Poultry supply functions

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POULTRY SUPPLY FUNCTIONS

by

Yujiro Hayami

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I. INTRODUCTION

The study presented in this dissertation is a quantitative analysis of the farm supply relations of poultry products in the United States, and the variables which influence these relations.

Supply is one of the most basic concepts in economic theory. Supply, together with demand, determines a market equilibrium, toward which price and quantity tend to move. Without empirical knowledge of supply no one can say quantitatively how the price and quantity of a commodity will move. Obviously, it is necessary for anyone who is concerned with the movement of price and quantity of a commodity to know about the supply of that commodity.

There are several stages in the supply of a commodity—the supply at producers' level, at the wholesale level and the retail level. The analysis in this study is restricted purely to the supply of poultry products at the farm level, i.e., in what quantity farmers produce poultry products in response to the prices of those products. Marketing mechanisms from farm production to consumption are not included in the analysis.

Supply, the relation between the price offered for a commodity and the quantity of the commodity supplied, is influenced by related economic factors. In order to analyze supply relations in an actual economy, it is necessary to know how certain variables influence the supply relations. Therefore, the analysis of factors affecting the farm supply of poultry products such as production costs, competitive enterprises, etc. are included as an indispensable part of this study.
A. Poultry Industry in the United States

Poultry production is an important part of the United States agriculture. In value terms it comprises about 20 percent of total livestock production of the United States.

The poultry industry is composed of three major enterprises: (1) eggs with chicken meat as a by-product, (2) broilers and (3) turkeys. These three branches are distinctly independent operations. These enterprises are different not only in terms of final products, but also in terms of the patterns of production.

Egg production is carried on primarily as one of the enterprises of the family farm, though there is a tendency toward specialization. There is a distinct seasonality in egg production, due to the farmers' intention of making egg production conform to the operations of other enterprises.

Broiler production is the most specialized branch of the poultry industry. Geographically broiler growers are clustered in the South Atlantic region. Broiler production is highly commercialized, and continuous throughout the year like most industrial productions.

Turkey production started as a sideline of farm operation, but it is now highly specialized. The seasonality of production is strongest in the raising of turkeys. This, of course, is due to the seasonal demand for turkeys.

Due to differences in the final product and production pattern, each of the three major enterprises requires a separate analysis. Other poultry enterprises include the raising of ducks, geese, guineas, pigeons, quails and pheasants. However, these minor enterprises are negligible in terms of
the physical and value contribution to the total poultry production. Therefore, this analysis is not extended to these minor enterprises.

The poultry industry in this century has developed rapidly. During the period between 1925-29 and 1953-59, poultry production increased by 107 percent. In the same period the total agricultural production increased by 52 percent, and total livestock production, including poultry, increased by 59 percent. The rapid growth of poultry production can be seen in comparison to other livestock production in Fig. 1. The rate of growth of poultry production is twice as high as that of meat animals, and almost three times as high as that of dairy production.

The rates of growth differ among the enterprises of the poultry industry, as shown in Fig. 2. The production of eggs, which is the most important component of poultry production, increased at about the same rate as total poultry production. It nearly doubled during the period between 1925-29 and 1953-57. The development of the broiler enterprise is most remarkable. Starting at the negligible level of the mid-30's, the total output of broilers rose to more than five billion pounds of liveweight broilers in 1958. The increase in total output has been continuous, except in 1944 and 1946 when small decreases occurred. The total output doubled from 1935 to 1938; it doubled again by 1941; again by 1948; again by 1951; and then, again by 1958.

The upward trend in turkey production generally has been steady, though accompanied by minor fluctuations. The turkey output of 1953-57 was more than four times higher than that of 1930-35. Among the major poultry products only the output of farm chickens showed a decline. The output of farm chickens was fairly stable before World War II, increased rapidly dur-
Fig. 1. Index numbers of livestock output: poultry, meat animal and dairy (1947-49=100)
Fig. 2. Total poultry production, by products
ing the war and has been decreasing steadily since then.

The question is, what caused these rapid production developments in
the poultry industry? The increase in output must have been caused either
by the rise of the product price or the reduction of the production cost.
The price movements of major poultry products are shown in Fig. 3. There
is no indication that price levels have risen, except during the intra-war
period. The trends of product prices go appreciably downward after 1948.
It is not likely that the rise of prices has caused the growth of outputs.

It is reasonable to assume from these price movements that the supply
of poultry products has shifted to the right faster than the demand. The
cost of production, which shifts the supply, is determined by the prices
of inputs and the technology of production. Therefore, the rapid shift of
supply to the right must have been caused either by the decline of input
price or the progress of technology. However, it is likely that the de­
cline of input price is not the cause. Fig. 4 shows that the price of
poultry feed, which is the most important cost item, has remained at about
the same level, though there have been considerable fluctuations.

The technology of production is now left as a factor which might have
shifted the poultry supply. The rapid growth of the poultry industry can­
not be explained without considering technological progress. In Chapter
III the causes and the modes of technological progress in poultry produc­
tion are extensively discussed.

The relative profitability of competing enterprises is another im­
portant factor affecting production and supply. However, there does not
seem to be a particularly large decline of profitability among the enter­
prises competing against poultry. Such factors as the external economy
Fig. 3. Prices of poultry products, deflated by consumers' price index (cents per dozen eggs or a pound of meat)
Fig. 4. Poultry ration cost, deflated by consumers' price index (dollars per 100 pounds of poultry feed)
of scale and uncertainty of market conditions also would affect poultry production. The external economy of scale and the reduction of market uncertainty can be factors which accelerate growth, causing a shift in the supply function. Nevertheless, it is not likely that these factors are the primary agents which are responsible for the great development of the poultry industry.

After these considerations, it can be assumed that technological progress is the primary cause for the growth of production and for the shift of supply in the poultry industry. Since growth is a characteristic of poultry industry, and the growth is primarily due to technological progress, it is basic to analyze the effects of technological changes in studying poultry supply relations.

B. Approach for Analysis

The basic approach used in this study is the statistical estimation of linear 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 equations are meaningful if (1) the data are accurate, (2) the model used is a good approximation of real relations, (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 the conditions are sufficiently met or not should be judged in terms of the purpose of the analysis.

This approach for supply analysis is called positive as distinct from the derivation of supply function from production functions, budgeting or
linear programming. The estimation of supply relations from time series data attempts to analyze these relations on the basis of what has actually happened in price and quantity. On the other hand, the approach of deriving supply functions from farm records is called normative because it attempts to measure how much farmers will produce for a given price in order to maximize profit.

Each approach has advantages and disadvantages. What approach to use should be determined in terms of the information we are seeking. It is the great merit of the normative approach that we can see separately the effects of prices or of other factors. However, several difficulties are involved in making predictions from the results of normative analysis. First of all, not all farmers try to maximize profits. Also the existence of market uncertainty tends to reduce the response of production to price changes. These factors divert the results of normative analysis from actual outcomes. In addition it is often difficult to aggregate the results of farm record analysis to the national level. The positive approach of more aggregative data is called for because of its ability in making prediction about future outcomes.

How well the positive analysis accomplishes the task depends on whether the conditions previously mentioned are sufficiently met. This problem is examined for the analysis of poultry supply in Chapter IV.

The positive approach is used, because the purpose of this study is to analyze the aggregate poultry supply relations for the purpose of prediction. However, this does not deny the necessity that positive analysis should be supplemented by normative analysis.
C. Source of Data

Basic data used for estimation in this study are taken from the statistics of Agricultural Marketing Service, mostly (60) and (62) supplemented by (57) and (58). In the following text, data cited are from these sources unless specially noted otherwise.

D. Order of Presentation

In Chapter II the current issues in supply study are reviewed. The goal of meaningful supply study and the direction of efforts to attain the goal are discussed in general terms.

Chapter III deals with the construction of quantitative index of poultry production technology. The quantitative index of technology is constructed as a first requirement for attaining the goal of meaningful supply analysis of poultry products.

In Chapter IV considerations necessary for building poultry supply models are presented. The nature and limitations of the statistical model for economic analysis are discussed with specific references to poultry supply relations.

Chapters V, VI and VII deal with empirical analysis of poultry supply relations. Models for analysis, the results of estimation and their interpretations are presented in this order: V eggs and farm chickens; VI broilers; and VII turkeys.
II. REVIEW OF CURRENT ISSUES IN SUPPLY STUDIES

In the introduction the purpose of the study and the analytical framework are specified. This chapter reviews the current problems and principal objectives of supply analysis in general in order to lend perspective to the particular goal of this study.

A. Reflections on Supply Analysis

Schultz (48, p. 748) starts his challenging article about agricultural production and supply with the following statement:

Tell me what the supply of farm products will be five or ten years from now, and I shall give you meaningful answers to the more important economic problems of agriculture.

This is not an idle promise, as he himself asserts. The most reliable knowledge about demand has been brought forth during these last three decades. Basic economic theory assures us that if the reliable information concerning supply is added to that of demand we are in a safe position to solve some of the most urgent agricultural policy problems, such as the economic consequences of the price support program. Actually the study of supply response of agricultural products is one of the fields in agricultural economic research which has been most neglected, while a remarkably large amount of theoretical and empirical knowledge has been piled up in demand study. This unbalanced progress in these two fields of study has contributed greatly to the present impasse of policy evaluation in agricultural adjustment problems in general, either short-run or long-run.

Why, then, has there been such a divergence in the relative progress in these two fields? The supply study of agricultural commodities was
initiated by the pioneers of quantitative economic analysis as early as the
1920's, with the work of Moore, Bean, Ezekiel and Henry Schultz. But very
few studies were made throughout the 30's and 40's until the recent revival
of interest in the supply study among agricultural economists.* This inter-
mission can be explained in terms of the economic background of the period;
that is, agricultural industry was affected severely by the demand change
during the great depression and the following period. It was natural and
also practical for economists to put emphasis on demand study.

Besides the emphasis on demand study due to the need, there is intrin-
sic difficulty in analyzing supply phenomena and this has obstructed the
progress of study. Formally, the concepts of supply and demand relations
in economic theory are concerned with how the quantity of a product (or an
aggregate of products) is offered for sale, and demanded for purchase in
the market as its price varies, relative to other products with all other
influencing conditions being held constant. Major conditions for demand
which are held constant are these: (1) taste, (2) income and (3) popula-
tion; for supply: (1) technology, (2) supply conditions of inputs, (3)
producers' expectations and (4) quality of input (especially human). Each
of these conditions works as a factor which changes the demand or supply
function.

For a function to be useful, it must either be stable over time, or
if not stable, its change must be predictable. The difficulty of supply
study in comparison to demand study lies in this point. In general, the
demand function is far more stable and its change is easier to predict than

*For the description of developments in supply study, see Chapter III
of Dean (9) and Chapter III of Nerlove (42).
is the supply function. Taste, which determines the shape of the demand function through the consumption pattern, is known to be fairly stable for a meaningful length of time. And it is not difficult to predict the shift of demand from changes in income and population, since quantitative relationships can be set up between those variables and changes in demand.

In contrast to factors which affect demand functions, those of supply functions are hard to deal with. The problem is that there is no proper scheme known to quantify the factors which affect supply schedules like technology, quality of human input and producers' expectations. If they are stable, there is no problem. But, rapid change in technology characterizes today's agriculture. About producers' expectations and quality of human input very little is known, even whether they are stable. Without the proper scheme of quantification, it is impossible to predict accurately the change in supply due to the change in those variables. Schultz does not exaggerate when he says (48, p. 749), "We have no meaningful estimates of supply"--if we interpret meaningful as useful or valid for predicting the quantity to be supplied and for policy recommendations.

We have no meaningful estimates of supply because no one has ever taken all the variables which cause the changes in supply into his model when he estimates the supply elasticities.

B. Factor Inputs and Supply Response

The estimates of supply elasticities based on the time series data of quantity often have little meaning for predictive purposes. The well-known theorem of identification tells us that the supply function can only be
identified when demand shifts while supply stays the same. If the supply curve shifts together with the demand curve, the curve which plots the quantities against prices shows a locus of the equilibria of demand and supply, as is shown in Fig. 5. For instance, if the supply schedule shifts from \( S_1 \) to \( S_2 \) to \( S_3 \) with its corresponding changes in the demand schedule from \( D_1 \) to \( D_2 \) to \( D_3 \), the equilibrium point moves from \( E_1 \) to \( E_2 \) to \( E_3 \). The curve, \( M \), fitted to \( E \)'s shows a relation between price and quantity which is different from supply relations. This curve Heady (25) called a **mongrel** line and Cochrane (5) called it a **supply response** curve, as distinct from a pure supply curve. This mongrel line shows a trace of prices and quantities which are realized historically, but not necessarily a path into which the demand-supply equilibrium falls in the future. The mongrel curve is by its nature different from curves like those of demand or supply. In general, as the price of a commodity falls, consumers buy more, and producers sell less. Quantities supplied and demanded change accordingly to the behavior of consumers and producers in response to price changes in some determined way. Therefore, it is at least theoretically possible to predict the *ceteris paribus* change in quantity, in relation to the change in price by demand or supply curve. But in the mongrel curve, there is no valid basis for functional relationship between price and quantity as in the demand or supply curve. In the mongrel relation, the change of quantity against price depends on the way demand and supply shift simultaneously. Suppose we are now at the equilibrium point \( E_1 \) in Fig. 5. If supply shifted from \( S_1 \) to \( S_2 \) with a corresponding shift in demand from \( D_1 \) to \( D_2 \), then the equilibrium is \( E_2 \), which is on the mongrel line, \( M \). But it is rather accidental that the new equilibrium falls on \( M \), because the supply
Fig. 5. Supply, demand and mongrel curves

Fig. 6. Labor supply response in agriculture
shift from $S_1$ to $S_2$ is not necessarily accompanied by the demand shift from $D_1$ to $D_2$.

Demand may shift from $D_1$ to $D_3$, resulting in the new equilibrium at $E'_2$ which is far outside of $M$. Likewise, the equilibrium may move to $E''_2$, if the supply shift from $S_1$ to $S_3$ accompanies the demand shift from $D_1$ to $D_2$. Even if in the past the supply shift from $S_1$ to $S_2$ was accompanied by the demand shift from $D_1$ to $D_2$, what would assure the same kind of shift in supply and demand in the future? Therefore, the mongrel curve, which is the trace of equilibria in the past periods, is only of historical interest, and has no power of prediction, unless we can appropriately assume there exists a definite pattern or relationship in the simultaneous shifts in demand and supply. But does such a pattern exist?

The attempt of D. Gale Johnson (32) in explaining inelastic supply of agricultural commodities by inelastic supply of agricultural inputs gives us a part of the answer to this question. Johnson criticizes the traditional hypotheses* which have been thought to explain the inelastic supply of agricultural commodities, especially the hypothesis that a relatively high ratio of fixed capital in farm industry is the main cause of inelastic supply. He rejects the fixed capital hypothesis on the ground that not only family labor and owned land, but also hired labor and rented land did not decline appreciably during the depression. He insists that the inelastic supply of agricultural commodities (especially aggregate supply) can only be explained by the supply situation of agricultural inputs. The supply response of production factors in agriculture is extremely inelastic,

*See Galbraith and Black (18).
at least in the short-run, because there are hardly any alternative uses for land and most of the durable capital besides farming. The depression which causes a fall in demand for agricultural commodities brings forth unemployment in the non-farm sector. The opportunity costs for farm workers fall rapidly to zero, with a resulting downward shift in labor supply. The simultaneous shifts in supply and demand in the same direction cause a very sharp or even negative slope in the labor supply response curve for the agricultural industry. It is shown in Fig. 6 that the demand shift from $D_1$ to $D_2$ accompanies the supply shift from $S_1$ to $S_2$, resulting in the inelastic supply path from $E_1$ to $E_2$.

In the depression when the product price falls, this inelastic supply in inputs causes a drastic decline in factor cost, which shifts the supply curve of agricultural commodities to the right. The reverse of the process holds true in price-rising periods. Inelastic factor supply response causes rapid rise in the factor cost, which tends to reduce product supply. The shift in demand toward the right accompanies the corresponding shift in supply to the left, and vice versa for leftward shift in demand.

It is now clear that the shift in product supply is directed toward counter-balancing the change in quantity, due to the shift in demand through the factor supply mechanism, so as to maintain the same level of output. This causes the low elasticity in the supply response of agricultural commodities.

The elasticity which Johnson deals with is not a pure supply elasticity of traditional economic theory, but a mongrel elasticity of supply response to price in Heady's sense. But in this case the mongrel relation between price and quantity is not only meaningful historically, but also
meaningful for predictive purposes, because supply is related to demand through the factor supply mechanism and their simultaneous shifts follow a definite pattern.

C. Hidden Inputs and Supply Analysis

Johnson made an important contribution in bringing out a meaningful relationship between the shifts in demand and supply. But he answers only a part of the questions raised. The supply of production factors is one of the important conditions which influence the supply schedule, but that is not all. Technology, quality of inputs and expectation of producers are as important as the factor supply conditions.

Schultz (48) showed that only a fraction of the increase in agricultural production of the United States can be explained by the conventional inputs, namely labor, capital and land. This fraction has been declining rapidly. According to his estimates, up until 1920 about 80 percent of the increase in output can be explained by the conventional inputs. But since the start of the agricultural revolution in the 20's the fraction went down to about 50 percent, and the figure was further reduced to about 20 percent in the postwar period. Schultz insists that the increase in outputs, disproportional to the increase in inputs, is due to some hidden inputs. Meaningful analysis of production and supply can only be attained by introducing those hidden inputs, especially technological advance and improvement in the quality of inputs.

Disregarding the accuracy of Schultz's figures, it is still an undeniable fact that the advance in technology and improvement in the quality of
inputs (especially human input) are changing agricultural production rapidly and causing corresponding shifts in the supply function. Without taking them into the frame of our analysis in some way or other, we cannot expect to accomplish our research goal, namely the meaningful estimates of supply elasticities.

Extreme difficulties are involved, however, in order to bring technology and the quality of inputs into our analytical model. The difficulties in measurement and aggregation are certainly great, but the more basic difficulties are methodological. Both the technological advance and the improvement of inputs are qualitative changes. First of all we have to find a proper scheme to quantify quality. These qualitative changes are expressed in the shifts in production functions, but the shifts in production functions are ex post facts. What are the forces which cause these shifts? Through what mechanism are those shifts caused? What are their magnitude and direction in response to the changes in the shifters? Those are the questions to be answered. To explain the shift in production by a time trend, and to construct a functional relationship are not appropriate for our purpose. As Cochrane (5) showed, the increase in productivity in United States agriculture has been discrete. It stayed fairly stable until 1920, and jumped up during the 1921-24 period, and came back to a stable stage until another jump in the 1936-44 period. In the long-run the trend may appropriately explain the change in productivity, but for our purpose, that is, to predict what will be the production and supply in five years or ten years, the time trend cannot be adequate.

No proper scheme exists to set up a quantitative relationship between production and technological advance. But even if it exists, it is not
enough for supply analysis. Supply is the relation between price and quantity offered for sale, and the change in the actual quantity supplied depends on the interaction between supply and demand, which appears as a mongrel relation. The estimate of elasticity of a supply response or mongrel relation can be meaningful if we can conceive some definite patterns in the demand shift in relation to the supply shift caused by technological change.

One possible way to introduce the relationship in the simultaneous shifts in demand and supply would be to use Cassels' hypothesis (3) of the irreversible supply curve. Cassels assumes a reservoir into which the technology of agriculture flows during the periods when farm income is declining or stable, and flows out during the periods when farm income is rising, that is, farmers adopt new technology when the price situation is favorable. This means that due to technological advance supply shifts to the right during the period of a favorable market situation, when demand shifts to the right, tending to cause an elastic supply response. When prices drop, however, this path is not reversed, because the new technology will be retained. As is shown in Fig. 7, in the period of price rising the supply shifts due to the adoption of technology from $S_1$ to $S_2$ with the corresponding shift in demand from $D_1$ to $D_2$, resulting in the path of equilibrium from $E_1$ to $E_2$. While in the period of price falling, supply does not shift back due to the retention of technology. The equilibrium point moves down from $E_2$ to $E_3$ along the pure supply curve, $S_2$.

If we accept Cassels' hypothesis, the definite pattern can be established in the simultaneous shifts in demand and supply in relation to technological advance. But is this hypothesis acceptable? The changes in pro-
Fig. 7. Irreversible path of supply response
ductivity, which Cochrane referred to, partly support Cassels' hypothesis. It is true the periods 1921-24 and 1936-44 were prosperous, but not as prosperous as the 1916-18 or 1945-48 periods. It is rather dangerous to relate the farmers' adoption of new technology and income in a simple fashion. Various influencing factors such as time lag or farmers' expectations cause critical deviations from the simple relation.

Farmers' expectations for future prices affect supply through the changes in conventional as well as hidden inputs like technology. The attempt of Nerlove (43) is in this direction. Nerlove hypothesized that farmers revise the price they expect to prevail in the coming year in proportion to the error they made in predicting price in the current year. By introducing Hicks' idea of elasticity of expectation (27, p. 205), he sets up a model of price expectation:

\[
(2.1) \quad P_t^* - P_{t-1}^* = \beta \left( P_{t-1} - P_{t-1}^{*} \right)
\]

where \( P_t^* \) and \( P_{t-1}^* \) are expected price in period \( t \) and \( t-1 \), and \( P_{t-1} \) is a realized price in period \( t-1 \), and \( \beta \) is the coefficient or elasticity of expectation. A certain pattern of farmers' expectation being assumed, it is to be analyzed how farmers adjust their production over time. This turns up the problem of short-run versus long-run elasticities of supply (44).

Nerlove's expectation model is an important contribution to include one of the influencing conditions into the supply model. But it is only a first step, and far from sufficient. In Nerlove, \( \beta \) is assumed to stay constant, but this assumption does not match reality. \( \beta \) would be different between price-rising periods and price-falling periods, or between the
beginning and ending stages of each period. The value of $\beta$ and its change would affect the inputs of conventional inputs directly and the hidden inputs through some complicated mechanism.

D. Toward Meaningful Supply Study

Thus, supply, demand, conventional inputs, hidden inputs, and expectation of farmers, which determine price and quantity supplied, make up an intricately knitted whole. It is extremely difficult to analyze all of the complicated relations, and construct a quantitative model which includes all major influencing factors. But without doing that, the final goal of meaningful supply study cannot be attained. Naturally the work should proceed slowly and steadily on the ground, without vain dreams for perfection.

