index is preferred to the use of time in the broiler supply equation.

As a final step in analysis of monthly data, a Koyck-Nerlove model is estimated as follows:

$$(66) \log X_{b(m)} = -2.3520 + 0.2517 \log \left(\frac{P_b}{P_f} \right)_{m-1} \\ (0.1510) \\ -0.1443 \log \left(\frac{P_c}{P_f} \right)_{m-1} + 2.8294 \log R_{b(m)} \\ (0.0931) \quad (0.4524) \\ + 0.0569 \log Q_{b(m-1)} \\ (0.0259) \\ R^2 = 0.7355 \quad d = 0.67$$

The long-run elasticities computed from equation 66 are: 0.2669 with respect to $(P_b/P_f)_{m-1}$ and -0.1530 with respect to $(P_c/P_f)_{m-1}$. There is very little difference between the values of the short-run elasticities in equation 64 and the values of the long-run elasticities computed from equation 66. The values obtained from 66 probably underestimate the long-run elasticities. The coefficient for $\log Q_{b(m-1)}$ is extremely small for time series of the nature analyzed. This is the reversal of the outcome in estimation of the long-run elasticities obtained from the annual data. The continuous upward trend in the technology index again dominates the effects of the lagged output variable. With the coefficient of adjustment being overestimated, the long-run elasticities are probably too small, and the model has little efficacy in broiler supply analysis.

EMPIRICAL ANALYSIS: TURKEYS

This section includes empirical analysis of turkey supply functions. The relationships in turkey supply are indicated by block diagram in fig. 21. A model somewhat paralleling fig. 21 is presented as equation 67 and later is used in quantitative estimation of the turkey supply function.

$$(67) Q_T = f \left[\left(\frac{P_T}{P_f} \right)'_{t-1}, \left(\frac{P_T}{P_f} \right), \left(\frac{P_f}{A} \right)', E_c, E_b, R_T \right]$$

The variables in the model are:

- $\left(\frac{P_T}{P_f} \right)'_{t-1}$: Turkey-feed price ratio, average for October-December of the previous year.
- $\left(\frac{P_T}{P_f} \right)$: Turkey-feed price ratio, year average for the current year.
- $\left(\frac{P_f}{A} \right)'$: Poultry ration cost per 100 pounds, average for January-June of the current year, deflated by agricultural price index (dollars).

E_c : Egg profitability index, November-May weighted average of egg-feed price ratio of the current year multiplied by the technology index of turkey production.

E_b : Broiler profitability index, November-May weighted average of broiler-feed price ratio of the current year multiplied by the technology index of broiler production.

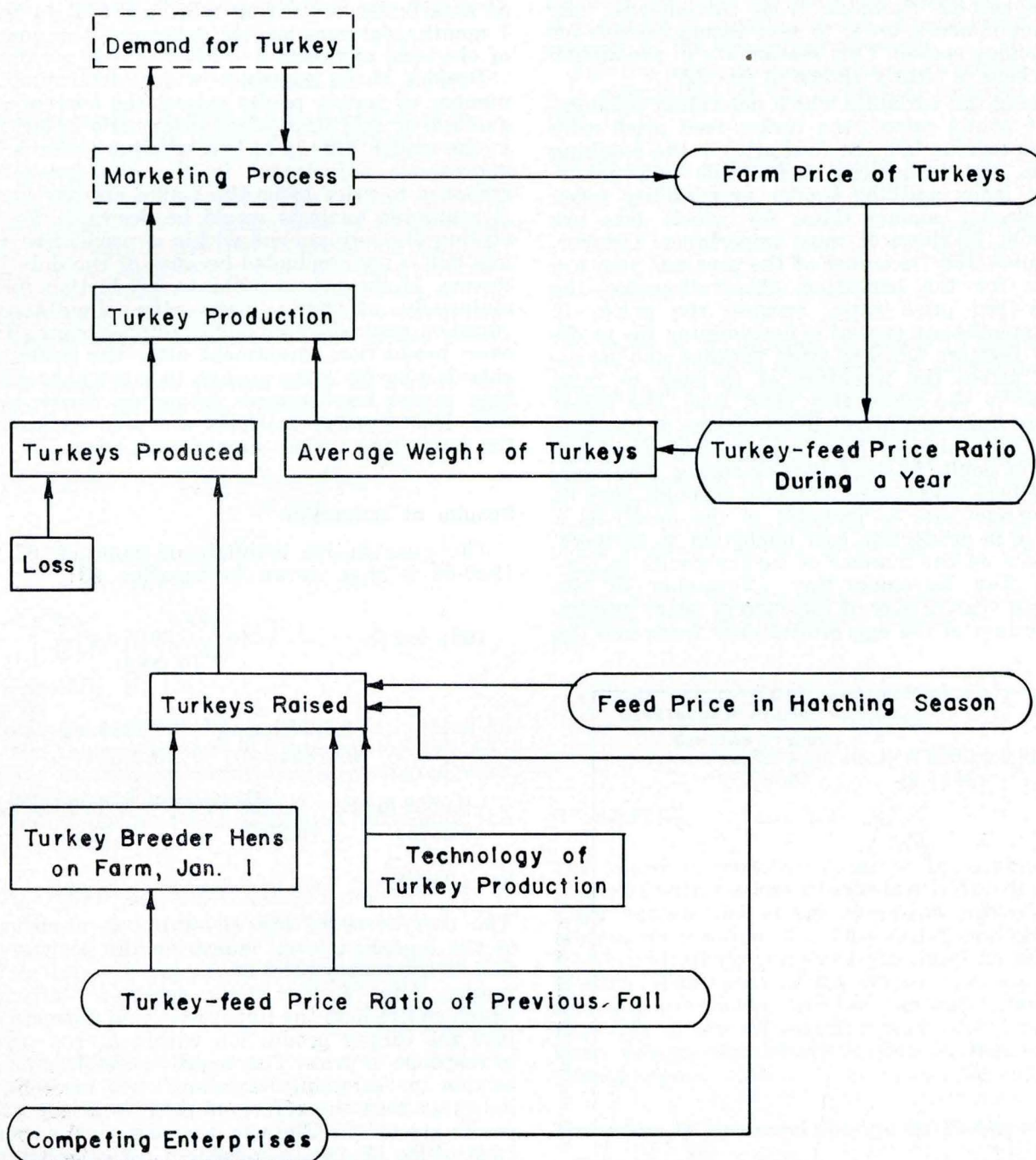
Q_T : Quantity of turkeys produced in the current year, liveweight (million pounds).

