# A Study of the Economics of Force Molting in Commercial Egg Production

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## Contents

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# A Study of the Economics of Force Molting in Commercial Egg Production

JAMES W. PARLOUR and A. N. HALTER

## INTRODUCTION

The trends in egg prices and production costs which have occurred since 1950 have effected marked changes in the commercial egg-producing industry. A decline in the per capita consumption, combined with a relatively fixed supply of eggs, has resulted in a steady downward trend in egg prices (*74*).[1] As a consequence of increasing quantities of broiler meat on the market, the salvage value for a culled laying hen decreased from a level of 23 cents per pound in 1950 to 7 cents per pound in 1968 (*74*). This decline has caused a significant increase in the cost of flock depreciation. Increased costs for other inputs such as labor and equipment also have added to what might be termed a cost-price squeeze in the industry.

These trends have resulted in considerable long-term structural adjustments in the industry. These structural changes have, in the main, involved long-run technological adaptations resulting in a substantial changeover from extensive to intensive (controlled environment) housing, increased physical size and scale of operation, and vertically integrated operations with complete control of input and output flows. These changes have resulted indirectly in lower product prices and have hastened the exit of nonadaptive high-cost producers from the industry.

In an attempt to increase the short-run efficiency of resource utilization in their operations, producers have looked at ways of making more efficient use of the laying bird. The increasing cost of flock depreciation has caused producers to question the continued use of "traditional" annual replacement policies and to consider the feasibility of extending the laying life of their birds beyond the end of the first year (cycle) of production.[2] The use of extended laying cycles of up to two years in length proved to be moderately successful in as far

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[1] Numbers in parentheses refer to Literature Cited, page 66.

[2] This has been made possible by the move from extensive to intensive housing. Under extensive conditions the pattern of egg production and the onset of a natural molt (rest period) is governed by daylength. The move to intensive housing gives the producer greater control over production and, in the absence of declining daylength, birds can be kept in-lay for extended periods without molting.

as they resulted in increased total output per bird, hence reducing the cost of livestock depreciation per unit of output (*16, 62*).

The advantage of the lower depreciation cost was countered, however, by a number of serious economic disadvantages caused by poor egg quality, resulting in a high percentage of B grade and reject eggs, and by high feed/eggs conversion ratios. Both these factors become increasingly important after the end of the first year. Poor egg quality caused the greatest loss in egg revenue to the producer, especially as retail outlets increased the demand for eggs of high quality. Also, high levels of mortality were sustained by birds in their second year of production.

It has been known for some time that a natural molt was followed initially by favorable increases in egg quality, egg size, and hen-month egg production (*40*). Experimental laying trials have been conducted to investigate the influence of force molting[3] on these factors of production (*6, 15, 17, 29, 34, 35, 38, 41, 46, 51, 55, 59,* and *65*). The results of these trials show: (1) that a molt can be induced using several different methods, e.g., by using drugs or by the imposition of unnatural stress such as the removal of light, food, or water for a short period, and (2) that an enforced rest period in the laying cycle resulted in a significant improvement in egg quality, egg size, and hen-month egg production. The results from these trials also have indicated that replacement policies, using extended laying cycles which incorporate a force molting program, might provide effective economic alternatives to traditional annual replacement policies.

## THE PROBLEM

The main interest of this study was to examine the economic feasibility of using force molting programs in commercial egg production. This involves the programming of production and those decisions pertaining to the periodic replacement of the laying bird when a force molting program is included in the producer's set of alternative actions.

It will be assumed that problems in the industry related to optimum size, scale, and rate of growth can be separated from those actually involving the programming of production. Thus, assuming that the price-cost relationships are such that a producer would be willing

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[3] Force molting is a procedure conducted under controlled environment conditions. It involves subjecting birds to unnatural stress, such as starvation and removal of light or water for a short period (*6, 58, 35, 46*), or the administering of anti-pituitary drugs such as ICI 33828 and progestins which inhibit secretion of oestrogenic hormones (*4, 12, 15, 71*). This induced "rest" period lasts from 4 to 8 weeks. See Himeno and Tanabe (1957) for a discussion of the mechanism of molting in the hen.

and able to stay in production, the principal decision to be examined is the replacement policy to be used by the producer.

Thus, given that the producer has one or more laying houses and other resources, the problem becomes one of determining what laying flock replacement policy the producer could follow in order to maximize net revenue, minimize costs, or to optimize some other decision criterion. This problem involves questions concerning: (1) the optimum timing of replacements, (2) the optimum length of the laying cycle, and (3) the desirability of using a force molting program.

The problem of determining optimum replacement policies for egg laying has received some attention in the literature, but little emphasis has been placed on the importance of force molting programs and how their inclusion might alter the nature of the replacement problem and its solution. This omission has been mainly due to the fact that the results from force molting trials have only recently become available for economic analysis. The work that has been published on the importance of force molting programs for the planning of flock replacements has been somewhat limited in nature, in that it has failed to emphasize the magnitude and complexity of the decision-making problem when extended laying cycles are included in the producer's set of alternative actions. The replacement problem can be treated as:

1. A decision-making problem under certainty, where it is assumed that the consequence of each action is known (each action invariably leads to a specific single valued outcome); or
2. A decision-making problem under uncertainty, where the decision requires a choice when it is uncertain as to what the possible outcomes of an action or the respective likelihood of these outcomes might be.

Most of the published research on the replacement of poultry flocks can be classified under certainty. It was the intent of this study to complement the work in this area and to contribute to an understanding of the replacement problem under conditions of uncertainty.

## STUDY OBJECTIVES

### *The Decision-Making Problem Under Certainty*

The first objective of this study was to develop an analysis of the optimum replacement policy, assuming levels of costs, prices, and production variables were known with certainty. The analysis was divided into the following sections:

- A review of some of the literature concerning the optimum replacement policy.

- The specification of the nature of the replacement policy when five force molting programs are included in the producer's set of alternatives.
- The specification of an enumerative procedure to define the producer's replacement alternatives (actions) and the study of the choice of optimum action under a wide range of price, cost, and production conditions, assuming the criterion of maximizing net revenue.

Attention was focused on both the optimum and near-optimum actions for the range of economic conditions studied. Of particular interest was the relative ranking of those actions which called for a force molt at some stage in the planning period, and those that did not. Attention also was given to the economic conditions which caused the producer's optimum action to change from a nonforce molted action (an annual replacement policy) to a force molted action.

The following sections show that the producer's initial set of actions (A) was large. It was anticipated that the certainty analysis would indicate a small subset of actions ($\alpha$) which could then be used in the uncertainty analysis.

### *The Decision-Making Problem Under Conditions of Uncertainty*

The second objective was to study the producer's choice of an optimum replacement policy under conditions of uncertainty. This analysis was divided into the following sections:

- Specification of the producer's sources of income variability.
- Determination of the stochastic nature of the price, cost, and production variables affecting the decision-making process.
- Design of a simulation procedure used to estimate the moments of the distribution of net income for each of the producer's alternatives.
- Specification of the procedure whereby estimates of the moments of the distribution of net income, along with information on the form of the producer's utility function, can be used to obtain the expected utility from each of the producer's alternatives. A choice of action can then be made, using the criterion of maximizing expected utility.

## THE REPLACEMENT PROBLEM UNDER CERTAINTY —A REVIEW OF PAST RESULTS

Past studies of the flock replacement problem under conditions of certainty have assumed models based upon single valued structural relationships. These relationships have, in turn, been based upon a programming approach to production. The models that have been proposed in the literature have been concerned with the problem of ***reinvestment*** in the laying enterprise rather than with the problem of ***net investment.*** There is a clear distinction here between replacement and output expansion decisions. Replacement decisions are regarded as being of the reinvestment type, where investment is necessary to replace a unit of capital stock (e.g., the laying bird) in order to maintain, rather than expand, production capacity (*65*).

The models in the literature have varied according to the relationship presumed to exist between the length of life for each flock of birds $t_i$ in the renewal chain, and the length of the planning period N relevant to the enterprise. If a flock's economic length of life is $t_i$ (each $t_i = N$), then only a single investment decision need be made. If, however, $t_i \neq N$, then an optimum policy must be determined and incorporated into the analysis (*72*). Thus, the economic life of a unit of replaceable capital stock cannot be determined in isolation from the specification of the time span of the planning horizon.

### *Length of the Planning Period N*

The length of the planning period (planning horizon or enterprise life) assumed in the studies to date has varied from one (*43*) to ten years (*33, 43, 76*). The planning period should be clearly distinguished from the terms "production period" and "enterprise period," which were defined by Halter and White as follows:

> A production period is the length of time over which the product is accumulated and numbered here over the twelve months of the year, whereas each enterprise period is of the same length as the production period, but numbered over the life of the enterprise.

The choice of length of planning period determines the length of time over which the decision process is to be considered. This choice is a function of an evaluation as to what the "life of the enterprise" should be; the programming method itself dictates that the recursive process must be continued over a long enough period of time so that the choice of the initial allocation does not affect the optimum policy.[4] A 10-year planning period has been the choice for most analyses. Low and Brookhouse used a one-year planning period, and concluded:

> The feature that is unrealistic about the example worked out above [assuming a 12-month planning period] is the length of the planning period. Changing the end date changes the problem. It almost certainly changes the solution in detail, if not in emphasis. The shorter the planning period, the more pronounced the effect of a change in end date.

This conclusion, that with such a short planning period the choice of allocation to the first stage affects the solution, could have been predicted from the theory of dynamic programming. Noles (1967) stated

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[4] Dynamic programming was the method originally used in these studies to derive the optimum replacement policies. For a clarification of this statement, see the discussion of dynamic programming in Parlour's dissertation (*60*).

the replacement problem as one of finding the optimum combination of flocks which could be held in production for any one of seven laying season lengths (varying from 48 to 72 weeks). It was assumed that a flock could be housed on any one of the 13 housing dates during the year. The method Noles used to find this optimum combination was based on the assumption that:

> One could maximize net returns over time if one could determine the sequence of flocks with the highest average net income [per 28-day period] where the sequence of flocks constituted a cycle of flock replacements.

Noles' statement of the method used to find this optimum combination illustrates two points of crucial importance. The first concerns the need to state specifically the length of the planning period over which this optimum combination is to be determined *prior* to solution of the problem, and the second concerns the manner in which the magnitude of this problem expands as the length of the planning period increases.

> The first step in the determination of the optimum policy was the *arbitrary selection* of five consecutive flocks for the initial planning period. With five flocks the planning period extended from 5.0 to 7.3 years, since flocks could be kept in-lay from 48 to 72 weeks [emphasis added].

The selection of the "initial planning period" as "five consecutive flocks" implies a logical contradiction in terms. A planning period is either 5.0 or 7.3 years long. These two events are mutually exclusive. Since all the possible combinations of "five consecutive flocks" covered a large range of different time spans (or planning periods), it was invalid for Noles to assume that these combinations were even comparable.

The fallacy in Noles' choice criterion lies in his assumption that the optimum policy determines the length of the planning period. This obviously is incorrect, since the object of any optimizing policy is to determine the best action or series of actions which can be taken subject to the constraint that only a limited quantity of resources are available to allocate over the length of the planning period. For as Bellman and Dreyfus stated: "The maximizing problem *arises* from the fact that we have only a limited quantity of resources available" [emphasis added]. Thus, the definition of the planning period (over which these limited resources are to be allocated) must precede and not follow the solution to the optimizing policy.

### *The Production Period*

The choice of the production period determines the upper constraint on the age at which a bird is allowed to remain in the renewal chain. Thus, if a production period of 12 months is assumed, then an optimum replacement policy is determined, subject to the constraint that when a bird has been in production (in-lay) for 12 months it must be culled, and the producer has no alternative but to replace it. It represents an evaluation of the economic laying life of the bird. This constraint has been specified as 12 months (*33*), 16 months (*43*), and 30 months (*61*) in the studies completed to date.

## *Entry of Birds Into the Renewal Chain*

The assumptions made concerning the entrance of laying birds into the replacement chain have had an important effect on the optimum policies resulting from the studies completed to date. These differences can best be illustrated by comparing the assumptions made by Halter and White (1962) with those of Low and Brookhouse (1967).

In their analysis of the replacement problem, Halter and White assumed that at each stage of the decision process two courses of action could be taken: either the presently held bird could be kept in-lay for another time period or it could be replaced with another laying bird of a different age; i.e., if the presently held bird had been in-lay for j months, it could be replaced with *any other* bird that had been in-lay for i months, $i = 1, 2, \cdots, 13$, $i \neq j$.

In their later study, Low and Brookhouse, although assuming that only two courses of action could be taken at each decision point (as in Halter and White's study), included the important constraint that the presently held laying bird could be replaced *only* with a point-of-lay pullet ($i = 1$).

These assumptions resulted in the two studies arriving at markedly different conclusions as to the "optimum" replacement policy that should be followed. The distinction between the assumptions made in the two studies centered on an *a priori* assumption regarding the market valuation of the laying birds entering and leaving the replacement chain. Thus, Halter and White assumed that the purchase price (or equally, the sale price) of a laying bird was a function of its salvage value *plus* its egg-laying potential. By assuming that the laying bird was an asset that could not be meaningfully valued after reaching point-of-lay by estimating the price it could bring on the open market,[5] Low and Brookhouse restricted the birds allowed to enter the replacement chain to point-of-lay pullets only.

## *Critique*

The conclusions reached as to the optimum laying cycles for commercial egg layers have differed considerably; there has been no consensus of opinion to date. This has been mainly due to the fact that the models proposed are operational only within the bounds of the re-

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[5] Cocks and Murray (1966) maintain that this is because the market is prepared to buy birds culled from the laying flock for their carcass value only.

strictive assumptions made in the analysis, as has been shown in the preceding discussion. The results attained have depended on the assumptions about the length of the planning horizon, the production period, and the age at which a bird enters and leaves the renewal chain. In addition, the models in the literature have used different input specifications concerning egg prices, cost levels, and production coefficients; hence the results of these models hold only for the set of parameter values used in the particular analysis.

In general, too little attention has been focused on the sensitivity of the replacement policies to imposed changes in costs, prices, and input coefficients, and too much attention has been centered on the determination of the "optimum policy" using a single set of parameter values. Notable exceptions to this criticism are found to some extent in the work of Low and Brookhouse (*43*), and to a much greater degree in Pouliquen's study (*61*).

### *Force Molting Policies*

The work on the economics of force molting policies has been stimulated by the results of some recent force molting trials. The most thorough study of force molting was completed by one of the authors in a master's thesis project (*58*). In this thesis a simple comparative procedure was used in attempting to answer the question as to whether a producer should force molt birds at 13 months of age and continue for a second cycle of production, or whether it would be more economical to replace with a new flock of pullets at this time. These were the only alternative actions considered.

Major emphasis was placed on the influence of egg prices and the cost of the replacement pullet on the final solution. Questions concerning the best way to force molt birds (conventional or drug-induced method), and the influence of breed differences (medium-heavy versus light) on performance over the two cycles also were considered. This work indicated the need for further investigation of the effects of force molting at different periods in the laying cycle (after 6, 12, and 18 months, or after 9 and 18 months in-lay). This investigation was later completed at the Washington Agricultural Experiment Station.

## MODEL OF THE FLOCK REPLACEMENT PROCEDURE

A model of the replacement procedure, when force molting is included in the producer's set of alternative actions, can be represented visually in a decision tree diagram. Such a diagram, with the inclusion of five force molting programs, is shown in Figure 1. A description of these force molting programs and the relevant states of production for birds in-lay for different lengths of time is given below:

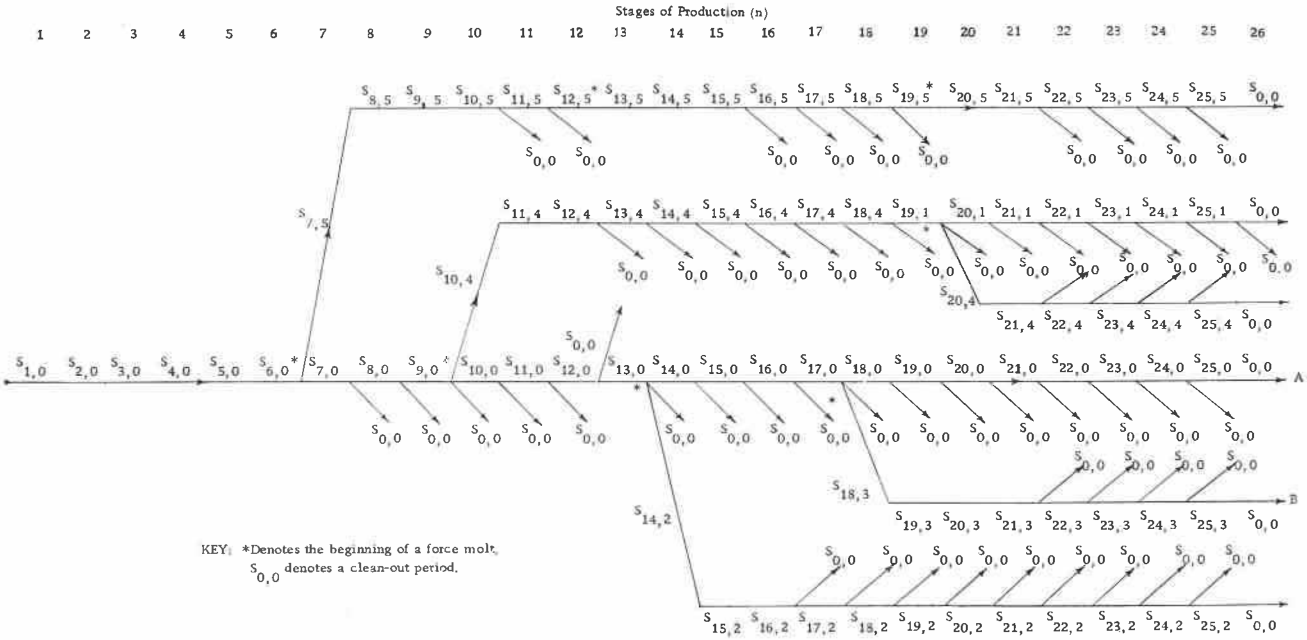

Figure 1. Decision tree diagram showing the sequence of states of production for five force molted and one non-force molted alternatives over a 26-month planning period.