Enough conventional estimates should be collected, through which the influences of unconventional factors can be accurately grasped. As Heady (25, p. 238) pointed out, "Urgently needed is an empirical study which predicts the many coefficients in the set of structural relationships."

Parallel to that, efforts must be made to include the unconventional factors in the analytical framework, one by one. The relative importance of unconventional factors in production and supply differs among the various enterprises of agriculture. The influence of future expectation would be more significant in hogs, for instance, than in government support products like wheat. Technological change would not have been so crucial in cattle ranching as in corn production. Crucial unconventional factors can be evaluated better separately in each enterprise. An attempt should be made to include in the analysis the unconventional factor crucial for each
enterprise. When the formulation of unconventional factors is accomplished separately, we will have the basis for carrying out a meaningful supply analysis.

The author hopes that the following analysis of poultry supply will be one of the steps toward this final goal of agricultural supply study.
III. CONSTRUCTION OF TECHNOLOGY INDEX

In the introduction we see that the poultry industry of the United States has been characterized by its rapid growth in total output. This growth is explained largely by technology which reduced cost and increased supply of poultry products, causing them to be substituted for other meat and protein foods. Hence, a meaningful study of poultry supply must include variables representing technological changes. Accordingly, technology of poultry production has been included as a crucial variable in this study. The first step is to find a proper scheme to quantify the technology of poultry production.

A. Economic Concept of Technology

Before proceeding to the specific problem of quantifying technology in poultry production, the meaning of technology or technological change in economic analysis must be clarified.

Schumpeter (49, p. 87) defines an innovation as "setting up of a new production function". Schumpeter's innovation is an economic concept, and a mere change in physical technique is not the same thing as innovation. An invention of a new machine for production is not an innovation as long as the machine is kept in the laboratory. It becomes an innovation when it is adopted by firms. An innovation appears only when it is possible for firms to increase effective profit by adopting a new technique.

Lange's supplement (40, p. 20) to Schumpeter's definition of an innovation clarifies the point:
Innovations are such changes in production functions..., which make it possible for the firm to increase the discounted value of the maximum effective profit obtainable under given market conditions.

However, Lange's definition, though clarifying, does not add anything to Schumpeter's original definition. A new technique, if it is to increase the discounted effective profit, can be adopted by a firm, thus setting up a new production function. Firms simply neglect the technique, if there is no increase of profit expected, and a new production function is not set up. The contention of Lange's definition, thus, amounts to the same as Schumpeter's.

If we adopt the Schumpeter-Lange definition, a technology of poultry production can be specified as a particular poultry production function, and an innovation is the set-up of a new production function. The change in technology is manifested by the difference between old and new production functions. Technological change can be quantified by measuring this difference.

The process of innovation has very important implications on Schumpeter's theory of business cycle and economic development. But the latter is not the direct object of analysis in this study. The initiation and diffusion of new techniques affect aggregate supply functions by changing aggregate production functions. The changes in aggregate production functions are the \textit{ex post} outcomes of innovations. If we can measure these changes, and formulate their effects on aggregate supply functions, we can estimate the changes in aggregate supply caused by technological progress.

Therefore, for the time series analysis of poultry supply, the problem of quantifying technology is the problem of measuring changes in aggregate
poultry production functions over time. However, for the purpose of predicting supply in the future, it is not enough to measure these changes in the past. It also is necessary to estimate future shifts in aggregate production functions. Hence, we must analyze the nature of innovations in the poultry industry and find the way that poultry production functions change over time.

B. Output-Input Ratios: Indicators of Technology

A direct way to approach the problem is to estimate poultry production functions for each year separately from farm survey data, and to measure the differences between these estimated functions. However, this is not practically feasible, because there is no data available for estimating a sufficient number of production functions as a step in evaluating the change in technology over time. It is impossible to conduct a survey about the facts of several decades ago. We could try to extract the necessary information from farm records which have been accumulated in the U. S. Department of Agriculture, land grant colleges and other institutions. But to sort the data of poultry production from a whole maze of farm record information would involve a prohibitive amount of work. Even if accomplished we could hardly expect the process to provide production functions which represent the industry unless the farm records were randomly collected in different regions and different periods. The records which are available from the past do not meet this last criterion.

Since the direct measurement of change in the production function over time is not feasible due to data limitations, we are forced to use some mag-
nitudes 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 an average productivity for a certain input level, which is realized under a given market situation. Not only the production function but also the prices of output and input affect the output-input ratio. For a given production function, the output-input ratio varies for different market or price situations. This is shown in Fig. 8. in respect to a given production function. Output-input ratio or average productivity is expressed as a slope of a line connecting origin to the point where the output-input price ratio line is tangent to the production curve. Suppose we have different output-input price ratio lines, $M_1$ and $M_2$, which are tangent to a production function, $H$, at points $E_1$ and $E_2$. For the same production function, we have different output-input ratios, $E_1I_1/O_1I_1$ and $E_2I_2/O_2I_2$.

It is difficult to determine from actual time series data whether a change in the output-input ratio is caused by a change in the production function or a change in the market situation. The effect of market situation on the output-input ratio depends on the slope of the production function. If the slope of a production curve is greater, a change in price ratio will cause a larger change in the output-input ratio, and *vice versa* for the smaller slope of a production curve.

Since output-input ratios in time series data themselves do not provide any information about the slope of a production function, we cannot isolate the percentage of change in an output-input ratio caused either by a change in production function or by a change in market situation. This is
Fig. 8. Output-input ratio in relation to output-input price ratio for a given production function
especially true if we take uncertainty into consideration. Actually farmers do not extend inputs for the production function to the extent that the price ratio equals the marginal physical productivity of the resource. Discounting future receipts and over-evaluating future expenditures, the farmers' certainty equivalent of future output-input price ratio becomes smaller than the actual price ratio. The farmers' rate for discounting future uncertainty varies over time, depending on the institutional setting of the market. This makes it more difficult to determine the net effect of a change in the production function on the output-input ratio.

It follows that, in order to use the output-input ratio as the indicator of 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 follows a similar pattern over the 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.

C. Choice of Technology Indicators in Poultry Production

We now examine which output-input ratio best indicates the techno-
logical 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 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, semi-variable inputs like flocks, fixed inputs like houses and equipment. Changes in the ratio between output and aggregate input, market situation remaining constant, would give an exact measure of the change in the hidden inputs. However, it is difficult to aggregate the inputs for poultry production to a reasonably accurate degree. The major portion of poultry production, especially egg production, has been, and still is, carried as a sideline of the total farm operation, though there has been a strong tendency toward specialization. It is difficult to disentangle the amount of labor devoted to poultry production from labor imputed in the total farm operation. In the production of early years much feed was salvaged from feed wasted in other major livestock operations, the magnitude of which is hard to measure. Also no national aggregative data are available for the fixed capital of poultry. Under these limitations the aggregation of all inputs would result in insignificant figures, even after a successive process of guestimates.

A practically feasible way would be to choose a factor which is thought to have made the greatest contribution in the development of the industry. According to Heady (23, p. 818-819) innovations can be classified into two categories, biological or mechanical:
By the term 'biological', we refer to those which have a physiological effect in increasing the total output (per acre, animal, unit of feed) from a given land base. The term 'mechanical' refers to innovations as a machine which substitutes capital for labor but does not change the physiological outcome of the plants or animals to which it may apply.

In poultry production, developments in breeding, nutrition, disease control and environmental control belong to the first category, and the new devices of ventilation, feeding and water systems, etc. belong to the second category.

Mechanical innovations in poultry production are reflected in the average productivity of labor or the output-labor ratio. As is seen in Fig. 9, poultry output per man hour of labor has increased faster than other livestock products. Poultry output per man hour of labor was 76.3 percent larger in the period 1950-56 than in the period 1910-29. Between these two periods, the increase of output per man hour increased by 21.6 percent for meat animals and 65.8 percent for dairying. The increase in the labor productivity of poultry production has followed a trend similar to that for total farm output. It had remained fairly stable, with only a slight upward trend, until the middle of the 30's. Then it started to increase in an exponential fashion. This similarity in the increase of labor productivity for poultry production and total farm output supports the argument for using labor productivity as a measure of poultry production technology.

However, it is rather doubtful if the increase in labor productivity has been the major factor in the development of the poultry industry. First of all, the relative weight of labor cost is not large. The records of poultry farms in Iowa (30) show that labor cost, though it varies widely from farm to farm, has rarely been above 30 percent of total cost throughout
Fig. 9. Index numbers of livestock production per man-hour: poultry, meat animal, and dairy (1947-49=100)
these three decades, while the feed cost, which is the biggest single cost item, has ranged from 50 to 80 percent.

Secondly, poultry production has predominantly been a sideline enterprise, and labor has been used for which opportunity cost is more or less zero. This is no longer true for broilers and turkeys, but in egg production it is still common practice that farm flocks are left to the care of housewives. It seems that labor has been an implicit cost item in poultry production, at least in early years.

If so, the initial development of the poultry industry, especially during the middle of the 30's, should be explained by innovations other than labor-saving devices. This is not to deny the fact that mechanical innovations have contributed to the development of the poultry industry. In fact, labor is becoming an explicit cost item for poultry farmers as specialization proceeds. Still the main sources of technological progress which encouraged the development of the poultry industry in the past three decades are likely to be biological rather than mechanical.

Biological innovations have been effected in the various physiological facets of poultry production—(1) nutrition, (2) breeding, (3) disease control, (4) environmental control. Since farmers started supplementing poultry feed with skimmed milk, scrap meat and cod liver oil in the 1920's, the poultry ration formula has greatly improved. The improvement in the levels of energy and protein was accompanied by the supplementation of vitamins, minerals, antibiotics and arsenicals. Improved breeding is a rather new innovation, compared to nutritional improvement. Breeding has become particularly important since the 40's. It not only increased the efficiency of production, but also created new products suited to the con-
sumers' preference. The dramatic increase in light breed turkeys originating in Beltsville is a good example.

The control of poultry disease has been of great concern to the farmer. The discovery that blackhead is transmitted to turkeys from chickens led the farmers to raise turkeys in confinement. This discovery is considered one of the biggest momenta in the technological progress of turkey production. The development in disease control contributed to the growth of the industry by reducing technological uncertainty as well as increasing aggregate efficiency.

The improvements in nutrition, breeding and disease control are not fully effective without adequate environmental conditions. For example, a high protein diet is more effective with artificial light during feeding. The process of developments in these innovations is summarized by Bird (2), Comb (7) and Scott (50).

In all, those innovations caused the enormous increase in output per unit of input. U.S.D.A. figures (31, p. 126) show that in 1935, 100 pounds of feed produced 18.9 pounds of broiler or 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 from 122 eggs to 198 per year.

Feed is by far the largest cost item in poultry production. Feed cost presently comprises more than 50 percent of the total cost of poultry production. In fact, in the early days feed was almost the sole item for cash expenditure in poultry production. It is obvious that farmers have re-

sponded to the change in feed efficiency. Therefore, we assume that biological innovations, which are expressed in the change in output-feed ratio, have been the major elements in the development of poultry industry in this century. This is the reason why we choose the output-feed ratios or the feed conversion rates as the technology indicators of poultry production.

Broiler-feed conversion rates and turkey-feed conversion rates are used in constructing the technology indices of broilers and turkeys. However, in egg production the number of eggs per layer is preferred to the egg-feed conversion rate for the following reasons:

Firstly, the increase in the number of eggs per layer is "...the object to which the greatest attention has been given in the past 50 years by laying flock owners, agricultural colleges and the feed industry", (2, p. 10). Secondly, the accuracy of statistics is supposedly much higher for the number of eggs than for the egg-feed conversion rate. Since there is a known causal relation between the number of eggs per layer and the egg-feed conversion rate, it seems appropriate to use the number of eggs per layer, which has more accurate statistics.

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. 10. The trends of these technology indicators are very similar to the trends in the total outputs. This strengthens the stand that the changes in the number of eggs, the broiler-feed conversion rate and the turkey-feed conversion rate indicate the technological progress in poultry production.

The changes in these technology indicators are mostly brought by
Fig. 10a. Number of eggs per layer and total output of eggs.

Fig. 10b. Broiler-feed conversion rate and total output of broilers (liveweight).

Fig. 10c. Turkey-feed conversion rate and total output of turkeys (liveweight).
biological innovations, but, at the same time, they are very closely re­
lated to mechanical innovations. Many devices for environmental control
turn out to be the labor-saving devices, and vice versa. For example,
ventilation facilities are designed to keep poultry houses dry and fresh.
At the same time the ventilation facilities save a considerable amount of
labor in cleaning the poultry houses. Also, the increase in output per
unit input saves the labor required to produce the same amount of output.
For example, as the number of eggs per layer increases, a smaller number
of hens is needed to produce the same quantity of eggs, and this reduces
the amount of labor required. High correlation is expected between the
biological and the mechanical developments of technology. To some extent,
therefore, mechanical innovations are also reflected in the increase in the
number of eggs per layer, the broiler-feed conversion rate and the turkey-
feed conversion rate used as the poultry technology indicators.

D. Method for Extracting Technological Progress

The number of eggs per layer, the broiler-feed conversion rate and the
turkey-feed conversion rate are, by themselves, not the measures of the net
effects of technological changes. The changes in market situation as well
as the changes in production functions affect the values of these output-
input ratios. Whether we can measure the net effect of technological changes
from the data of the output-input ratios depends on whether these output-
input ratios satisfy either one of the three necessary conditions mentioned
in section B.

It is difficult to judge if the first condition is satisfied or not.
The effect of the market situation on the output-input ratios is expected to be smaller than the effect of technology. But we don't know if it is relatively small enough to be ignored. The effect of price change partly depends on the slope of the production curve. We do not have sufficient information about the slope of poultry production functions to make any judgment about the relative magnitude of the effect of market situation on the output-input ratios.

The second condition does not seem to hold. The fluctuations in the output-input ratios are not consistent with the changes in the prices in the market. For example, the period of 1934-37 when the turkey-feed conversion rate was above trend is the period when the turkey-feed price ratio was below the average level. Also, the decline in the turkey-feed conversion rate since 1955 was accompanied with a decline in the turkey-feed price ratio. It is not likely that turkey growers were working with decreasing marginal productivity in the former period, and that they were working with the increasing marginal productivity in the latter period.

A change in output-input ratio is explained either by a change in the production function or by a change in the market situation, other things remaining constant. Actually, other things do not remain constant. The other factors which affect the output-input ratios for poultry technology indicators are (1) environmental conditions and (2) compositions of input or output. Poultry productions are subject to many environmental changes. This was particularly true in early days when only a small portion of flocks were raised in confinement. Under unfavorable weather the rate of lay or the rate of feed conversion declined. The attack of epidemics killed many birds, resulting in the decrease in the national average of the output-
input ratios. The fluctuations in the rate of lay and the feed conversion rates in the early days are largely explained by the environmental conditions.

Changes in the composition of input and output have important effects also. These changes explain the decline in the turkey-feed conversion rate since 1955. The percentage of light breed birds among the total number of turkeys raised has decreased since 1955. This decline is caused by the shift of consumers' preference from light breed to heavy breed turkeys due to the improvements in processing and refrigeration. The feed conversion rate is higher for light breed than for heavy breed. But the shift of production from light breed to heavy breed does not mean a decrease in efficiency. In the late stage of turkey fattening, additional pounds of meat can be gained by feeding only corn which is much cheaper than supplemented turkey mash. Efficiency per se of turkey production has continued to increase since 1955, though the turkey-feed conversion rate has decreased. In other words, the turkey production functions adjusted to the heterogeneity in input and output has continued to move upwards.

Thus, the realized changes in the output-input ratios are the combinations of the effects of various factors. It is very difficult to find a way to eliminate these effects. Then, the extraction of trends from the data of the output-input ratios seems to be the only possible way to measure the net effects of technological changes.

There are marked upward trends in the number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate. Such strong trends can only be caused by the effects of technological progress.

The problem is how to extract the trends of technological changes over
time. More specifically, we have to decide what functional form to use for approximating the trends. Considerations for specifying a mathematical function among infinite alternatives for fitting to economic data are discussed by Heady and Dillon (26). The criteria of choice which we should consider are these: (1) a priori knowledge about the materials of data, (2) the degree of association between original observations and estimated values, (3) computational conveniences.

The first consideration we should make is to see what sort of a priori knowledge we have about the trends in the number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate. What should be remembered is that technological advances which have raised these values are mainly biological by nature.

It is hypothesized that the phenomena of biological growth follows a logistic curve. Observations in experiments and surveys confirm this hypothesis. Pearl (47) reports the results of fitting the logistic function to the data of growth in living organisms as well as in the groups of living organisms from several sources. The logistic curve fits remarkably well to these data. From these results Pearl derives a hypothesis that the growth of human population also follows the logistic curve.

The hypothesis that the growth of living objects follows a logistic curve is not only confirmed by empirical observations, but also has a biological basis. As Lotka (41) conceived it, the logistic function defined as

\[ X = \frac{k}{1 + e^{-ct}} \]

where \( X \) is the magnitude of a growing object, \( t \) is time, and \( k, c \) and \( d \) are the parameters, is a special solution of the fundamental equation of ki-
netics. The fundamental equation of kinetics is the mathematical expression of an assumption that the growth rate of a life-bearing system, organism or group of organisms depends on the abundance in which each is presented,

\[ \frac{dX}{dt} = f(X) \]

where \( X \) is the magnitude of a growing system and \( t \) is time.

The life-bearing system will pass a number of equilibria in the course of growth, at which the growth rate is zero, that is

\[ \frac{dX}{dt} \cdot f(X) = 0. \]

The logistic function is the solution of differential equation under the condition that equation is a second degree polynomial having two roots, one of which is zero.*

Expanding equation into Taylor series,

\[ \frac{dX}{dt} = F(X) = ax + bx^2 + cx + \ldots. \]

where we have no constant term, because the equation has a root at \( X=0 \). Equation has two roots, if we terminate the expression at the second degree term:

\[ \frac{dX}{dt} = ax + bx^2. \]

The solution of equation is

\[ X = G_1e^{at} + G_2e^{2at} + G_3e^{3at} + \ldots. \]

Substituting equation in equation and equating coefficients of homogeneous terms we find

\[ G_2 = \frac{b}{a} G_1^2 \]

\[ G_3 = \left(\frac{b}{a}\right)^2 G_1^3 \]

so that equation is a simple geometric series. Its sum is

\[ X = \frac{G_1e^{at}}{1 - k e^{at}} = \frac{\frac{a}{b} e^{-at}}{1 - \frac{a e^{-at}}{bG_1}} \]

Decoding the symbols such that

\[ -a = c, \quad a = d, \quad -\frac{a}{b} = k \]

Equation becomes

\[ X = \frac{k}{1 - de^{at}} \]
This condition is equivalent to the expression that a life-bearing system proceeds from the equilibrium of a lower asymptote at zero, to the equilibrium of an upper asymptote.

Lotka's derivation of logistic function from the fundamental equation of kinetics presents a logical basis for the logistic law of biological growth. The process of logistic growth in life-bearing systems is regarded as a balancing process between the fundamental power of life to grow and the restraints imposed by nature. The restraints can be the control of a central mechanism, or the limit of space for survival, etc.

Since the biological innovations are essentially physiological phenomena, the author hypothesizes that the growth in biological technology also follows a logistic curve.

It is a common observation that the marginal return of research effort directed toward improvement in the physiological features of biological objects, gradually increases in the beginning stage of research, and turns to decline beyond a certain point. Research for increasing the size of fruits, the per-acre yield of grains and the feed conversion rates are examples of this. It requires slow and tedious work to try to solve an unexploited problem. It is something like establishing a beachhead. As research proceeds, literature and data about the problem gradually pile up. Then, research workers utilize the existing knowledge as a spring board for the faster progress of research. However, certain limits are set by nature for physiological improvements. The return to the research effort starts decelerating as physiological efficiencies approach the limits, and room for improvements gets smaller. By analogy to the biological growth, this process can be regarded as a balancing process between human efforts to im-
prove the physiological efficiencies and the limits imposed by nature.

It is certain that there is a physical maximum for the output per animal unit or feed unit. The number of eggs per layer won't go up beyond 365 a year, because at least 24 hours are needed for each ovulation. In either broilers or turkeys, one pound of feed cannot produce more than one pound of meat.

Until the beginning of this century, poultry production per animal unit or feed unit did not appreciably change as compared to the dramatic change in the past three decades. Per-unit output levels fifty years ago can be regarded as the lower limits. Increases in the per-unit outputs were slow at the beginning, and then accelerated. It is to be expected that the rates of these increases will decline as the per-unit outputs approach their upper limits.

From the nature of progress in the physiological efficiencies, and from the movements in the number of eggs, the broiler-feed conversion rate and the turkey-feed conversion rate, it seems reasonable to assume that the growth of technology in poultry productions follows a logistic curve. For this reason we use the logistic function to extract the trends in the technological progress of poultry productions from the data of the number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate.

E. Estimation of Logistic Trends in Technological Changes

There are several methods of estimating the parameters of the logistic function.* The problem is that we can hardly expect to obtain the reason-
able estimates of upper asymptotes from the data on hand by 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 quite appreciable yet. The turkey-feed conversion rate has declined since 1955. But the efficiency of turkey production is still rising in an exponential fashion. From these data the estimates of upper asymptotes will be subject to great error. Therefore, instead of estimating statistically, we have to find the appropriate asymptote values from a priori knowledge.

It is very difficult to predict the values of upper asymptotes for the output-input ratios in poultry production. The physical limits would be 365 eggs per layer and 1 pound of broiler or turkey meat per pound of feed. But it is generally believed the national average figures will level off before reaching the physical limits.

As for egg production, it is reported (2, p. 11) in 1952 that the average production of hens in a Connecticut egg laying contest appeared to have levelled off at about 240 eggs per year. Examination of the records of some more recent egg laying contests indicates some of the egg production per year has come up to about 250.* If the number of eggs per layer has levelled off at 250 for the selected hens which go into the contest, it seems reasonable to adopt this figure for the upper asymptote value for the national average.