R_T : Technology index of turkey production.

The quantity of turkeys produced is directly associated with the factors which are deemed important in affecting the raising of turkey poults. The intermediate relations of fig. 21 are not analyzed, partly because of the nature of turkey production and partly because of the data limitations.

The turkey enterprise is a single-product enter-

Fig. 21. Relations in turkey supply.



Prices are enclosed inside of semicircular rectangles and quantities are enclosed inside of squares. Arrows show direction of influence. Demand and marketing relations are enclosed inside of dashed squares.

prise like broilers. Once farmers purchase a certain number of poults, they can do little to adjust output, except through marketing weight. Adjustment of output through feeding and other care is more difficult in turkey production than in broiler production and, when compared with the adjustments made through the number of

poults purchased, can be considered to be negligible.

In contrast to broilers, turkey production is seasonal because of the seasonal pattern of demand for turkeys and of egg-laying. Turkeys are consumed mainly during the holiday season — Thanksgiving through Christmas. Farmers start

raising poults during the spring months, when poults become available from current-year egg production and in order to have them available for the holiday season. This seasonality in production of turkeys is clearly shown in fig. 22.

Among the variables which determine the number of poults raised, the turkey-feed price ratio in the previous fall, the feed price in the hatching season, the technology index, the egg profitability index and the broiler profitability index are selected, among those for which data are available, as those of most importance. October, November and December of the previous year are chosen for the period of observation for the turkey-feed price ratio, because the prices in these months are crucial in determining the profit which farmers can get from turkeys and necessarily affect the intention of farmers to raise turkeys in the succeeding year. Also, the prices in these 3 months affect the decisions of hatcheries to keep breeder hens and, hence, affect the prices of poults in the following spring. The average of feed prices from January through June of the current year is included in the model as a variable in production cost important to farmers' decisions on the number of turkey poults to purchase. The November-May (November of the previous year to May of the current year) weighted averages of the egg profitability index and the