Let $s_{jk}$ = a state of production for a bird in-lay for j months[6] subjected to the $k^{th}$ force molting procedure. The set of all states is denoted:

$$S = \{s_{jk}\},\ j = 0,1,2, \cdots ,26,\ k = 0,1, \cdots ,5$$

where

$j = 0$ designates a four-week clean-out period,

$j = 1,2, \cdots ,26$ designates the number of months in-lay (or months from point-of-lay),

$k = 0$ designates a bird that has not been force molted,

$k = 1$ designates a bird that has been force molted once after nine months in-lay,

$k = 2$ designates a bird that has been force molted once after 13 months in-lay,

$k = 3$ designates a bird that has been force molted once after 17 months in-lay,

$k = 4$ designates a bird that has been force molted twice after 9 and 19 months in-lay, and

$k = 5$ designates a bird that has been force molted three times, after 6, 13, and 19 months in-lay.

The decision tree diagram (model) was based upon the following important assumptions and constraints:

✓ The enterprise was of the simplest possible form, i.e., a single laying unit.

✓ The producer followed an all-in all-out replacement policy for this laying unit.

✓ Only point-of-lay birds (20-24 weeks of age) were allowed to enter the replacement chain.

✓ Birds were not kept in-lay for longer than two years (26 months).

✓ Birds would not be replaced until they had been in-lay for at least seven months, nor would they be replaced until at least two months following the onset of a force molt.

✓ The producer would allow a minimum clean-out period of four weeks every two years.

A verbal description of the model shown diagrammatically in Figure 1 should help in understanding the model and the difficulties encountered in the search for a programming method to solve the flock replacement problem. Referring to Figure 1, the following points should be noted:

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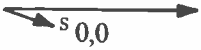
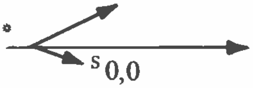
[6] All future references to "a month" will refer to a 28-day period, except where otherwise specified.

1. All possible stages[7] and states of production are shown for a *26-month* planning period only (i.e., $n = 1,2, \cdots, N$ where $N = 26$). The $s_{jk}$ states are listed along the six horizontal pathways.[8] Each of these six pathways indicates a replacement policy which involves keeping a bird (flock) in-lay for a 26-month period (25 months of lay plus a one-month clean-out period). Over this 26-month period the flock theoretically could be subjected to one of the five force molting procedures listed above, or it could be kept in-lay for the 26 months without a force molt. Examples of these two pathways are shown in Figure 1 along paths B and A respectively.

2. Besides these six horizontal pathways, the figure shows the stages at which the producer theoretically could make a choice (decision) as to what course of action he should pursue in subsequent stages of the planning period. These branches indicate decision points. In most cases the decision calls for a simple replace/continue choice, indicated by , while at some a three-way choice (replace/continue/force molt) is called for, indicated by . If all the possible combinations of the stages of production had been listed over the 26 stages shown in the diagram, then it should be apparent that there would be many more alternative pathways which extend over the length of the planning period besides the six shown in the figure. An example of such an alternative pathway might be:

$$s_{1,0}\ s_{2,0} \cdots s_{7,0}\ s_{0,0}\ s_{1,0}\ s_{2,0} \cdots s_{7,0}\ s_{0,0}\ s_{1,0}\ s_{2,0} \cdots s_{9,0}\ s_{0,0}.$$

Such a pathway satisfies the constraints of the model and indicates a replacement policy over the 26-month period which calls for the first flock to be held in-lay seven months, the second for seven months, and the third for nine months.

The alternative pathways are far too numerous to include all of them in the decision tree diagram for even such a short planning period as 26 months. It also should be apparent that as the planning period is lengthened, the number of alternative paths expands exponentially.

With these points in mind, the replacement problem can be stated as one of determining the optimal combination or mapping of the $s_{jk}$

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[7] The stages are defined as the four weekly periods into which the planning period is divided.

[8] A pathway being defined as: any sequence of states of production which begins with state $s_{1,0}$ and extends over the length of the planning period, subject to the assumptions and constraints listed above.

states in S over the N stage process such that $n = 1,2, \cdots ,N$ (where N is the length of the planning period), given some optimizing criterion such as maximizing net revenue and subject to the assumptions and constraints listed previously.

### *Choice of a Programming Method*

The description of the model shown in Figure 1 establishes that the replacement problem with the inclusion of a set of force molting procedures is far more complex than any similar type problem that has been encountered. This can be appreciated by considering that all previous models, with one exception, have dealt with the problem of mapping together states of production along a single pathway, (path A in Figure 1). Halter and White (1962) and Low and Brookhouse (1967) have demonstrated that this problem can be solved without difficulty, using dynamic programming methods. The replacement problem posed by Pouliquen (1966) included the possibility of introducing a force molt at 13 months of age, and he was therefore concerned with the mapping of states along two pathways (A and B in Figure 1).

The review of the literature on optimum policies in commercial egg production showed that dynamic programming methods have found wide application in this area of research. Thus it seemed in order to consider the possibility of using an approach based upon this programming method. However, further examination of the replacement model and the resulting methodological problems when the possibility of a large number of force molting programs were included in the producer's set of possible actions, led to a rejection of this method as computationally inefficient. A discussion of the merits and demerits of using the dynamic programming method for this problem is given in Parlour's dissertation (*60*).

It was decided to use a simple enumerative procedure to compare the producer's alternative actions over some specified planning period N. In order to simplify the enumerative problem, the following assumptions were made:

- The producer's planning period extended over a two-year (26-month) period. This planning period was regarded as the longest period of time over which a replacement decision would be made. This appeared to be a realistic assumption, both from the standpoint of the uncertainty involved in egg production and the conceivable length of egg-laying cycles for birds of present genetic stock.

- The state of the enterprise would be the same at the end as at the beginning of the planning period. This ensured that all alternative actions were compared under identical conditions as well as over the same length of time. In this analysis, this state was set at $s_{0,0}$ or a clean-out period.

The inclusion of these assumptions made it possible to enumerate all possible actions the producer theoretically could follow over the two-year planning period. These actions were included in the set A where an action $a_i$ is a series of states of production where the state of production prevailing in any one of the 26 stages of the planning period is defined by $s_{jk}$. Let this action begin at the commencement of the first stage of production in state $s_{1,0}$ and conclude at the end of a clean-out period in state $s_{0,0}$.

Thus, the series of states of production listed below are examples of an action in A over the 26-stage planning period:

$$s_{1,0}\ s_{2,0}\ \cdots\ s_{25,0}\ s_{0,0}. \tag{1}$$

This series defines the laying cycle over the planning period for a bird which is kept in-lay for 25 months without a force molt, with a one-month clean-out period ($s_{0,0}$) at the end of the planning period. Another example is:

$$s_{1,0}\ s_{2,0}\ \cdots\ s_{12,0}\ s_{13,0}\ s_{14,2}\ \cdots\ s_{25,2}\ s_{0,0}. \tag{2}$$

This series of states of production defines the laying cycle over the planning period for a bird which is force molted after 13 months in-lay and kept in production a further 12 months, with a one-month cleaning-out period at the end of the planning period.

With the aid of the decision tree diagram (Figure 1) and the definition of an action, it was possible to make a complete listing of the states of production over all stages of production for each action in A. States of production prevailing in each stage of the planning period for these actions are given in Tables 1 and 2. For the sake of clarity it was decided to differentiate between those actions which included a force molting program during the planning period and those which did not. The actions in the former category were included in the set $A^f$, and those in the latter in set $A^\circ$. Thus, the series (1) above would be included in the set $A^\circ$, and the series (2) in the set $A^f$.

From the actions listed in Table 1, it will be seen that:

$$A^\circ = \{a_i\},\ i = 1,2,\cdots,27,$$

and from Table 2 that

$$A^f = \{a_i\},\ i = 28,29,\cdots,54.$$

Thus, $$A = A^\circ \cup A^f = \{a_i\},\ i = 1,2,\cdots,54.$$

In order to make a comparison among the alternative actions in A on an economic basis, costs and returns must be calculated for each alternative. The following sections define the variables and parameters used in determining the economic benefits from each alternative.

Table 1. The set A° (tabulated j, k indices for the $s_{jk}$ states of production comprising each non-force molted action over the planning period)[a]

| $A^{\circ}$ | Stages of Production (n) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| i | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 1 | 1,0 | 2,0... | | | | | | | | | | | | | | | | ...18,0 | 1,0 | 2,0... | | | | | ...7,0 | 0,0 |
| 2 | 1,0 | 2,0... | | | | | | | | | | | | | | | ...17,0 | 1,0 | 2,0... | | | | | | ...8,0 | 0,0 |
| 3 | 1,0 | 2,0... | | | | | | | | | | | | | | ...16,0 | 1,0 | 2,0... | | | | | | | ...9,0 | 0,0 |
| 4 | 1,0 | 2,0... | | | | | | | | | | | | | ...15,0 | 1,0 | 2,0... | | | | | | | | ...10,0 | 0,0 |
| 5 | 1,0 | 2,0... | | | | | | | | | | | | ...14,0 | 1,0 | 2,0... | | | | | | | | | ...11,0 | 0,0 |
| 6 | 1,0 | 2,0... | | | | | | | | | | | ...13,0 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 0,0 |
| 7 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 1,0 | 2,0... | | | | | | | | | | | ...13,0 | 0,0 |
| 8 | 1,0 | 2,0... | | | | | | | | | ...11,0 | 1,0 | 2,0... | | | | | | | | | | | | ...14,0 | 0,0 |
| 9 | 1,0 | 2,0... | | | | | | | | ...10,0 | 1,0 | 2,0... | | | | | | | | | | | | | ...15,0 | 0,0 |
| 10 | 1,0 | 2,0... | | | | | | | ...9,0 | 1,0 | 2,0... | | | | | | | | | | | | | | ...16,0 | 0,0 |
| 11 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | | | | | | | | | | | ...17,0 | 0,0 |
| 12 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | | | | | | | | | | | ...18,0 | 0,0 |
| 13 | 1,0 | 2,0... | | | | | | | | | ...11,0 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | ...7,0 | 0,0 |
| 14 | 1,0 | 2,0... | | | | | | | | ...10,0 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | ...8,0 | 0,0 |
| 15 | 1,0 | 2,0... | | | | | | | ...9,0 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | | ...9,0 | 0,0 |
| 16 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | | | ...10,0 | 0,0 |
| 17 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | | | | ...11,0 | 0,0 |
| 18 | 1,0 | 2,0... | | | | | | | | ...10,0 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | ...7,0 | 0,0 |
| 19 | 1,0 | 2,0... | | | | | | | ...9,0 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | | ...8,0 | 0,0 |
| 20 | 1,0 | 2,0... | | | | | | | ...9,0 | 1,0 | 2,0... | | | | | | | ...9,0 | 1,0 | 2,0... | | | | | ...7,0 | 0,0 |
| 21 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | | | ...9,0 | 0,0 |
| 22 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | | | ...9,0 | 1,0 | 2,0... | | | | | | ...8,0 | 0,0 |
| 23 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | | | | ...10,0 | 1,0 | 2,0... | | | | | ...7,0 | 0,0 |
| 24 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | | | | ...10,0 | 0,0 |
| 25 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | | ...9,0 | 1,0 | 2,0... | | | | | | | ...9,0 | 0,0 |
| 26 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | | | ...10,0 | 1,0 | 2,0... | | | | | | ...8,0 | 0,0 |
| 27 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | | | | ...11,0 | 1,0 | 2,0... | | | | | ...7,0 | 0,0 |

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[a] Where j represents the age of the bird, and k represents the force molting treatment.

Table 2. The set $A^f$ (tabulated j, k indices for the $s_{jk}$ states of production comprising each of the force molted actions over the planning period)[a]

| $A^f$ | Stages of Production (n) | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| i | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 28 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5... | | | | | | | | | | | | | | | | | ...25,5 | 0,0 |
| 29 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5... | | | | | | | | | ...17,5 | 1,0 | 2,0... | | | | | | ... 8,0 | 0,0 |
| 30 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5... | | | | | | | | ...16,5 | 1,0 | 2,0... | | | | | | | ... 9,0 | 0,0 |
| 31 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5... | | | | | | | ...15,5 | 1,0 | 2,0... | | | | | | | | ...10,0 | 0,0 |
| 32 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5... | | | ...11,5 | 1,0 | 2,0... | | | | | | | | | | | | ...14,0 | 0,0 |
| 33 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5... | | | ...11,5 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | ... 7,0 | 0,0 |
| 34 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5..... | | 10,5 | 1,0 | 2,0... | | | | | | | | | | | | | ...15,0 | 0,0 |
| 35 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5..... | | 10,5 | 1,0 | 2,0... | | | | | ...7,0 | 1,0 | 2,0... | | | | | | ... 8,0 | 0,0 |
| 36 | 1,0 | 2,0... | | | | ...6,0 | 7,5 | 8,5..... | | 10,5 | 1,0 | 2,0... | | | | | | ...8,0 | 1,0 | 2,0... | | | | | ... 7,0 | 0,0 |
| 37 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,4 | 11,4... | | | | | | | | | | | | | | ...25,4 | 0,0 |
| 38 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,4 | 11,4... | | | | | | ...17,4 | 1,0 | 2,0... | | | | | | ... 8,0 | 0,0 |
| 39 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,4 | 11,4... | | | | | ...16,4 | 1,0 | 2,0... | | | | | | | ... 9,0 | 0,0 |
| 40 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,4 | 11,4... | | | | ...15,4 | 1,0 | 2,0... | | | | | | | | ...10,0 | 0,0 |
| 41 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,4 | 11,4... | | | ...14,4 | 1,0 | 2,0... | | | | | | | | | ...11,0 | 0,0 |
| 42 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,4 | 11,4...... | | 13,4 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 0,0 |
| 43 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 13,0 | 14,2... | | | | | | | | | | | ...25,2 | 0,0 |
| 44 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 13,0 | 14,2... | | | | ...18,2 | 1,0 | 2,0... | | | | | ... 7,0 | 0,0 |
| 45 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 13,0 | 14,2... | | | ...17,2 | 1,0 | 2,0... | | | | | | ... 8,0 | 0,0 |
| 46 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 13,0 | 14,2...... | | 16,2 | 1,0 | 2,0... | | | | | | | ... 9,0 | 0,0 |
| 47 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,1 | 11,1... | | | | | | | | | | | | | | ...25,1 | 0,0 |
| 48 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,1 | 11,1... | | | | | | | ...18,1 | 1,0 | 2,0... | | | | | ... 7,0 | 0,0 |
| 49 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,1 | 11,1... | | | | | | ...17,1 | 1,0 | 2,0... | | | | | | ... 8,0 | 0,0 |
| 50 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,1 | 11,1... | | | | | ...16,1 | 1,0 | 2,0... | | | | | | | ... 9,0 | 0,0 |
| 51 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,1 | 11,1... | | | | ...15,1 | 1,0 | 2,0... | | | | | | | | ...10,0 | 0,0 |
| 52 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,1 | 11,1... | | | ...14,1 | 1,0 | 2,0... | | | | | | | | | ...11,0 | 0,0 |
| 53 | 1,0 | 2,0... | | | | | | | ...9,0 | 10,1 | 11,1...... | | 13,1 | 1,0 | 2,0... | | | | | | | | | | ...12,0 | 0,0 |
| 54 | 1,0 | 2,0... | | | | | | | | | | | | | | | ...17,0 | 18,3 | 19,3... | | | | | | ...25,3 | 0,0 |

[a] Where j represents the age of the bird, and k represents the force molting treatment.

### *Net Revenue Equation for the $i^{th}$ Action in A Over the Planning Period N*

Let $\pi_i$ = the net revenue (income) accruing to the producer as a result of taking action $a_i$, over N, i.e.,

$$\pi_i = TR_i - (LD_i + TCF_i + FC_i)$$

where:

$TR_i$ = total revenue from egg production of all sizes and qualities,

$LD_i$ = flock depreciation (the difference between the cost of the point-of-lay pullet flock and the salvage value of the flock when culled),

$TFC_i$ = total feed cost, and

$FC_i$ = fixed costs.

A complete description of the equations and calculations are given by Parlour (*60*).

## PRODUCTION DATA

The hen-month egg production data, the monthly distribution of eggs by grade, and monthly feed consumption figures for each of the $s_{jk}$ states of production used in the analysis are listed in Table 1 of Appendix B. Every effort was made to ensure that data were compiled from essentially homogeneous sources. In most cases the conventional force molting method was used. The differences in production due to the influence of breed differences were minimized by considering only data from those trials which used a light hybrid (Leghorn type) bird. Only data from those experiments conducted under intensive (controlled) environment housing conditions over the laying cycle were considered. Differences in production due to the influence of age at point-of-lay were minimized by considering only those flocks housed in the laying quarters at 21 to 23 weeks of age.

### *Sources of Information*

The primary sources of production data were: (1) Washington State Agricultural Experiment Station trials, (2) New York State (Cornell) Agricultural Experiment Station trials, (3) Wye College (University of London) trials, and (4) Skylane Farms, Oregon.

In addition to the production data obtained from these trials, useful information was supplied by secondary sources reported in the literature (*5, 14, 19, 35, 41, 46, 48, 51*).

**Washington State Agricultural Experiment Station trials, 1964-1966.** These trials, conducted under the direction of Reed Hansen, were designed primarily to determine the effect of a number of force molting procedures on egg production and egg quality. A conventional force molting method was used, requiring a reduction in lighting followed by complete removal of feed and water for 48 hours. This was followed by a three-week period of reduced feeding in order to keep the birds on an enforced rest.