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

*Bird, H. R., University of Wisconsin, Dept. of Poultry Husbandry, Madison, Wisconsin. Information on the upper asymptote for the number of eggs per layer. Private Communication. 1959.
of liveweight broiler per 100 pounds of feed is adopted. This ratio is based on information given by Comb:

The actual limit of feed conversion for broilers should be considerably lower than one might estimate now, simply because we would expect to have broilers which would grow faster and reach in appreciably better feed conversions. We had some feed with feed conversion as low as 1.29 with practical type feed, although these were very high in fat. Perhaps some day we can expect the industry to arrive at the values as low as 1.5 after faster-growing birds obtained.

For the upper asymptote of the turkey-feed conversion rate, 33 pounds of liveweight turkey per 100 pounds of feed is used. This is based on the estimate of the poultry scientists at Iowa State University. This figure conforms to the figure predicted by Scott (50, p. 19) about turkey feeding.

These values for asymptotes are based on fallible assumptions, but we are forced to use them due to the data limitations.

The estimates of lower asymptotes are obtained by extending the trend curves fitted by free hand. The values on the trend curves of 1900 are used as the values for lower asymptotes. 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 more or less conform to the knowledge of the poultry scientists of Iowa State University.

Once the upper and lower asymptotes are given, the estimation of logistic functions is easily made. The standard least-squares regression is applied, after transforming the logistic function into linear logarithmic form. The estimated logistic functions are as follows:

*Comb, 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. Comb used the word feed conversion as broiler output divided by feed input, which is the reverse of the feed conversion rate used in this study.)
The number of eggs per layer, the broiler-feed conversion rate and the turkey-feed conversion rate estimated by the logistic function as given above, can be regarded as the measure of the net effect of technological progress in poultry production. These estimates will be called the technology index of egg production, of broiler production and of turkey production. These indices will be used as the variables of technology in the supply analysis of poultry products.
Table 1. Technology indicators of poultry production: values of actual observations and estimated values from logistic function.

<table>
<thead>
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<th>Year</th>
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<th>Turkey-feed conversion rate</th>
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aJennings (31).
Fig. 11a. Number of eggs per layer: values of actual observations and estimated values from logistic function.

Fig. 11b. Broiler-feed conversion rate: values of actual observations and estimated values from logistic function.

Fig. 11c. Turkey-feed conversion rate: values of actual observations and estimated values from logistic function.
The logical basis for using the logistic function for extracting the net technological effects is already described. However, there are two points to discuss concerning the technology indices of poultry production thus constructed.

For one thing, the extraction of the net effects of technological changes by the logistic function is, in principle, not the same as the extraction of technological trends by fitting some other functions, like exponential, logarithmic, and polynomial. Those functions may fit to the data as well as the logistic function. For example, these are the results of the exponential function fitted to the same data:

\[
\begin{align*}
\text{Eggs per layer} & \ \\
(3.7) & \quad R_e = 105.2 \ e^{0.0186t} \\
\text{Broiler-feed conversion rate} & \ \\
(3.8) & \quad R_b = 17.8 \ e^{0.0223t} \\
\text{Turkey-feed conversion rate} & \ \\
(3.9) & \quad R_t = 12.4 \ e^{0.0140t}
\end{align*}
\]

The correlation coefficients between the original observations and the exponential estimates are .9830 for eggs, .9594 for broilers and .9406 for turkeys. As far as the degree of fit is concerned, there is not much difference between the logistic function and the exponential function. In fact, the exponential function fits better for turkeys. The decisive factor in choosing the logistic function is not how well it fits the data, though it is very important. The logistic function is chosen for extracting the technological trends because it is related to the basic nature of technology in poultry production. The development of poultry production technology is,
by its biological nature, expected to follow a path analogous to the growth of life-bearing systems. On the other hand, the fit of the exponential function or other functions is a sort of mechanical association, and has no a priori ground. The difference is particularly evident in long-range predictions. However good the fit is to the past data, much confidence cannot be put in the exponential estimates of future values, because there is no logical basis for the fact that the technology of poultry production continues to grow in an exponential fashion, while a priori knowledge about the growth of poultry technology provides an assurance for future predictions performed by the logistic function.

Another consideration also is important. The values used for the asymptotes in estimating the logistic functions are obtained on the basis of present knowledge. It is possible that some dramatic innovations may change the whole picture. For example, some unforeseeable innovations may reduce the ovulation period to considerably less than 24 hours. Then, a hen may lay more than one egg a day, pulling up the upper limit for the number of eggs per layer drastically. In reference to this possibility, the author would like to point out the population growth of Germany in Pearl (147).

The rate of population growth in Germany slowed down in the middle of the 18th century, and started to increase at the period of the Franco-Prussian War. Pearl interpreted this phenomena as the change in the upper limit of population due to the dramatic change in the social and economic conditions of Germany from an agricultural state to an industrial state.

No one knows whether the same type of a dramatic change may occur in the biological technology in poultry production. But even if it will occur,
the historical path along which the technology in poultry production grows will remain as it is. Changes in the upper limits will cause errors in prediction. But at least we can see what has been the technological change in poultry production.

Without considering this sort of dramatic innovation, the inaccuracy of the values used for the upper asymptotes is the biggest weakness in the construction of the technology indices. These values simply represent the guesses of experts in the field. Errors in the predictions are expected from the inaccuracy of the asymptote values. It is not difficult to see many other defects in constructing the technology indices of poultry production. However, the construction of these indices is an attempt to quantify technology. It is a necessary requirement for attaining the meaningful supply analysis of poultry products. Though these indices are far from perfection, they may be at least a step forward to attain the goal.
IV. CONSIDERATIONS IN BUILDING SUPPLY MODELS

In the previous chapter the technology indices of the poultry productions were constructed. We now have to consider how to construct the models for the supply analysis of poultry products with these technology indices incorporated.

A. Nature and Limitations of Linear Equation Model

The supply relation we want to estimate is the one between the price offered and the quantity supplied of a commodity with influential factors remaining constant. In the real world this ceteris paribus condition is never satisfied. If we want to estimate supply relation from time series data, we have to adjust the relation to the influence of other factors.

A linear equation or a system of linear equations is generally used as a model for estimating economic relations from time series data. When we say a linear equation, we mean the equation of linear coefficients, but not necessarily of linear variables. Whatever transformations of original observations, e.g. logarithmic, quadratic, etc., are used, the coefficients of variables should remain constant over the range of variables.

A linear equation is a first approximation of a real economic relationship. This approximation is required in order to estimate economic relations statistically. Non-linear models are difficult to estimate. As the number of variables increases, the difficulty multiplies and makes the statistical estimation practically unfeasible.

Though a linear model is a necessary device it has several limitations. We have to see if a linear equation can be used as a model for analyzing
the poultry supply relations from time series data.

Suppose a supply relation can be formulated in a general form,

\[(4.1) \quad F\left(x_1, x_2, x_3, \ldots, x_n, \alpha_1, \alpha_2, \ldots, \alpha_m, \varepsilon\right) = 0\]

where \(x_1\) is price offered, \(x_2\) is quantity supplied, \(x_3, \ldots, x_n\) are variables which affect supply, \(\alpha\)'s are the parameters, and \(\varepsilon\) is a stochastic residual. The linear approximate of equation 4.1 is written as:

\[(4.2) \quad \beta_0 + \beta_1x_1 + \beta_2x_2 + \ldots + \beta_nx_n + \eta = 0\]

where \(\beta\)'s are the parameters and \(\eta\) is a residual. The question is raised if it is valid to use equation 4.2 in analyzing the relation formulated as equation 4.1. Some deviations from equation 4.1 are inevitable in equation 4.2. However, the deviation of a model from a true relation does not deny the use of equation 4.1 for equation 4.2. Concerning this problem, Friedman (17, p. 15) states:

The relevant question to ask about the assumptions of a theory is not whether they are descriptively realistic, for they never are, but whether they are sufficiently good approximations for the purpose on hand.

The problem is not concerned with whether or not there is any deviation in equation 4.2 from the true relation, but how well equation 4.2 can approximate equation 4.1. Then, the validity of using a linear equation for estimating a supply relation will depend on whether it is a good approximation of the relation.

B. Market Conditions and Structural Conditions

It now must be determined what factors affect supply relations, and if
their effects can be approximated by a linear equation. The factors which affect supply can be classified into two categories: (1) market conditions and (2) structural conditions. The first category includes 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 in which farmers operate.

Two categories of these influential factors are different in the way they affect supply relations. The structural conditions specify its position. This can be seen easily in the relation between the production function and the supply function. Suppose a farmer has a production function,

\[ Y = f(X) \]

where \( Y \) is output and \( X \) is input. Total cost is expressed as,

\[ T.C. = XP_x \]

where \( P_x \) is the price of input. The marginal cost is,

\[ M.C. = \frac{dX}{dY} P_x \]

where \( \frac{dX}{dY} \) is a function of \( Y \), say \( g(Y) \). The supply curve of an individual firm can be obtained by equating the price of output to the marginal cost above the average cost,

\[ P_y = g(Y) \cdot P_x \]

where \( P_y \) is the price of output. The supply curve shifts in a geometrical fashion, as \( P_x \) changes. Change in production function, on the other hand,
would generally result in change of $g(Y)$. The supply curve changes its shape and position, as $g(Y)$ changes. If the change in production function is due to technological progress, the supply curve would likely move to the right, changing the shape of the curve.

Changes in the input and output prices of competing enterprises would alter the opportunity cost of input. These changes have the same effect as a change in the price of direct input. Changes in the production functions of competing enterprises would likely alter the effects of input-output prices on the opportunity cost in the competing enterprises, as well as changing the production possibility curve.

The institutional settings within which farmers work greatly influence the farmers' response to price changes. If uncertainty is reduced due to institutional change, it is expected that farmers respond more to price changes, *vice versa* for an increase in uncertainty.

In general, we can say that the changes in market conditions cause the shift of the supply curve, 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 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.

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. Farmers may respond to the larger change in input price more than or less than the linear coefficient of input price shows, so that a linear equation is not an adequate model beyond a certain range of input price, while on the other hand, the structural change can be well approximated by a linear equation if its effect is primarily to shift supply, and has little effect on the coefficient. In order to decide if a linear equation can approximate the supply relations of poultry products, we should know the influence of the specific factors which affect poultry supply.

C. Factors Affecting Supply

The next step is the determination of the specific variables to be included in the supply analysis of poultry products. Variables for the market conditions are readily available in official statistics. We use the price of poultry feed as representing the price of the main input for poultry production. The price of feed is used for the same reason that the feed conversion rates are chosen for the indicators of poultry technology. That is, feed comprises the major portion of variable cost, and farmers are likely to respond to the change in feed cost almost exclusively.

As for enterprises which compete with egg production, hogs and broilers are selected for this study. Eggs are selected as an enterprise to compete with broiler production, and eggs and broilers are selected as enterprises to compete with turkey production. These enterprises are the ones which may possibly affect the respective enterprises of the poultry industry in a nationally appreciable magnitude. Hogs are the most important enterprise which may compete against eggs among non-specialized family farms. Broilers
and eggs are competitive among specialized broiler growers. Eggs and turkeys or broilers and turkeys are in a competitive relation. However, turkey production is relatively a minor enterprise in the poultry industry. Turkeys won't give a nationally appreciable effect on broilers and eggs, although turkeys may be affected by eggs or broilers. There are several more enterprises which may compete against poultry, such as milk cows and cattle feeding, but probable multicollinearity limits the number of variables in an equation.

Variables for the structural conditions are generally difficult to obtain. However, we have the technology of poultry production quantified. The problem is how the technology affects the supply relations of poultry products. The answer to this question determines the way to incorporate the technology indices into supply models.

It must be remembered that the technology indices of poultry production 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 output-input ratios are fairly uniform over a wide range of input. The number of eggs per layer will stay about the same as farmers increase their flocks. High laying hens usually require more care. Increase in the rate of lay may become smaller when the size of flock becomes so large that farmers cannot take sufficient care of the hens. But the range of constant improvement in efficiency must be wide. The feed conversion rates will also be uniform, because the number of production units, namely birds, varies almost in proportion to feed input. Therefore, technological progress reflected in the technology indices will raise the production functions in parallel fashion. Parallel shifts of the production
functions cause the shifts of supply functions rather than the changes in supply coefficients. Then, the effects of technological progress on poultry supply can be formulated in a linear equation.

D. Structural Changes in Poultry Supply Relations

The dominant effects of technological progress in poultry production are those of shifting supply. But we cannot neglect its effects on the coefficients or elasticities of supply. Also, besides technological changes, other structural conditions such as institutional settings affect the supply coefficients.

It is mentioned in the previous chapter that the poultry technology indices also represent mechanical innovations. These indices reflect the changes in the institutional settings, too, because technological progress has been a primary factor in changing the institutional settings. The tendency towards specialization and concentration in the poultry industry is brought about by technological progress. As number of poultry farms decreases, and as their size increases, farmers can obtain better information and stronger bargaining power. This change reduces the market uncertainty for the farmers. Technological progress thus affects the supply coefficients or elasticities directly by changing the production functions, and indirectly through altering the institutional settings.

If these direct and indirect effects of technological progress on the supply coefficients are of appreciable magnitude, it is necessary to incorporate the technology indices into the supply models in such a way that their effects can be evaluated.
The first step is to see if any change has occurred in the supply coefficients. A whole period is divided into the relatively homogeneous sub-periods, and the supply relations are approximated by a linear equation in each sub-period. Comparing the supply elasticities in different sub-periods, any change which may have occurred over time can be seen. If there is a significant change between sub-periods, how the change is related to technological progress must be determined. The following formulation evaluates the change in the elasticities due to technological progress.

Suppose a linear supply function,

\[(4.7) \quad Q = a \cdot bP\]

where \(Q\) is the quantity supplied and \(P\) is the price offered. Assuming the supply coefficient, \(b\), as a linear function of technology index, \(R\),

\[(4.8) \quad B = c \cdot dR\]

This equation shows that the supply coefficient, \(b\) (elasticity if \(P\) and \(Q\) are logarithmic) changes by \(d\) for a unit change of technology index, \(R\). Substitute equation \(4.8\) to \(b\) of equation \(4.7\),

\[(4.9) \quad Q = a \cdot (c \cdot dR)P\]

This equation is transformed into an equation for estimation,

\[(4.10) \quad Q = a \cdot cP \cdot d \cdot (RP)\]

Now the coefficients of variables, \(P\) and \((RP)\), are readily estimated by the standard methods for estimating a linear equation.
E. Forms of Equations and Variables

A linear equation for estimation is linear in coefficients, but not necessarily in variables. The specific forms to use for variables should be determined.

The factors affecting supply are already specified. It is theoretically possible to include all these factors--prices of input and output, technology indices, prices of input and output in the competing enterprises--as independent terms in a linear equation. However, it is desirable for estimation to reduce the number of variables in an equation as much as possible. Since the number of observations is limited for time series data, it is desirable to save some degrees of freedom by reducing the number of variables. This is particularly important when a whole series of data is divided into small segments. Another consideration concerns multicollinearity. Correlation between prices is very common because prices tend to move together through business cycles. Technology indices of two or more enterprises are correlated through their upward trends.

With these considerations the effect of feed price on supply is adjusted by deflating output price by feed 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. By the deflation and the synthesis of variables the information which may be obtained by using each variable as an independent term in an equation will be lost. But these transformations are justified in terms of possible gain over possible loss.
The original observations are transformed into the logarithmic forms. The logarithmic transformation of variables is used because of its convenience in interpreting the estimates. The coefficients of a logarithmic function are the coefficients of elasticities. This characteristic in logarithmic transformations is particularly helpful in evaluating the change in the structure of supply because it is the elasticity or the relative change of output to price rather than the absolute change that characterizes the structure of supply.

One of the limitations for logarithmic functions is the constant elasticity over the entire range. However, this limitation does not seem serious enough to deny the use of the logarithmic functions. Constant elasticity can be a good approximation for the purpose of prediction within a limited range. Any other mathematical functions are based on equally unrealistic assumptions. Unless it is shown that the other forms of variables have some definite advantages, the logarithmic forms are preferred for their convenience in interpretation.

F. Methods of Estimation: Single Equation vs Simultaneous Equations

The single equation least-squares has been traditionally used for estimating a linear equation. It is assumed in applying the least-squares that one variable can be singled out in one side of the equation so as to be unilaterally dependent on the other variables. One of the conditions necessary for the least-squares to generate the unbiased estimates of parameters is that the variables used as regressions are measured without error, and error only appears in the variable which is singled out as being
dependent. This is a condition generally met in the analysis by experimental data. By experiment we can measure the effect of one variable on another in a purely causal fashion. The least-squares as applied to experimental data is considered as a logical prototype (65, p. 35) of the least-square analysis in general.

Least-square estimation as applied to economic time series data will provide the unbiased estimates, if the condition is satisfied. But there are very few economic variables which are strictly independent. In most economic relations two or more variables are simultaneously determined.

Haavelmo (22) showed the least-squares, if applied to the relation of simultaneous determination, will generate asymptotically biased estimates. If two variables are simultaneously determined, we cannot single out a particular variable to be unilaterally dependent on others. Both variables are subject to error. Haavelmo insists that most economic relations should be formulated in terms of a system of equations, and the equations in the system should be estimated simultaneously. This is not the place to explore the theory of simultaneous equation estimation, developed by the Cowles Commission (36). It is only pointed out that the simultaneous equation method provides the asymptotically unbiased estimates.

The question arises as to which method to use for estimating the supply relations of poultry products. Price and quantity of a product are simultaneously determined at an equilibrium of demand and supply. The simultaneous equation method may seem adequate for estimating the supply relations. However, Fox (15) shows that the single equation least-squares is generally appropriate for the analysis of agricultural products. 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 outputs are the prices of the previous period. Once crops are planted, or livestock are farrowed, there is not much room left for the farmers to adjust output. The prices in the previous period affect the output in the present period, but are not affected by the output in the present period. In other words, the prices in the previous period are predetermined for the output in the present period.

Some degree of simultaneity may be brought in by the adjustment during a production period. But usually the adjustment is relatively small, and would not produce appreciable bias in the least-square estimates.

There is no general criterion in choosing which method should be used. It should be determined in reference to the nature of the specific problem on one hand, and the limitation of research resources on the other. The computational burden of simultaneous equation estimation is much greater than the estimation by the single equation least-squares. Moreover, though the simultaneous equation method is theoretically superior, the single equation method usually provides the better estimates for predictions.

The simultaneity in the demand and supply of the poultry products is considered in the empirical analysis. As we closely examine the poultry productions, we find distinct seasonalities in them, except in broilers. These seasonalities and the certain time lags between farmers' plans and their outcomes make it valid to use the traditional single equation least-square method in the supply 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 provides meaningless results.

G. Distributed Lags and Long-Run Elasticity of Supply

In the time series analysis of supply relations we have to consider time as one of the crucial elements. Farmers make their decisions about production not instantaneously but over a length of time. In considering the farmers' response over time, the problems of time lag in production adjustment and of the expectation about future market, arise.

The importance of farmers' expectation is stressed in presenting Nerlove's expectation model in Chapter II. If a certain pattern of farmers' expectation is assumed, the problem becomes one of how farmers adjust production in response to price over time.

Supply elasticities can be classified on the basis of length of time needed for adjusting inputs. A supply elasticity over a period which is 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 the length of time, so short that all inputs cannot be altered. The short-run elasticities are ranged from zero to the long-run elasticity, depending on what inputs are fixed.

The supply elasticity we estimate from the time series data is one of these short-run elasticities. Long-run elasticities are not measurable directly from time series data, but can be estimated indirectly by setting up a certain model of distributed lags in the farmers' adjustment of production.
Koyck (38) suggests a model of distributed lags for statistical estimation. His method is as follows: Suppose a general model of distributed lags for supply is formulated as,

\[(4.11) \quad Q_t = a + b_0 P_t + b_1 P_{t-1} + b_2 P_{t-2} + \cdots \]

where \(Q_t\) and \(P_t\) are output and price at a period \(t\). If the variables in equation 4.11 are logarithmic, the long-run price elasticity of supply is

\[(4.12) \quad E_l = \sum_{i=0} b_i \]

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

\[(4.13) \quad b_k = \delta b_{k-1} \quad 0 < \delta < 1 \]

It follows from equation 4.11 and 4.13 that

\[(4.14) \quad Q_t = a + b_0 P_t + b_0 \delta P_{t-1} + b_0 \delta^2 P_{t-2} + \cdots \]

If we lag equation 4.14 by one period, and multiply it by \(\delta\), we get

\[(4.15) \quad \delta Q_{t-1} = a \delta + b_0 \delta P_{t-1} + b_0 \delta^2 P_{t-2} + \cdots \]

By subtracting equation 4.15 from equation 4.14, we obtain,

\[(4.16) \quad Q_t = a (1 - \delta) + b_0 P_t + \delta Q_{t-1} \]

Equation 4.16 is readily estimated statistically and the long-run price elasticity of supply is given by

\[(4.17) \quad E_l = \sum_{i=0} \delta^i b_0 = \frac{b_0}{1 - \delta} \]
Koyck derives the model for estimating distributed lags and long-run elasticities from a general form of distributed lags. Nerlove (44) arrives at the same model 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

\[(4.18)\quad Q_t - Q_{t-1} = \gamma (Q_t^* - Q_{t-1})\]

where \(Q_t\) and \(Q_t^*\) are an actual output and a long-run equilibrium output at period \(t\) and \(\gamma\) is the coefficient of adjustment. Equation 4.18 shows that in each period producers adjust output in proportion to the difference between the actual output and the long-run equilibrium output. Assuming the static expectation of producers, a long-run supply function is written as

\[(4.19)\quad Q_t^* = a \cdot bP_t\]

where \(b\) is the long-run elasticity of supply. By substituting equation 4.19 to 4.18, we obtain

\[(4.20)\quad Q_t = a \gamma \cdot b \gamma \cdot P_t \cdot (1 - \gamma) \cdot Q_{t-1}\]

Equation 4.20 has exactly the same form as equation 4.16, if we replace for \((1 - \gamma)\) and \(b_0\) for \(b \gamma\). If variables are logarithmic, the long-run elasticity of supply is given by

\[(4.21)\quad E_l = \frac{b}{1 - (1 - \gamma)} = b\]

The Koyck-Nerlove method of estimating the long-run elasticity is based on the assumption of a static expectation. Nerlove elaborates a method of incorporating the expectation model of equation 2.1 presented in Chapter II into supply analysis. In this study, however, the long-run supply elas-
ticities of poultry products are estimated, assuming a static expectation of farmers. It is desirable to incorporate farmers' expectation into the model, but the statistical complication is much greater, especially when the number of variables becomes large. This study is primarily aimed at the inclusion of technology into supply analysis. As was mentioned, it is difficult to analyze all factors affecting supply at the same time.