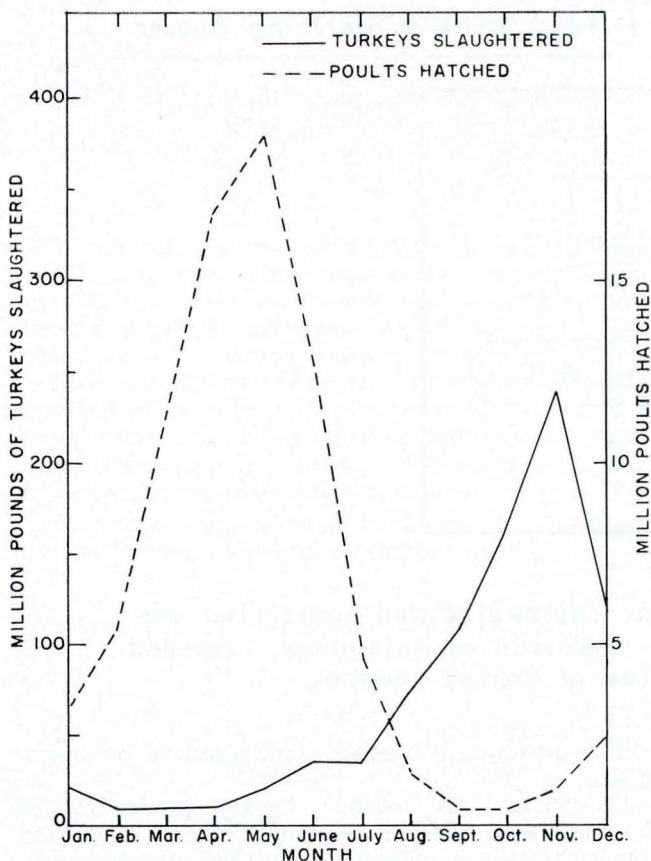


Fig. 22. Seasonal movements in poultry hatching and turkey slaughter, 1955-57 average.

broiler profitability index are used as the variables of enterprises competing with turkeys. In those 7 months, farmers largely determine the number of chickens to raise.

Besides those variables which determine the number of turkey poults raised, the current-year average of the turkey-feed price ratio is included in the model. This is to test whether there is any appreciable adjustment in the total output in response to price after the poults are purchased. A multistep analysis would be desirable for analyzing the adjustment within a production period, but is not conducted because of the data limitation. If the prices within a production period materially affected output, the simultaneous-equation method would be most appropriate. However, production adjustment after the poults are raised is hardly large enough to cause appreciable bias in the least-squares estimates. Single-equation, least-squares methods are used exclusively for estimating turkey supply functions.

Results of Estimation

The quantitative estimate of equation 67 for 1930-58 is that shown in equation 68:

$$(68) \log Q_T = -1.3680 + 0.3916 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \quad (0.1783)$$

$$-0.2203 \log \left(\frac{P_T}{P_f} \right) - 0.3387 \log \left(\frac{P_f}{A} \right)' \quad (0.1780) \quad (0.2981)$$

$$-0.0558 \log E_a - 0.1826 \log E_b + 3.7929 \log R_T \quad (0.2375) \quad (0.2078) \quad (0.3450)$$

$$R^2 = 0.9694$$

The coefficient of $\log (P_T/P_f)'_{t-1}$ is significant at the 5-percent level, indicating the positive effect of the turkey price of the previous fall on the output. $\log (P_T/P_f)$ has a negative coefficient which contradicts the hypothesis that farmers adjust the turkey production within a crop period in response to price. The negative coefficient may be due to "sampling variation," but more likely indicates that the effect of price is minor after poults are raised. The negative sign in the coefficient of $\log (P_f/A)'$ is consistent with the hypothesis that farmers reduce the number of turkeys when the feed price is high and increase it when the feed price is low. The negative coefficients of $\log E_a$ and $\log E_b$ would indicate that, as profitability of the competitive enterprises increases, turkey production decreases. However, the standard error for the coefficient of $\log E_b$ is large relative to the magnitude of the coefficient itself. The coefficient of $\log R_T$ is highly significant, again indicating the positive effect of technological progress on turkey production.

To evaluate the effects of the competitive enterprises more clearly by removing possible multi-

collinearity, the turkey supply function is estimated after (P_T/P_f) and $(P_f/A)'$ are dropped:

$$(69) \log Q_T = -1.9933 + 0.3514 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.1481) \\ + 0.0352 \log E_e - 0.2195 \log E_b + 4.0114 \log R_T \\ (0.2310) \quad (0.1880) \quad (0.3174)$$

$R^2 = 0.9658$

In this estimate, the coefficient of $\log E_b$ is increased relative to the magnitude of its standard error. The sign of the coefficient of $\log E_e$, however, is now negative. In general terms, the statistics fail to quantify, with definiteness at the national level, the competitive effect between the egg and broiler enterprises and the turkey enterprise.

The model is recomputed after E_e and E_b are dropped to examine the effects of (P_T/P_f) and $(P_f/A)'$:

$$(70) \log Q_T = -1.5740 + 0.3519 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.1502) \\ - 0.2627 \log \left(\frac{P_T}{P_f} \right) - 0.2674 \log \left(\frac{P_f}{A} \right)' \\ (0.1572) \quad (0.2818) \\ + 3.5951 \log R_T \\ (0.2420)$$

$R^2 = 0.9682$

No improvement in this estimate is created in the coefficients of $\log (P_T/P_f)$ and $\log (P_f/A)'$, relative to their standard errors, compared with the estimate of equation 68.