The following force molting procedures were used over a two-year laying cycle:

1. Control—no force molting over the two-year period.
2. Six-month molts—birds were force molted at 6, 13, and 19 months from point-of-lay.
3. Nine-month molts—birds were force molted at 9 and 19 months from point-of-lay.
4. Thirteen-month molt—birds were force molted at 13 months from point-of-lay.

Three replicate flocks of 50 birds, housed at point-of-lay, were used for each of the above procedures. Complete weekly production records on these trials were available for analysis.[9] Some additional information was obtained from the published reports of the trials (*35*).

**Cornell University Agricultural Experiment Station trials, 1959-1961.** These trials, directed by D. Marble, covered two years of egg production for 11 different breed combinations in two consecutive New York random sample tests. A total of 44 flocks (50 birds housed per flock) were used in the trials. All the experimental flocks were force molted 17 months from point-of-lay, using the same procedure as for the Washington trials. Complete original production records were furnished by Cornell.[10] These trials were reported by Marble (1963).

**Wye College (University of London) trials.** These trials, under the direction of A. H. Sykes, also covered a two-year laying period. Three treatments and two different breeds of birds were used. These treatments were:

1. Control—no force molting over the two-year period.
2. Birds force molted after 13 months in-lay, using conventional force molting procedure.
3. Birds force molted after 13 months in-lay, using a drug-molting procedure (ICI 33828).[11]

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[9] R. Hansen and G. Bearse of the Washington State Agricultural Experiment Station were most cooperative in allowing access to the original records of these trials, and in providing valuable information in personal communications.

[10] Professor Bruckner of Cornell University was kind enough to provide the complete records from these trials.

[11] A drug developed by Imperial Chemical Industries of Great Britain, as a result of work in the area of the control of female ovulation using the "pill." In chickens it acts upon the pituitary gland to prevent ovulation. Information on the effectiveness of this drug and its possible further use in the poultry industry can be found in the literature (*4, 12, 15, 63, 71*).

Two breeds, a light and a medium-light hybrid, were used, giving a total of six breed-by-treatment groups. There was no replication within these six groups. These trials have been reported in the literature (*17*, *58*, *59*).

**Other sources.** Information pertaining to flocks force molted after nine months in-lay and kept for an extended laying cycle, was supplied by B. Franken of Skylane Farms, Oregon, a large commercial egg-laying enterprise.

### *Hen-Month Egg Production*

One of the major determinants of the monthly distribution of net revenue over the planning period for an action in the set A is the pattern of monthly egg production, which is influenced by the age of the bird and the force molting treatment to which a bird is subjected. The egg production patterns for five force molting procedures are shown in Figures 2 through 6. The egg production data relevant to the figures are given in Table 1 of Appendix B.

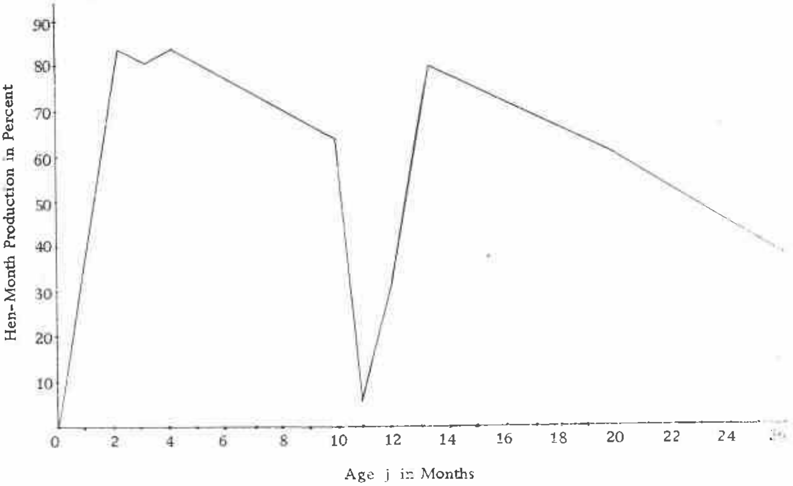

**Figure 2. Hen-month egg production percentages for a flock force molted after 9 months in-lay (k= 1, j =0 means point-of-lay bird).**

The decline in the percentage hen-month production with age is well illustrated by Figure 4.[12] All the figures show the manner in

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[12] These percentages were calculated on the basis of 100 percent production being equal to one egg per day over the 28-day month, or 2.33 dozen per hen-month. Thus 50 percent production would represent 1.16 dozen eggs per hen-month, i.e., 1.16/2.33 x 100 = 50%.

which force molting affected egg production for the duration of the molt, and how post-molt production figures increase above pre-molt levels. Figures 2 through 6 also show that force molting resulted in a halt in the decline in hen-month egg production (at least temporarily) and caused a subsequent return to a level that approximated the level observed four to five months prior to the onset of the molt.

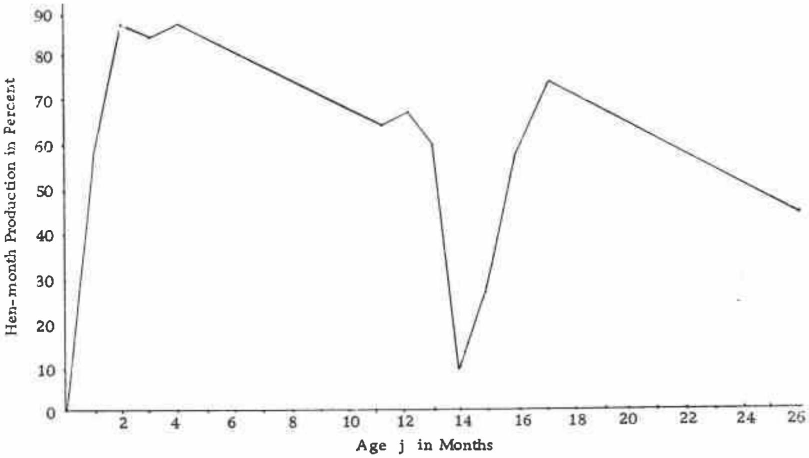

**Figure 3.** Hen-month egg production percentages for a flock force molted after 13 months in-lay ($k = 2$, $j = 0$ means point-of-lay bird).

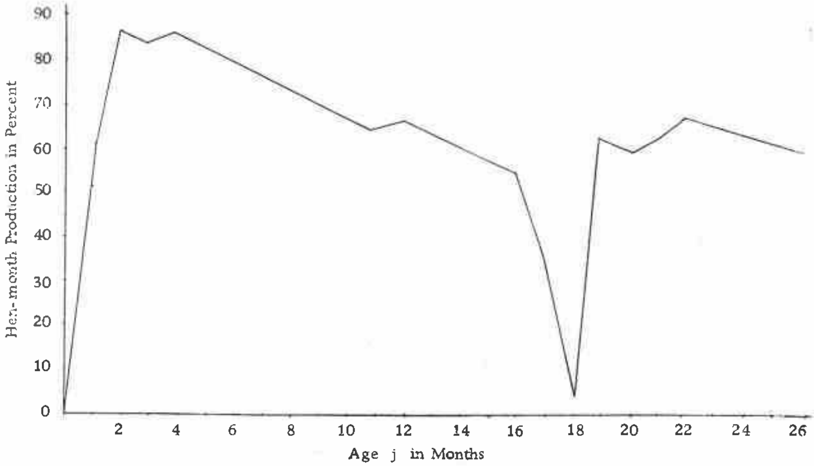

**Figure 4.** Hen-month egg production percentages for a flock force molted after 17 months in-lay ($k = 3$, $j = 0$ means point-of-lay bird).

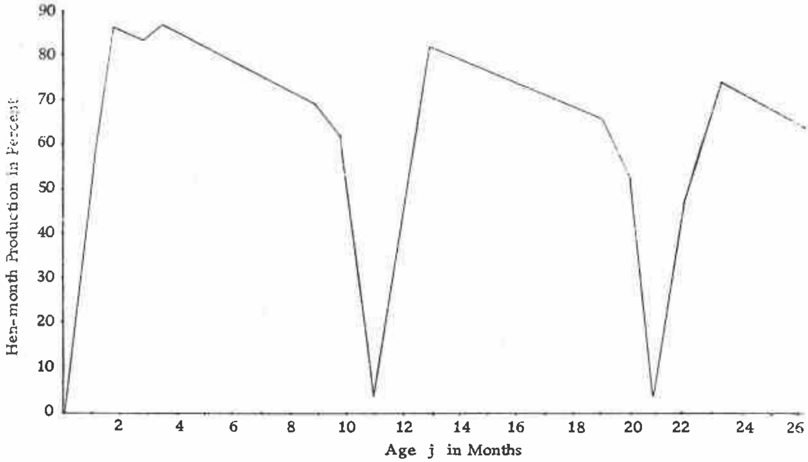

**Figure 5.** Hen-month egg production percentages for a flock force molted after 9 and 19 months in-lay ($k = 4$, $j = 0$ means point-of-lay bird).

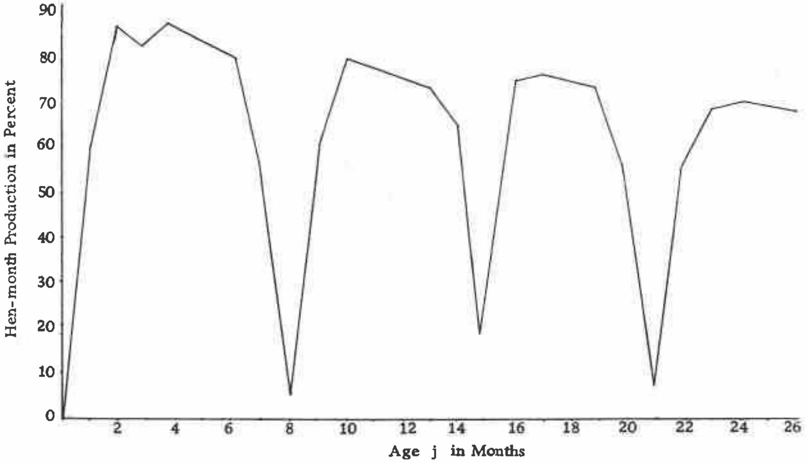

**Figure 6.** Hen-month egg production percentages for a flock force molted after 6, 13, and 19 months in-lay ($k = 5$, $j = 0$ means point-of-lay bird).

## *Egg Size Distribution*

A second determinant of the distribution of monthly net revenue is the distribution of egg size by age and force molting procedure. Figures 7 and 8 show how this egg size distribution changed with age for a flock force molted after 17 months in-lay, and for one force molted three times—after 6, 13, and 19 months in-lay.[13] These figures

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[13] The data used to derive these figures are shown in Table 1 of Appendix B.

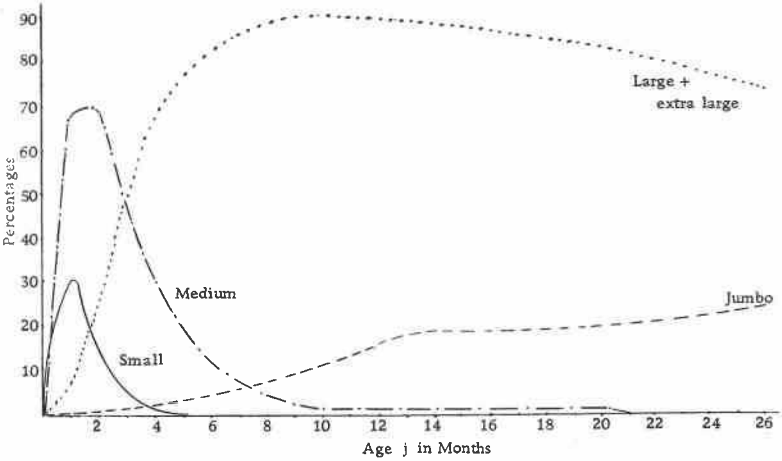

**Figure 7.** **Egg size distribution for a flock force molted after 17 months in-lay ($k = 3$, $j = 0$ means point-of-lay bird).**

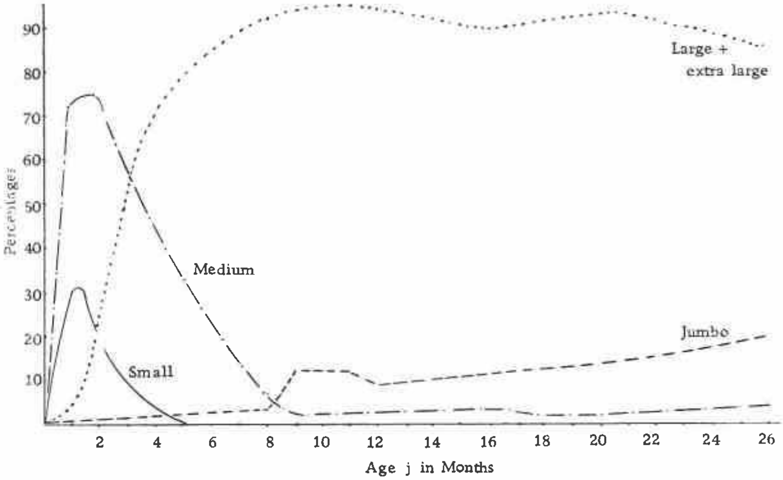

**Figure 8.** **Egg size distribution for a flock force molted three times after 6, 13, and 19 months in-lay ($k = 5$, $j = 0$ means point-of-lay bird).**

show that during the first six months of production small and medium size eggs predominated, after which time 90 to 98 percent of all eggs laid fell into the large-jumbo size categories. Neither the first molt after six months of production nor subsequent molts after 13 and 19 months of production had any significant effects on the monthly egg size distribution (Figure 8).

## *Egg Quality*

Whether a producer sells his eggs on a private retail market, to a cooperative, or to a wholesale buyer, he will obtain a quality price premium for AA grade eggs over A or B grade eggs. These price premiums can be quite large, with the result that low quality eggs can lead to significant losses in potential egg revenue to the producer. Thus, another determinant of the monthly distribution of net revenue is the difference in egg quality between flocks of different ages and force molting procedures.

As an example of how age and force molting procedure affect egg quality, Figure 9 shows the incidence of B grade eggs for four flocks—

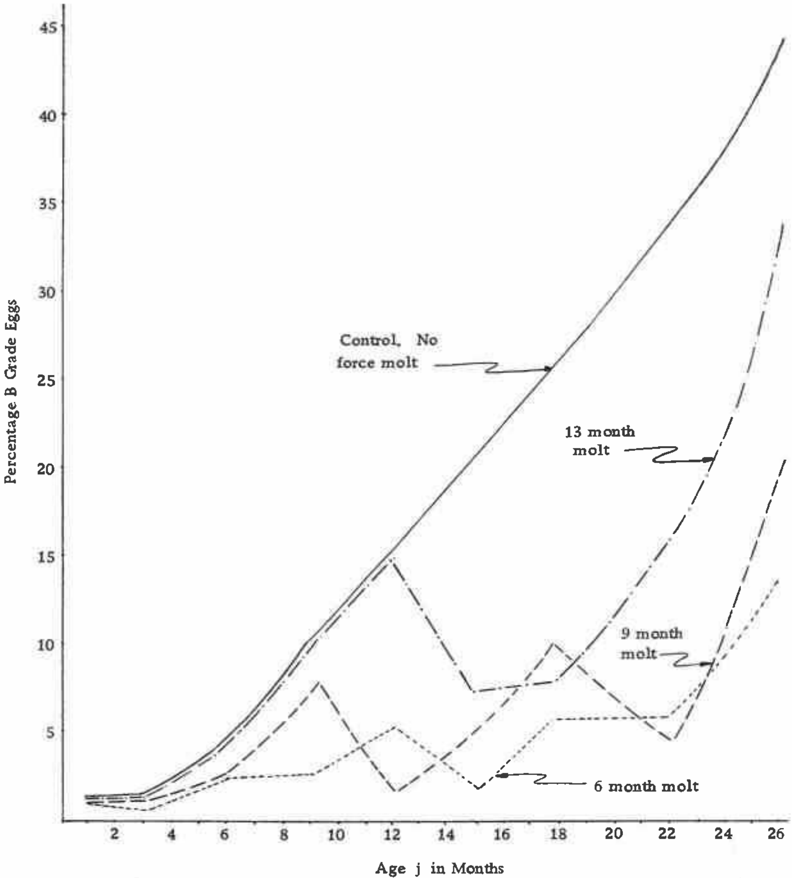

**Figure 9. The incidence of B grade (including commercial and reject) eggs for three force molted and one non-force molted flocks over a two-year period (j = 0 means point-of-lay bird; Washington State Agricultural Experiment Station data).**

three subjected to force molting procedures and the fourth in continuous production over a two-year period.

One of the major problems when keeping birds in-lay for extended periods without a force molt concerns the increasing preponderance of B grade and reject eggs with increasing age of the birds. This is well illustrated in Figure 9 by the upward trend in low quality eggs for those flocks kept for the two-year period without a force molt. Also, the relationship between the frequency of force molting and the incidence of low quality eggs is apparent from the figure.

The trends in egg and shell quality following force molting have been reported in the literature. Mehner and Torges (1967) reported that egg breaking strength as well as albumen quality improved in direct ratio (correlation) to the level shown prior to the molt; the lower this level, the greater the post-molt improvement. Improvements in egg and shell quality following force molting also were recorded by Berg and Bearse (1967), Len and others (1964), Snyder and Orr (1960), Hansen (1960, 1966), Parlour (1966), and Hyre (1966). In most cases force molting had the effect of increasing egg and shell quality to the levels shown five to seven months prior to the molt, but it was noted that this improvement was a function of the length of the enforced rest.