The importance of farmers' expectation cannot be overemphasized, but considering the primary purpose of this study the expectation problem is discarded.

H. Single-Step Analysis vs Multi-Step Analysis

In economic theory, supply is treated as one of the unit structural relations. A unit structural relation means that two variables are related directly, not indirectly through some intermediate variables. In supply, quantity supplied is related directly to price offered.

In reality there are several steps in going from price offered to quantity supplied. Take an example of eggs. Other conditions being given, for a certain price offered for eggs, farmers decide the number of pullets raised. The number of pullets raised determines the number of layers on farm. The number of layers largely determines the output of eggs.

As far as the relation in each step remains the same, the direct association between price offered and quantity supplied is adequate in finding a relation which makes it possible to predict quantity supplied in the future. This relation is something like the relation between power generated by an engine and the speed of a car. With a fixed gear, the speed of
a car is directly determined by power generated by an engine. Without knowledge of the transmission system, the speed of the car is known for a given power of the engine. However, if the gear can be changed, we cannot know the speed of a car without knowledge about the transmission system.

The same thing can be said about a supply relation. If the intermediate relations between price offered and quantity supplied may change, the simple association between price and quantity will not give us information useful for prediction. Take for example the farm chicken supply. Assuming farm chickens are a by-product of eggs, the quantity of farm chickens supplied is determined by the price of eggs. Egg price determines the number of pullets raised. The number of cockerels raised is given as a certain fraction of pullets raised. Cockerels raised, together with hens culled, determine the output of farm chickens. For the past three decades the ratio between the number of pullets and the number of cockerels raised has been changed greatly, due to the development of sexing practice. As a result, the response of farm chicken production to egg price has changed. The simple association between the quantity of farm chickens supplied and egg prices does not provide useful information for us.

Then, it may appear more appropriate to include, in the model for analysis, every possible step from price offered to quantity supplied. It is, however, impossible to carry the division of a process to the extreme because theoretically there are an infinite number of possible steps. For example, the number of pullet chicks purchased or raised in a certain day will determine the number of pullets for the next day, which will determine the number of pullets the day after the next.

It is only possible to divide the process into a feasible number of
steps of practical significance. Whether a particular division of a process is practically significant can be judged in terms of the accuracy in prediction. Therefore, how a process should be divided is determined in reference to the nature of a problem, and the purpose of an analysis.

In quantitative analysis the reason why a relation like supply or demand is treated as a unit structural relation is not necessarily because there is no change in the intermediate steps. Rather, it is because the magnitude of the change is not large enough to cause a significant error in prediction. Also, there are cases where the data are not available for analyzing the intermediate steps. Or the data, even if available, may not be so accurate that the prediction is better performed by the model of a unit structural relation.

In general, the simpler the model is, the better. The following remark of Friedman (17, p. 14) clarifies the point:

A hypothesis is important, if it explains much by little, that is, if it abstracts the common and crucial elements from the mass of complex and detailed circumstances surrounding the phenomena to be explained, and permits valid predictions on the basis of them alone.

the treatment of supply as a unit structural relation is one of the devices to abstract the common and crucial elements from the mass of complex phenomena. For this reason a simple association between price offered and quantity supplied is used as a fundamental model for supply analysis.

However, in many cases the analysis of intermediate steps is a useful subsidiary. And if the changes in intermediate steps are supposed to be crucial like the case of farm chicken supply, it is necessary to perform the multi-step analysis.
V. EMPIRICAL ANALYSIS: EGGS AND FARM CHICKENS

A. Presentation of Model

The model used for the empirical analysis of eggs and farm chickens can be deduced from the relations shown in Fig. 12. The figure contains the relations which are supposed to be crucial for understanding the supply of eggs and farm chickens at the farm level. These relations in the figure are presented in such a fashion that the diagrammatical presentation can be converted directly to mathematical models for estimation.

Two models for the different approaches are constructed from the relations presented in Fig. 12.

Model for single-step analysis of egg supply

\[
Q_e = f \left[ \left( \frac{P_e}{P_f} \right), \left( \frac{P_e'}{P_{f_t-l}} \right), \left( \frac{P_c}{P_f} \right), E_{ht-l}, E_{bt-l}, R_e \right]
\]

Model for multi-step analysis of egg and farm chicken supply

Pullet raising

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

Cockerel raising

\[
X_k = \phi X_p
\]
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.

Fig. 12. Relations in egg supply
Hen culling

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

Pullet culling

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

Counting of young farm chickens produced

\[ X_{y.c} = X_k  \times X_n - X_d  \times X_{p.c} \]

Output of farm chickens

\[ Q_c = W_m \times X_{h.c} + W_y \times X_{y.c} \]

Counting of average number of layers on farm

\[ X_l = X_h  \times X_p - X_{h.c} - X_{p.c} - X_r \]

Output of eggs

\[ Q_e = R \times X_l \]

Variables in the models are:

\[ \frac{P_e}{P_f} \] : Egg-feed price ratio, year average.

\[ \frac{P_e}{P_f}' \] : Egg-feed price ratio, November-May weighted average. Weights are: for November -- 1, December -- 2, January -- 3, February -- 4, March -- 5, April -- 3, May -- 1.
\[
\frac{P_c}{P_f} : \text{Chicken-feed price ratio, year average.}
\]

\[E_h : \text{Hog profitability index, average of hog-corn price ratio for October, November and December in the previous year.}\]

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

\[Q_e : \text{Number of eggs produced in a year (billion).}\]

\[Q_c : \text{Quantity of farm chickens produced, liveweight (million pounds).}\]

\[R_e : \text{Technology index of egg production.}\]

\[R : \text{Average number of eggs per layer.}\]

\[X_{k} : \text{Number of cockerels raised (million).}\]

\[X_{p} : \text{Number of pullets raised (million).}\]

\[X_{h} : \text{Number of hens and pullets on farm, January 1 (million).}\]

\[X_{n} : \text{Number of cockerels on farm, January 1 (million).}\]

\[X_{h.c} : \text{Number of hens culled (million).}\]

\[X_{p.c} : \text{Number of pullets culled (million).}\]

\[X_{d} : \text{Number of cockerels lost (million).}\]

\[X_{l} : \text{Average number of layers on farm (million).}\]

\[X_{r} : \text{Residual in counting the number of layers (million).}\]

\[W_m : \text{Average weight of mature chickens, liveweight (pounds).}\]

\[W_y : \text{Average weight of young chickens, liveweight (pounds).}\]

The following is the logic in constructing the models.
1. Composition of the enterprise

In this study it is assumed that farm chickens, but not broilers or fryers produced independently by specialized farmers, are a by-product of eggs. It implies that farmers determine the output of eggs and the output of farm chickens in response to the price of eggs but not the price of farm chickens. This assumption is a device to reduce the greatest complexity involved in the egg-farm chicken production.

It is a characteristic feature of the enterprise that eggs and farm chickens are produced as joint products. The formulation of the multi-product enterprise is far more complicated than that of the single-product enterprise, and is difficult to estimate statistically.

The assumption that farm chickens are the by-product of eggs is not without logical basis. The cash receipt from marketing farm chickens has rarely exceeded one-fourth of the total cash income generated from the eggs and farm chickens. And the relative importance of farm chickens to eggs has been decreasing. Today the total value product of farm chickens is around 10 percent of the total value product of eggs. For this relative importance of eggs, it is not too inaccurate to suppose that farmers determine the output of eggs mainly in response to the profitability of eggs.

The decline in the relative importance of farm chickens to eggs is due to the development in poultry technology, especially the practice of chicken-sexing. The number of cockerel chicks raised in proportion to that of pullet chicks raised has declined appreciably. Until sexing was introduced, the number of cockerels raised should have been, on the average, 50 percent of the total number of chickens raised. Today it is around 20
percent.

The change in the percentage of chicks sexed can be formulated as a process of a new technique being accepted by farmers. The process is essentially no different from the acceptance process of other techniques in agricultural production, like hybrid seeds, fertilizers and insecticides.

According to Griliches (20), the percentage of total corn acreage planted with hybrid corn seeds has increased in each region of the United States in such a fashion that it can well be approximated by a logistic curve. Pullet chicks sexed as a percentage of total chicks purchased by farmers are plotted over time in Fig. 13. Available series of data 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 0 as a lower asymptote and 100 as an upper asymptote. The result of estimation is

\[
S = \frac{100}{1 + 54.1e^{-0.1285t}}
\]

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. 13.

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
Fig. 13. 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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of chickens raised</th>
<th>Sexed pullets as a percentage of chicks purchased</th>
<th>Sexed cockerels as a percentage of chicks purchased</th>
<th>Straight-run chicks as a percentage of chicks raised</th>
<th>Sexed pullets run</th>
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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 (2) by 1/5. 1/5 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(4) = 100 - (2) - (3).
d(5) = (1) . (2).
e(6) = 1/5 (1) . (4).
f(7) = (5) * (6).
g(8) = (1) - (7).
Table 2. Continued

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<th>Sexed cockerels as a percentage of chicks purchased (3)b (million)</th>
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<th>Sexed pullets (5)d (million)</th>
<th>Straight-run cockerels raised (6)e (million)</th>
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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.

2. Relations of raising pullets and cockerels

The relation of 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 is determined by the prices of input and output 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 indices of hogs and broilers are chosen for the variables in the model on the basis of what is discussed in Chapter IV.

The problem is what periods should be chosen for the observation of these variables. There is a definite seasonal pattern in pullet-raising, the majority of chicks being hatched during the spring months, especially March, April and May. Before 1940, about 80 percent of the chicks were hatched during these three months, and more than 90 percent during the first half of the year. Though this seasonality has been gradually leveling off due to the recent specialization tendency, 70 to 80 percent of the chicks are still being hatched during the first six 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 seven months, November of the previous year to May of the present year, are averaged with weights. The same period is chosen for the broiler profitability index.
But before 1953, when monthly broiler data are not available, the average of the present year's price and the previous year's price is used as a substitute for the seven month weighted average. October, November and December are chosen for the period of observation for the hog profitability index. These three months are the period in which the winter farrowing of sows is determined.

The seasonality in pullet raising and the resulting specification of the observation periods have very important implications for estimation. 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 two or three months of lay, and the quantity of eggs produced by the spring-hatched pullets during the spring months would not be appreciable in its 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 does not affect the output in the hatching season itself. The relation between the number of pullets raised and the prices in spring is unilateral rather than simultaneous. For this reason the single equation least-squares is 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 is formulated in equation 5.3. The cockerel-pullet ratio, , in equation 5.3 can be derived from the procedures for estimating the number of pullets and cockerels in table 2 in the previous section.

The number of cockerels, , is, by definition, obtained by subtract-
ing the number of pullets, \( X_p \), from the total number of chickens raised, \( X_c \),

\[(5.11) \quad X_k = X_c - X_p \]

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

\[(5.12) \quad X_p = sX_c + \frac{1 - s - k}{2} X_c \]

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. \( s \) is obtained from the logistic function estimated in equation \( 5.10 \).

Sexed cockerels have occupied 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 five years can be extrapolated as a rough approximation.

Equation \( 5.12 \) can be transformed into

\[(5.13) \quad X_p = \frac{1 - s - k}{2} X_c \]

Solving equation \( 5.13 \) for \( X_c \),

\[(5.14) \quad X_c = \frac{2X_p}{s - k} \]

By substituting equation \( 5.14 \) into equation \( 5.11 \), we obtain

\[(5.15) \quad X_k = \left( \frac{2}{s - k} \right) X_p = X_p \]
The cockerel-pullet ratio is thus derived from the percentage of chicks sexed.

3. 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 in four months after being hatched, and the rate of lay increases until it reaches the peak at about twelve months. After that, the rate of lay 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 depends on how many hens and pullets are on the farm at the beginning of the year. The data are reported for the number of hens and pullets on the farm, January 1. The other factors 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 farm, January 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.

However, this simultaneity would not 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 about whether they should cull hens or not. Moreover, the effect of culling on the output of eggs should be discounted because the hens culled are low-laying.

Baker (1) 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 year 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 crop year.

Hence, even if the prices 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-square estimates. The least-squares seems sufficient for analyzing the hen-culling relation, too.

As is mentioned, culling becomes a problem usually after hens are kept for one year or longer. However, every year a small fraction of pullets raised is culled for home consumption. A few are sorted out 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 when the market situation is unfavorable for eggs or
favorable for chickens. In order to test whether market situations affect the 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.

4. Counting relations

The output of eggs and the output of farm chickens are primarily determined by the relations of raising and culling chickens. In order to connect the outputs to the number of chickens raised and culled, we have to 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. We assume that on the farm mature birds are hens culled, and young birds are cockerels raised and pullets culled.

Data are reported for the number of young birds and the number of mature birds sold from farms. The number of young birds and the number of mature birds consumed on the farm where produced are estimated by multiplying the total number of chickens consumed on the farm where produced by the percentage of young birds sold and the percentage of mature birds sold 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. The procedures of estimation 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 January 1 and pullets culled minus the number of cockerels lost by death. Cockerels lost during the year are estimated in Table 4. The procedures of 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 up the number of young chickens produced multiplied by the average weight of young chickens and 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 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, January 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
Table 3. Numbers of young and mature chickens produced: estimation procedures from reported data on chickens sold and consumed on farm where produced, 1931-58.

<table>
<thead>
<tr>
<th>Year</th>
<th>Chickens sold</th>
<th>Chickens consumed</th>
<th>Estimated number of chickens produced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young (m)</td>
<td>Mature (m)</td>
<td>Percentage</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
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<td>245.1</td>
<td>183.5</td>
<td>57.2</td>
</tr>
<tr>
<td>1931</td>
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</tr>
<tr>
<td>1932</td>
<td>260.7</td>
<td>180.4</td>
<td>59.1</td>
</tr>
<tr>
<td>1933</td>
<td>220.0</td>
<td>183.3</td>
<td>54.5</td>
</tr>
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<td>1934</td>
<td>217.9</td>
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</tr>
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<td>235.4</td>
<td>159.6</td>
<td>59.5</td>
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<td>173.8</td>
<td>50.6</td>
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<td>141.3</td>
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</tr>
<tr>
<td>1938</td>
<td>217.2</td>
<td>159.4</td>
<td>57.7</td>
</tr>
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\[a(3) = \frac{(1)}{(1) \cdot (2)}\]

\[b(4) = \frac{(2)}{(1) \cdot (2)}\]

\[c(6) = (3) \cdot (5)\]

\[d(7) = (4) \cdot (5)\]

\[e(8) = (1) \cdot (6)\]

\[f(9) = (2) \cdot (7)\]
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<tr>
<th>Year</th>
<th>Chickens sold</th>
<th>Chickens sold</th>
<th>Chickens consumed on farm where produced</th>
<th>Estimated number of chickens produced</th>
</tr>
</thead>
<tbody>
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<td>Mature (million)</td>
<td>Percentage of young chickens (%)</td>
<td>Percentage of mature chickens (%)</td>
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</tr>
<tr>
<td>1941</td>
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<td>175.5</td>
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</tr>
<tr>
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<td>139.6</td>
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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.

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<tr>
<th>Year</th>
<th>Chickens raised (1)</th>
<th>Chickens lost (2)</th>
<th>Rate of loss (3)</th>
<th>Cockerels raised on farm (4)</th>
<th>Cockerels lost on January 1 (5)</th>
<th>Estimated loss of cockerels (6)</th>
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</thead>
<tbody>
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<td>1930</td>
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<td>353.4</td>
<td>51.0</td>
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<tr>
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<td>98.1</td>
<td>18.4</td>
<td>21.7</td>
</tr>
</tbody>
</table>

\(a(3) = \frac{(2)}{(1)}\).

\(^b\)Estimated in Table 2.

\(^c\)(6) = (3) \cdot (4) \cdot (5).\)
Table 5. Number of pullets culled: estimated as residuals in counting young chickens produced, for 1931-58.

<table>
<thead>
<tr>
<th>Year produced</th>
<th>Young chickens raised (1)a</th>
<th>Cockerels on farm January 1 (2)b</th>
<th>Cockerels (3)</th>
<th>Loss of cockerels (4)c</th>
<th>Estimated number of pullets culled as residual (5)d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
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*a Estimated in Table 3.

*b Estimated in Table 2.

*c Estimated in Table 4.

\[ d(5) = (1) - \left[ (2) \times (3) - (4) \right] . \]
of such items as the loss by death, the pullets which do not reach the age of laying and the errors in estimation. The layer counting relation is shown in Table 6.

5. Model for single-step analysis

The preceding discussions explain the logic in constructing the model for multi-step analysis. The model for 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 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 in order to avoid the 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 average 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
Table 6. Counting of average number of layers on farm during a year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Layers on farm during a year on farm, January 1</th>
<th>Hens and pullets raised during a year</th>
<th>Hens culled</th>
<th>Pullets culled</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>303.0 (1)</td>
<td>243.6 (2)</td>
<td>366.8 (3)</td>
<td>282.3 (4)</td>
<td>21.2 (5)</td>
</tr>
<tr>
<td>1931</td>
<td>299.1</td>
<td>229.6</td>
<td>382.1 (2)</td>
<td>270.6 (4)</td>
<td>24.4 (5)</td>
</tr>
<tr>
<td>1932</td>
<td>299.7</td>
<td>236.7</td>
<td>391.9 (2)</td>
<td>284.4 (4)</td>
<td>33.4 (5)</td>
</tr>
<tr>
<td>1933</td>
<td>290.7</td>
<td>238.3</td>
<td>338.3 (2)</td>
<td>283.0 (4)</td>
<td>21.1 (5)</td>
</tr>
<tr>
<td>1934</td>
<td>276.4</td>
<td>211.8</td>
<td>347.9 (2)</td>
<td>236.0 (4)</td>
<td>30.5 (5)</td>
</tr>
<tr>
<td>1935</td>
<td>284.9</td>
<td>226.4</td>
<td>380.1 (2)</td>
<td>254.9 (4)</td>
<td>33.5 (5)</td>
</tr>
<tr>
<td>1936</td>
<td>288.0</td>
<td>249.3</td>
<td>332.0 (2)</td>
<td>280.0 (4)</td>
<td>9.3 (5)</td>
</tr>
<tr>
<td>1937</td>
<td>275.9</td>
<td>215.0</td>
<td>351.4 (2)</td>
<td>240.0 (4)</td>
<td>13.1 (5)</td>
</tr>
<tr>
<td>1938</td>
<td>289.6</td>
<td>241.8</td>
<td>379.7 (2)</td>
<td>254.4 (4)</td>
<td>26.4 (5)</td>
</tr>
<tr>
<td>1939</td>
<td>296.6</td>
<td>253.6</td>
<td>348.8 (2)</td>
<td>275.6 (4)</td>
<td>5.7 (5)</td>
</tr>
<tr>
<td>1940</td>
<td>300.9</td>
<td>239.9</td>
<td>414.6 (2)</td>
<td>225.7 (4)</td>
<td>52.9 (5)</td>
</tr>
<tr>
<td>1941</td>
<td>341.6</td>
<td>277.7</td>
<td>492.7 (2)</td>
<td>244.5 (4)</td>
<td>85.4 (5)</td>
</tr>
<tr>
<td>1942</td>
<td>383.0</td>
<td>318.6</td>
<td>559.8 (2)</td>
<td>309.6 (4)</td>
<td>112.6 (5)</td>
</tr>
<tr>
<td>1943</td>
<td>395.8</td>
<td>349.6</td>
<td>480.1 (2)</td>
<td>344.5 (4)</td>
<td>88.4 (5)</td>
</tr>
<tr>
<td>1944</td>
<td>369.4</td>
<td>301.5</td>
<td>506.2 (2)</td>
<td>309.0 (4)</td>
<td>100.3 (5)</td>
</tr>
<tr>
<td>1945</td>
<td>357.6</td>
<td>322.1</td>
<td>434.9 (2)</td>
<td>327.4 (4)</td>
<td>65.7 (5)</td>
</tr>
<tr>
<td>1946</td>
<td>345.1</td>
<td>281.0</td>
<td>437.0 (2)</td>
<td>281.3 (4)</td>
<td>90.8 (5)</td>
</tr>
<tr>
<td>1947</td>
<td>331.6</td>
<td>278.0</td>
<td>386.0 (2)</td>
<td>274.8 (4)</td>
<td>52.4 (5)</td>
</tr>
<tr>
<td>1948</td>
<td>330.7</td>
<td>258.3</td>
<td>447.8 (2)</td>
<td>244.7 (4)</td>
<td>97.4 (5)</td>
</tr>
<tr>
<td>1949</td>
<td>339.5</td>
<td>286.8</td>
<td>393.6 (2)</td>
<td>275.2 (4)</td>
<td>61.9 (5)</td>
</tr>
<tr>
<td>1950</td>
<td>327.8</td>
<td>258.2</td>
<td>398.7 (2)</td>
<td>249.8 (4)</td>
<td>72.5 (5)</td>
</tr>
<tr>
<td>1951</td>
<td>320.5</td>
<td>261.4</td>
<td>370.3 (2)</td>
<td>243.0 (4)</td>
<td>73.1 (5)</td>
</tr>
<tr>
<td>1952</td>
<td>312.1</td>
<td>237.6</td>
<td>375.1 (2)</td>
<td>237.8 (4)</td>
<td>60.2 (5)</td>
</tr>
<tr>
<td>1953</td>
<td>314.2</td>
<td>255.1</td>
<td>386.1 (2)</td>
<td>235.6 (4)</td>
<td>74.0 (5)</td>
</tr>
<tr>
<td>1954</td>
<td>309.1</td>
<td>257.2</td>
<td>330.3 (2)</td>
<td>226.9 (4)</td>
<td>32.9 (5)</td>
</tr>
<tr>
<td>1955</td>
<td>309.9</td>
<td>238.6</td>
<td>349.4 (2)</td>
<td>219.1 (4)</td>
<td>41.7 (5)</td>
</tr>
<tr>
<td>1956</td>
<td>304.8</td>
<td>250.0</td>
<td>305.6 (2)</td>
<td>223.0 (4)</td>
<td>19.0 (5)</td>
</tr>
<tr>
<td>1957</td>
<td>301.3</td>
<td>224.6</td>
<td>337.7 (2)</td>
<td>210.7 (4)</td>
<td>34.3 (5)</td>
</tr>
<tr>
<td>1958</td>
<td>296.6</td>
<td>243.6</td>
<td>366.8 (2)</td>
<td>282.3 (4)</td>
<td>21.2 (5)</td>
</tr>
</tbody>
</table>

*a* Estimated in Table 2.