Finally, the model is estimated with only the two variables:

$$(71) \log Q_T = -2.0902 + 0.2861 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.1106) \\ + 0.38268 \log R_T \\ (0.1557)$$

$R^2 = 0.9639$ $d = 0.72$

In this estimate, the coefficients of both independent variables have values significant at the 5-percent level and have signs consistent with theory. The d-statistic, however, indicates serial correlation in the residuals. Figure 23 shows that equation 71 underestimates the output of turkeys for 1936-42 and overestimates it for 1955-58. In the years from the great depression through the start of World War II, the level of turkey price was generally low, but the technology of turkey production advanced rapidly during this period. The unusually large elasticity of turkey supply with respect to R_T in this period causes the consistent underestimation of output for 1936-42. Since 1954, the turkey price has been declining consistently. This declining price must have made the farmers' price expectation pessimistic and resulted in the reduction in the price elasticity of

turkey supply. This is likely the cause of overestimation for 1955-58. Thus, the serial correlation of residuals in equation 71 can be explained by the changes in the elasticities of supply.

For the sake of comparison, the variable time, t , is substituted for the technology index in equation 72.

$$(72) \log Q_T = 1.9706 + 0.0186 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.1923) \\ + 0.6976 \log t \\ (0.0537)$$

$R^2 = 0.8830$ $d = 0.45$

The value of R^2 declines by about 10 percent as the time variable in equation 72 is substituted for the technology variable in equation 71. Also, the value of the coefficient for $\log (P_T/P_f)'_{t-1}$ becomes statistically nonsignificant in equation 72. The d-statistic indicates that serial correlation is high in equation 72. Equation 71 appears superior to equation 72 in estimating the turkey supply function. As for eggs and broilers, the technology index evidently has an advantage over the time variable.

The Koyck-Nerlove model is used to allow estimation of long-run supply elasticities for turkeys:

$$(73) \log Q_T = -1.2908 + 0.3462 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.0908) \\ + 1.8264 \log R_T + 0.5592 \log Q_{T(t-1)} \\ (0.5360) \quad (0.1456)$$

$R^2 = 0.9773$ $d = 1.36$

The long-run elasticity obtained by equation 73 is 0.7854 with respect to $(P_T/P_f)'_{t-1}$. This value is about double that of the short-run elasticity estimated in equation 71. This difference between long-run elasticity and short-run elasticity appears realistic. The value of the long-run elasticity is also fairly reliable because the coefficients in equation 73 are all significant at the 1-percent level, though the d-statistic falls in the indeterminate region.

Evaluation of Structural Change for Turkeys

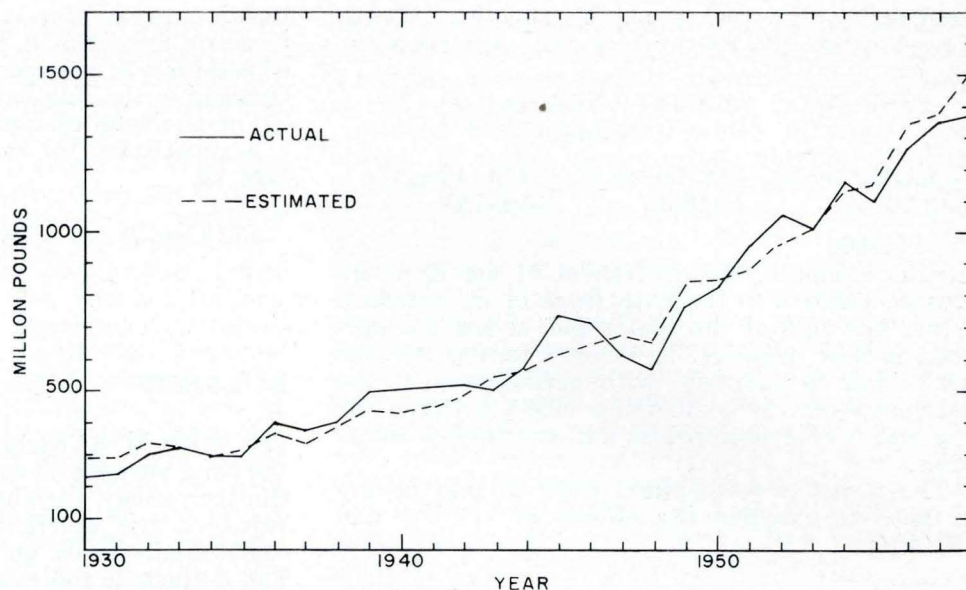
To determine whether change has occurred in the supply elasticity, the turkey supply model is estimated for two separate periods: 1930-41 and 1942-58. The results of estimation are:

1930-41

$$(74) \log Q_E = -4.8424 + 0.2616 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.0871) \\ + 6.2739 \log R_T \\ (0.4377)$$

$R^2 = 0.9582$ $d = 1.64$

Fig. 23. Quantity of turkeys produced (liveweight), values of actual observations and estimated values from equation 71.