The estimated figures for the egg quality breakdown are shown in Table 1 of Appendix B, and are listed as the percentage of total eggs laid per hen-month in each of the seven market grades of eggs. The large-egg category was the only one which was subdivided into quality divisions—AA, A, and B. This is not to imply that all eggs laid in the other egg size categories were AA eggs; having no information on the subdivisions of these other size categories, this was a necessary assumption.

### *Feed Consumption*

The figures for feed consumption in pounds per hen-month are shown in Table 1 of Appendix B. This table also shows the weight of feed consumed per dozen eggs laid, as a measure of feed conversion efficiency. The decrease in feed conversion efficiency with age and the subsequent improvement in efficiency following a force molt were indicated by the results of these trials.

### *Mortality*

The results of these trials show that flock mortality is subject to extreme variation depending on severity of the force molting method, the general health of the flock prior to a force molt, breed of bird used, overall husbandry and management conditions, and whether or not a culling program is used prior to force molting. Thus, it was not possible to obtain a consistent set of figures to be used in the analysis. The figures shown in Table 3 are based upon the actual results obtained from the experimental sources. Because of the extreme variability of these figures, the mortality figures used in the analysis were modified to take account of other estimates obtained from secondary sources of information.[14] On the basis of information from these sources, the trial mortality percentages were adjusted to approximate commercial conditions, while at the same time maintaining the relative levels of mortality shown in Table 3 for the different force molting treatments. These adjusted mortality figures are given in Table 4.

Table 3. Flock mortality over first and second years of production for the experimental force molted flocks

| Source | Force molting after | Strain of bird | Percent mortality | |
|---|---|---|---|---|
| | | | First year | Second year |
| Wye College trials | 13 months in-lay | Light hybrid, | 17.0 | 26.0 |
| | | medium-heavy hybrid | 9.0 | 14.0 |
| Washington State Agricultural Experiment Station trials | No molt | Light hybrid | 2.0 | 8.0 |
| | 13 months in-lay | Light hybrid | 6.0 | 15.0 |
| | 9 and 19 months in-lay | Light hybrid | 5.0 | 7.0 |
| | 6, 13, and 19 months in-lay | Light hybrid | 5.0 | 8.0 |
| Cornell University Agricultural Experiment Station trials | 17 months in-lay | Light hybrid | 6.6 | 12.8 |
| California random sample tests[a] | No molt | Mixed light hybrid and light-heavy | 10.0 | 6.5 |
| | 17 months in-lay | Crosses | 10.0 | 6.0 |

[a] Reported by Len and others (1964).

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[14] Flock mortality estimates obtained from commercial flocks in the field indicate that mortality, at least over the first year of production, is distributed lognormally with a mean of approximately 14 percent.

Table 4. Adjusted flock mortality percentages used in the analysis

| No. of force molts over a two-year period | Force molted after | Percentage mortality | |
|---|---|---|---|
| | | First year | Second year |
| 1 | 17 months in-lay | 12.0 | 13.0 |
| 1 | 13 months in-lay | 12.0 | 11.0 |
| 1 | 9 months in-lay | 10.0 | 13.0 |
| 2 | 9 and 19 months in-lay | 10.0 | 10.0 |
| 3 | 6, 13, and 19 months in-lay | 9.0 | 10.0 |
| No molt | | 12.0 | 14.0 |

### *Final Body Weight*

The final body weight of the light hybrids used in the Washington trials was 4.95 pounds, with a range of 4.88 to 4.98 for the four treatment groups. The birds used in the Wye College trials were weighed out at a mean of 5.00 pounds. The birds used by B. Franken of Skylane Farms showed a mean weight of 4.00 pounds at the end of the first year and 4.06 pounds at the end of the second.

On the basis of these observations, birds were assumed to weigh 4.00 pounds up to the end of the first year of production and 5.00 pounds up to the end of the second year.

## OUTPUT AND INPUT PRICES

### *Egg Prices*

In obtaining estimates for egg prices to be used in the model, two conditions had to be satisfied. First, they had to be monthly (if possible, weekly) prices paid to producers at the farm in cents per dozen eggs. Second, the prices had to reflect both size and quality differentials. The price quotations from major egg markets such as Los Angeles, Chicago, and New York failed to satisfy both these conditions. Some of the smaller market quotations gave prices paid at the farm but failed to give the necessary quality breakdown. The source of egg prices finally selected was a large local producers' cooperative which was able to supply the required weekly price information for the 10-year period, 1958 to 1967. These egg prices for all market grades are given by Parlour (*60*).

Figure 10 illustrates the seasonal fluctuations in mean monthly egg prices over the 10-year period, 1958 to 1967. The fluctuations were periodic (every 13 months). Low prices predominated in the summer months, with peak prices occurring in the later autumn and winter months. These price fluctuations reflected the seasonal supply and demand situation in the market (*30*). Figure 10 indicates the gen-

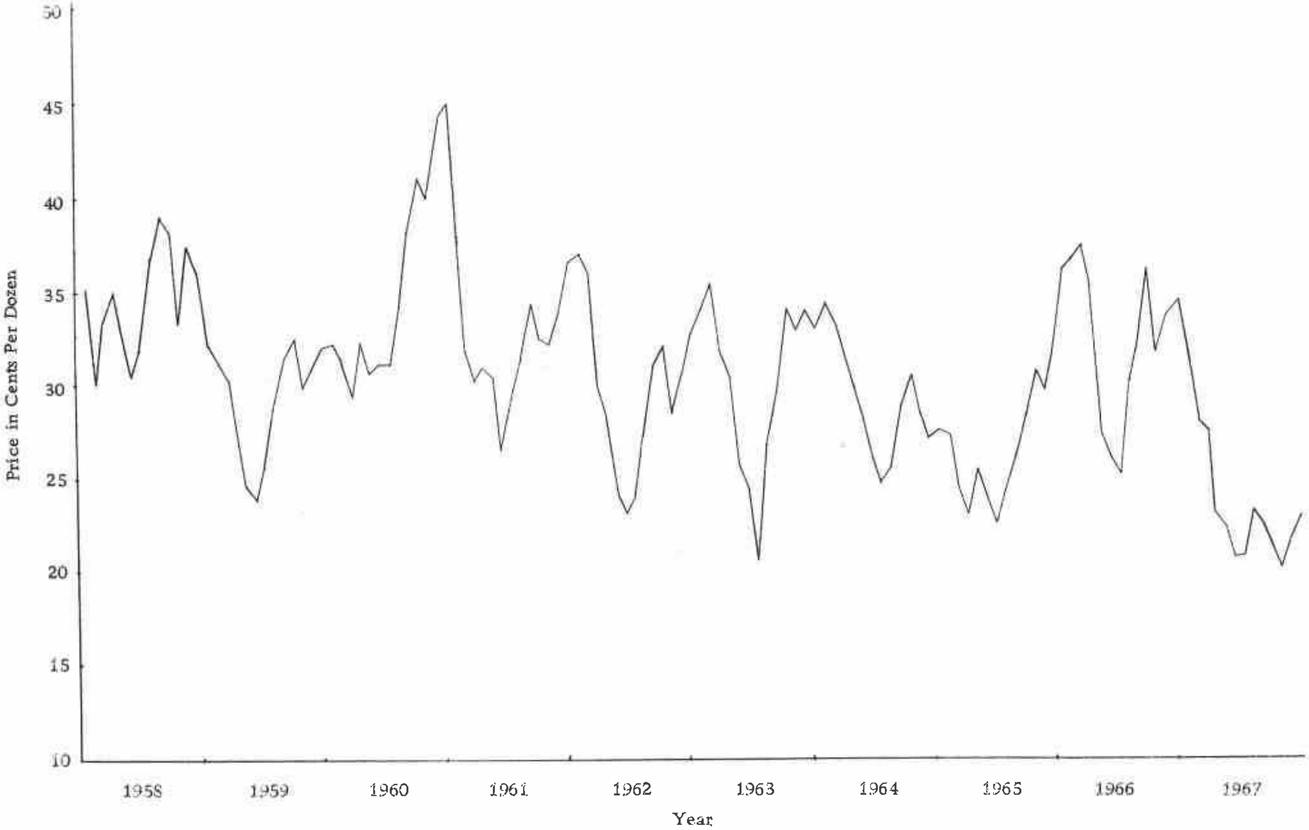

**Figure 10. Producer egg prices, monthly means, 1958-1967.**

eral downward trend in egg prices over the 10-year period.[15] The prices for the 10-year period were used to derive five historical price structures, each of two years' duration (Table 5). These price structures, numbered 1 to 5 in the table, are listed according to the mean egg price prevailing over the planning period.

The trend analysis of the 10 years' annual means for the historical price data indicated a significant downward trend in egg prices over this period.[16] In order to investigate the effect of an extrapolation of this downward trend, four hypothetical series (designated Pext 1, ···, Pext 4 in the text) were used in the analysis. The mean annual prices pertaining to each of these four price years are given in Table 5 under price structures 6 and 7. The tabulated prices include the addition of price premiums of two cents per dozen for extra large AA and four cents per dozen for jumbo AA grade eggs over the price of large A grade eggs. Estimates of net revenue also were obtained, assuming no price premium for eggs above large A grade, i.e., all eggs in the large AA-jumbo AA grades were priced at the large A grade price.

### *Cull Prices*

The monthly salvage prices paid to producers for culled birds over the 10-year period, 1958 to 1967 (*60*) were compiled by the USDA. The tabulated mean annual figures show that salvage prices have not fluctuated significantly from month to month over any single year. It was therefore assumed that cull prices were fixed for the length of the planning period. Price levels of 6, 10, and 12 cents per pound liveweight were used in the analysis.

### *Feed Cost*

The cost of feed amounts to some 50 to 65 percent of the producer's total costs. A wide range of costs are given in the literature, depending on whether the producer mills his own feed or whether he buys from a retail supplier. Most of the budget studies conducted on the results of the force molting trials used a feed price comparable to the cost of obtaining feed from a retail supplier. Thus, Hansen (1966) used a cost of $82.87 per ton, Hyre (1966) $70 per ton, and Morrison and Aho (1964) a cost of $72 per ton. USDA quotations for the period 1960 to 1968 (*60*) show that the cost of layer ration purchased from a retail supplier has maintained a level of approximately $86 per ton. Cost studies of commercial enterprises emphasize just how vari-

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[15] A trend analysis was carried out on these 10-year egg prices, using the method suggested by H. B. Mann and reported by Tintner (1965, p. 212). The analysis yielded an r value of –0.4667, which indicated a significant negative trend over the 10-year period.

[16] Ibid.

Table 5. Egg price structures

| | | | | Mean egg price in cents per dozen | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | In-lay period[b] | | | | | | | | | | | |
| | | | Historical or hypothetical price structure | 1 | | | 4 | | | 7 | | | 10 | | |
| | Price years | | | | | | | | | | | | | | |
| Price structure[a] | 1 | 2 | | Year 1 | Year 2 | $P^p$ | Year 1 | Year 2 | $P^p$ | Year 1 | Year 2 | $P^p$ | Year 1 | Year 2 | $P^p$ |
| 1 | 1960 | 1958 | Historical[d] | 35.45 | 34.83 | 35.14 | 36.10 | 34.18 | 35.14 | 36.42 | 33.86 | 35.14 | 36.63 | 33.65 | 35.14 |
| 2 | 1966 | 1961 | Historical | 32.37 | 32.07 | 32.22 | 31.88 | 32.56 | 32.22 | 28.83 | 35.61 | 32.22 | 32.12 | 32.32 | 32.22 |
| 3 | 1963 | 1962 | Historical | 29.72 | 29.70 | 29.71 | 30.18 | 29.24 | 29.71 | 29.90 | 29.52 | 29.71 | 30.22 | 29.20 | 29.71 |
| 4 | 1959 | 1964 | Historical | 29.70 | 28.84 | 29.27 | 30.22 | 28.32 | 29.27 | 30.66 | 27.88 | 29.27 | 29.63 | 28.91 | 29.27 |
| 5 | 1965 | 1967 | Historical | 27.22 | 23.72 | 25.47 | 28.09 | 22.85 | 25.47 | 27.71 | 23.23 | 25.47 | 26.81 | 24.13 | 25.47 |
| 6 | Pext 1[c] | Pext 2 | Hypothetical[e] | 26.11 | 25.92 | 26.01 | 25.86 | 26.16 | 26.01 | 26.04 | 25.98 | 26.01 | 25.59 | 26.43 | 26.01 |
| 7 | Pext 3 | Pext 4 | Hypothetical | 23.48 | 21.26 | 22.37 | 22.50 | 22.24 | 22.37 | 22.36 | 22.38 | 22.37 | 22.00 | 22.74 | 22.37 |

[a] Prices include the addition of price premiums for extra large AA and jumbo AA grade eggs.

[b] $P^p$ = mean egg price per month over the two-year planning period.

[c] Pext = price extrapolation.

[d] From observed egg prices.

[e] Extrapolation of the downward trend in egg prices, 1958-1967.

able feed cost can be. In order to account for this variability, eight feed costs (1.5, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, and 5.0 cents per pound) were used in the analysis. The upper and lower levels of 1.5 and 5.0 cents represented feed costs which have not yet been observed in the field; it was hoped that their use in the analysis might provide valuable information on the effects of such extreme feed cost levels on the optimum and near optimum actions.

### *Cost of the Replacement Pullet*

The cost of the replacement pullet depends on whether the producer rears his own birds or whether he buys from an outside supplier. If he rears his own replacements, the cost may be as low as $1.20 for a point-of-lay bird. The upper range on this cost is about $1.70 per bird for purchased pullets (*67, 68, 69*).

The budget studies of the force molting trials completed to date have assumed a fairly high cost for the replacement pullet. Marble (1963) used a cost of $1.75 for a 22-week-old pullet. Hansen (1966) used a cost of $1.60 for a 20-week-old pullet, Hyre (1966) a cost of $1.50, Morrison and Aho (1964) a cost of $2.00. Bell (1965b) used a cost of $1.80 for a purchased pullet and $1.40 for a home-reared pullet. Commercial cost studies also show an appreciable range in producer price for this factor of production (*7, 39, 54, 67, 68, 69*). To investigate the effects of varying the replacement cost, eight cost levels were used—1.0, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, and 2.0 dollars per pullet.

### *Other Costs*

The transfer cost (cost of transferring the point-of-lay pullet from the rearing to the laying unit) was set at one cent per bird housed. The clean-out cost (cost of cleaning and disinfecting the laying unit at the end of the planning period) was set at two cents per bird housed.

It was assumed that miscellaneous costs such as wages, equipment, depreciation, vaccines, medication, repairs, taxes, and utilities were fixed in the short run (over the length of the planning period) and would not vary as a result of the producer's replacement policy. The only cost which is likely to be regarded as variable in the short run is labor, in that some temporary labor may be necessary for the short period when houses are cleaned out and refilled with point-of-lay pullets. These extra charges have been accounted for by including transfer and clean-out costs in the net revenue equation.

## CALCULATION PROCEDURE

The previous sections have discussed the levels of production variables, input and output costs, and other costs used in the analysis.

The values of net revenue were calculated for each action in A for the following levels of prices and costs:

✓ Five egg price structures, each of two years' duration. Estimates of $\pi_i$ were obtained, assuming: (1) price premiums on extra-large AA and jumbo AA grade eggs, and (2) no price premiums on these grade eggs.

✓ Three levels of prices (6, 10, and 12 cents per pound liveweight) for culled birds.

✓ Eight levels of feed cost (1.5, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, and 5.0 cents per pound) for layer ration.

✓ Eight levels of replacement cost (1.0, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, and 2.0 dollars) for a point-of-lay pullet.

In addition to these price and cost levels, a number of hypothetical levels for egg prices and egg quality were introduced into the analysis in order to study their effects both on the optimum action in A and on the relative ranking of these actions over the two-year planning period.

### *Hypothetical Egg Quality Distributions*

In addition to using the egg quality distributions obtained from the experimental data (listed in Table 1 of Appendix B), it was decided to investigate the effect of increasing egg quality for those stages of production involving birds in-lay for more than *13* months. This had the effect of increasing the comparative advantage of those actions in which birds were kept in-lay for extended laying periods. The object was to see whether increasing the egg quality would alter the relative ranking of actions in $A^f$ and $A^{\circ}$ significantly. These increases in egg quality were confined to the *large* egg size category. The hypothetical distributions used were:

$Ho^1$: The original monthly egg quality distributions for large eggs (Table 1, Appendix B), with the number of large eggs AA increased by 10 percent and the numbers of eggs in both the large A and large B grades decreased by 5 percent each.

Thus, suppose that the original quality distribution for large eggs in a particular month was:

| Grade | B | A | AA | Total |
|---|---|---|---|---|
| No. of eggs (dozen) | 10 | 20 | 70 | 100 |
| Percentage large eggs | 10% | 20% | 70% | 100% |

Then the revised percentages under $Ho^1$ would be:

| Grade | B | A | AA | Total |
|---|---|---|---|---|
| No. of eggs (dozen) | 5 | 15 | 80 | 100 |
| Percentage large eggs | 5% | 15% | 80% | 100% |

$Ho^2$: As for $Ho^1$, but with the number of large AA eggs increased by 20 percent and the number of large A and large B decreased by 10 percent each.

In both $Ho^1$ and $Ho^2$, *only* the distribution of large eggs between the quality grades AA, A, and B was altered. The *total* number of eggs allocated to the large egg size category was not altered.