*b* Estimated in Table 3.

*c* Estimated in Table 5.

\[ d(6) = (2 \times (3) - (4) - (5)) - (1) \]
supply of farm chickens, the change in the intermediate relations due to sexing practice is so great as to make meaningless the simple association between the output of farm chickens and the price of eggs.

5. Modification of models

The models presented so far are constructed on the basis of a priori knowledge. Some variables may be found to be insignificant, or to have large multicollinearity with other variables. It may happen that the results of estimation suggest some additional variables are needed. The models are modified in reference to the results of estimation.

B. Single-Step Analysis of Egg Supply

The result of estimation of equation 5.1 for 1926-58 is

\[
\log Q_e = -3.5179 + .2052 \log \left( \frac{P_e}{P_f} \right) + .4879 \log \left( \frac{P_e}{P_f} \right)_t - 1 + .1133 \log \left( \frac{P_e}{P_f} \right) + .3257 \log \left( \frac{P_c}{P_f} \right) + .0507 \log E_{b_{t-1}} \\
- .1934 \log E_{b_{t-1}} + 1.6534 \log R_{e_{t-1}} \quad R^2 = .9779
\]

In this estimate the coefficients of \( \log \left( \frac{P_e}{P_f} \right) \) and \( \log \left( \frac{P_e}{P_f} \right)_{t-1} \) 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 seasons of the previous year, and of the present year on the output of eggs through the raising of pullets. The coefficient of the lagged value of \( \left( \frac{P_e}{P_f} \right)_t \) is estimated to be larger than that of the present value. This conforms with
the knowledge that pullets raised in a year lay eggs mainly in the following year.

The coefficient of \( \log\left( \frac{P_e}{P_f} \right) \) is considerably smaller than that of \( \log\left( \frac{P_e}{P_f} \right) \) and is significant at a probability level of less than 30 percent. This means that the effect of egg price through culling hens is much smaller than through raising pullets. The positive sign in the coefficient of \( \log\left( \frac{P_c}{P_f} \right) \) seems to reject the hypothesis that farmers cull more hens when the chicken price is favorable. However, the positive sign is likely caused by the positive correlation between the output of eggs and the price of farm chickens through the business cycle of national economy.

Both the hog profitability index and the broiler profitability index have positive coefficients. It seems that hogs and broilers are not the main products competing with eggs. However, these positive coefficients are also explained by positive correlations between the variables and the output of eggs due to the business cycle and the trend of the economy. Especially the upward trends in the broiler profitability index and in the output of eggs must cause a high correlation between them, resulting in the positive coefficient which is statistically significant at the 1 percent level.

The coefficient of \( \log R_e \) is large in value and also highly significant, which indicates farmers have responded strongly to the technological progress in expanding production. This supports the hypothesis that technological progress is the most important factor in the development of egg production.

In order to see the effects of competing enterprises by removing
possible multicollinearity, the model is estimated after \( \frac{P_e}{P_f} \) and \( \frac{P_c}{P_f} \) are dropped,

\[
(5.17) \quad \log Q_e = -2.2270 \times 0.3242 \log \left( \frac{P_c}{P_f} \right) + 0.3750 \log \left( \frac{P_e}{P_f} \right)_{t-1}^\prime \\
+ 0.0772 \log E_h + 0.2201 \log E_b + 1.2011 \log R_e \\
(0.0584) (0.1001) (0.1110)
\]

\[ R^2 = 0.9264 \]

In this estimate, also, the coefficients of \( \log E_h \) and \( \log E_b \) are positive. Judging from the statistical estimation, the competitive relation between eggs and broilers is not strong, at least not strong enough to overcome the positive correlation due to business cycle or trend.

It is reported in Baker's study (1) that the competitive relation between eggs and hogs cannot be found statistically even in Iowa. The competitive relation between these two enterprises is supposedly most prominent in Iowa. If the competitive relation is not found statistically in Iowa, it is rather natural that it cannot be found in the United States as a whole.

The competitive relation between eggs and broilers is becoming important as the broiler industry develops and as broiler growers start considering egg-laying hens as a substitute for broilers. However, the competitive relation between eggs and broilers is a recent phenomenon. Therefore it is not strange that the competitive relation between eggs and broilers cannot be found statistically from the analysis of time series data for 1926-58.

It is expected a priori that the effect of culling hens on the output of eggs is much smaller than that of raising pullets. In order 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 competing enterprises are dropped,

\[(5.18) \quad \log Q_e = -3.5171 + 0.2836 \log \left( \frac{P_e}{P_f} \right) - 0.5219 \log \left( \frac{P_e}{P_f} \right)^{t-1} - 0.0842 \log \left( \frac{P_e}{P_f} \right) + 0.4369 \log \left( \frac{P_c}{P_f} \right) + 1.8658 \log R_e\]

\[R^2 = 0.9674\]

In this estimate the coefficient of \( \log \left( \frac{P_e}{P_f} \right) \) turns out to be negative, though statistically significant only at the 50 percent level. The positive value of the coefficient may be due to the multicollinearity between \( \log \left( \frac{P_e}{P_f} \right) \) and \( \log \left( \frac{P_e}{P_f} \right) \). The coefficient of \( \log \left( \frac{P_c}{P_f} \right) \) has still 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 the pullet-raising more than on the culling of hens. However, it is more plausible 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 the simultaneity causes the bias in the least-square 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,
(5.19) \[ \log Q_e = -2.2430 + 0.3637 \log \left( \frac{P_e}{P_r} \right) + 0.4824 \log \left( \frac{P_e}{P_r} \right)_{t-1} + 1.3898 \log R_e \]

\[ R^2 = 0.9056 \quad d = 0.76 \]

In this estimate the coefficients of all three variables are significant at the 1 percent level, and have signs which do not contradict theory. However, the value of the Durbin-Watson d-statistics 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 we see in Fig. 14, equation 5.19 consistently underestimates the output of eggs for the years from 1941 through 1953, and consistently overestimates it for the years from 1954 on. The consistent underestimation and overestimation for a certain length of period cause the positive serial correlation of residuals. This underestimation and overestimation of the output must be due to the underestimation of the price elasticity of supply for 1941-1953, 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 and this resulted in the dramatic increase in the output of eggs. For the price decline in the early post-war years, the output did not decline as much as it rose during the war. This can be explained by the hypothesis of the irreversible supply curve of Cassels(3) which is explained in Chapter II. The adoption of technology and the investment of fixed capital during the boom of the war could not be reversed when the war was over.

Hence the price elasticity of egg supply was inflated in the booming
Fig. 14. Total number of eggs produced: values of actual observations and estimated values from equation 5.19
period of the war and early post-war years and it 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. The elasticity with respect to \(\frac{P_e}{P}\) in equation 5.19 is an average of the elasticities for different periods. It underestimates the price elasticity for 1941-53 and overestimates the price elasticity for 1954-58. As a result the residuals of equation 5.19 become serially correlated. Therefore, this serial correlation of residuals is expected to decrease if we estimate the model for each of the sub-periods in which the price expectation of farmers is relatively homogeneous.

For the sake of comparison, the model which substitutes time, t, with \(t=1\) at 1926 for the technology index is estimated:

\[
\begin{align*}
\log Q_e &= 1.1405 + .1090 \log \left( \frac{P_e}{P_f} \right) + .1604 \log \left( \frac{P_e}{P_f} \right)_{t-1} \\
&\quad + .2151 \log t \\
R^2 &= .5770 \quad d = .12
\end{align*}
\]

The value of \(R^2\) is markedly reduced, compared to equation 5.19. The coefficients of \(\log \left( \frac{P_e}{P_f} \right)\) and \(\log \left( \frac{P_e}{P_f} \right)_{t-1}\) turn out to be nonsignificant at the 5 percent level. The serial correlation seems extremely high. On those points equation 5.20 is much inferior to equation 5.19 in terms of the results of statistical estimation.

Time is traditionally used as a substitute for the variable of technology for the time series analysis of supply. The intrinsic weakness of using time for representing technological progress is discussed in Chapter III. Here we find the results of estimation also support the advantage of
the use of the technology index over the use of time.

In order to obtain the long-run elasticities of egg supply, the Koyck-Nerlove model is estimated:

\[
\log Q_e = -0.9094 \times 0.1839 \log \left( \frac{P_e}{P_f} \right) - 0.2290 \log \left( \frac{P_e}{P_f} \right) t-1
\]

\[
+ 0.4104 \log P_e - 0.7520 \log Q_e \quad R^2 = 0.9752 \quad d = 0.85
\]

In this estimate the coefficients have signs consistent with theory, and values significant at the 5 percent level. But the value of d-statistics indicates the positive serial correlation in the residuals. The cause of the serial correlations in this estimate must be the same as that of equation 5.19. The long-run elasticities obtained from equation 5.21 are:

- 0.7414 with respect to \( \frac{P_e}{P_f} \) and 0.9234 with respect to \( \frac{P_e}{P_f} \) t-1. These values are reasonable, compared to the short-run elasticities estimated in equation 5.19: 0.3637 with respect to \( \frac{P_e}{P_f} \) and 0.4824 with respect to \( \frac{P_e}{P_f} \) t-1.

C. Evaluation of Structural Change

In Chapter IV the discussion suggested technological changes not only cause the shift of supply, but also generally alter the elasticities of supply. Now the structural change in egg supply due to technological progress must be evaluated.

The first step is to estimate the supply elasticity for two or more sub-periods. The series of data from 1926 to 1958 are divided into two: 1926-41 and 1947-58. Intra-war years are excluded from the analysis.
The estimates of the egg supply model for these periods are,

\[
\begin{align*}
1926-41 & \\
\log Q_e &= .1972 - .0981 \log \left( \frac{P_e}{P_f} \right) + .1674 \log \left( \frac{P_e}{P_f} \right) \\
& \quad - .5199 \log R_e \\
R^2 &= .3803 \quad d = .48 \\
(5.22) & \\
\end{align*}
\]

\[
\begin{align*}
1947-58 & \\
\log Q_e &= .6367 - .0529 \log \left( \frac{P_e}{P_f} \right) + .0819 \log \left( \frac{P_e}{P_f} \right) \\
& \quad - .4386 \log R_e \\
R^2 &= .8726 \quad d = 1.37 \\
(5.23) & \\
\end{align*}
\]

The elasticities with respect to \( \left( \frac{P_e}{P_f} \right) \) and \( \left( \frac{P_e}{P_f} \right) \) \( t-1 \) 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 intra-war years from the analysis. As a result of the exclusion of intra-war years, the estimate for each sub-period is exempted from the influence of the unusually high price elasticities during the war, which inflate the elasticities with respect to \( \left( \frac{P_e}{P_f} \right) \) and \( \left( \frac{P_e}{P_f} \right) \) \( t-1 \) 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 d-statistics of equation 5.23 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 d-statistics of equation 5.22. As we see in Fig. 15, this serial correlation is caused by the overestimation of the outputs in the years of the great depression when the farmers' expectation became unusually pessimistic, and they reduced the output of eggs more than the usual rate for the decline of egg price. This change in the price expectation causes the overestimation
Fig. 15. Total number of eggs produced: values of actual observations and estimated values from equations 5.22 and 5.23
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, a marked difference
is that the elasticities of supply with respect to \( \frac{P_e}{P_f} \) and \( \frac{P_e}{P_f} \t-1 \)
for the former period are twice as large as those for the latter period.
Considering the advances of technology between these two periods, the
difference in these elasticities seems to 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 30's, only a negligible amount of fixed capital investment
was required for raising farm flocks. Chickens were raised in the yard,
range or corner of the barn, salvaging the wasted grains, weeds and in­
sects. Today, most chickens are confined in poultry houses with the de­
vices 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.

Obviously, technological progress has caused the tendency toward
specialization of egg production. As an enterprise is specialized, it be­
comes more difficult for farmers to enter or quit the enterprise. When
egg production is one of the branches of a multi-enterprise farm, the
farmer can easily shift the resources of production from eggs to other
enterprises or from other enterprises to eggs. Once the farmer special­
izes 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. The difference in the magnitude of supply elasticity between equation 5.22 and equation 5.23 can thus be explained by the technological progress of egg production.

The equation is estimated for the divided periods in order to obtain the long-run supply elasticities:

\[
(5.24) \quad \log Q_e = -1.0973 + 0.1060 \log \left( \frac{P_e}{P_f} \right) + 0.1857 \log \left( \frac{P_e}{P_f} \right)_{t-1} \\
\quad + 0.4914 \log R_e + 0.8414 \log Q_e, \quad R^2 = 0.7074, \quad d = 0.98
\]

\[
(5.25) \quad \log Q_e = 0.4598 + 0.0620 \log \left( \frac{P_e}{P_f} \right) + 0.0886 \log \left( \frac{P_e}{P_f} \right)_{t-1} \\
\quad + 0.3779 \log R_e + 0.1689 \log Q_e, \quad R^2 = 0.9366, \quad d = 1.42
\]

The long-run elasticities obtained from equations 5.24 and 5.25 are: .6683 with respect to \( \left( \frac{P_e}{P_f} \right)' \) and 1.1709 with respect to \( \left( \frac{P_e}{P_f} \right)'_{t-1} \) for the period 1926-41, and .0746 with respect to \( \left( \frac{P_e}{P_f} \right)' \) and .1066 with respect to \( \left( \frac{P_e}{P_f} \right)'_{t-1} \) for the period of 1947-58.

The long-run elasticities for the period of 1926-41 seem unreasonably large. This seems to 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 pre-war years than in the post-war years. The decline in the long-run elasticities can be explained by the difficulty of entry and exit due to the specialization.

However, from these statistical estimates 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, estimation is performed for smaller segments of the period. The pre-war years are divided into two periods: 1926-33 and 1934-40. The former period is the period prior to the beginning of the dramatic progress in technology, while in the latter period technological progress was initiated and proceeded rapidly. In order to see the structure of supply during the war, the analysis is also conducted for the period 1941-46.

Considering the small number of observations in each period, $\left( \frac{P_e}{P_f} \right)$ is dropped from the equation to save one degree of freedom. $\left( \frac{P_e}{P_f} \right)$ is dropped because the egg-feed price ratio in the hatching season of the present year has a relatively minor importance on the output of eggs in the present year. Also, the technology index is dropped from the equation for the period 1926-33 because the appreciable change in technology did not come before 1933.

The results of estimation for the four sub-periods are summarized in Table 7. The elasticity of supply with respect to $\left( \frac{P_e}{P_f} \right)_{t-1}$ is shown to have decreased except for the war years. The elasticity estimated for 1934-
Table 7. Results of estimation of supply equation for four sub-periods.

<table>
<thead>
<tr>
<th>Period</th>
<th>Degrees of freedom</th>
<th>Constant term</th>
<th>Coefficient of ( \log \left( \frac{P_e}{P_f} \right)_{t-1} )</th>
<th>Coefficient of ( \log R_e )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926-33</td>
<td>6</td>
<td>1.2346</td>
<td>.3106</td>
<td></td>
<td>.6612</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>((.0230))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1934-40</td>
<td>4</td>
<td>-2.4229</td>
<td>.0704</td>
<td>1.8508</td>
<td>.9182</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>((.0946))</td>
<td>((.3357))</td>
<td></td>
</tr>
<tr>
<td>1941-46</td>
<td>3</td>
<td>-2.9125</td>
<td>.5017</td>
<td>1.7921</td>
<td>.8190</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>((.2158))</td>
<td>((.6458))</td>
<td></td>
</tr>
<tr>
<td>1947-58</td>
<td>9</td>
<td>.7909</td>
<td>.0386</td>
<td>.4141</td>
<td>.8609</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>((.0390))</td>
<td>((.0565))</td>
<td></td>
</tr>
<tr>
<td>1926-58</td>
<td>30</td>
<td>-1.4008</td>
<td>.3752</td>
<td>1.2324</td>
<td>.8733</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>((.1282))</td>
<td>((.0906))</td>
<td></td>
</tr>
</tbody>
</table>

*Figures in parentheses are the standard errors of coefficients.*

Table 8. Supply elasticity of eggs with respect to \( \left( \frac{P_e}{P_f} \right)_{t-1} \) for sub-periods.

<table>
<thead>
<tr>
<th>Period</th>
<th>Average of the technology index for the period</th>
<th>Supply elasticity of eggs with respect to ( \left( \frac{P_e}{P_f} \right)_{t-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Computed from equation 5.27</td>
<td>Estimated separately for each period</td>
</tr>
<tr>
<td>1926-33</td>
<td>118.34</td>
<td>.5566</td>
</tr>
<tr>
<td>1934-40</td>
<td>129.45</td>
<td>.4844</td>
</tr>
<tr>
<td>1941-46</td>
<td>147.41</td>
<td>.3676</td>
</tr>
<tr>
<td>1947-58</td>
<td>181.61</td>
<td>.1453</td>
</tr>
<tr>
<td>1926-58</td>
<td>148.99</td>
<td>.3573</td>
</tr>
</tbody>
</table>
40 seems too small, compared to the elasticity for 1926-33. Probably the elasticity with respect to \( \left( \frac{P_e}{P_f} \right)_{t-1}' \) is underestimated for the period 1934-40 because of the multicollinearity between \( \left( \frac{P_e}{P_f} \right)_{t-1}' \) and \( R_e \). That is, the trend in the technology index takes over the upward trend in the egg price during the period of recovery from the great 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 \( \left( \frac{P_e}{P_f} \right)_{t-1}' \) is largest for the period 1941-46. The causes for this large price elasticity of supply for the war years are already explained in connection with the serial correlation in the residuals of equation 5.19.

The results of estimation in Table 7 seem to support the hypothesis that the price elasticity of supply has decreased, except for the period 1941-46. However, the statistical evidence is still insufficient, since the estimates of elasticity with respect to \( \left( \frac{P_e}{P_f} \right)_{t-1}' \) are not significant at the 5 percent level except for the period 1941-46.

It is hypothesized that technological progress is the cause of the decrease in the elasticity with respect to the egg-feed price ratio. In order to test this hypothesis, and also to evaluate how much effect technological progress has had on the elasticity of supply, the non-linear equation model formulated in equation 4.10 is estimated.

\[
(5.26) \quad \log Q_e = -6.3771 \times 1.3258 \log \left( \frac{P_e}{P_f} \right)_{t-1}' + 3.5299 \log R_e
\]

\[
-0.065 \times \left[ R_e \log \left( \frac{P_e}{P_f} \right)_{t-1}' \right] \quad R^2 = .8965 \quad d = .71
\]
In this estimate the coefficient of \( \log \left( \frac{P_e}{P_f} \right) \) \( t-1 \) and the coefficient of \( \log R_e \) have significant values at the 1 percent level. The coefficient of the interaction term is significant in value at the 5 percent level. Equation 5.26 can be transformed into the form with the non-linear coefficient of \( \left( \frac{P_e}{P_f} \right) \) \( t-1 \):

\[
(5.27) \quad \log Q_e = -6.3771 \times (1.3258 - .0065 R_e) \log \left( \frac{P_e}{P_f} \right) \text{ \( t-1 \)} + 3.5299 \log R_e
\]

The coefficient of \( \log \left( \frac{P_e}{P_f} \right) \) \( t-1 \) in the above equation shows that the supply elasticity with respect to \( \left( \frac{P_e}{P_f} \right) \) \( t-1 \) decreases by .0065 for a unit increase in the technology index of egg production. The outputs of eggs estimated from equation 5.26 are plotted over time in Fig. 16, together with the values of actual observations in order to see the fit of the equation 5.26 to the data.

The elasticity with respect to \( \left( \frac{P_e}{P_f} \right) \) \( t-1 \) is computed for the average value of the technology index in each period. The results are presented in Table 8 in comparison to the separate estimates. There is a considerable difference between the value computed from equation 5.27 and the value estimated separately in each sub-period. This difference can be explained by the change in the expectation patterns of farmers. Since this change is not incorporated into the model, the value computed from equation 5.27 deviates from the value estimated separately for each period.

Hence, the non-linear coefficient in equation 5.27 is not sufficient for predicting the value of supply elasticity with respect to \( \left( \frac{P_e}{P_f} \right) \) \( t-1 \).
Fig. 16. Total number of eggs produced: values of actual observations and estimated values from equation 5.26
There is another weakness of the model for predictive purposes. The non-linear coefficient is assumed 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 5.27 cannot be extrapolated beyond a certain range.

The estimate of the non-linear coefficient of \( \log \left( \frac{P_e}{P_f} \right)_{t-1} \) 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 provides statistical evidence that the price elasticity of egg supply has been reduced as the technology advances. Also, by the estimate we can evaluate the effect of technological progress on the elasticity with respect to \( \left( \frac{P_e}{P_f} \right)_{t-1} \).

D. Multi-Step Analysis

As presented in section A of this chapter, the supply of eggs and farm chickens consists of four major economic relations: (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 will be 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 5.6 and 5.7, and for farm chickens through counting equations 5.8 and 5.9.
1. Relation of raising pullets

The relation of pullet-raising is formulated in equation 5.2. However, in the single-step analysis it is made apparent that the effects of competing enterprises on the supply of eggs are not large enough to be found statistically from the nationally aggregated data. Hence, we start our analysis in estimating equation 5.2 with $E_h$ and $E_b$ dropped.

The result of estimation for 1926-58 is,

\[
(5.28) \quad \log X_p = 1.2317 + .7194 \log \left( \frac{P_e}{P_f} \right) ' + .2732 \log R_e \\
\hat{R}^2 = .3869 \quad d = .42
\]

In this estimate the coefficient of $\log \left( \frac{P_e}{P_f} \right)$ is positive in sign and significant at the 1 percent level. This indicates the positive effect of the egg price and cost in the hatching season on the number of pullets raised. The coefficient of $\log R_e$ has a significant positive value at the 5 percent level. This value shows that farmers have increased the 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 upwards.

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 .3869, indicating the low degree of association between the values of actual observations for the number of pullets raised and the estimated values from equation 5.28. Also, the value of $d$-statistics shows the residuals in the estimates from equation 5.28 are serially correlated. We have to find out what causes these defects in the estimate.
for the pullet-raising relation.