1942-58

$$(75) \log Q_E = -2.1619 + 0.4103 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.1742) \\ + 3.7852 \log R_T \\ (0.3252)$$

$$R^2 = 0.9401 \quad d = 1.29$$

The coefficient of $\log (P_T/P_f)'_{t-1}$ is significant at the 5-percent level in the estimate for 1930-41. In the estimate for 1942-58, it is significant at the 1-percent level. In both estimates, the coefficients of $\log R_T$ are significant at the 1-percent level. The d-statistic for 1930-41 rejects the hypothesis of serial correlation of residuals at the 5-percent level, and the value for 1942-58 falls in the indeterminate range.

By comparing these two estimates, the supply elasticity with respect to $(P_T/P_f)'_{t-1}$ for 1930-41 is appreciably smaller than for 1942-58. This change is in contrast to that for the egg supply elasticity. For eggs, the price elasticity was larger in the prewar years than in the postwar years. A possible explanation for the growth in price elasticity for turkey supply is: Turkey growers tend to be more price-conscious and adjust output more between years, in response to price change, as the turkey enterprise becomes more specialized and commercialized. But why has this specialization tendency not affected the elasticity of egg supply in the same direction?

An answer to this question might be as follows: Two forces in specialization of an enterprise influence the price elasticity of supply in opposite directions. Specialization with greater fixed investment makes it more difficult for farmers to enter into or drop from production as prices vary between years. On the other hand, as the operation of an enterprise becomes larger in scale and more commercialized, farmers become more price-

conscious. Small producers with less flexible supplementary enterprises represent a smaller portion of the industry aggregate. In turkey production, specialization started earlier than for egg production. Turkeys were raised almost exclusively by specialized turkey growers as early as 1945. Even today, however, the major portion of United States egg production comes from nonspecialized farms where other enterprises dominate laying flocks in total returns.

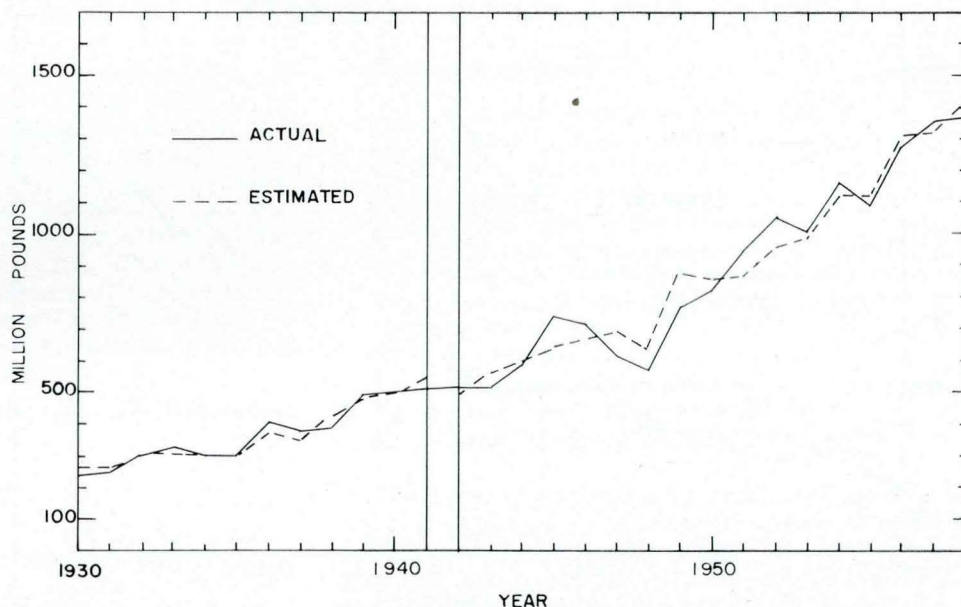
In contrast to the change in the elasticity with respect to $(P_T/P_f)'_{t-1}$, the elasticity of turkey supply with respect to R_T declined in the second period. Evidently farmers responded to technological progress at a faster rate in the period 1930-41 than in the period 1942-58. The reduction in the serial correlation of residuals in the estimates for the divided periods, corresponding to the difference in the elasticity with respect to R_T between the two periods, supports the previous argument; namely, that the major cause for the serial correlation in the residuals of equation 71 is the change in the elasticity with respect to R_T . Consistent overestimation or underestimation is not indicated in fig. 24.