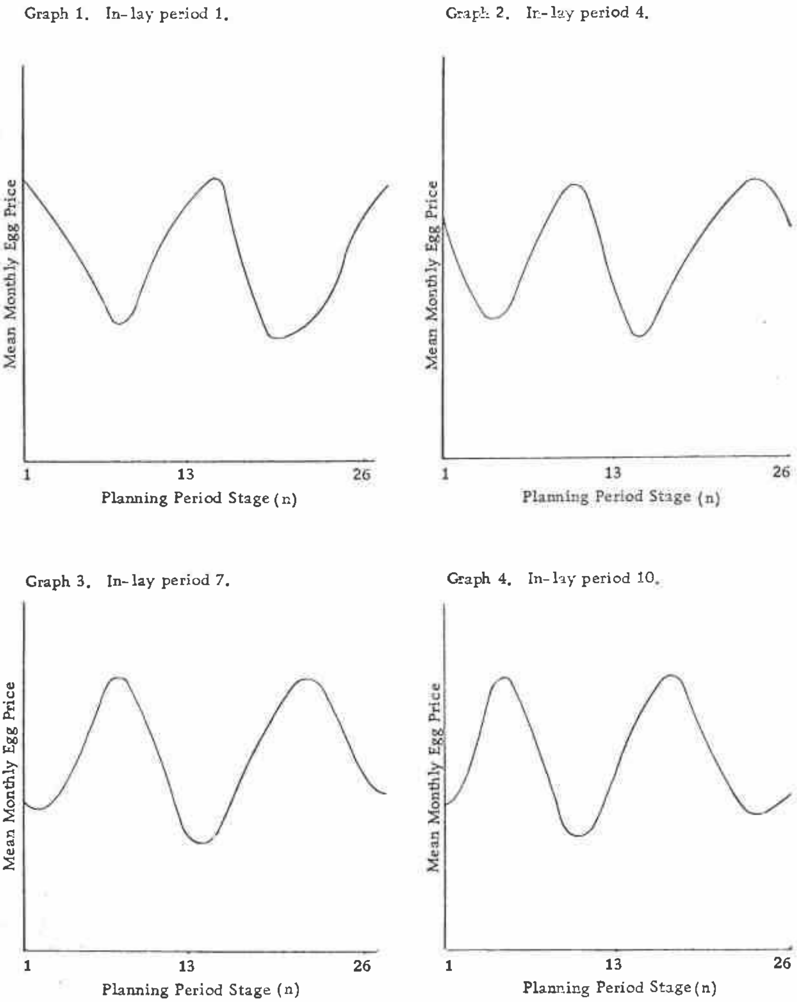
## THE IN-LAY PERIOD

The in-lay period refers to the time of the year when a bird (flock) begins egg production. This period usually coincides with the transfer of the birds from rearing to laying units when the birds are between 21 and 23 weeks of age. The choice of the in-lay period is assumed to be under direct producer control. The annual periodic fluctuations in egg prices (Figure 10), combined with the changing nature of egg production (in terms of monthly output, grade, and quality distributions) with increasing age and force molting treatment (Figures 7, 8, and 9) cause the choice of in-lay period to have a significant influence on the total revenue from egg sales over the planning period.

In order to account for the effects of altering the in-lay period on the optimum actions in A and also on the relative ranking of actions in A, four in-lay periods were used in the analysis. These were set at periods 1, 4, 7, and 10. The possible form of the egg price cycle for each of these periods is shown in Figure 11.

## RESULTS OF THE CERTAINTY ANALYSIS

The levels of the production variables, input and output prices, and in-lay periods produced a wide range of possible economic conditions under which estimates of the net income ($\pi_i$) for each action in A were calculated. These values of $\pi_i$ were then used to rank the 54 actions in A in descending order of magnitude for each of these combinations. These rankings were studied for each combination in order to determine those actions which consistently appeared among the top 10 actions. It was found that seven actions consistently appeared among the top 10 actions. These seven actions were termed the "dominant" actions and were included in the set $\alpha$. The other four actions included in $\alpha$ were regarded as only "marginally dominant"; they appeared among the top 10 actions for the majority of the combinations studied but fell below the 10th position for some combinations. In no case was an action which fell below the 15th position for more than one of the variable combinations included in $\alpha$.


Graph 1. In-lay period 1.

Graph 2. In-lay period 4.

Graph 3. In-lay period 7.

Graph 4. In-lay period 10.

Figure 11. A series of four graphs showing how the egg price cycle over the planning period might change in relation to the in-lay period (based upon the historical price series 1958-1967, shown in Figure 10).

## *Actions Included in the Set $\alpha$*

The 11 actions selected on the criterion of being "undominated" and included in the set $\alpha$ were: $a_4$, $a_5$, $a_6$, $a_7$, $a_{28}$, $a_{32}$, $a_{37}$, $a_{39}$, $a_{43}$, $a_{47}$, $a_{54}$. Table 6 shows the number of months of production for the first and second replacement flock over the planning period for the actions in

Table 6. Description of the actions included in the set $\alpha$

| $\alpha_i$ | Number of months for which the first flock is in-lay | Stage of production when second flock housed | Number of months for which the second flock is in-lay | Flock force molted after |
|---|---|---|---|---|
| 4 | 15 | 16 | 10 | ........................[a] |
| 5 | 14 | 15 | 11 | ........................[a] |
| 6 | 13 | 14 | 12 | ........................[a] |
| 7 | 12 | 13 | 13 | ........................[a] |
| 28 | 25 | ---- | ---- | 6, 13, and 19 months in-lay |
| 32 | 11 | 12 | 14 | 6 months in-lay |
| 37 | 25 | ---- | ---- | 9 and 19 months in-lay |
| 39 | 16 | 17 | 9 | 9 months in-lay |
| 43 | 25 | ---- | ---- | 13 months in-lay |
| 47 | 25 | ---- | ---- | 9 months in-lay |
| 54 | 25 | ---- | ---- | 17 months in-lay |

[a] No force molting over the two-year planning period.

the set $\alpha$, and the month of production at which the flock underwent a force molting treatment.

The 11 actions in the set $\alpha$ had several important common characteristics. First, none of these actions required more than two replacement flocks, even though several of the actions in A included this possibility. Second, only one of the actions, $a_{32}$, showed a flock being culled before 11 months of production, even though the possibility of culling at seven months was included. However, this action was of limited significance, as it belonged to that set of actions previously defined as "marginally dominant." Third, all of the force molting treatments, in one way or another, were included in $\alpha$ (Table 6).

Tables 7 and 9 summarize the major results of the certainty analysis. Table 7 shows the optimum actions resulting when all egg price levels (Table 5) and four in-lay periods (1, 4, 7, and 10) were used; replacement cost varied from $1.20 to $1.70, and feed cost varied from 2.4 to 3.4 cents per pound. These ranges were regarded as critical in that they were likely to indicate the effects of small cost changes on the resulting optimum policy and, what is more important, show the relationships between the force molted and non-force molted actions in A. Table 9 shows the results for a much wider variable range than used in Table 7. Table 8 is very useful in detecting general trends as prices and cost levels change.

Table 7 is divided into four main sections according to the in-lay period used. Within each section the possible combinations of cull

Table 7. Tabulated 'i' indices for the optimum actions, four in-lay periods, and various cost and price conditions

| Price Structure ($p^p$)[a] | Replacement Cost ($C^r$) Per Hen Housed $ | In-Lay Period 1 | | | | | | | | | | | | | | | | | | In-Lay Period 4 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cull Price in Cents Per Pound Liveweight ($P^c$) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 12.0¢ | | | | | | 10.0¢ | | | | | | 6.0¢ | | | | | | 12.0¢ | | | | | | 10.0¢ | | | | | | 6.0¢ | | | | | |
| | | Feed Cost in Cents Per Pound ($C^f$)[b] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.4 | | | | | | | | | 6 | | | | | | | | | | | | | | | | | | | 7 | | | | | | | | |
| | 1.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 1.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.4 | | | | | | | | | 7 | | | | | | | | | | | | | | | | | | | 7 | | | | | | | | |
| | 1.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.7 | | | | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | | 37 |
| 3 | 1.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.4 | | | | | | | | | 7 | | | | | | | | | | | | | | | | | | | 7 | | | | | | | | |
| | 1.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 54 |
| | 1.6 | | | | | | | | | | | | | | | | | 37 | 37 | | | | | | | | | | | | | 54 | | | | | |
| | 1.7 | | | | | | | | | | | 37 | | | | | | | | | | | | | | 54 | | | | | | | | | | | |
| 4 | 1.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.4 | | | | | | | | | | 7 | | | | | | | | | | | | | | | | | | 7 | | | | | | | | |
| | 1.5 | | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | | 54 | | |
| | 1.6 | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | 54 | | | | | | | | |
| | 1.7 | | | | | | | 37 | | | | | | | | | | | | | | | | | | 54 | | | | | | | | | | | |
| 5 | 1.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 37 | | |
| | 1.3 | | | 7 | | | | | | | | | | | | | | | 37 | | | | 7 | | | | | 37 | | | | | | | | | |
| | 1.4 | | | | | | | | | | | 37 | | | | | | | | | | | | | | 37 | | | | | | | | | | | |
| | 1.5 | | | | | | | 37 | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | |
| | 1.6 | | | | 37 | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | |
| | 1.7 | 37 | | | | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | |
| 6 | 1.2 | | | | | | | | | | | | | | | | | | 37 | | | | | 28 | 28 | 7 | 7 | 7 | 28 | 28 | 28 | 7 | 7 | 7 | 28 | 28 | 28 |
| | 1.3 | 7 | | | | | | 37 | | | | | | | | | | | | | | 7 | | 28 | 28 | 37 | 37 | 37 | 28 | 28 | 28 | 37 | 37 | 37 | 37 | 37 | 37 |
| | 1.4 | | | | 37 | | | | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | |
| | 1.5 | 37 | | | | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | |
| | 1.6 | 37 | | | | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | |
| | 1.7 | 37 | | | | | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | |
| 7 | 1.2 | | | | | | 28 | | | 6 | | | 28 | 37 | | | | | | 7 | | 28 | 28 | 28 | 28 | 37 | | | | | | | | | | | |
| | 1.3 | | 6 | | | | 28 | 37 | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | |
| | 1.4 | | | | | 37 | | | | | | | | | | | | | | 37 | | | | | | | | | | | | | | | | | |
| | 1.5 | 37 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.6 | 37 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1.7 | 37 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Table 7 (Continued)

| Price Structure ($P^p$)[a] | Replacement Cost ($C^r$) Per Hen Housed $ | In-Lay Period 7 | In-Lay Period 10 |
|---|---|---|---|
| | | Cull Price in Cents Per Pound Liveweight ($P^c$): 12.0¢ 10.0¢ 6.0¢ | Cull Price in Cents Per Pound Liveweight ($P^c$): 12.0¢ 10.0¢ 6.0¢ |
| | | Feed Cost in Cents Per Pound ($C^f$)[b]: 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 | Feed Cost in Cents Per Pound ($C^f$)[b]: 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 |
| 1 | 1.2 | | |
| | 1.3 | | |
| | 1.4 | | |
| | 1.5 | 7 | 5 37 |
| | 1.6 | | 37 |
| | 1.7 | 37 | 37 |
| 2 | 1.2 | | |
| | 1.3 | | |
| | 1.4 | | |
| | 1.5 | 7 | 5 |
| | 1.6 | | |
| | 1.7 | 37 | 37 |
| 3 | 1.2 | | |
| | 1.3 | | |
| | 1.4 | 6 | 5 37 |
| | 1.5 | | 37 |
| | 1.6 | 37 | 37 |
| | 1.7 | 37 | 37 |
| 4 | 1.2 | | 37 |
| | 1.3 | 6 | 37 |
| | 1.4 | | 5 37 |
| | 1.5 | 37 | 37 |
| | 1.6 | 37 | 37 |
| | 1.7 | 37 | 37 |
| 5 | 1.2 | 37 | 5 37 |
| | 1.3 | 7 37 | 37 |
| | 1.4 | 37 | 37 |
| | 1.5 | 37 | 37 |
| | 1.6 | 37 | 37 |
| | 1.7 | 37 | 37 |
| 6 | 1.2 | 37 | |
| | 1.3 | 5 37 | 6 37 |
| | 1.4 | 37 | 37 |
| | 1.5 | 37 | 37 |
| | 1.6 | 37 | 37 |
| | 1.7 | 37 | 37 |
| 7 | 1.2 | 28 37 | 54 |
| | 1.3 | 7 37 | 54 |
| | 1.4 | 37 | 4 54 |
| | 1.5 | 37 | 54 |
| | 1.6 | 37 | 54 |
| | 1.7 | 37 | 54 |

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[a] See Table 5 for the levels of $P^p$ for each of the in-lay periods.

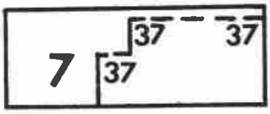
[b] Where 1, 2, 3, 4, 5, and 6 designate feed cost levels of 2.4, 2.6, 2.8, 3.0, 3.2, and 3.4 cents per pound respectively.

prices and feed costs are listed in such a way as to provide a spectrum of increasing costs in passing from left to right across a particular section. The *rows* within each section are divided according to price structure and replacement cost ($C^r$). The egg price structures are listed according to the mean egg price ($P^p$) prevailing over the planning period in approximately descending order of magnitude from 1 to 7. The replacement costs are listed in ascending order of magnitude from $1.20 to $1.70 per hen housed. Thus, considering the possible combinations of cull prices, feed costs, replacement costs, and price structures, these factors reflect an increasing total variable cost level and a decreasing egg price level in passing from the *top left* corner to the *lower right* corner of a given section of the table. The designation of the optimum action used in the table was as follows:

Consider the actions listed for in-lay period 1. For the price structure 1, only one figure appears in the center of the table thus:

This indicates that the optimum action for *all* price/cost combinations in this particular block was $a_6$ (an annual replacement policy).

Consider now the same in-lay period, but for the block pertaining to price structure 3, which looks like:



This indicates that for all price/cost combinations to the left of the dotted line, action $a_7$ (an annual replacement policy) was the optimum action. To the *right* of this line the optimum actions for the combinations take on the *first* number listed for the particular row of the table. In this case, action $a_{37}$ (a flock force molted after 6, 13, and 19 months of production) was optimum for all combinations to the right of the dotted line.

## EFFECTS OF ALTERING THE IN-LAY PERIOD

### *In-Lay Period 1 (January 1)*

The planning period in this case covered a two-year period from January 1 of the first price year to December 31 of the second price year. The approximate form of the egg price cycle that might be expected to prevail over this period is shown in Graph 1 of Figure 11.

With the mean egg price over the planning period equal to or greater than 32.0 cents per dozen, the optimum action was a non-force molted action ($a_6$ or $a_7$). When the mean egg price was decreased from 32.0 to 22.0 cents per dozen, $a_6$ and $a_7$ were replaced by force molting actions $a_{28}$ and $a_{37}$ at progressively lower total variable cost levels.[17] The historical price structures used (1 to 5) show that for the lowest replacement cost of $1.20 per bird the optimum action always involved a non-force molted action, regardless of feed cost or cull price level. With a further lowering of the mean egg price to 22.0 cents per dozen, actions $a_{28}$ and $a_{37}$ became optimum only at the upper end of the total variable cost range.

The effect of increasing total variable costs on the optimum action can best be seen by following the changes that occurred for any given price structure, e.g., 4 (Table 7). Thus, with the mean price level equal to 29.0 cents per dozen and a replacement cost greater or equal to $1.40 per bird, a non-force molted action $a_{37}$ became optimum when the cull price was set at six cents per pound and the feed cost was greater or equal to 3.0 cents per pound. A ten-cent increase in the replacement cost to $1.50 per bird further increased the range of cull prices and feed costs over which the force molted action $a_{37}$ was optimum. Similar series of changes were observed for each of the price structures listed.

The hypothetical price structures 6 and 7 served to further emphasize that low egg prices favored the force molting actions $a_{28}$ and $a_{37}$. At the lowest egg price levels used in the analysis, the force molted actions $a_{28}$ and $a_{37}$ almost completely dominated the non-force molted action $a_6$.

### *In-Lay Period 4 (April 1)*

The shift in the in-lay period resulted in changing the form of the egg price cycle from that shown in Graph 1 to that shown in Graph 2 (Figure 11). The results shown in Table 7 indicate that the price/cost combinations that resulted in a force molting action becoming optimum were very similar to those given for in-lay period 1. The major change was in the appearance of action $a_{54}$ as the optimum action[18] under price structures 3 and 4. The shift in in-lay period also resulted in a force molting action becoming optimum at somewhat lower total cost levels for any given egg price structure, i.e., the shift of in-lay period from 1 to 4 favored the force molted actions. This change became more prominent at the lower egg price levels. This can be seen by comparing the optimum actions under structures 4 and 5 for these two in-lay periods (Table 7).

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[17] $a_{28}$ is the force molted action with molts after 6, 13, and 19 months in-lay. $a_{37}$ is the force molted action with molts after 9 and 19 months in-lay.

[18] $a_{54}$ is a force molted action with one molt after 17 months in-lay.

### *In-Lay Period 7 (June 30)*

The form of the expected egg price cycle for this in-lay period is shown in Graph 3 of Figure 11. The results shown in Table 7 did not show any significant differences between the optimum actions under in-lay periods 7 and 1. There were, however, some differences between the optimum actions under in-lay periods 7 and 4. For the higher egg price structures (1 and 2), force molted actions appeared as optimum actions with greater frequency under in-lay period 7 than under either 1 or 4. At the lower price levels (3 through 7), there were no obvious differences between the frequency with which force molted actions appeared as optimum (Table 7).

### *In-Lay Period 10 (October 1)*

The form of the expected egg price cycle for this in-lay period is shown in Graph 4 of Figure 11. With this in-lay period the optimum non-force molted action under most of the egg price structures used was $a_5$ (Table 7). Action $a_5$ indicated that the first flock should be kept in-lay for 14 months, and the second for only 11 months. This result represented a slight change from the annual replacement policies ($a_6$ and $a_7$) indicated as optimum for in-lay periods 1, 4, and 7.