As we see in Fig. 17, equation 5.28 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 can 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 for the latter period is partly explained by the compensation process in the least-square estimation for the underestimation of the former period. But the more important factor which causes the overestimation for the period 1953-58 must be the reduction in the price elasticity due to technological progress.

It is shown in the previous section that the elasticity of egg supply with respect to \( \frac{P_e}{P_f} \) has decreased as technology has advanced. Technological progress has equally affected the demand elasticity for pullets with respect to the egg price and cost. But the relative reduction in elasticity is larger in the demand for pullets than in the supply of eggs. Technological progress is reflected in the increase in the number of eggs per layer. As the number of eggs per layer increases, farmers can increase or decrease the output of eggs with a smaller change in the number of hens. Hence, for the period of analysis the change in the demand elasticity for pullets with respect to \( \frac{P_e}{P_f} \) should have been much larger than the change in the supply elasticity of eggs. The small value of \( R^2 \) and the high serial correlations in the estimate of the pullet-raising equation can be explained by this greater change in the demand elasticity for pullets with respect to \( \frac{P_e}{P_f} \).
Fig. 17. Number of pullets raised for 1926-58: values of actual observations and estimated values from equation 5.28

Fig. 18. Number of pullets raised for 1926-58: values of actual observations and estimated values from equation 5.29
In order to improve the degree of association and to decrease the serial correlation of residuals, it is necessary to incorporate the change in the demand elasticity for pullets. The effect of technological progress on elasticity of product supply or on elasticity of factor demand can be incorporated into the model formulated as equation 4.10. Equation 4.10 as applied to the analysis of the demand for pullets is estimated for 1926-58,

\[
(5.29) \quad \log X_p = -10.9742 + 2.9904 \log \left( \frac{P_e}{P_f} \right) \quad + 5.9256 \log R_e \\
- .0155 \left( R_e \log \left( \frac{P_e}{P_f} \right) \right) \\
R^2 = .6372 \quad d = 1.39
\]

This equation can be transformed into the form of the non-linear coefficient,

\[
(5.30) \quad \log X_p = -10.9742 \times (2.9904 - .0155 R_e) \log \left( \frac{P_e}{P_f} \right) \\
+ 5.9256 \log R_e
\]

The non-linear coefficient of \( \log \left( \frac{P_e}{P_f} \right) \) indicates that the demand elasticity for pullets with respect to \( \frac{P_e}{P_f} \) decreases by .0155 for a unit change in the technology index. This value is significantly larger than the value of reduction in the supply elasticity of eggs for a unit increase in the technology index, .0065 in equation 5.27.

The estimates for the coefficients in equation 5.29 are all significant at the 1 percent level. Marked improvements in the degree of association and in the serial correlation of residuals are displayed in equation 5.29 over equation 5.28. The value of \( R^2 \) increases by 65 percent in equation 5.29 compared to equation 5.28. And the value of d-statistics com-
puted from equation 5.29 falls in the indeterminate region at the 5 percent level, while equation 5.28 has the value of d-statistics which accepts the hypothesis of positive serial correlation in the residuals. These improvements in the estimate can be seen in Fig. 18 in comparison to Fig. 17.

The change in the d-statistics supports the hypothesis that the effect of technological progress on the demand elasticity for pullets is the major factor in causing the serial correlation in the residuals of equation 5.28. This change is contrasted to the results of egg supply analysis. No appreciable change in the value of d-statistics is caused by adding the interaction term of price and technology to the egg supply equation, as we see in comparing equation 5.19 with equation 5.26. This is because in egg supply the farmers' expectation is the major factor in changing the elasticity, and the technological advances have relatively minor effects.

The model of equation 4.10 cannot deal with changes in elasticity due to the change in the farmers' price expectation.

Improvements in the estimate indicate that the model of the non-linear coefficient is not only useful for analysis of the pullet-raising relation in evaluating the change in elasticity due to technological progress, but also for the purpose of prediction. The limitation of equation 5.29 for predictive purposes is that the coefficient of \( \log \left( \frac{F_e}{P_f} \right) \)' is formulated as a linear function of \( R_e \) and cannot be extrapolated beyond a certain range.

2. **Relation of raising cockerels**

Assuming the farm chickens to be a by-product of eggs the number of
cockerels raised is determined as a fraction of the number of pullets raised. This relation between the number of pullets raised and the number of cockerels raised is formulated as equation 5.3. If we estimate the number of pullets raised from equation 5.29, then the number of pullets raised is given by multiplying the estimated value for the number of pullets by the cockerel-pullets ratio, $r$, 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. 19 with the values of actual observations.

3. Relation of culling hens

The effects of prices on the egg production through culling hens and pullets are not statistically found in the single-step analysis. However, this does not mean the market situations do not have any influence on the farmers' decision of culling hens or pullets. The effects of the market situations are not statistically found in the single-step analysis because the culling relations are minor in their effects on the output of eggs, relative to the effects of the raising relations.

In order to test whether the prices of eggs and farm chickens influence the number of hens culled, the relation of hen-culling, formulated in equation 5.4, is estimated for 1931-58,

$$
(5.31) \quad \log X_{h.c} = 1.1876 - .5242 \log \left( \frac{P_e}{P_f} \right) + .3391 \log \left( \frac{P_c}{P_f} \right) - .6210 \log X_h
$$

$$
R^2 = .8522 \quad d = 1.52
$$
Table 9. Number of cockerels raised: estimation procedures from the number of pullets raised estimated by equation 5.29.

<table>
<thead>
<tr>
<th>Year</th>
<th>s (1)a</th>
<th>k (2)b</th>
<th>( \gamma ) (3)c</th>
<th>( x_p ) (4)d</th>
<th>( x_k ) (5)e (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td>0.023</td>
<td>0.005</td>
<td>0.965</td>
<td>400.0</td>
<td>386</td>
</tr>
<tr>
<td>1927</td>
<td>0.026</td>
<td>0.005</td>
<td>0.959</td>
<td>398</td>
<td>382</td>
</tr>
<tr>
<td>1928</td>
<td>0.030</td>
<td>0.006</td>
<td>0.953</td>
<td>358</td>
<td>341</td>
</tr>
<tr>
<td>1929</td>
<td>0.034</td>
<td>0.007</td>
<td>0.947</td>
<td>391</td>
<td>370</td>
</tr>
<tr>
<td>1930</td>
<td>0.038</td>
<td>0.008</td>
<td>0.942</td>
<td>419</td>
<td>395</td>
</tr>
<tr>
<td>1931</td>
<td>0.043</td>
<td>0.009</td>
<td>0.934</td>
<td>313</td>
<td>292</td>
</tr>
<tr>
<td>1932</td>
<td>0.049</td>
<td>0.010</td>
<td>0.925</td>
<td>352</td>
<td>326</td>
</tr>
<tr>
<td>1933</td>
<td>0.056</td>
<td>0.011</td>
<td>0.914</td>
<td>449</td>
<td>410</td>
</tr>
<tr>
<td>1934</td>
<td>0.063</td>
<td>0.013</td>
<td>0.905</td>
<td>339</td>
<td>307</td>
</tr>
<tr>
<td>1935</td>
<td>0.071</td>
<td>0.014</td>
<td>0.812</td>
<td>362</td>
<td>323</td>
</tr>
<tr>
<td>1936</td>
<td>0.079</td>
<td>0.016</td>
<td>0.881</td>
<td>424</td>
<td>374</td>
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<tr>
<td>1937</td>
<td>0.089</td>
<td>0.018</td>
<td>0.867</td>
<td>310</td>
<td>269</td>
</tr>
<tr>
<td>1938</td>
<td>0.100</td>
<td>0.020</td>
<td>0.852</td>
<td>382</td>
<td>325</td>
</tr>
<tr>
<td>1939</td>
<td>0.113</td>
<td>0.023</td>
<td>0.835</td>
<td>425</td>
<td>355</td>
</tr>
<tr>
<td>1940</td>
<td>0.126</td>
<td>0.025</td>
<td>0.817</td>
<td>364</td>
<td>297</td>
</tr>
<tr>
<td>1941</td>
<td>0.141</td>
<td>0.028</td>
<td>0.797</td>
<td>403</td>
<td>321</td>
</tr>
<tr>
<td>1942</td>
<td>0.209</td>
<td>0.042</td>
<td>0.714</td>
<td>455</td>
<td>325</td>
</tr>
<tr>
<td>1943</td>
<td>0.172</td>
<td>0.054</td>
<td>0.789</td>
<td>493</td>
<td>389</td>
</tr>
<tr>
<td>1944</td>
<td>0.203</td>
<td>0.049</td>
<td>0.733</td>
<td>408</td>
<td>299</td>
</tr>
</tbody>
</table>

a(2) of Table 2.

\( b(3) \) of Table 2.

\[ c \gamma = \frac{2}{1 + s - k} - 1. \]

\( d \) Estimated from equation 5.29.

\( e(5) = (3) \cdot (4). \)
Table 9. Continued

<table>
<thead>
<tr>
<th>Year</th>
<th>Ratio of the number of sexed pullets to the number of chickens raised</th>
<th>Ratio of the number of sexed cockerels to the number of chickens raised</th>
<th>Pullet-chicken ratio</th>
<th>Estimated number of pullets raised (million)</th>
<th>Estimated number of cockerels raised (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)(^a)</td>
<td>(2)(^b)</td>
<td>(3)(^c)</td>
<td>(4)(^d)</td>
<td>(5)(^e)</td>
</tr>
<tr>
<td>1945</td>
<td>.185</td>
<td>.048</td>
<td>.759</td>
<td>447</td>
<td>339</td>
</tr>
<tr>
<td>1946</td>
<td>.223</td>
<td>.044</td>
<td>.696</td>
<td>427</td>
<td>297</td>
</tr>
<tr>
<td>1947</td>
<td>.260</td>
<td>.045</td>
<td>.646</td>
<td>414</td>
<td>267</td>
</tr>
<tr>
<td>1948</td>
<td>.300</td>
<td>.045</td>
<td>.594</td>
<td>387</td>
<td>230</td>
</tr>
<tr>
<td>1949</td>
<td>.310</td>
<td>.040</td>
<td>.575</td>
<td>428</td>
<td>246</td>
</tr>
<tr>
<td>1950</td>
<td>.320</td>
<td>.050</td>
<td>.575</td>
<td>384</td>
<td>221</td>
</tr>
<tr>
<td>1951</td>
<td>.330</td>
<td>.050</td>
<td>.563</td>
<td>400</td>
<td>225</td>
</tr>
<tr>
<td>1952</td>
<td>.370</td>
<td>.050</td>
<td>.515</td>
<td>376</td>
<td>194</td>
</tr>
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<td>1953</td>
<td>.420</td>
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<td>1955</td>
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<td>1956</td>
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<td>1957</td>
<td>.610</td>
<td>.060</td>
<td>.290</td>
<td>353</td>
<td>102</td>
</tr>
<tr>
<td>1958</td>
<td>.610</td>
<td>.060</td>
<td>.290</td>
<td>332</td>
<td>96</td>
</tr>
</tbody>
</table>
Fig. 19. Number of cockerels raised: values of actual observations and values obtained through equation 5.3 from number of pullets raised estimated by equation 5.29
The coefficients of all three independent variables have values significant at the 1 percent level. The value of d-statistics rejects the hypothesis of the serial correlation in the residuals at the 5 percent level. The negative sign in the coefficient of \( \log \left( \frac{P_e}{P_f} \right) \) indicates that farmers continue keeping hens for a favorable egg price and cull them for an unfavorable egg price. The positive sign in the coefficient of \( \log \left( \frac{P_c}{P_f} \right) \) shows that farmers cull more hens when the market situation is favorable for chickens and cull less hens when the market situation is unfavorable.

The number of hens culled is largely determined by the number of hens and pullets on the farm at the beginning of a year. But the results of estimation in equation 5.31 support the hypothesis that farmers also adjust the number of hens to cull in response to the prices of eggs and farm chickens during a year. The estimated values for the number of hens culled from equation 5.31 are plotted over time in comparison to the values of actual observations in Fig. 20, to show how equation 5.31 fits the data.

4. 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 raising pullets is estimated for 1931-58 as formulated in equation 5.5,

\[
(5.32) \quad \log X_{p,c} = -10.9533 + 1.1079 \log \left( \frac{P_e}{P_f} \right) - 1.5237 \log \left( \frac{P_c}{P_f} \right) - 4.8976 \log X_p \\
(1.0617) \quad (.3972) \quad (.7352) \\
R^2 = .7104
\]

In this estimate only the coefficient of \( \log X_p \) has the value statistically
Fig. 20. Number of hens culled: values of actual observations and estimated values from equation 5.31

Fig. 21. Number of pullets culled: values of actual observations and estimated values from equation 5.33
significant at the 1 percent level. The coefficients of \( \log \left( \frac{P_e}{P_f} \right) \) and 
\( \log \left( \frac{P_c}{P_f} \right) \) are not significantly different from zero. Moreover the signs 
in the coefficients of \( \log \left( \frac{P_e}{P_f} \right) \) and \( \log \left( \frac{P_c}{P_f} \right) \) contradict the hypothesis 
that farmers cull less hens when the market situation is favorable for 
eggs or unfavorable for chickens, and cull more hens when the market situa­
tion is unfavorable for eggs or favorable for chickens.

It may be hypothesized that farmers cull pullets in response to egg 
price but not chicken price. Since pullets are the birds which continue 
laying eggs for longer periods in the future than hens, the price of eggs 
must be much more important in determining effective profit than the price 
of chickens. In order to test this hypothesis the pullet-culling equation 
is estimated with \( \left( \frac{P_c}{P_f} \right) \) being dropped.

\[
(5.33) \quad \log X_{p,c} = -8.6911 - .6773 \log \left( \frac{P_e}{P_f} \right) + 4.2576 \log X_p \\
\quad \quad \quad \quad \quad (1.1876) \quad (8911)
\]

\[ R^2 = .5328 \quad d = 1.21 \]

In this estimate the coefficient of \( \log \left( \frac{P_e}{P_f} \right) \) has a sign consistent with 
the hypothesis. But it is not statistically significant at the 5 percent 
level. We do not have sufficient evidence for accepting the hypothesis 
that farmers respond to egg price in culling pullets. It is more likely 
that the pullets are culled exclusively for physical causes like sickness 
and physical deformity. The estimated values for the number of pullets 
culled from equation 5.33 are plotted in comparison to the values of actual 
observations in Fig. 21 to see how equation 5.33 fits the data.
VI. EMPIRICAL ANALYSIS: BROILERS

A. Presentation of Model

The relations in the broiler supply are presented in Fig. 22. The following model for estimating the broiler supply relation from annual data is used:

\[ Q_b = f \left[ \left( \frac{P_b}{P_f} \right), \left( \frac{P_b}{P_f} \right)_{t-1}, E_e, E_{e_{t-1}}, R_b \right] \]

The variables in the model are:

\( \left( \frac{P_b}{P_f} \right) \) : Broiler-feed price ratio, year average.

\( \left( \frac{P_b}{P_f} \right)_{t-1} \) : Broiler-feed price ratio of the previous year, year average.

\( E_e \) : Egg profitability index, year average of egg-feed price ratio multiplied by the technology index of egg production.

\( E_{e_{t-1}} \) : Egg profitability index of the previous year.

\( R_b \) : Technology index of broiler production.

\( Q_b \) : Quantity of broilers produced, liveweight (million pounds).

In the model of equation 6.1 the quantity of broilers produced is associated directly with the factors which affect the raising of broilers. The intermediate relations are not analyzed because of the nature of broiler supply and also because of the data limitations. The structure of broiler supply is much simpler than that of egg supply, because
Fig. 22. Relations in broiler supply
(1) the broiler enterprise is a single product enterprise and (2) the period of broiler production is relatively short.

In the supply of eggs and farm chickens there are two major steps in the farmers' decision making: how many pullets to raise and how long to keep hens. These two decisions should be made over a production period of more than one year. In the broiler supply there is only one major step in decision making, that is, how many broilers to raise. Once broilers are raised, farmers cannot do much to adjust the output. It may be possible to feed more when the market situation is favorable, and feed less when the market situation is unfavorable. But this adjustment must be negligible in its effect on the total output, compared to the adjustment in the raising of broilers.

If the raising of broilers is the only major step in the production of broilers, the total output can be accurately predicted solely on the basis of information about the factors which affect the raising of broilers. Hence, the single-step analysis is sufficient for the supply analysis of broilers. Actually it is difficult to analyze the intermediate relations because of the data limitations. The data of broiler chicks purchased are not reported before 1954. Among the factors affecting the raising of broilers, the broiler-feed price ratio, the egg profitability index and the technology index of broiler production are selected as variables in the model. The lagged values of the broiler-feed price ratio and of the egg profitability index are also included in the model, because the time lag is expected in adjusting the relatively fixed facilities of production.

The characteristic feature in broiler production is that it is continuous. The production period has been reduced for these three decades
from about a hundred days to less than seventy days. Broiler growers have three to six crops in a year. Hence, broiler farmers can adjust the number of broilers in response to price in a year. If we take a calendar year as a unit period for the analysis of broiler supply, price and output are simultaneously determined. The simultaneous equation approach is necessary for estimating the relation of broiler supply from annual data.

A model of the consumers' demand for broilers to be used for the simultaneous equation estimation is as follows:

\[
(6.2) \quad \left( \frac{F_b}{L} \right) = f \left( \left( \frac{Q_b}{N} \right) \cdot \left( \frac{Q_c}{N} \right), \left( \frac{I}{N} \right), F_c \right)
\]

The variables in the model are:

- \(\frac{F_b}{L}\) : Farm price of broilers deflated by consumers' price index (cents per pound).
- \(\frac{Q_b}{N}\) : Per capita output of broilers, liveweight (pounds).
- \(\frac{Q_c}{N}\) : Per capita output of farm chickens, liveweight (pounds).
- \(\frac{I}{N}\) : Per capita disposable income deflated by consumers' price index (dollars).
- \(F_c\) : Percentage of farmers' share in retail price of chickens.

In the demand equation per capita output of broilers and per capita production of farm chickens are aggregated into a variable, because broilers and farm chickens are a homogeneous commodity for consumers after they are processed for the ready-to-cook meat. There must be no difference in the effect of quantity supplied on the retail price between broiler meat and farm chicken meat. But the farm price of broilers is about 10 percent higher than the farm price of farm chickens in terms of liveweight. This
difference is due to the difference in the dressing efficiency between broilers and farm chickens, and in the bargaining power between the specialized broiler growers and the farmers who raise a small flock for eggs. Considering this 10 percent difference in price, we put 10 percent less weight on farm chickens in aggregation.

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 the consumption through the relations of marketing. It is possible to construct a large system of simultaneous equations, including the equations of marketing relations. However, it is not the primary object of this study to analyze the marketing relations. The formulation of a complex system not only increases the computational burden, but also usually results in a poorer estimate. Hence, the relations of demand and supply for broilers is formulated as a simple two equation system.

Thus far the model is presented for the analysis of annual data. The short period of broiler production requires analysis of monthly data. The monthly data of broiler chicks purchased by farmers have been reported since 1954. It takes about three weeks for chicks to be delivered after a farmer issues a purchase order to 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 for the variables affecting the broiler production. The model for the broiler supply analysis of monthly data is
The variables in the model are:

\[
X_b = f\left( \frac{P_b}{P_{r_{m-1}}} , \frac{P_e}{P_{r_{m-1}}} , R_{b_{m}} \right)
\]

Equation 6.3 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 two or three months later. The single equation least-squares is sufficient for estimating equation 6.3, because the prices which determine the number of broiler chicks to purchase are the prices of the previous month.

B. Analysis of Least-Square Estimates

Before proceeding to the simultaneous equation approach, the relation of broiler supply is estimated by the single equation least-squares. For 1935-58 the estimate of equation 6.1 is
(6.4) \[ \log Q_b = -11.0858 + 0.9396 \log \left( \frac{P_b}{P_f} \right) + 0.2115 \log \left( \frac{P_b}{P_f} \right)_{t-1} \\
+ 1.1580 \log E_e + 1.3217 \log E_e + 5.5065 \log R_b \]

\[ \times 0.5992 \times 0.5460 \times 0.7033 \]

\[ R^2 = 0.9527 \]

The coefficients of \( \log \left( \frac{P_b}{P_f} \right) \) and \( \log \left( \frac{P_b}{P_f} \right)_{t-1} \) have signs consistent with theory, but the coefficient of \( \log \left( \frac{P_b}{P_f} \right) \) is statistically significant at the 20 percent level and that of \( \log \left( \frac{P_b}{P_f} \right)_{t-1} \) only at the 90 percent level. The coefficient of \( \log \left( \frac{P_b}{P_f} \right)_{t-1} \) has a positive value larger than that of \( \log \left( \frac{P_b}{P_f} \right) \). This indicates farmers adjust the production of broilers more in response to the price of the present year than they do to the price of the previous year. However, the statistical evidence is not sufficient, because the values of both coefficients are not significantly different from zero.

The coefficients of \( \log E_e \) and \( \log E_e_{t-1} \) have positive values. This contradicts the hypothesis that eggs are the enterprise competing 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 through the business cycle of economy. The coefficient of \( \log R_b \) has a large positive value which is highly significant. This confirms our a priori knowledge that the technological progress is the major factor which has contributed to the miraculous growth of broiler production.

Since the effect of profitability of eggs on broiler production does not show up statistically in a meaningful fashion, the model is simplified for estimation by dropping \( E_e \) and \( E_e_{t-1} \). The result of estimation for the simplified model is
In this equation all coefficients are consistent in sign with theory, but
the coefficients of \( \log \left( \frac{P_b}{P_t} \right) \) and \( \log \left( \frac{P_b}{P_t} \right)_{t-1} \) are not statistically signifi-
cant at the 5 percent level. The nonsignificant estimates of price co-
coefficients are explained by the rapid progress of broiler production tech-
nology. The cost of broiler production has been reduced consistently as
the technology of broiler production has advanced. The total output of
broilers has increased almost consistently since 1934, because the increase
in the efficiency of production has more than offset the effect of price
fall in the years of unfavorable market. The price fluctuations must have
had a small effect on the total output of broilers, relative to the increase
in efficiency due to technological progress. The effect of technological
progress must overshadow the effect of the change in broiler price in the
statistical estimation.