For the two subperiods above, the intrawar years are included in the last period under the assumption that the war did not greatly disturb the normal turkey supply relations. It might be suspected, however, that the war years inflate the price elasticity of turkey supply for the entire 1942-58 period. To test this hypothesis, the supply model of turkeys is estimated for 1947-58, excluding the war years:

$$(76) \log Q_T = -2.6440 + 0.3937 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ (0.1604) \\ + 4.1751 \log R_T \\ (0.3692)$$

$$R^2 = 0.9447 \quad d = 0.74$$

Fig. 24. Quantity of turkeys produced (liveweight), values of actual observations and estimated values from equations 74 and 75.



No appreciable difference exists between the elasticity estimate for this period and the estimate for the entire 1942-58 period. The hypothesis that the normal relation of turkey supply was not much disturbed by war influences appears acceptable, and these years are included in further analysis.

To obtain the long-run elasticities for the divided periods, the Koyck-Nerlove model is estimated:

1930-41

$$(77) \log Q_T = -4.3071 + 0.2859 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ + 5.4548 \log R_T + 0.1471 \log Q_{T(t-1)} \\ (0.1020) \quad (1.6311) \quad (0.2813) \\ R^2 = 0.9596 \quad d = 1.52$$

1942-58

$$(78) \log Q_T = -1.9348 + 0.4844 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ + 2.5831 \log R_T + 0.4101 \log Q_{T(t-1)} \\ (0.1644) \quad (0.6959) \quad (0.2145) \\ R^2 = 0.9532 \quad d = 1.85$$

The results for these equations are quite positive. Regression coefficients for price and technology indexes are significant at levels of probability acceptable for time-series data. Signs of coefficients are logically consistent, and over 95 percent of the variance in poultry production is explained by each equation. But again, as in the previous applications of the long-run model, the coefficients for lagged output, $Q_{T(t-1)}$, are not significant.

The long-run elasticities with respects to $(P_T/P_f)'_{t-1}$ obtained from these estimates are: 0.3352

for 1930-41 and 0.8212 for 1942-58. The long-run elasticity seems decisively larger in the period 1942-58 than in the period 1930-41. However, since the coefficients of $\log Q_{T(t-1)}$ are extremely small relative to their standard errors in the estimates for both periods, the values of the long-run elasticities are not highly reliable.

Finally, to test whether technological progress per se has had an effect on the price elasticity of turkey supply, the model with a nonlinear price coefficient is estimated for 1930-58:

$$(79) \log Q_T = -1.6894 + 0.1403 \log \left(\frac{P_T}{P_f} \right)'_{t-1} \\ + 3.4832 \log R_T + 0.0099 \left[R_T \log \left(\frac{P_T}{P_f} \right)'_{t-1} \right] \\ (1.0386) \quad (2.4387) \\ R^2 = 0.9639 \quad d = 0.76$$

Equation 79 is now transformed into the form of a nonlinear price coefficient:

$$(80) \log Q_T = -1.6894 + (0.1403 + 0.0099 R_T) \log \left(\frac{P_T}{P_f} \right)'_{t-1} + 3.4832 \log R_T$$

The nonlinear coefficient shows that the elasticity with respect to $(P_T/P_f)'_{t-1}$ increases by 0.0099 for a unit increase of R_T , the variable of technological progress. The positive association between the price elasticity and technological change conforms to the separate estimates for the divided periods. Since the coefficient of the interaction term is not significant in equation 79, the statistical evidence from equation 80 would appear weak. In table 10 the values obtained from the separate periods are compared with those for