Those actions appearing as optimum in Table 7 under in-lay period 10 were the same as those indicated for the other three in-lay periods used in the analysis. Under the price structure 1 ($P^p$ equal to 35.14 cents per dozen), a force molted policy, $a_{37}$, was optimum for a larger range of price/cost combinations than for any of the other in-lay periods. This did not hold for the other six price structures. In fact, the results showed that under price structures 3, 4, and 5, in-lay period 10 favored a force molted action ($a_{37}$) more so than any of the other three in-lay periods, whereas for structures 6 and 7 it was the least favorable.

### *The Effect of Price Premiums*

The results showed that the addition of price premiums increased the comparative advantage of the force molted actions $a_{28}$ and $a_{37}$, which was not a totally unexpected result. The effect, however, was not as marked as might be expected from a comparison of the percentage of all eggs laid in the extra-large AA and jumbo grades for both of these force molted actions and the non-force molted actions $a_6$ and $a_7$.

### *The Effect of Changing the Egg Quality Distributions for Large Grade Eggs*

The results of introducing the two additional egg quality distributions for large eggs, $Ho^1$ and $Ho^2$, can be summarized as follows:

Ho$^1$: There was no increase in the frequency with which force molted actions ($A^f$) appeared as optimum actions. The change in the large egg quality distribution had no effect on the non-force molted actions, but it decreased the comparative advantage of *two* force molts ($a_{37}$) relative to *three* force molts ($a_{28}$ )over the planning period.

Ho$^2$: There was only a marginal increase in the frequency of appearance of the force molted actions ($A^f$) as optimum actions, as compared to the non-force molted actions ($A^{\circ}$).

## *The Relative Rankings of the Actions in A*

One of the stated objectives of this analysis was to study the relative ranking of the actions in A in order to determine those actions which would be included in the set $\alpha$. One of the outcomes of this ranking procedure was that it was possible to inspect those actions which produced $\pi_i$ values which were close to those produced by the optimum actions. The results of this procedure led to two conclusions. First, for many of the variable combinations studied, the top three actions produced $\pi_i$ values which were close to each other, the spread between the optimum and the third from optimum $\pi_i$ values being as little as three cents per bird housed, and for most combinations only one to two cents per bird separating the top two $\pi_i$ values. By examining the top *five* actions in A for each of the variable combinations studied, it was possible to trace the movement of an action from, say, the fifth-ranked position to the optimum position. Of particular interest was the movement of the force molted actions in relation to the non-force molted actions. These relative movements can best be illustrated by considering the actions listed in Table 8.

Consider the movement of action $a_{37}$ for the cases denoted $\boxed{37}$ and ㊲ in Table 8. Under price structure 1 with a feed cost of 5.0 cents per pound, a replacement cost of \$2 per hen, and a cull price of 12 cents per pound, action $a_{37}$ $\boxed{37}$ was the fourth-ranked action. A decrease in the cull price to six cents per pound caused this action to become optimum. The relative ranking of the actions $a_6$, $a_7$, and $a_{37}$ was extremely sensitive to small changes in the cull price level. A similar large change in the ranking of $a_{37}$ was indicated by the movement of ㊲. This followed as a result of a 50-cent increase in the replacement cost.

These two examples show that in many cases the relative ranking of the actions in A was very sensitive to small changes in the levels of the variables used in the analysis.

Table 8. The top five actions in A, in-lay period 1 (price structures 1 and 5 only)

| Egg Price Structure $p^P$ | Mean Egg Price | Feed Cost Per Pound ($C^f$) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1.5¢ | | | | | | 3.0¢ | | | | | | 5.0¢ | | | | | |
| | | Replacement Cost Per Hen-Housed ($C^r$) | | | | | | | | | | | | | | | | | |
| | | 1.00 | | 1.50 | | 2.00 | | 1.00 | | 1.50 | | 2.00 | | 1.00 | | 1.50 | | 2.00 | |
| | | Cull Price Per Pound Liveweight ($P^c$) | | | | | | | | | | | | | | | | | |
| | | 12 | 6 | 12 | 6 | 12 | 6 | 12 | 6 | 12 | 6 | 12 | 6 | 12 | 6 | 12 | 6 | 12 | 6 |
| 1 | 30.8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | $\boxed{37}$ |
| | | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 28 |
| | | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 37 | 5 | 5 | 5 | 5 | 28 | 7 |
| | | 4 | 4 | 4 | 4 | 4 | 37 | 4 | 4 | 4 | 4 | 4 | 28 | 4 | 4 | 4 | 4 | $\boxed{37}$ | 6 |
| | | 32 | 32 | 32 | 32 | 37 | 4 | 32 | 32 | 32 | 32 | 37 | 5 | 32 | 32 | 32 | 28 | 5 | 5 |
| 5 | 25.2 | 7 | 7 | 7 | 7 | ㊲ | 37 | 7 | 7 | 7 | 7 | 37 | 37 | 7 | 7 | 7 | 37 | 37 | 37 |
| | | 6 | 6 | 6 | 6 | 7 | 28 | 6 | 6 | 6 | 37 | 28 | 28 | 6 | 6 | 6 | 28 | 28 | 28 |
| | | 5 | 5 | 5 | 5 | 6 | 7 | 5 | 5 | 5 | 6 | 7 | 43 | 5 | 5 | 37 | 7 | 7 | 43 |
| | | 4 | 4 | 4 | ㊲ | 28 | 6 | 4 | 4 | 37 | 28 | 6 | 7 | 4 | 37 | 28 | 6 | 6 | 54 |
| | | 32 | 32 | 37 | 4 | 5 | 43 | 32 | 32 | 4 | 5 | 5 | 6 | 32 | 4 | 5 | 5 | 5 | 7 |

### *Summary and Conclusions of Certainty Analysis*

Table 9 summarizes the general economic conditions under which the producer could select either a non-force molted action (NFA) from the set $A^o$ or a force molted action (FMA) from the set $A^f$. When the cost of replacement ($C^r$) was $1 per bird (or less), the producer's optimum action was to replace his flocks every year (annual replacement). At a cost of $C^r$ equal to $1.50, the influence of the cull price became an important factor. At the lower cull price of six cents per pound, the choice of all optimum actions became sensitive to the effect of feed cost and egg price conditions. At the highest cost of replacement ($C^r = \$2$) the levels of cull price, feed cost, and egg prices must all be considered to determine the optimum action (Table 7).

The general conclusions from the certainty analysis were as follows:

1. With the mean egg price over the planning period greater than 32.0 cents per dozen and the cost of a replacement pullet at $1.50, an annual replacement policy was the optimum action, regardless of the in-lay period. With higher replacement costs of $1.60 and $1.70, attention is centered on the levels of feed costs and cull prices. Thus, a 0.2 cent increase in the cost of a pound of layer ration resulted in the optimum policy changing from an annual replacement policy to one which required a force molting program.

2. At the lower egg price levels (less than 25.5 cents per dozen), unless the producer is able to either rear or buy replacements for less than $1.40 per bird, force molting ($a_{28}$, $a_{37}$, or $a_{54}$) would be the optimum action.

3. With egg prices at the intermediate levels of 25.0 to 29.0 cents per dozen, a low replacement cost of $1.20 to $1.30 per bird in the main tended to favor a non-force molted action ($a_5$, $a_6$, or $a_7$). As the replacement cost increased, however, a force molted action ($a_{28}$, $a_{37}$, or $a_{54}$) became optimum at progressively lower total variable cost levels.

4. The hypothesis that altering the beginning of the in-lay period would change the relative ranking of the actions in A was supported to a certain extent by these results. It was demonstrated that such changes resulted in some differences in those price/cost combinations for which a force molted action became optimum. These changes were no doubt due to the manner in which altering the in-lay period changed the form of the egg price cycle over the planning period. Because of the significant differences between the egg production patterns for force molted and non-force molted actions over the planning period, these changes in the egg price cycle had different effects on both the monthly pattern of egg income and the net revenue for the force molted and non-force molted actions.

Table 9. A summary of the effects of the variable combinations on the optimum actions

| | Replacement cost per hen housed | | | | | |
|---|---|---|---|---|---|---|
| | $C^r = \$1.00$ | $C^r = \$1.50$ | | $C^r = \$2.00$ | | |
| Cull price ($P^c$) 12 cents per pound liveweight | NFA optimal for all combinations of feed costs, egg prices, and other production conditions | NFA optimal for all combinations of feed costs, egg prices, and other production conditions | | $C^f = 1.5$ cents | $P^p = 1, 2, (3, 4)$<br>$P^p = (3, 4), 5, \ldots, 7$ | NFA<br>FMA |
| | | | | $C^f = 3.0$ cents | $P^p = 1, (2)$[a]<br>$P^p = (2), 3, 4, \ldots, 7$ | NFA<br>FMA |
| | | | | $C^f = 5.0$ cents | $P^p = (1)$<br>$P^p = (1), 2, \ldots, 7$ | NFA<br>FMA |
| Cull price ($P^c$) 6 cents per pound liveweight | | $C^f = 1.5$ cents NFA optimal for all combinations of egg prices and production conditions | | $C^f = 1.5$ cents | $P^p = 1$<br>$P^p = 2, 3, \ldots, 7$ | NFA<br>FMA |
| | | $C^f = 3.0$ cents | $P^p = 1, 2, 3$. NFA<br>$P^p = 4, 5, 6, 7$. FMA | $C^f = 3.0$ cents | $P^p = (1)$<br>$P^p = (1), 2, \ldots, 7$ | NFA<br>FMA |
| | | $C^f = 5.0$ cents | $P^p = 1, (2)$. NFA<br>$P^p = (2), 3, \ldots, 7$. FMA | $C^f = 5.0$ cents | FMA for all $P^p = 1, 2, \ldots, 7$ | |

The following explanation of abbreviations should aid in understanding the table:

NFA = a non-force molted action ($a_6$ or $a_7$).
FMA = a force molted action ($a_{28}$ or $a_{37}$).
$C^f$ = cost of feed in cents per pound.
$C^r$ = replacement cost.
$P^p$ = egg price structure (see Table 5).

[a] $P^p = 1, (2)$ indicates that under price structure 2 there was no clear-cut distinction between the non-force molted and the force molted policies.

5. Of the 54 actions included in A at the outset of the analysis, only four non-force molted actions ($a_4$, $a_5$, $a_6$, and $a_7$) and three force molted actions ($a_{28}$, $a_{37}$, and $a_{54}$) appeared as optimum actions (Table 7).

6. Only a limited number of the actions included in the set A need to be considered in the final section of this study, which considers the problem of choosing between the producer's alternatives under conditions of uncertainty. The seven actions listed in No. 5 above were included in the set of actions to be considered. Four other actions ($a_{32}$, $a_{39}$, $a_{43}$, and $a_{47}$) which were consistently very close to appearing as optimal were included in the set $\alpha$ of 11 actions to be considered under conditions of uncertainty.

7. The ranking procedure used in the certainty analysis showed that for all combinations of variables studied, the top five actions resulted in net revenues which were quite close to each other. Without any information on the degree of variability of net revenue for these actions, it was not possible to state categorically that the producer's "best" action would be confined to the optimum actions shown in Table 7. The methodological procedure for choosing between the top actions will be given in the next section.

The results of the certainty analysis demonstrate how important it is to consider the question of the economic feasibility of force molting policies as alternatives to, say, an annual replacement policy in the light of the complete range of feed costs, replacement costs, cull prices, and egg prices that are likely to occur.

## REPLACEMENT PROBLEM UNDER CONDITIONS OF UNCERTAINTY

The results of the certainty analysis showed that only a small set $\alpha$ of 11 actions needed to be studied under conditions of uncertainty. Thus:

$$\alpha = \{a_4, a_5, a_6, a_7, a_{28}, a_{32}, a_{37}, a_{39}, a_{43}, a_{47}, a_{54}\}.$$

Assuming that one can restrict the field of choice to the actions contained in this set, the replacement problem under conditions of uncertainty can be expressed as one of choosing between these actions, given that the expected levels of costs, prices, and production variables which define the state of nature prevailing over the length of the planning period are not known with certainty.

One way in which a choice among risky actions can be effected is on the basis of information about the moments of the distribution of net income (X) for each action over the state space $\theta$, where the space $\theta$ represents all possible states of nature which might prevail over the planning period.[19] The procedures for deciding among the alternative actions, when information on the moments of these distributions is known, have been detailed in the literature on decision making under uncertainty. In particular, Halter and Dean (1969) gave the methodology for the general case where no prior information is available on the form of the distribution of net income (defined as f(X)) over the states of nature, and Markowitz (1967) gave the details for the specific case when it is assumed that this distribution is normal.

Information about the moments of the distribution of f(X) can be incorporated into the decision-making problem via the producer's utility function when the choice criterion is one of maximizing expected utility. The manner in which this is achieved has been detailed by Halter and Dean (1969) for the general case mentioned previously. This procedure can be summarized as follows:

Let U(X) denote the utility of some action a where the random variable X represents the continuous outcomes from the action a over the state space $\theta$. Then expected utility for an action a is given by the equation

$$U(a) = EU(X) = U[E(X)] + \frac{1}{2}\sigma^2 \frac{d^2U[E(X)]}{dX^2} + \frac{1}{3!}g_1 \frac{d^3U[E(X)]}{dX^3} + \frac{1}{4!}g_2 \frac{d^4U[E(X)]}{dX^4} + \cdots$$

where: the expectation of the constant E(X) $= E(X)$,
the expectation of the constant $[X - E(X)]$ $= 0$,
the expectation of the constant $[X - E(X)]^2$ $= \sigma^2$ i.e., the variance of the distribution of X,
the expectation of $[X - E(X)]^3$ $= g_1$ i.e., the skewness of the distribution of X, and
the expectation of $[X - E(X)]^4$ $= g_2$ i.e., the kurtosis of the distribution of X.

The above equation gives the expected utility U(a) for any probability distribution of net income f(X) over the state space $\theta$ for any action in terms of: (1) the moments of the distribution f(X), i.e., the mean (E(X)), variance ($\sigma^2$), skewness ($g_1$), and kurtosis ($g_2$), and (2) the first four derivatives of the utility function.

If prior information shows f(X) to be normally distributed, then the estimation of U(a) from the equation is simplified considerably. For the replacement problem in this study, no such prior information

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[19] Where the state set $\theta$ is defined in terms of the price, cost, and production variable conditions prevailing over the planning period.

was available. Because of this, it was necessary to estimate the form of the distribution $f(X_i)$ for each of the 11 actions over the state space $\theta$ from available empirical data.[20] This estimation was carried out using a computer simulation procedure. The following sections outline the approach to the estimation of the distribution of net income for each of the actions in $\alpha$, beginning with definition of the sources of producers' income variability, which must be considered in the estimation procedure. The utility function and its incorporation into the decision problem will be discussed later.

## SOURCES OF PRODUCERS' INCOME VARIABILITY

By defining the sources of producers' income variability, the decision-making problem is placed in a more realistic framework in that emphasis is placed on decision-making in an *ex ante* context. In planning his replacement policy, the producer is planning for a future time period where uncertainties regarding costs, prices, and levels of production influence his decision and directly affect his expected net income level.

The major sources of uncertainty are:

- The future levels of input and output prices, where variations are due to forces outside the producer's sphere of control. The fluctuations in egg prices have, by far, the greatest influence on the variability of producer income. The form and magnitude of the fluctuations in egg prices which have occurred over the past 10 years are shown in Figure 10.

- The expected levels of egg production performance. Evaluation of the available technical information suggests that many of the biological, environmental, and physical factors which underlie and influence egg production have been presented in the literature in a form not readily amenable to the type of analysis envisaged in this study. The level of egg production is subject to wide variation, and the relationship that exists between egg production, feed consumption, and other variable inputs is also subject to variation that cannot be described by an exact single valued function, i.e., the production function may be stochastic in nature. Observations of commercial producers' actual practices also suggest that little direct control is exercised over the short-run variable inputs such as feed and water. The accepted practice is to follow an ad lib feeding program, so that the *precise* functional relationship between the amount of feed consumed and the level of output is difficult to ascertain.

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[20] The distribution $f(X_i)$ has the 'i' subscript to indicate its dependence on the $a_i{}^{th}$ action in $\alpha$.

The distribution of egg size is a source of uncertainty rarely mentioned in the literature pertaining to optimum replacement policies. Because of existing price differentials, the variation in the distribution of eggs between each of the five market sizes (small, medium, large, extra large, and jumbo) can result in appreciable variation in total revenue from egg sales. The reason for neglecting the importance of the egg size distribution in previous replacement studies is difficult to understand, considering the large price differentials that exist between eggs in the small and large egg-size categories.

Egg quality does not maintain a constant level over the life cycle of the bird (Figure 9). Throughout this cycle egg quality is subject to gradual deterioration, resulting in increasing losses in potential egg revenue to the producer. Expected values for the percentage of eggs laid in each grade over the life cycle of a bird have been measured (Table 1, Appendix B), but no information was available on the degree of variability of egg quality from the trial data. The influence of environmental, managerial, and various stress factors on the distribution of egg quality were not measured. Because of the high price premiums paid on the market for eggs in the A and AA categories, lack of knowledge regarding the degree of variability of the distribution of total egg production between C, B, A, and AA quality grades adds to the uncertainty problem facing the producer.

Flock mortality is a variable which the producer can control to a limited extent under controlled environment conditions, but it is still subject to random effects beyond his control. Even under intensive conditions, variations in the levels of flock mortality still exist.

These are the major factors affecting income variability facing the commercial egg producer. Consideration of these factors emphasizes the fact that, in an *ex ante* sense, the producer must make a choice between alternative actions without perfect knowledge about the state of nature likely to prevail over the planning period.