Other possible causes of the nonsignificant price coefficients are the
simultaneous bias in the least-square estimates, and the bias due to the
serial correlation in the residuals. The possibility of simultaneous bias
is examined later when the simultaneous equation estimation is conducted.
The value of \( d \)-statistics indicates the residuals of equation 6.5 are ser-
ially correlated. As we see in Fig. 23, equation 6.5 is consistently under-
estimating the total output for the period 1939-45. This underestimation
of the total outputs must be caused by the optimistic price expectations of
farmers during the war years. On the other hand, the change in the price
Fig. 23. Quantity of broilers produced (liveweight): values of actual observations and estimated values from equation 6.5.
elasticity of supply due to technological progress might have caused the overestimation in the recent years. The effect of technological progress on the elasticity is examined in the following section.

For the sake of comparison the model, which substitutes time, t with \( t=1 \) at 1935 for the technology index of broiler production, is estimated:

\[
\text{log } Q_b = 3.0342 - .8898 \text{ log } \left( \frac{P_b}{P_t} \right) - .7447 \text{ log } \left( \frac{P_b}{P_t} \right)^{t-1} + 1.1860 \text{ log } t
\]

\[
R^2 = .9171 \quad d = .64
\]

In comparing equation 6.6 with equation 6.5, there is little difference in the values of \( R^2 \) and of \( d \)-statistics. But the coefficients of \( \text{log } \left( \frac{P_b}{P_t} \right) \) and \( \text{log } \left( \frac{P_b}{P_t} \right)^{t-1} \) in equation 6.6 are negative in sign, which is not consistent with theory. On this point the use of the technology index is preferred to the use of time in the analysis of supply.

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

\[
\text{log } Q_b = .7145 - .3914 \text{ log } \left( \frac{P_b}{P_t} \right)^{t-1} - .0440 \text{ log } \left( \frac{P_b}{P_t} \right) + .1991 \text{ log } R_b
\]

\[
R^2 = .9907 \quad d = 2.31
\]

The results of estimation in equation 6.7 seem meaningless. Above all the coefficient of \( \text{log } R_b \) has a negative value. Technological progress is the basic factor which has caused the fantastic growth of broiler production. The negative coefficient of \( \text{log } R_b \) indicates that the total output has decreased as technology has advanced. This does not make sense. The nonsensical estimate for the coefficient of the technology index shows the
inapplicability of the Koyck-Nerlov 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.

C. Simultaneous Equation Estimation

The simultaneous equation estimation is required for the analysis of broiler supply of the annual data, since the price and output of broilers are simultaneously determined. The model to be used is the system of two equations: equation 6.1 with \( E_e \) and \( E_{et-1} \) dropped, for supply; and equation 6.2 for demand. The limited information maximum likelihood method* is used for estimating these two equations.

The results of estimation for 1935-58 are these:

\[
\begin{align*}
\text{Supply Equation} \\
(6.8) \quad & \log Q_b = -11.7960 + 7.3182 \log \left( \frac{P_b}{P_T} \right) - 3.8503 \log \left( \frac{P_b}{P_T} \right)_{t-1} \\
& + 8.8600 \log R_b \\
& (1.2429) \\
& (2.9219) \quad (2.3939) \\
\end{align*}
\]

\[
\begin{align*}
\text{Demand Equation} \\
(6.9) \quad & \log \frac{P_b}{N} = 4.2331 - .2848 \log \left( \frac{Q_b}{N} \right) - 1.6295 \log \left( \frac{I}{N} \right) \\
& + 1.5453 \log F_c \\
& (.0964) \quad (.4122) \quad (.1655) \\
\end{align*}
\]

*For a discussion of the limited information maximum likelihood method see Chernoff and Divinsky (4), Chapters III and IV of Klein (35) and Koopmans and Hood (37).
In comparing the results of estimation in equation 6.8 with the results in equation 6.5, it is difficult to determine which method is superior for estimating the broiler supply model of equation 6.1, the least squares or the limited information maximum likelihood. In the least-square estimate the coefficients of $\log \left( \frac{P_b}{P_f} \right)$ and $\log \left( \frac{P_b}{P_f} \right)_{t-1}$ have signs consistent with theory, but have values which are statistically nonsignificant at the 5 percent level. On the other hand, in the limited information estimate $\log \left( \frac{P_b}{P_f} \right)$ has a coefficient with a sign consistent with theory and with a value which is statistically significant at the 5 percent level. However, the value of the coefficient seems too large. And, the coefficient of $\log \left( \frac{P_b}{P_f} \right)_{t-1}$ has a negative sign which contradicts theory. It is hard to determine why the coefficient of $\log \left( \frac{P_b}{P_f} \right)_{t-1}$ becomes negative in the limited information estimate. The multicollinearity between the exogenous variables in the system is likely the cause. In terms of the results of estimation the simultaneous equation estimation does not make an appreciable contribution to the analysis of broiler supply.

For the sake of comparison, the least-square estimate of the demand equation is shown below:

\[
(6.10) \quad \log \left( \frac{P_b}{L} \right) = 0.0301 - 0.0238 \log \left( \frac{S_b}{N} \right)_{t-1} + 0.3792 \log \left( \frac{R}{N} \right)_{t-1} - 1.447 \log F_c = 0.414 \quad R^2 = 0.8880
\]

In comparing the results of estimation in equation 6.9 with the results in equation 6.10, the limited information seems superior for the analysis of broiler demand. In both equations the coefficients of per capita output of chickens and of farmers' share for retail price of farm chickens have signs
consistent with theory, and the coefficients of per capita income have negative signs which contradict theory. But in the limited information estimate the coefficient of per capita output of chickens is statistically significant at the 1 percent level, while it is nonsignificant at the 5 percent level in the least-square estimate. On this account the limited information estimate is preferred.

D. Evaluation of Structural Change

In order to evaluate the possible change in the supply structure of broilers, the 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-square estimates for these two periods are,

1935-46

\[
\log Q_b = -16.8371 - 0.2080 \log \left( \frac{P_b}{P_f} \right) - 2.6733 \log \left( \frac{P_b}{P_{ft-1}} \right) + 16.3584 \log R_b \\
R^2 = .9055 \quad d = .95
\]

1947-58

\[
\log Q_b = -3.7252 - 0.0684 \log \left( \frac{P_b}{P_f} \right) + 0.3127 \log \left( \frac{P_b}{P_{ft-1}} \right) + 4.7807 \log R_b \\
R^2 = .9505 \quad d = .49
\]

In the estimate for 1935-46, the coefficients of \( \log \left( \frac{P_b}{P_f} \right) \) and \( \log \left( \frac{P_b}{P_{ft-1}} \right) \) are negative in sign. During the period 1935-46, the growth of broiler production increased at a surprisingly rapid rate. The total output increased by 800 percent during this period. The upward trend in the total output is so dominant that the effects of prices are completely overshadowed.
And the nonsensical results of estimation must be brought about by a negative correlation between price and output due to some capricious causes.

The same explanation can be applied to the negative coefficient of \( \log \left( \frac{P_b}{P_T} \right) \) in the estimate for 1947-58. Besides that, the multicollinearity between \( \log \left( \frac{P_b}{P_T} \right) \) and \( \log \left( \frac{P_b}{P_T} \right)_{t-1} \) which is brought about by the downward trend in broiler price since 1950 must be counted as another cause for the negative sign. From the estimates for 1935-46 and 1947-58 it is difficult to determine whether there was any change in the elasticity of supply, because the price coefficients are meaningless in sign, and statistically nonsignificant in these estimates.

In order to test whether technological progress has had any influence on the farmers' response to price, the model of a non-linear coefficient is estimated for 1935-58:

\[
(6.13) \quad \log q_b = -17.2010 + 5.7630 \log \left( \frac{P_b}{P_T} \right) + 13.6848 \log R_b \\
+ (-1.1675) \left[ R_b \log \frac{P_b}{P_T} \right] \\
R^2 = .9296 \quad d = .44
\]

In this estimate the coefficients are nonsignificant at the 5 percent level except for the coefficient of \( \log R_b \). Judging from the value of d-statistics, there is no improvement in the serial correlation of residuals in equation 6.13 over equation 6.5. This indicates that the effect of technological progress on the elasticity of supply is not the major factor in causing the serial correlation of residuals in equation 6.5. The estimated outputs from equation 6.13 are plotted over time together with the values of actual observations in Fig. 24 for the sake of comparison with Fig. 23 on which estimated outputs from equation 6.5 are plotted.
Fig. 24. Quantity of broilers produced (liveweight): values of actual observations and estimated values from equation 6.13
Equation 6.13 is transformed into the form with a non-linear coefficient of $\log \left( \frac{P_b}{P_T} \right)$:

$$
(6.14) \quad \log Q_b = -17.2010 \times (5.7630 - .1675 \log \left( \frac{P_b}{P_T} \right)) + 13.6848 \log R_b
$$

The non-linear coefficient in equation 6.14 shows that the elasticity with respect to $\left( \frac{P_b}{P_T} \right)$ decreases by .1675 for a unit increase in the technology index of broiler production. However, the statistical evidence is not sufficient because the coefficient of the interaction term is not significant.

As far as can be seen from the statistical estimates, technological progress seems to have shifted broiler supply upwards rather than changed the elasticity of supply. 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 of the supply curve.

E. Analysis of Monthly Data

The next step is the analysis of broiler supply of monthly data. The model of equation 6.3 is estimated by least-squares from the data of 56 months from January, 1955 through August, 1959:

$$
(6.15) \quad \log X_{bm} = -3.2683 + .3998 \log \left( \frac{P_b}{P_T} \right)_{m-1} - .1121 \log \left( \frac{P_e}{P_T} \right)_{m-1} - 3.4241 \log R_b \quad \text{m} (.1412) (.0961) (.0651) (.03789)
\quad R^2 = .7109 \quad d = .58
$$
The coefficient of \( \log \left( \frac{P_b}{P_{f,m-1}} \right) \) has a value significant at the 1 percent level with a sign consistent with theory. The coefficient of \( \log \left( \frac{P_e}{P_{f,m-1}} \right) \) is negative in sign, indicating the competitive relation between eggs and broilers, though statistically significant only at the 30 percent level. The coefficient of \( \log R_{b,m} \) has a highly significant value. The value of d-statistics shows the positive serial correlation of residuals. Equation 6.15 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 consistently in a rapid pace since 1955. The farmers' expectation on price has become darker, and the rate of increase in the output has been slowed down. This change in farmers' expectation must have caused the serial correlation in the residuals of equation 6.15.

The important change in the results of the analysis of monthly data in equation 6.15, compared with the results of the annual time series analysis, is that the effect of broiler price on the total output is statistically found significant by the monthly series analysis. In the annual series analysis the effect of price on the output is overshadowed by the upward trend in the total output. The results in equation 6.15 provide evidence that farmers adjust the output of broilers in response to the price. However, some degree of bias is expected due to the serial correlation of residuals.

For the sake of comparison, the model with the monthly unit of time, \( m = 1 \) at January 1955 substituted for the technology index, is computed:
Little change is wrought in the value of $R^2$ by substituting time for the technology index. But the value of the coefficient of $\log \left( \frac{P_b}{P_r} \right)_{m-1}$ is reduced, and becomes nonsignificant. On the other hand, the coefficient of $\log \left( \frac{P_e}{P_r} \right)_{m-1}$ becomes larger than that of $\log \left( \frac{P_b}{P_r} \right)_{m-1}$ and becomes significant. It contradicts our a priori knowledge that the egg price is greater in its effect on the output of broilers than the chicken price. On this account the use of the technology index also is preferred to the use of time in the broiler supply analysis of the monthly data.

In order to obtain the long-run elasticities, the equation of the Koyck-Nerlove model is estimated:

\[
\log X_m = -2.3520 + 0.2517 \log \left( \frac{P_b}{P_r} \right)_{m-1} - 0.1443 \log \left( \frac{P_e}{P_r} \right)_{m-1} \\
+ 2.8294 \log R_{bm} - 0.0569 \log Q_{bm-1} \\
R^2 = 0.7355 \quad d = 0.67
\]

The long-run elasticities computed from equation 6.17 are: 0.2669 with respect to $\frac{P_b}{P_r}$ and -0.1530 with respect to $\frac{P_e}{P_r}$. There is very little difference between the values of the short-run elasticities in equation 6.15 and the values of the long-run elasticities computed from equation 6.17. It seems that the values obtained from equation 6.17 are the underestimation of the long-run elasticities. The value of the
coefficient of \( \log Q_{b_{m-1}} \) is estimated unreasonably small. This must be the reversal of what happens in the estimate of the long-run elasticities obtained from the annual data. The upward trend in the technology index takes over the trend in the total output. The underestimation of the coefficient of \( \log Q_{b_{m-1}} \) leads to the overestimation of the coefficient of adjustment, resulting in the underestimation of the long-run elasticities.
A. Presentation of Model

The relations in the turkey supply are presented in Fig. 25. A model to be used for the supply analysis of turkeys is,

\[ Q_T = f \left[ \frac{P_T}{P_f} t-1 , \frac{P_T}{P_f} , \frac{P_f}{A} , E_e , E_b , R_T \right] \]

The variables in the model are:

- \( \frac{P_T}{P_f} t-1 \): Turkey-feed price ratio, average for October-December.
- \( \frac{P_T}{P_f} \): Turkey-feed price ratio, year average.
- \( \frac{P_f}{A} \)': Poultry ration cost per 100 pounds, average for January-June, deflated by agricultural price index (dollars).
- \( E_e \): Egg profitability index, November-May weighted average of egg-feed price ratio multiplied by the technology index of turkey production.
- \( E_b \): Broiler profitability index, November-May weighted average of broiler-feed price ratio multiplied by the technology index of broiler production.
- \( Q_T \): Quantity of turkeys produced, liveweight (million pounds).

In this model the quantity of turkeys produced is directly associated with the factors which affect the raising of turkey poults. The intermediate relations 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 enterprise like broilers. Once farmers purchase a certain number of poults, they cannot do much to
Fig. 25. Relations in turkey supply
adjust the output, except through weight of marketing. Adjustment of the output through feeding and other care would be greater in turkey production than in broiler production. But compared to the adjustment through the number of poults to purchase, it must be negligible.

In contrast to broilers the production of turkeys is seasonal because of the seasonal pattern of demand for turkeys. Turkeys are consumed mainly during the holiday season, Thanksgiving through Christmas. So as to deliver the product to market in this season, farmers start raising poults during the spring months. This seasonal pattern in the production of turkeys is clearly shown in Fig. 26 in which the number of poults hatched and the quantity of turkeys slaughtered in each month are plotted.

Considering the structure of the enterprise and the seasonality in production and consumption, the variables in the turkey supply model are specified. 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.

October, November and December 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 farmers can get from turkeys, and necessarily affect the intention of farmers to raise turkeys in the succeeding year. Also, the prices in these three 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 is included in the model as a variable of the production cost to which farmers refer in deciding the number of turkey poults to purchase. The
Fig. 26. Seasonal movements in poultry-hatching and turkey-slaughter, 1955-57 average
November-May weighted averages of the egg profitability index and the broiler profitability index are used as the variables of enterprises competing with turkeys. In those seven months farmers largely determine the number of chickens to raise.

Besides those variables which determine the number of turkey poults raised, the 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. The multi-step analysis is desired for analyzing the adjustment within a production period, but is not conducted because of the data limitation. If the prices within a production period affect the output, we have to consider the simultaneous equation approach. However, the production adjustment after the poults are raised cannot be large enough to cause appreciable bias in the least-square estimates. The single equation least-squares is used exclusively for estimating the supply model of turkeys.

B. Results of Estimation

The estimate of equation 7.1 for 1930-58 is,

\[
(7.2) \quad \log Q_t = -1.3680 + 0.3916 \log \left( \frac{P_t}{P_{t-1}} \right) - 0.2203 \log \left( \frac{P_t}{P_{t-1}} \right) \\
- 0.3387 \log \left( \frac{P_t}{A} \right) - 0.0558 \log E_t - 0.1826 \log E_b \\
+ 3.7929 \log R_t
\]

\[R^2 = 0.9694\]

In this estimate the coefficient of \[\log \left( \frac{P_t}{P_{t-1}} \right)\] is significant at the 5 percent level, indicating the positive effect of the turkey price of the
previous fall on the output. Log \( \frac{P_T}{P_F} \) 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 must be due to the sampling variation, and indicates that the effect of price is minor after poults are raised. The negative sign in the coefficient of log \( \frac{P_T}{A} \) is consistent with the hypothesis that farmers reduce the number of turkeys to raise when the feed price is high, and increase it when the feed price is low. However, the value of the coefficient is not significantly different from zero at the 5 percent level. The negative coefficients of log \( E_e \) and log \( E_b \) seem to show the negative effects of the profitabilities in the competitive enterprises on the production of turkeys. But the statistical evidence is not sufficient for accepting the hypothesis that eggs and broilers are competing in production with eggs, because those coefficients are nonsignificant at the 5 percent level. The coefficient of log \( R_T \) has a highly significant value, indicating the importance of technological progress on the development of turkey production.

In order to evaluate the effects of the competitive enterprises more clearly by removing possible multicollinearity, the model of turkey supply is estimated after \( \frac{P_T}{P_F} \) and \( \frac{P_F}{A} \) are dropped:

\[
(7.3) \quad \log Q_T = -1.9933 + 0.3514 \log \left( \frac{P_T}{P_F} \right)' + 0.0352 \log E_e - 0.2195 \log E_b \\
\quad + 4.0114 \log R_T \\
\quad R^2 = 0.9658
\]

In this estimate the level of significance is increased for the coefficient of log \( E_b \), though still nonsignificant at the 5 percent level. On the
other hand, the sign of the coefficient of log $E_e$ becomes negative. This negative sign can be explained by the sampling variations. The influence of the competitive enterprises on turkey production is not found statistically.

The model is recomputed after $E_e$ and $E_b$ are dropped in order to examine the effects of $\left( \frac{P_t}{\bar{P}_t} \right)$ and $\left( \frac{P_f}{\bar{P}_f} \right)$:

$\begin{align*}
\log Q_t &= -1.5740 \cdot 0.3519 \log \left( \frac{P_t}{\bar{P}_t} \right)' - 0.2627 \log \left( \frac{P_t}{\bar{P}_t} \right) \\
&\quad - 0.2674 \log \left( \frac{P_f}{\bar{A}} \right)' + 3.5951 \log R_T \\
&= -1.5740 \cdot 0.3519 \log \left( \frac{P_t}{\bar{P}_t} \right)' - 0.2627 \log \left( \frac{P_t}{\bar{P}_t} \right) \\
&\quad - 0.2674 \log \left( \frac{P_f}{\bar{A}} \right)' + 3.5951 \log R_T \\
R^2 &= 0.9682
\end{align*}$

No improvement is created in the coefficients of log $\left( \frac{P_t}{\bar{P}_t} \right)$ and log $\left( \frac{P_t}{\bar{A}} \right)'$ in this estimate over the estimate of equation 7.2. This strengthens the hypothesis that there is no appreciable adjustment in turkey production in response to price within a crop year, and that the price of feed is a minor factor in determining the number of poults purchased.

Finally, the model is estimated with all nonsignificant variables being dropped:

$\begin{align*}
\log Q_t &= -2.0902 \cdot 0.2861 \log \left( \frac{P_t}{\bar{P}_t} \right)' + 0.38268 \log R_T \\
&= -2.0902 \cdot 0.2861 \log \left( \frac{P_t}{\bar{P}_t} \right)' + 0.38268 \log R_T \\
R^2 &= 0.9639 \quad d = 0.72
\end{align*}$

In this estimate the coefficients of both independent variables have values significant at the 5 percent level, and have signs consistent with theory. However, the value of $d$-statistics accepts the hypothesis of the serial correlation in the residuals at the 5 percent level. Figure 27 shows equation 7.5 underestimates the output of turkeys for 1936-42 and overestimates
Fig. 27. Quantity of turkeys produced (liveweight): values of actual observations and estimated values from equation 7.5
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. However, this is the period when the technology of turkey production has advanced at a most rapid pace. The farmers must have expanded turkey production more in response to the improvement in production efficiency during this period than in other periods. 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 7.5 can be explained by the changes in the elasticities of supply.

The model with time, $t$, substituted for the technology index is estimated for the sake of comparison:

\[
(7.6) \quad \log Q_T = 1.9706 + .0186 \log \left( \frac{P_T}{P_{T-1}} \right) + .6976 \log t
\]

\[
(7.6) \quad \log Q_T = 1.9706 + .0186 \log \left( \frac{P_T}{P_{T-1}} \right) + .6976 \log t
\]

\[
R^2 = .8830 \quad \text{d} = .45
\]

The value of $R^2$ is about 10 percent smaller in this estimate than the value of $R^2$ in equation 7.5. The value of the coefficient of $\log \left( \frac{P_T}{P_{T-1}} \right)$ becomes nonsignificant in equation 7.6. The value of d-statistics indicates that the residuals of equation 7.6 are high in their serial correlation. Equation 7.5 is a much superior estimate of turkey supply relation to equation 7.6. This shows the advantage of using the technology index over time in the supply analysis of turkeys.
The Koyck-Nerlove model is estimated for obtaining the long-run supply elasticity of turkeys:

\[
\log Q_t = -1.2908 + 0.3462 \log \left( \frac{P_t}{F_t} \right)_{t-1} + 1.8264 \log R_t \\
+ 0.5592 \log Q_{t-1} \\
\text{(.0908)} \quad \text{(.5360)} \quad \text{(.1456)} \\
R^2 = 0.9773 \\
\hat{d} = 1.36
\]

The long-run elasticity obtained by equation 7.7 is 0.7854 with respect to \( \frac{P_t}{F_t} \). This value is about double that of the short-run elasticity estimated in equation 7.5. This difference between long-run elasticity and short-run elasticity seems reasonable. The value of the long-run elasticity is also fairly reliable because the coefficients in equation 7.7 are all significant at the 1 percent level, though the value of d-statistics fall in the indeterminate region.

C. Evaluation of Structural Change

In order to see whether any change has occurred in the supply elasticity, the turkey supply model is estimated for two divided periods: 1930-41 and 1942-58. The results of estimation are,

\[
\begin{align*}
\text{1930-41} \quad & \log Q_E = -4.8424 + 0.2616 \log \left( \frac{P_t}{F_t} \right)_{t-1} + 6.2739 \log R_t \\
& \text{(.0871)} \quad \text{(.4377)} \\
& R^2 = 0.9582 \\
& \hat{d} = 1.64 \\
\text{1942-58} \quad & \log Q_E = -2.1619 + 0.1039 \log \left( \frac{P_t}{F_t} \right)_{t-1} + 3.7852 \log R_t \\
& \text{(.1742)} \quad \text{(.3252)} \\
& R^2 = 0.9401 \\
& \hat{d} = 1.29
\end{align*}
\]

The coefficient of \( \log \left( \frac{P_t}{F_t} \right)_{t-1} \) 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 value of d-statistics 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 region.