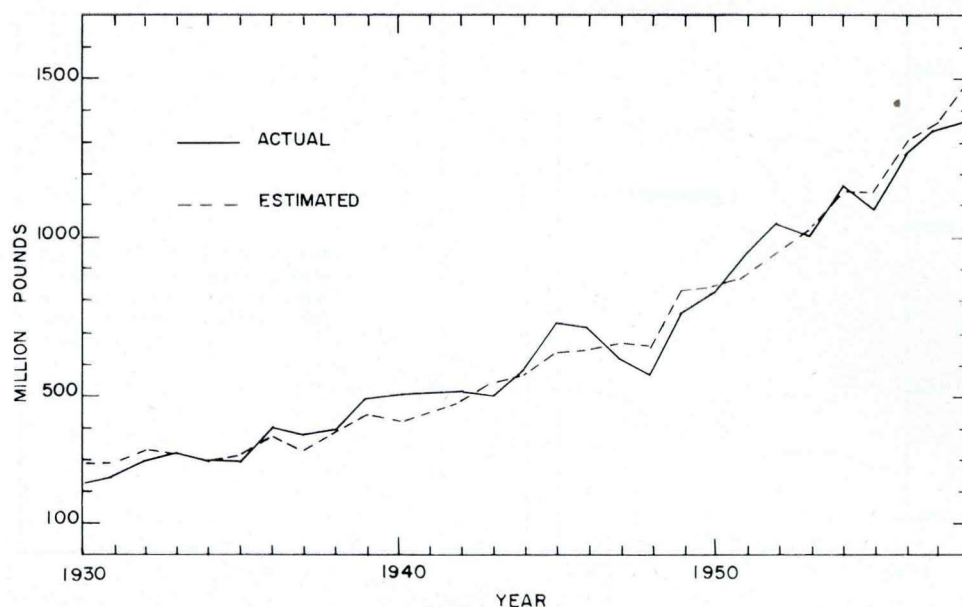


Fig. 25. Quantity of turkeys produced (liveweight), values of actual observations and estimated values from equation 79.

equation 80. The average elasticities computed from equation 80 are very close to the values estimated separately for the subperiod 1930-41 and for the total period 1930-58. But for the subperiod 1942-58, the value computed from equation 80 is appreciably smaller than the separately estimated value. Also, by comparing fig. 25 with fig. 24, it is seen that the model of non-linear coefficient does not improve predictions of turkey output.

Table 10. Supply elasticity of turkeys with respect to $(P_T/P_t)'_{t-1}$ for subperiods.

Subperiod	Average of the technology index for the period	Supply elasticity of turkeys with respect to $(P_T/P_t)'_{t-1}$	
		Computed from equation 80	Estimated separately for each period ^a
1930-41	13.67	0.2758	0.2616
1942-58	17.40	0.3125	0.4103
1930-58	15.86	0.2973	0.2861

^a From equations 77 and 78.

APPENDIX

The possible simultaneous determination of prices and quantities in the culling relations of hens and pullets was discussed in the text. It was suggested that simultaneity was probably not great enough to cause appreciable bias in least-squares estimates of culling relations. Nevertheless, since the possibility of simultaneity exists, regression equations also were generated by simultaneous-equations methods, to serve as a basis of comparison with least-squares estimates. The system of simultaneous equations projected for this analysis was as follows:

(1) Layers (mature birds) sold and consumed on farms

$$X_m = f \left[\frac{P_e}{P_f}, \frac{P_c}{P_f}, X_h \right]$$

(2) Pullets sold and consumed on farms

$$X_r = f \left[\frac{P_e}{P_f}, \frac{P_c}{P_f}, X_p \right]$$

(3) Counting relation of young farm chickens produced

$$X_y = X_k + X_{nh} - X_d + X_r$$

(4) Total output of farm chickens

$$q_c = X_y W_y + X_m W_m$$

(5) Counting relation of average number of hens on farms

$$X_L = X_h + X_p - X_m + X_R$$

(6) Total egg output

$$q_e = X_L \cdot R_e$$

(7) Demand for eggs

$$\frac{P_e}{L} = f \left[\frac{q_e}{N}, \frac{I}{N}, F_e \right]$$

(8) Demand for farm chickens

$$\frac{P_c}{L} = f \left[\frac{q_c}{N}, \frac{q_e}{N}, \frac{I}{N}, F_c \right]$$

The variables indicated in these equations are as follows where all quantities refer to the same year; namely, the current year in which egg output is measured:

Endogenous Variables

- P_e : farm price of eggs
- P_c : farm price of chickens
- q_e : quantity of eggs produced
- q_c : quantity of chickens produced
- X_m : mature birds (layers) culled
- X_r : pullets culled
- X_y : young chickens sold and consumed on farms
- X_L : average number of layers on farms
- P_f : price of poultry feed

Predetermined Variables

- X_h : hens and pullets on farms, Jan. 1
- X_p : pullets raised
- X_{nh} : cockerels on farms, Jan. 1
- X_k : cockerels raised
- X_d : death loss, young chickens
- X_R : residual, average number of layers
- W_y : average liveweight, young birds
- W_m : average liveweight, mature birds
- R_e : eggs per layer
- N : population
- L : consumer price index
- F_e : farm share of egg retail price
- F_c : farm share of chicken retail price

The logic of the equations was explained in the text. In principle, the form of the demand equation parallels that for broilers. The farmers' share of egg and chicken retail price is included to reflect market mechanisms. Among eight equations in the system, equations 1, 2, 7 and 8 are equations to be estimated (i.e., are not equations of identity). All equations are linear in original observations, for consistency with the identity equations. The limited-information method has been used in estimation, because all equations are over-identified.