## ESTIMATION OF VARIABLES AFFECTING EXPECTED NET INCOME LEVELS

The variables which affect the levels of the producer's expected net income as a result of following one of the actions in $\alpha$ also can be regarded as describing the continuous range of states of nature contained in the state space $\theta_i$.[21] Since egg prices vary seasonally and egg production varies with the age of the hen, a convenient aggregate variable to represent the time dimension is a four-week period (a month, or stage of production). Also, since available price, cost, and produc-

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[21] The state space $\theta_i$ is subscripted to indicate that it is in fact a function of which of the 'i' actions, $i = 1,2, \cdots ,11$ in $\alpha$ is being considered.

tion data usually are collected on a monthly basis, it is consistent to regard the state space $\theta_i$ as being composed of a series of 26 subspaces $\theta_{ni}$, $n = 1, 2, \cdots, 26$. Thus, it was possible to estimate the stochastic nature of the relevant variables on a monthly basis and to use this information to derive the estimates of the monthly distribution of net income $(f(X_{ni}))$. The distribution of net income over the 26-month planning period then could be derived on the basis of these monthly estimates.

## *Production Variables*

**Egg production.** Estimates of the expected value of hen-month egg production $(\overline{Q}_{ni})$ and the variance of $Q_{ni}$ $(\text{var}\,(Q_{ni}))$ for each stage of production $(n)$ for each action were required. Theoretically, the best method for deriving these estimates would have involved a prior estimation of the stochastic nature of the production function:[22]

$$Q_{ni} = f(Y_{ni}, X_{1ni}, X_{2ni}, X_{3ni} \mid X_4, X_5, \cdots, X_n)$$

where:

$Y_{ni} =$ hen-month feed consumption in the $n^{th}$ stage of production,
$X_{1ni} =$ number of months in-lay,
$X_{2ni} =$ a dummy variable to account for the effects of force molting on egg production, and
$X_3, X_4, \cdots, X_n =$ fixed parameters which include breed characteristics, climatic conditions, and management factors such as housing, lighting, and degree of environmental control.

Unfortunately, such an estimation could not be made because of the lack of sufficient trial data. The lack of sufficient treatment replication in the Washington and Wye College trials resulted in estimates of $\overline{Q}_{jk}$ for many of the $s_{jk}$ states of production based on only one to three treatment replicates. Without secondary sources of information on the $\overline{Q}_{jk}$ values, the trial estimates listed in Table 1 of Appendix B had to

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[22] Note that: $Q_{ni} = f(Q_{jk})$, where $Q_{jk} =$ the hen-month egg production in the $s_{jk}{}^{th}$ state of production,

$Y_{ni} = f(Y_{jk})$ where $Y_{jk} =$ hen-month feed consumption in the $s_{jk}{}^{th}$ state of production, and

$Y_{ni} = f(Z_1, Z_2, \cdots, Z_n)$ describe the feed mix in terms of such variables as protein, mineral and vitamin content, digestive protein, starch levels, and starch/protein ratios.

The subscripts 'n' and 'i' are used to indicate the stage of production n for the action i, whereas the subscripts 'j' and 'k' are used to indicate the number of months in-lay j and the force molting treatment k. In the following sections it will often be more convenient to use variables subscripted by stage (n) and action (i), but the functional relationships indicated above should be remembered.

be used in the analysis. Obviously, with so few degrees of freedom, it would have been impossible to obtain significant estimates of var $(Q_{jk})$ from the trial data. It would have been interesting to have subjected the hypothesis that var $(Q_{jk})$ was a constant and not a function of age or force molting treatment, to statistical test.

In order to obtain indirect estimates of var $(Q_{jk})$, it was necessary to use a data source that provided sufficient treatment replication for these estimates to be made for at least some of the $s_{jk}$ states of production. These data were supplied by the New York State Agricultural Experiment Station (Cornell) trials. It was necessary to assume that estimates made from this data source could be applied to explain the variability in monthly egg production for those states of production where direct estimates from trial data were not available.

The procedure used was to calculate monthly variance estimates of egg production on a per-bird basis from the New York State (Cornell) data. Eleven treatment replicates were available from these trials, over two years of egg production, on which to base these estimates. Prior to making these estimates, the following hypotheses were proposed:

1. That all the variances of monthly egg production over the stages of the first year of production $(j = 1,2, \cdots ,13)$ were equal.
2. That all the variances over the stages of the second year of production $(j = 14,15, \cdots ,26)$ also were equal.

The Bartlett test of variances (*28*) was used to test these hypotheses. Neither of the hypotheses was rejected at the 5 percent significance level, i.e., there were no significant differences between the monthly variability of egg production over either the first or second years of production at this significance level.

Pooled estimates of the monthly variances of hen-month production were then estimated for the first year $(S_1^2)$, the second year $(S_2^2)$, and the combined first and second years $(S^2_{1+2})$, using the procedure given by Bartlett. These estimates were:

$$S_1^2 = 0.14322$$
$$S_2^2 = 0.14655.$$

A pooled variance estimate of hen-month egg production for the 26 months of production produced an estimate of

$$S^2_{1+2} = 0.15010 = \hat{\sigma}_q^2.$$

It was assumed, on the basis of these results, that the distribution of egg production for each monthly stage of production for each action in $\alpha$ could be represented as

$$Q_{ni} \backsim N(\overline{Q}_{ni},\ 0.15010).$$

**Egg size distribution.** The degree of variability of the distribution of hen-month egg production between the five egg sizes (small, medium, large, extra large, and jumbo) could not be estimated even by indirect methods. Data needed to make such estimates were not available from the experimental trial sources or from other sources. It was possible to obtain estimates of the expected values for the percentage of each of the five egg sizes in the total hen-month egg production. These values are listed in Table 1 of Appendix B.

**Egg quality distribution.** Obtaining estimates of the quality distribution between the different sizes of eggs was extremely difficult because of the lack of sufficient measurements on the flocks in the experimental force molting trials. In the light of the premiums the producer is able to obtain for high quality (A and AA grade) eggs, collection of information on this variable would have some economic justification.

The present state of information provided only the estimates of the mean percentage of total eggs laid per bird, in each quality grade, for each state of production. These figures for $GD_{gjk}$ are listed in Table 1 of Appendix B.

**Feed consumption.** Theoretically, the best method for including the variability of the hen-month feed consumption in the analysis would have been via the production function. However, the stochastic nature of the production function could not be estimated due to the fact that the influence on feed consumption of many of the factors which underlie this function were not quantified in the force molting trials. Because it was not possible to approach this problem directly through the production function, an indirect method was used to incorporate the variability in hen-month feed consumption into the uncertainty analysis. The method used involved expressing hen-month feed consumption as a function of percentage hen-month egg production, age of the bird, and the force molting procedure used. Thus:

$$Y_{jk} = f(X_{1jk}, X_{2jk}, X_{3jk}, \cdots, X_{7jk} \mid X_8, X_9, \cdots, X_n)$$

where:

$Y_{jk}$ = hen-month feed consumption in pounds,

$X_{1jk}$ = percent hen-month egg production (see Table 1, Appendix B),

$X_{2jk}$ = number of months in-lay,

$X_{3jk}$ = 1 prior to the first force molt, 0 otherwise,

$X_{4jk}$ = 1 for those stages of production prior to the second and after the first force molt, 0 otherwise,

$X_{5jk}$ = 1 for those stages of production prior to the third and after the second force molt, 0 otherwise,

$X_{6jk}$ = 1 for those stages of production after the third force molt, 0 otherwise,

$X_{7jk}$ = 1 for the first stage of production after a force molt, 0 otherwise, and

$X_8, X_9, \cdots, X_n =$ fixed environmental factors such as lighting, housing, and the general level of husbandry.

On the basis of the above functional relationship, the following model was proposed:

$$Y_{jk} = \beta_0 + \beta_1 X_{1jk} + \beta_2 X_{2jk} + \cdots + \beta_7 X_{7jk} + S_y$$

assuming $Y_{jkm} \neq Y_{jkn}$, $m \neq n$, i.e., $Y_{jk}$ values are uncorrelated; and

$$S_Y \backsim N(0, \sigma_Y^2).$$

A stepwise regression analysis of this model, using the data collected from the force molting trials, produced the following estimated relationship:[23]

$$\hat{Y}_{jk} = 6.27280 + 0.01555X_{1jk} - 0.01902X_{2jk} - 0.52251X_{3jk} + 0.19463X_{5jk} + 0.73363X_{7jk},$$

$$R^2 = 0.5779,$$

$$\hat{\sigma}_Y^2 = 0.14169 \text{ (estimates } \sigma_Y^2\text{), and}$$

$$S_Y \backsim N(0, 0.14169).$$

**Flock mortality.** The effect of the variability of flock mortality could have been included in the analysis, using one of the following methods:

- By obtaining estimates of the mean and variance of *monthly* flock mortality for each of the states of production directly from the experimental data. Insufficient data were available to follow this procedure.

- By obtaining the mean and variance of the distributions of annual flock mortality for each of the actions in $\alpha$. The monthly estimates then could be obtained by dividing the expected value for annual flock mortality by 13 (assuming a constant variance for each month of production).[24] The experimental data allowed for estimates of the means of these annual distributions, but not of the variances. The variances were obtained, by an indirect estimation procedure, from data collected from 80 commercial flocks in California (*5, 6, 7, 67, 68, 69*). A histogram of the California data, showing the distribution of this mortality, was constructed (*60*). This histogram showed that the mortality distribution had a significant positive skew. Eidman, Carter, and Dean (1968) described a similar mortality distribution for turkey flocks, and used a lognormal function to describe this distribution.

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[23] The t-ratios for the included variables were: $X_1$, 2.4563; $X_2$, –1.3669; $X_3$, –2.8855; $X_5$, 1.3127; and $X_7$, 4.1291. Variables $X_4$ and $X_6$ did not enter at the F level specified for inclusion.

[24] A classical least squares regression analysis of the mortality figures from the New York (Cornell) trials showed a significant positive linear relationship between the age of the flock and the percentage accumulative mortality. This relationship held for both first and second years of production.

Visual inspection of the data indicated that this distribution also might provide a good fit to describe mortality among poultry flocks.

The lognormal distribution permitted the fitting of the normal curve to the logarithmic transformations of the observations, thus making the function relatively easy to handle in the analysis. The following analysis is after Aitchison and Brown (1957, pp. 37-54).

Let $M =$ a positive variate $(0 < M < \infty)$ be the annual percentage mortality for a flock of birds. Then if $Y = \log M \sim N(\mu_M, \sigma_M^2)$, $M \sim \Lambda(\mu_M, \sigma_M^2)$ and the distribution of M is completely specified by $\mu_M$ and $\sigma_M^2$.

A plot of log M against $P_M$ on probability paper provided a quick check as to whether the mortality distribution might feasibly be regarded as lognormally distributed. This plot resulted in a positive linear relationship between log M and $P_M$, indicating a lognormal fit such that

$$M \sim \Lambda(\mu_M, \sigma_M^2).$$

A subsequent $X^2$ goodness of fit test showed that the hypothesis $M \sim \Lambda(\mu_M, \sigma_M^2)$ could not be rejected at the 5 percent significance level. Estimates of $\mu_M$ and $\sigma_M^2$ were calculated, using the maximum likelihood method given by Aitchison and Brown. This method yielded the estimates $\overline{M} = 14.765$ and $S_M^2 = 1.471$. It followed from these estimates that:

$$M \sim \Lambda(14.765, 1.471)$$

$$\text{and} \quad Y = \log M \sim N(2.6919, 0.3859).$$

The value of $\overline{M}$ estimated above could not realistically be applied to all actions in $\alpha$ over the two-year planning period because the force molting procedure had a significant effect on the expected mortality level over the planning period (Table 3). To account for these differences, it was assumed that the variance estimate $S_M^2 = 1.471$ would hold for all actions in $\alpha$ over both first and second years of the planning period[25] and that the differences in flock mortality between the various actions would be reflected simply in the mortality percentages (Table 4).

**Egg prices.** The seasonal and cyclical fluctuations in producer egg prices have been the major source of income variability in the commercial poultry industry (Figure 10). Over the past 10 years, egg prices have shown cycles of annual periodicity, and those months when egg prices have been at their highest (peaks) and lowest (troughs) have varied somewhat between years. Another facet of the egg price cycle has been the extent of the price differentials between

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[25] This assumption was based on the testable hypothesis that the variance of the monthly mortality distribution was a constant, i.e., it was independent of force molting procedure and age of the bird.

the different grades of eggs at different periods of the egg price cycle. Of special interest in accounting for egg price variability are the price differentials for the five lower egg grades (small AA through large B). Inspection of the price data indicated that the grade differentials between the five lower grades of eggs have maintained a fairly constant relationship to each other over time, i.e., these differentials have been smallest during the period of peak prices (in the autumn and winter months) and largest during the periods of trough prices (spring and summer months). The following procedure was used to incorporate both the monthly fluctuations in the egg price cycle and the differential relationship between the various egg grades within a particular month, into the description of the state spaces $\theta_{ni}$:

✓ The monthly prices of small AA grade eggs ($P_{1t}$) were used as *indicator prices* on which price estimates of medium AA, large B, and large A grade eggs were based. Using the 10-year price data for small AA eggs, a series of 13 discrete frequency distributions were derived—one for each month of the price year. These frequency distributions then were used to derive accumulative probability distributions for small AA grade eggs. Thus, for a particular month of the year (t) the discrete probability density function for small AA grade eggs ($f(P_{1t})$ could be represented as follows:

$$\begin{array}{rl} f(P_{1t}) = 0.0, & 0 \leq P_{1t} < 17 \\ = 0.2, & 17 \leq P_{1t} < 21 \\ = 0.2, & 21 \leq P_{1t} < 23 \\ = 0.3, & 23 \leq P_{1t} < 26 \\ = 0.3, & 26 \leq P_{1t} < 33 \end{array}$$

✓ Other differential grade prices were estimated from the following linear relationships:

$$\hat{P}_{2t} = 10.34027 + 0.92837P_{1t} \quad (R^2 = 0.7776)$$

$$\hat{\sigma}^2 = 6.3044, \qquad S_2 \sim N(0, 6.3044)$$

$$\hat{P}_{3t} = 5.16122 + 0.10409P_{1t} + 0.64742P_{2t} \quad (R^2 = 0.7269)$$

$$\hat{\sigma}^2 = 6.2655, \qquad S_3 \sim N(0, 6.2655)$$

$$\hat{P}_{4t} = 8.16419 - 0.31381P_{1t} + 0.78122P_{2t} + 0.40368P_{3t} \quad (R^2 = 0.8718)$$

$$\hat{\sigma}^2 = 3.3142 \qquad S_4 \sim N(0, 3.3142).$$

where:

$P_{2t}$ = the price of medium AA grade eggs in cents per dozen,
$P_{3t}$ = the price of large B grade eggs in cents per dozen,
$P_{4t}$ = the price of large A grade eggs in cents per dozen, and
$S_2$, $S_3$, and $S_4$ are disturbance terms.

Thus, given an initial value for $P_{1t}$ in a particular month t, it was possible to generate successive estimates of $P_{2t}$, $P_{3t}$, and $P_{4t}$ for that month on the basis of these linear relationships. Estimates for the prices of large AA ($P_{5t}$), extra large AA ($P_{6t}$), and jumbo AA ($P_{7t}$) grade eggs were obtained by adding a constant differential to the estimated price for $P_{4t}$ such that:

$$P_{5t} = P_{4t} + 1.5,$$
$$P_{6t} = P_{4t} + 3.5, \text{ and}$$
$$P_{7t} = P_{4t} + 5.5.$$

## MOMENTS OF THE DISTRIBUTION OF NET INCOME OVER THE STATES OF NATURE

A necessary condition for obtaining the information needed to effect a choice between the producer's alternative actions was the estimation of the distribution of net income ($f(X_i)$) over the state space $\theta_i$ for each of the 11 actions in $\alpha$. It was proposed to approach this problem by first determining the monthly distributions of net income ($f(X_{ni})$) over the state spaces $\theta_{ni}$ for each action and then using these estimates to arrive at the distribution of $f(X_i)$. Theoretically, such a procedure requires prior specification of the distribution of the states of nature over the state set $\theta_{ni}$ for each month (stage) of production for each of the 11 actions in $\alpha$. However, any attempt to specify these distributions analytically would have involved extreme difficulties (these distributions are continuous or discrete functions of the six variables discussed previously). The analytical problem was further complicated by the introduction of the in-lay period as a parameter whose particular value altered the form of the state space $\theta_{ni}$ due to its effect on the form of the egg price cycle over the planning period.

Fortunately, a simulation procedure provided a method whereby estimates of the distribution $f(X_{ni})$ could be attained without first having to specify $\theta_{ni}$. The simulation procedure used was, briefly, as follows: For a particular action ($a_i$ and a given in-lay period), 100 sets of "observation" of the variables such as monthly egg production, feed consumption, mortality, and egg prices were generated using the estimated distributions and relationships described previously. These monthly "observations" then were used to calculate 100 estimates of expected monthly net income ($E(X_{ni})$). These estimates were used to derive the distribution of $f(X_{ni})$ and to calculate the moments of this distribution. This procedure was repeated for each of the 26 months of the planning period. The monthly estimates of $f(X_{ni})$, $n = 1,2, \cdots, 26$, then were used to estimate the moments of the distribution of $f(X_i)$. This procedure was repeated for each of the 11 actions and for the 13 in-lay periods considered.

During the course of this procedure it was possible to hypothesize the form of the distribution of $f(X_{ni})$ and to subject this hypothesis to a statistical test. The hypothesis was that:

$$f(X_{ni}) \backsim N(\mu_{X_{ni}}, \sigma^2_{X_{ni}}), n = 1,2, \cdots ,26$$
$$i = 1,2, \cdots , 11$$

i.e., that expected monthly net income was distributed normally, with an expected value equal to $\mu_{X_{ni}}$ and a variance of $\sigma^2_{X_{ni}}$.