By comparing these two estimates, the supply elasticity with respect to the change in the elasticity of egg supply. In the case of egg supply the price elasticity is larger in the pre-war years than in the post-war years. The decrease in the price elasticity of egg supply is explained by the increase of fixed capital investment, and by the specialization of the enterprise due to technological progress. Then what caused the increase in the price elasticity of turkey supply? A possible explanation for this is that turkey growers tend to be more price-conscious and adjust output more readily to price changes as the turkey enterprise becomes more specialized and commercialized. Then why has this specialization tendency affected the elasticity of egg supply in an opposite direction?

An answer to this question would be as follows: There are two forces in the specialization of an enterprise, which influence the price elasticity of supply in opposite directions. Specialization makes it more difficult for farmers to enter into or exit from the production in response to the changes in market situations. On the other hand, as the operation of an enterprise becomes larger in scale and more commercialized, farmers become more price-conscious. The former tends to reduce the price elasticity of supply, and the latter tends to increase it, in the case of turkeys as well as eggs. But in turkey production the specialization tendency started
earlier than in egg production. By the beginning of the 40's, turkeys were raised almost exclusively by specialized turkey growers. Even in the pre-war days, entry into and exit from the turkey enterprise were not easy. On the other hand, even today the major portion of eggs is still being produced by non-specialized farmers. In other words, the element in the specialization of turkey production which tends to reduce the price elasticity of supply already functioned in the period 1930-41, and did not further reduce the elasticity appreciably in the period 1942-58. And the other element in the specialization which tends to increase the elasticity, dominated the former in its effect. The specialization of enterprise must have made farmers price-conscious in egg production, too. But this effect in the specialization of egg production was overcome by its elasticity-reducing factor. Thus, increase in price elasticity of turkey supply as well as decline in price elasticity of egg supply can be explained by specialization due to technological progress.

In contrast to the change in the elasticity with respect to \( \frac{P_t}{P_r} t^{-1} \), the elasticity of turkey supply with respect to \( R_T \) is shown to be reduced in the latter period, compared to the former period. This indicates that 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, seems to support the previous argument that the major cause for the serial correlation in the residuals of equation 7.5 is the change in the elasticity with respect to \( R_T \). The fit of the estimates to the data is seen in the Fig. 28.
Fig. 28. Quantity of turkeys produced (liveweight): values of actual observations and estimated values from equations 7.8 and 7.9
In dividing the whole period into two sub-periods, the intra-war years are included in the latter period because the war does not seem to have greatly disturbed the normal relation of turkey supply. It may be suspected that by including the war years the price elasticity of turkey supply is inflated in the estimate for 1942-58. In order to test this hypothesis, the supply model of turkeys is estimated for 1947-58,

\[
\begin{align*}
\text{(7.10)} & \quad \log Q_T = -2.6440 \times 0.3937 \log \left( \frac{P_T}{P_T'} \right) + 4.1751 \log R_T \\
& \quad \text{(1.604)} \times 4.1751 \log r_{t-1} \text{ (.3692)} \\
& \quad R^2 = 0.9447 \quad d = 0.74
\end{align*}
\]

No appreciable difference exists between the elasticity in this estimate and the elasticity in the estimate for 1942-58. This supports the hypothesis that the normal relation of turkey supply was not much disturbed by the influences of the war. Hence, it is appropriate to include the observations of war years in the analysis.

In order to obtain the long-run elasticities for the divided periods, the Koyck-Nerlov model is estimated,

\[
\begin{align*}
\text{(7.11)} & \quad \log Q_T = -4.3071 \times 0.2859 \log \left( \frac{P_T}{P_T'} \right) + 5.4548 \log R_T \\
& \quad \text{(1.020)} \times 5.4548 \log \frac{Q_T}{Q_T'} \text{ (1.6311)} \\
& \quad \text{(.2813)} \times 0.1471 \log Q_T_{t-1} \\
& \quad R^2 = 0.9596 \quad d = 1.52
\end{align*}
\]

\[
\begin{align*}
\text{(7.12)} & \quad \log Q_T = -1.9348 \times 0.4844 \log \left( \frac{P_T}{P_T'} \right) + 2.5831 \log R_T \\
& \quad \text{(1.1644)} \times 2.5831 \log \frac{Q_T}{Q_T'} \text{ (1.6959)} \\
& \quad \text{(.2145)} \times 0.4101 \log Q_T_{t-1} \\
& \quad R^2 = 0.9532 \quad d = 1.85
\end{align*}
\]
The long-run elasticities with respect to \( \frac{P_t}{P_t-1} \) obtained from these estimates are: \(.3352\) for 1930-41 and \(.8212\) 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 \( \log Q_{t-1} \) are not significant in the estimates for both periods, the values of the long-run elasticities are not so reliable.

Finally, in order to test whether technological progress has had any effect on the price elasticity of turkey supply, the model of a non-linear price coefficient is estimated for 1930-58:

\[
(7.13) \quad \log Q_T = -1.6894 + .1403 \log \left( \frac{P_T}{P_T-1} \right) + 3.4832 \log R_T + .0099 \left( R_T \log \left( \frac{P_T}{P_T-1} \right) \right) \quad R^2 = .9639 \quad d = .76
\]

In this estimate none of the coefficients is significant at the 5 percent level. Equation 7.13 is transformed into the form of a non-linear price coefficient,

\[
(7.14) \quad \log Q_T = -1.6894 \times (1.1403 \times .0099 R_T) \log \left( \frac{P_T}{P_T-1} \right) + 3.4832 \log R_T
\]

The non-linear coefficient shows that the elasticity with respect to \( \frac{P_T}{P_T-1} \) increases by \(.0099\) for a unit increase of \( R_T \). The positive correlation between the price elasticity and the technological change conforms to the results in the estimates for the divided periods. However, since the coefficient of the interaction term is not significant, the statistical evidence is not sufficient for the hypothesis that the technological progress has increased the elasticity of supply with respect to \( \frac{P_T}{P_T-1} \).
Average elasticities with respect to \( \frac{P_{t}}{P_{t-1}} \) for the sub-periods 1930-41 and 1942-58 are computed. These average elasticities are presented in Table 10, in comparison to the values obtained in the separate estimates. The average elasticities computed from equation 7.14 are very close to the values estimated separately for the sub-period 1930-41 and for the total period 1930-58. But for the sub-period 1942-58, the value computed from equation 7.14 is appreciably smaller than the separately estimated value. This seems to indicate that some factors other than technological progress have made a major contribution to the increase in the elasticity of turkey supply with respect to \( \frac{P_{t}}{P_{t-1}} \) in the post-war period. The estimated outputs of turkeys from equation 7.13 are plotted in Fig. 29 in comparison to the values of actual observations to show how equation 7.13 fits to the data. By comparing Fig. 29 with Fig. 28, it is seen that the model of non-linear coefficient does not improve the accuracy of predicting the output of turkeys.
Table 10. Supply elasticity of turkeys with respect to $\left(\frac{p_t}{p_{t-1}}\right)'$ for sub-periods.

<table>
<thead>
<tr>
<th>Period</th>
<th>Average of the technology index for the period</th>
<th>Supply elasticity of turkeys with respect to $\left(\frac{p_t}{p_{t-1}}\right)'$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Computed from equation 7.14 Estimated separately for each period</td>
</tr>
<tr>
<td>1930-41</td>
<td>13.67</td>
<td>.2758 .2616</td>
</tr>
<tr>
<td>1942-58</td>
<td>17.40</td>
<td>.3125 .4103</td>
</tr>
<tr>
<td>1930-58</td>
<td>15.86</td>
<td>.2973 .2861</td>
</tr>
</tbody>
</table>
Fig. 29. Quantity of turkeys produced (liveweight): values of actual observations and estimated values from equation 7.13
VIII. SUMMARY AND CONCLUSION

The purpose of this study is specified as the supply analysis of poultry products at the farm level. A knowledge of both demand and supply is required for adequate understanding of price mechanism in the market. Yet the information we have about the supply of agricultural products is much less sufficient for the purpose of prediction than that of demand.

One of the basic causes of this unbalanced knowledge in these two fields of study is the difficulty in formulating for quantitative analysis the variables which affect supply, such as technology, quality of human input and farmers' expectation. Changes in these variables are qualitative by nature, and it is difficult to set up quantitative relations between these variables and supply. However, without incorporating these variables the analysis would not provide meaningful information about the supply of agricultural products. Especially in the supply analysis of poultry products, it is essential to incorporate technology because poultry production is characterized by the rapid progress of technology, and the resulting increase of total output. Hence the primary emphasis of this study is placed on the inclusion of technology in the poultry supply analysis.

As a first step an attempt is made to quantify the technology of poultry production. A technological change can be measured through the change in the production function. The output-input ratios or the average productivities are used as the magnitudes which represent the production functions. 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 in the production of eggs, broilers and turkeys, respectively. In order to extract the net change in technology from the data of these output-input ratios by eliminating the effects of such factors as market situation, the logistic function is fitted to the data. The values obtained from the estimated logistic functions are called the technology index of egg production, broiler production and turkey production.

The poultry supply models are constructed with these technology indices incorporated. Besides the standard linear equation model, the model of a non-linear price coefficient is elaborated in order to evaluate the effect of technological progress on the price elasticity of supply. The Koyck-Nerlove model is also estimated for obtaining the long-run elasticities. As a basic method of estimation the single equation least-squares is used. The simultaneous equations approach is restricted to the case of broiler supply analysis in which the simultaneous determination of price and output is so great as to cause appreciable bias in the least-square estimates.

The egg supply model is first estimated for 1926-58. The results of estimation 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. This effect of the egg price on the raising of pullets is confirmed by the results of estimation of farmers' demand for pullets. It is also shown clearly in the estimates that technological progress has shifted egg supply upwards. The effects of the competitive enterprises are estimated in a nonsensical fashion, and the effects of the egg price and chicken price on the total output of eggs through cull-
ing are not found to be statistically significant, though those effects are detected by the estimation of the hen-culling relation.

An important finding in the estimation of egg supply is that the use of the technology index is proved superior to the use of time trend in terms of the results of estimation. The coefficient of determination is reduced from .9056 to .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 the supply elasticities of eggs the egg supply model is estimated for two sub-periods 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 those sub-periods suggest the price elasticity of egg supply has been reduced for these three decades. In order to test the hypothesis that the recent specialization tendency in egg production due to technological progress has caused the reduction, the elasticity of egg supply with respect to the egg-feed price ratio is formulated as a linear function of the technology index for statistical estimation. The results show that the elasticity is reduced by .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 .0155 for a unit increase in the technology index.

The broiler supply model is first estimated by the least-squares from annual data for 1935-58. In the estimates the effect of broiler price as
well as that of the competitive enterprise is not found statistically significant. This result does not necessarily mean that broiler growers do not adjust the output for price changes, but that technological progress has had such a strong influence on broiler production that the effects of market fluctuations are overshadowed. In fact, the broiler price is shown to have a significant effect on the farmers' demand for broiler chicks in the analysis of monthly data. The system of simultaneous equations for broiler demand and supply is formulated for estimation. But no improvement over the single equation least-square estimate is wrought in the simultaneous equation estimate of broiler supply.

In terms of the results of estimation the use of the technology index is shown to be superior to the use of time trend in the analysis of broiler supply. There is little difference in the value of the coefficient of determination, but by using time instead of the technology index the sign of the coefficient of the broiler-feed price ratio becomes inconsistent with theory.

To see whether or not any change has occurred in the price elasticity, the broiler supply model is estimated for two divided periods, 1935-46 and 1947-58. However, in the estimates the price coefficients are either statistically significant at a low probability level or inconsistent in sign with theory, and it is impossible to decide whether the elasticity has increased or decreased. In order to test whether or not technological progress has influenced the price elasticity, the supply elasticity with respect to the broiler-feed price ratio is formulated as a linear function of the technology index. The estimate of the function shows that the elasticity has been reduced by .1675 for a unit increase in the technology index.
However, statistical evidence is not sufficient for the hypothesis that technological progress has reduced the price elasticity of broiler supply, because the value is not significant at the 5 percent level.

The turkey supply model is first estimated for 1930-58. It is estimated that the turkey price of the previous fall significantly influences the output of turkeys. The effects of the competitive enterprises and the adjustment within a production period are statistically shown as significant at a low level of probability. In the turkey supply analysis also the use of the technology index is preferred to the use of time. By substituting time for the technology index the coefficient of determination is reduced about 10 percent, and the effect of the turkey price on the total output is obscured.

To see whether any change has occurred in the price elasticity of turkey supply, the turkey supply model is estimated for two divided periods, 1930-41 and 1942-58. The results indicate that the elasticity has increased appreciably. It is hypothesized that technological progress has caused the increase in the price elasticity of turkey supply in contrast to the case of egg supply. In order to test this hypothesis the elasticity of turkey supply with respect to the turkey-feed price ratio is formulated for statistical estimation as a linear function of the technology index. It is estimated that the elasticity has increased by .0099 for a unit increase of the technology index. However, since this value is not statistically significant at the 5 percent level, evidence is not sufficient for accepting the hypothesis.

The Koyck-Nerlove model of distributed lags provides reasonable estimates of long-run supply elasticities for eggs and turkeys. But the results
of applying the model to the data of broiler supply are nonsensical. This
seems to show the danger of applying the distributed lag model of Koyck
and Nerlove to data where the dependent variable has a trend of consistent
increase or decrease.

In summary, the results of empirical analysis support the use of
technology indices in the supply analysis of poultry products. The incor-
poration of technology into supply analysis is accomplished, though sub-
ject to several limitations. However, it cannot be claimed that the goal
of meaningful supply analysis is attained in this study. Influential
factors such as farmers' future expectation and quality of human input are
not included in this analysis. In fact, appreciable defects of estimation
are found in this analysis--defects which are likely caused by neglecting
these factors. Efforts must be made to further incorporate other unconven-
tional inputs together with technology into the supply analysis. This
study is only a stepping stone towards a meaningful supply study of agri-
cultural products.
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XI. APPENDIX
Table 11. Basic data used in estimating the relations of egg supply and pullet-raising, 1926-58.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of eggs produced</th>
<th>Number of pullets raised</th>
<th>Egg-feed price of egg</th>
<th>Egg-feed ratio</th>
<th>Chicken-feed price of feed</th>
<th>Hog-corn ratio, price of feed</th>
<th>Broiler price of profitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>35.0</td>
<td>346.2</td>
<td>12.9</td>
<td>13.4</td>
<td>8.1c</td>
<td>14.1</td>
<td>113.2e</td>
</tr>
<tr>
<td>1926</td>
<td>37.2</td>
<td>365.6</td>
<td>14.3</td>
<td>10.0c</td>
<td>16.8</td>
<td>123.1e</td>
<td>114</td>
</tr>
<tr>
<td>1927</td>
<td>38.6</td>
<td>383.1</td>
<td>12.2</td>
<td>8.7c</td>
<td>11.5</td>
<td>125.1e</td>
<td>115</td>
</tr>
<tr>
<td>1928</td>
<td>38.7</td>
<td>358.4</td>
<td>12.4</td>
<td>8.7c</td>
<td>11.0</td>
<td>119.1e</td>
<td>116</td>
</tr>
<tr>
<td>1929</td>
<td>37.9</td>
<td>385.7</td>
<td>13.9</td>
<td>9.8c</td>
<td>10.4</td>
<td>125.1e</td>
<td>117</td>
</tr>
<tr>
<td>1930</td>
<td>39.1</td>
<td>400.2</td>
<td>12.1</td>
<td>8.8c</td>
<td>11.5</td>
<td>123.1e</td>
<td>118</td>
</tr>
<tr>
<td>1931</td>
<td>38.5</td>
<td>366.8</td>
<td>12.9</td>
<td>10.6c</td>
<td>11.9</td>
<td>115.1e</td>
<td>119</td>
</tr>
<tr>
<td>1932</td>
<td>36.3</td>
<td>382.1</td>
<td>14.4</td>
<td>10.3c</td>
<td>14.5</td>
<td>107.2e</td>
<td>121</td>
</tr>
<tr>
<td>1933</td>
<td>35.5</td>
<td>391.9</td>
<td>11.6</td>
<td>7.0c</td>
<td>8.8</td>
<td>87.3e</td>
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a Estimated in Table 2.

b Estimated in Table 1.

c Chicken price (all chickens) divided by poultry ration cost.

d Farm chicken price divided by poultry ration cost.

e Two-year average (present and previous years).
Table 11. Continued

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<th>Number of pullets raised</th>
<th>Egg-feed price of feed</th>
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<th>Chicken-feed price of feed</th>
<th>Hog-corn ratio, weighted average</th>
<th>Broiler technology profit index</th>
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Nov.-May weighted average.
Table 12. Basic data used in estimating the relations of hen-culling and pullet-culling, 1931-58.

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<th>Hens culleda (million)</th>
<th>Pullets culledb (million)</th>
<th>Egg-feed price ratio</th>
<th>Chicken-feed price ratio</th>
<th>Hens and pullets on farm January 1 (million)</th>
<th>Number of pullets raisedc (million)</th>
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a Estimated in Table 3.
b Estimated in Table 5.
c Estimated in Table 2.
Table 13. Basic data (annual) in estimating the relation of broiler supply, 1935-58.

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<th>Broiler-feed price ratio, year average</th>
<th>Egg profitability index, year average</th>
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aEstimated in Table 1.
bEstimated in Table 14.

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<th>Broiler price ratio (4)</th>
<th>Estimated broiler-feed price ratio (5)</th>
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*a Estimated from regression equation of Y on X for 1953-58:
Y = 1.98 + .8486X.

b(7) = \frac{(5)}{(4)}
Table 15. Basic data used in estimating demand for broilers, 1931-58.

<table>
<thead>
<tr>
<th>Year</th>
<th>Farm price of broilers deflated by consumers' price index (Dollars/pound)</th>
<th>Per capita output of broilers (liveweight) (Pounds)</th>
<th>Per capita output of farm chickens (liveweight) (Pounds)</th>
<th>Per capita disposable income (Dollars)</th>
<th>Percentage of farmers' share in retail price of chickens deflated by price index</th>
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<table>
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<tr>
<th>Year</th>
<th>Month</th>
<th>Number of broiler chicks hatched (million)</th>
<th>Broiler-feed price ratio at mid-month</th>
<th>Egg-feed price ratio at mid-month</th>
<th>Technology index of broiler productiona</th>
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<td>-</td>
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<td>13.9</td>
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1956 | Jan.  | 110.9                                    | 4.3                                  | 13.7                             | 32.308                                 |
|      | Feb.  | 114.9                                    | 4.4                                  | 11.8                             | 32.421                                 |
|      | Mar.  | 132.4                                    | 4.6                                  | 11.6                             | 32.535                                 |
|      | Apr.  | 134.9                                    | 4.2                                  | 11.0                             | 32.650                                 |
|      | May   | 142.6                                    | 4.2                                  | 10.4                             | 32.766                                 |
|      | June  | 137.9                                    | 4.0                                  | 10.0                             | 32.882                                 |
|      | July  | 128.4                                    | 4.2                                  | 10.0                             | 32.999                                 |
|      | Aug.  | 123.1                                    | 3.8                                  | 10.1                             | 33.118                                 |
|      | Sept. | 106.9                                    | 3.6                                  | 10.6                             | 33.236                                 |
|      | Oct.  | 107.3                                    | 3.5                                  | 10.8                             | 33.356                                 |
|      | Nov.  | 107.8                                    | 3.4                                  | 10.5                             | 33.476                                 |
|      | Dec.  | 108.8                                    | 3.4                                  | 10.4                             | 33.599                                 |

1957 | Jan.  | 128.6                                    | 3.7                                  | 9.3                              | 33.720                                 |
|      | Feb.  | 122.4                                    | 3.9                                  | 9.2                              | 33.844                                 |
|      | Mar.  | 139.3                                    | 4.0                                  | 8.6                              | 33.968                                 |
|      | Apr.  | 141.3                                    | 3.8                                  | 8.6                              | 34.093                                 |
|      | May   | 147.6                                    | 3.9                                  | 8.2                              | 34.218                                 |
|      | June  | 141.9                                    | 4.3                                  | 8.3                              | 34.346                                 |
|      | July  | 143.5                                    | 4.4                                  | 9.2                              | 34.473                                 |
|      | Aug.  | 132.2                                    | 4.2                                  | 10.5                             | 34.601                                 |
|      | Sept. | 119.4                                    | 3.7                                  | 11.7                             | 34.731                                 |
|      | Oct.  | 119.7                                    | 3.5                                  | 12.8                             | 34.861                                 |
|      | Nov.  | 116.4                                    | 3.5                                  | 13.6                             | 34.992                                 |
|      | Dec.  | 126.5                                    | 3.4                                  | 13.3                             | 35.124                                 |

aEstimated in Table 1.
Table 16. Continued.

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<th>Egg-feed</th>
<th>Technology</th>
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<td>price ratio</td>
<td>index of</td>
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<td></td>
<td>chicks</td>
<td>at mid-month</td>
<td>at mid-month</td>
<td>broiler</td>
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<tr>
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<td>(million)</td>
<td></td>
<td></td>
<td>production^a</td>
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Table 17. Basic data used in estimating the relation of turkey supply, 1929-58.

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<th>Turkeys produced (live-weight)</th>
<th>Turkey-feed ratio, Oct.-Dec. year</th>
<th>Turkey-feed price, average</th>
<th>Poultry ration cost</th>
<th>Egg-profitability index, deflated</th>
<th>Broiler-profitability index, by agri-cultural weighted price index, average</th>
<th>Technology index of broiler production weighing</th>
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a Estimated in Table 1.

b Two-year average.
Table 17. Continued

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<th>Quantity of turkeys produced (live-weight)</th>
<th>Turkey-of feed price ratio, Oct.-Dec. year average</th>
<th>Turkey-feed price ratio, Nov.-May weighted average</th>
<th>Poultry ration cost deflated by agricultural price index, Jan.-June average</th>
<th>Egg-profitability index, average</th>
<th>Broiler-profitability index, Nov.-May weighted production</th>
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cNov.-May weighted average.