Equations estimated by least-squares and presented in the text are those with observations converted to logarithms. To provide parallel observations with the limited-information estimates, equations 1, 2, 7 and 8 have been estimated by least-squares methods with linear equations for original observations.

The least-squares estimates for hen-culling provide coefficients which have signs consistent with theory and which are highly significant. In comparison, the coefficients for the limited-information equation are smaller, and the standard errors are relatively larger, with none of the price coefficients being significant. Both methods of estimation indicate that the variable for hens on farms on Jan. 1 strongly dominates predictions of mature birds culled.

In the pullet-culling relations estimated by limited-information methods, the sign for the coefficient of P_e/P_f is negative and indicates that a higher price for eggs causes more pullets to be retained on farms. However, the sign for P_c/P_f in both the least-squares and limited-information equations estimates is inconsistent with theory. Since it is negative, it suggests that more chickens are held on farms as their price increases relative to feed price. When P_c/P_f is deleted in the limited-information estimate, the coefficient of P_e/P_f is increased in level of significance (as was true for the same step in the least-squares estimate where the sign also turned consistent with theory). Both least-squares and limited-information methods suggest that physical or health con-

ditions of birds and number of pullets raised are the important variables relating to number of pullets culled.

The estimates for egg demand were not reasonable for either least-squares or limited-information methods: The variable q_e/N has a positive sign in both sets of estimates while I/N has a negative coefficient in both. Several factors may cause these results: (1) the "scanty" system in which competing commodities are not included, (2) positive correlation over time in price of eggs and per-capita production of eggs, (3) the declining per-capita consumption of eggs, evidently because of the occupational and diet patterns of

the population and (4) the continuous decline in egg prices over the last 15 years, resulting particularly from improved technology.

Estimates for chicken demand differ considerably between least-squares and limited-information methods. The coefficient for per-capita production of chickens is significant at a higher level in the latter than in the former. Second, the coefficient of I/N is negative in the least-squares estimates, when chickens are not expected to be an inferior good. This variable has a positive sign for the limited-information estimates. However, F_e has a negative sign, probably because of multicollinearity, in the limited-information estimates.

Limited-Information (Linear, Original Observations)

- (1) Hen-culling

$$X_m = 68.1020 - 0.0182 \frac{P_e}{P_f} + 0.0073 \frac{P_c}{P_f} + 0.7514 X_n$$

(0.2337) (1.5835) (0.2170)

- (2) Pullet-culling

$$X_r = -107.4468 - 1.2974 \frac{P_e}{P_f} - 1.0593 \frac{P_c}{P_f} + 0.4619 X_p$$

(1.1965) (0.6863) (0.0208)

- (7) Demand for eggs

$$\frac{P_e}{L} = 3,634.3758 + 2.5022 \frac{q_e}{N} - 3.9217 \frac{I}{N} + 1.2050 F_e$$

(0.1068) (2.5806) (10.1191)

- (8) Demand for chickens

$$\frac{P_c}{L} = -1,049.5313 - 2.0747 \frac{q_c}{N} + 1.1 \frac{q_e}{N} + 0.9919 \frac{I}{N} - 0.2432 F_e$$

(0.8926) (2.1044) (0.3376)

Least-Squares (Linear, Original Observations)

(1) $X_m = 133.2039 - 12.1605 \frac{P_e}{P_f} + 12.7161 \frac{P_c}{P_f} + 0.6843 X_n$

(2.6280) (1.8007) (0.0794)

(2) $X_r = -113.2245 + 1.2594 \frac{P_e}{P_f} - 7.6822 \frac{P_c}{P_f} + 0.5217 X_p$

(2.1410) (1.3360) (0.0402)

$$X_r = 87.9341 - 4.4877 \frac{P_e}{P_f} + 0.4856 X_p$$

(2.8606) (0.0599)

(7) $\frac{P_e}{L} = -88.0350 + 0.1578 \frac{q_e}{N} - 0.0297 \frac{I}{N} + 1.6314 F_e$

(0.0161) (0.0031) (0.8205)

(8) $\frac{P_c}{L} = 3.0354 - 0.1625 \frac{q_c}{N} + 1.1 \frac{q_e}{N} - 0.0042 \frac{I}{N} + 0.4602 F_e$

(0.2170) (0.0058) (0.0053)