The simulation procedure produced estimates of the moments of the distribution of net income $f(X_i)$ for each of the 11 actions in $\alpha$ for each of the 13 in-lay periods. The simulation procedure incorporated a subroutine to test the hypothesis that each of the monthly distributions of net revenue $f(X_{ni})$, $n = 1,2, \cdots, 26$ was normally distributed. The test was based on the chi-squared statistic (*37*). This hypothesis failed to be rejected at the 5 percent significance level for all $f(X_{ni})$. The moments of the $f(X_i)$ distributions were estimated on this basis, using a simple summation procedure. Thus, if $E(X_{ni})$ and var $(X_{ni})$ were the expected value and variance of the distribution $f(X_{ni})$, i.e., $f(X_{ni}) \backsim N(E(X_{ni}), \text{var}\,(X_{ni}))$, then the expected value and variance of $f(X_i)$ were estimated from the relationships:

$$E(X_i) = \sum_{n=1}^{N} E(X_{ni})$$

and

$$\text{var}(X_i) = \sum_{n=1}^{N} \text{var}(X_{ni}), \qquad \begin{matrix} n = 1,2, \cdots, 26 \\ i = 1,2, \cdots, 11. \end{matrix}$$

The expected values $E(X_i)$ and the standard errors $(\text{var}\,(X_i))^{1/2}$ of the net income distributions $f(X_i)$ obtained from the simulation procedure are shown in Table 10.

## *Expected Net Income Levels*

The non-force molted actions $a_4$, $a_5$, $a_6$, and $a_7$ produced lower net income levels than the force molted actions $a_{28}$, $a_{32}$, $a_{37}$, $a_{39}$, $a_{43}$, $a_{47}$, and $a_{54}$ for all of the in-lay periods (Table 10). The levels of $E(X_i)$ for the four non-force molted actions were close to each other, no more than \$20 separating these levels in any in-lay period. The income levels for actions $a_5$ and $a_6$ were consistently higher than for actions $a_4$ and $a_7$. The levels of $E(X_i)$ for the seven force molted actions were more widely dispersed than for the non-force molted actions; the difference between the highest ($a_{37}$) and lowest ($a_{39}$) values was about \$130 for most in-lay periods.

Of the 11 actions in $\alpha$, $a_{37}$ produced the highest net income for all the in-lay periods, while actions $a_{32}$ and $a_{39}$ produced the lowest net

Table 10. Means and standard errors of the net income distributions for actions in the set $\alpha$

| Action $a_i$ | Mean and standard error of $f(X_i)$ | In-lay period 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $a_4$ | $E(X_4)$ | 510 | 500 | 497 | 496 | 498 | 510 | 508 | 515 | 520 | 522 | 528 | 524 | 519 |
|  | $SE(X_4)$ | 326 | 324 | 321 | 360 | 384 | 417 | 431 | 434 | 452 | 461 | 437 | 400 | 367 |
| $a_5$ | $E(X_5)$ | 519 | 508 | 501 | 499 | 496 | 500 | 509 | 516 | 519 | 523 | 527 | 530 | 525 |
|  | $SE(X_5)$ | 321 | 318 | 307 | 324 | 354 | 404 | 431 | 439 | 444 | 463 | 469 | 447 | 378 |
| $a_6$ | $E(X_6)$ | 520 | 509 | 503 | 499 | 499 | 500 | 507 | 516 | 521 | 524 | 527 | 530 | 528 |
|  | $SE(X_6)$ | 329 | 323 | 308 | 332 | 355 | 418 | 438 | 437 | 447 | 474 | 473 | 454 | 403 |
| $a_7$ | $E(X_7)$ | 514 | 504 | 497 | 494 | 490 | 493 | 498 | 505 | 512 | 513 | 517 | 522 | 522 |
|  | $SE(X_7)$ | 354 | 304 | 291 | 293 | 317 | 372 | 426 | 442 | 452 | 461 | 478 | 472 | 425 |
| $a_{28}$ | $E(X_{28})$ | 605 | 595 | 593 | 592 | 592 | 584 | 581 | 589 | 596 | 602 | 607 | 612 | 611 |
|  | $SE(X_{28})$ | 737 | 723 | 724 | 735 | 730 | 719 | 700 | 699 | 727 | 754 | 769 | 772 | 758 |
| $a_{32}$ | $E(X_{32})$ | 531 | 517 | 513 | 510 | 505 | 501 | 500 | 506 | 513 | 517 | 533 | 533 | 537 |
|  | $SE(X_{32})$ | 568 | 529 | 494 | 524 | 527 | 536 | 542 | 557 | 591 | 597 | 608 | 625 | 613 |
| $a_{37}$ | $E(X_{37})$ | 624 | 611 | 602 | 598 | 599 | 596 | 601 | 610 | 619 | 624 | 626 | 629 | 630 |
|  | $SE(X_{37})$ | 686 | 670 | 641 | 636 | 642 | 657 | 671 | 679 | 702 | 722 | 723 | 720 | 709 |
| $a_{39}$ | $E(X_{39})$ | 490 | 475 | 469 | 466 | 469 | 475 | 483 | 491 | 519 | 522 | 519 | 517 | 515 |
|  | $SE(X_{39})$ | 589 | 571 | 550 | 550 | 551 | 575 | 589 | 602 | 604 | 606 | 589 | 589 | 582 |
| $a_{43}$ | $E(X_{43})$ | 562 | 555 | 553 | 552 | 554 | 557 | 563 | 569 | 572 | 575 | 576 | 575 | 569 |
|  | $SE(X_{43})$ | 506 | 489 | 475 | 487 | 499 | 537 | 553 | 561 | 577 | 599 | 598 | 584 | 548 |
| $a_{47}$ | $E(X_{47})$ | 579 | 569 | 557 | 551 | 550 | 557 | 563 | 572 | 581 | 584 | 587 | 589 | 588 |
|  | $SE(X_{47})$ | 632 | 605 | 557 | 538 | 539 | 577 | 604 | 628 | 656 | 671 | 685 | 687 | 660 |
| $a_{54}$ | $E(X_{54})$ | 577 | 572 | 571 | 569 | 572 | 572 | 576 | 581 | 581 | 578 | 579 | 583 | 585 |
|  | $SE(X_{54})$ | 522 | 513 | 508 | 520 | 523 | 550 | 563 | 559 | 570 | 580 | 569 | 560 | 542 |

Note: Tabulated figures were derived assuming a flock size of 100 birds housed at point-of-lay. A description of the actions in this table can be found in Table 6.

income for periods 9, 10, and 11, and periods 1 to 8, 12, and 13 respectively.

### *The Variance of Net Income*

The most important information obtained from the simulation procedure concerned the differences in income variability between non-force molted and force molted actions. Force molted actions were subject to significantly higher variability than non-force molted actions (Table 10). This could be explained in part by the fluctuations in egg production and feed consumption over the planning period for the force molted actions, as compared to the relative stability of these variables for the non-force molted actions (see Figures 2-6). If this were the case, one would expect the action with the highest frequency of force molting ($a_{28}$—three molts over the planning period) to have the highest net income variability. As can be seen from Table 10, this was the case. This argument was further supported by noting a direct correlation between frequency of force molting and the level of income variability. Thus the actions $a_{28}$, $a_{37}$, and $a_{43}$, with three, two, and one molt respectively over the planning period, resulted in income variances such that

$$\mathrm{var}(X_{28}) > \mathrm{var}(X_{37}) > \mathrm{var}(X_{43}).$$

### *The In-Lay Period*

Expected net income for the non-force molted actions $a_4$, $a_5$, and $a_6$ can be maximized by ensuring that the first stage of production for these actions begins at in-lay period 10, 11, or 12 (Table 10). For action $a_7$, and the force molted actions $a_{28}$, $a_{32}$, $a_{37}$, $a_{39}$, $a_{43}$, $a_{47}$, and $a_{54}$, the best in-lay periods are 11, 12, and 13. Thus, for most of the actions the optimum in-lay date lies between the end of August and the beginning of January of the first year of the planning period.

The results given in Table 10, together with information on the form of the producer's utility function, can be used to effect a choice between the actions in $\alpha$ under conditions of uncertainty.

## THE MEAN-VARIANCE EFFICIENCY FRONTIER

A useful initial theoretical framework for choosing between the actions in $\alpha$ is given by the mean-variance (E-V) efficiency framework. This method defines a boundary (frontier) as one providing the minimum variance (or standard error) of net income for each level of expected net income. In decision-making terms, any action not lying on the efficiency frontier is dominated by those that do. Since the distribution of net income for each of the actions in $\alpha$ was determined to be normal (specified by only two moments), it was possible to use this method to reduce the producer's field of choice to those actions lying on the efficiency frontier.

Figure 12 shows such a frontier derived for in-lay period 1 (from the results in Table 10). Table 11 lists the actions lying on the frontier for the 13 in-lay periods considered. This table shows that: (1) of the 11 actions in $\alpha$, only actions $a_{32}$, $a_{39}$, and $a_{47}$ were completely dominated (did not appear on the efficiency frontier for any of the in-lay periods) and (2) the actions lying on the frontier changed according to the in-lay period.

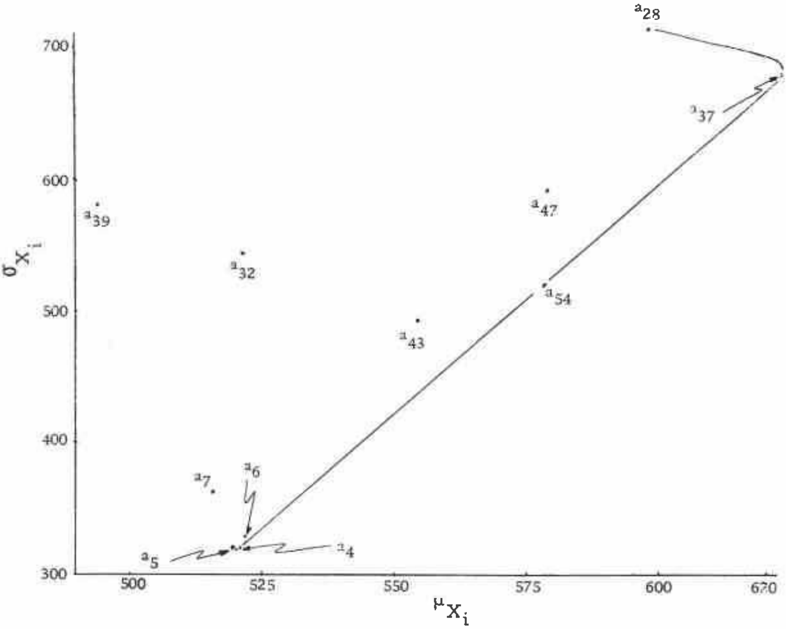


**Figure 12. Action on the mean-variance efficiency frontier (in-lay period 1).**

# THE CRITERION OF MAXIMIZING EXPECTED UTILITY

Maximizing expected utility will select an action along the E-V frontier for any producer. Since this study was not intended to derive utility functions for individual producers, the procedure of maximizing expected utility will be illustrated with three theoretical utility functions which reflect risk preference, indifference, and aversion for money gains. The object is to demonstrate how the choice of the optimum action (that which maximizes the producer's expected utility) depends on the producer's attitude towards risk.

Table 11. Actions lying on the mean-variance efficiency frontier for each of the in-lay periods

| | In-lay period | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Actions lying on the E-V frontier | $a_4$<br>$a_5$<br>$a_6$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_5$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_5$<br>$a_6$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_5$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_4$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{43}$<br>$a_{54}$ | $a_4$<br>$a_5$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{43}$<br>$a_{54}$ | $a_4$<br>$a_5$<br>$a_6$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_4$<br>$a_5$<br>$a_6$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_4$<br>$a_5$<br>$a_7$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_4$<br>$a_5$<br>$a_6$<br>$a_{28}$<br>$a_{37}$ | $a_4$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ | $a_4$<br>$a_5$<br>$a_6$<br>$a_{28}$<br>$a_{37}$<br>$a_{54}$ |

Key to actions in the table:

$a_4$ = non-force molted action. First flock kept in-lay for 15 months, and the second for 10 months.
$a_5$ = non-force molted action. First flock kept in-lay for 14 months, and the second for 11 months.
$a_6$ = non-force molted action. First flock kept in-lay for 13 months, and the second for 12 months.
$a_7$ = non-force molted action. First flock kept in-lay for 12 months, and the second for 13 months.
$a_{28}$ = force molted action. Three molts, after 6, 13, and 19 months of production.
$a_{37}$ = force molted action. Two molts, after 9 and 19 months of production.
$a_{43}$ = force molted action. One molt, after 13 months of production.
$a_{54}$ = force molted action. One molt, after 17 months of production.

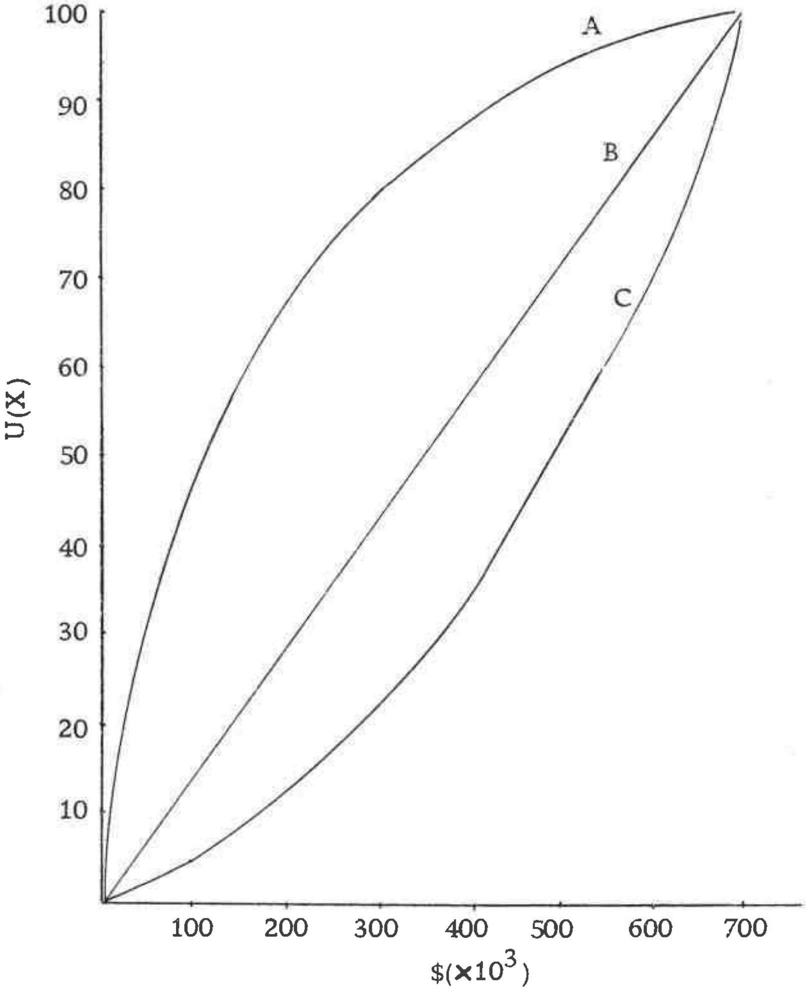
The three utility functions used in the analysis are shown in Figure 13. The utility functions were derived under the following assumptions:

- The size of the producer's laying unit was set at 100,000 birds capacity.
- The producer's utility scale was such that

$$U(\$0) = 0$$
$$U(\$700{,}000) = 100.$$

Given this arbitrary utility scale, the following utility functions were derived using the method proposed by Makeham, Halter, and Dillon:

$$U(X) = 0.015X + 0.000182X^2, 0 \leq X \leq 700$$
(Risk preference for money gains),
$$U(X) = 0.296X - 0.0002095X^2, 0 \leq X \leq 700$$
(Risk aversion for money gains), and
$$U(X) = 0.143X \qquad 0 \leq X \leq 700$$
(Risk indifference).



KEY: A $U(X) = 0.296X - 0.0002095X^2,\ 0 \leq X \leq 700$
Risk aversion for money gains

B $U(X) = 0.143X$
Risk indifference

C $U(X) = 0.015X + 0.000182X^2,\ 0 \leq X \leq 700$
Risk preference for money gains

**Figure 13. Three derived utility functions.**

These utility functions and the moments of the distribution of net income were then combined in the formula:

$$U(a_i) = U[E(X_i)] + \frac{1}{2} \operatorname{var}(X_i) \frac{d^2U[E(X_i)]}{dX^2}$$

as given previously. The formula gives the expected utility for any action when the parameters of the utility function are inserted. The expected utility from each of the actions lying on the efficiency frontier for each in-lay period was calculated. The actions that maximize and minimize[26] the producer's expected utility, assuming risk preference, risk aversion, and risk indifference, are given in Table 12.

Table 12. Actions* producing the maximum and minimum expected utility for conditions of risk preference, aversion, and indifference

| | Maximum or minimum | In-lay period | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Risk preference | Max. | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ |
| | Min. | $a_4$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_4$ | $a_4$ | $a_4$ |
| Risk aversion | Max. | $a_5$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_7$ | $a_5$ | $a_4$ | $a_5$ | $a_4$ | $a_4$ | $a_4$ | $a_4$ |
| | Min. | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ | $a_{28}$ |
| Risk indifference | Max. | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ | $a_{37}$ |
| | Min. | $a_{39}$† | $a_{39}$ | $a_{39}$ | $a_{39}$ | $a_{39}$ | $a_{39}$ | $a_{39}$ | $a_{39}$ | $a_7$ | $a_7$ | $a_7$ | $a_{39}$ | $a_{39}$ |

* A key to these actions was given in Table 11.

†$a_{39}$ = force molted action. One molt, after 9 months of production. First flock kept in-lay for 16 months, and the second for 9 months.

## *Risk Preference*

If the producer has a risk preference, he can follow the force molted action $a_{28}$ (three molts over the two-year planning period) to maximize his expected utility (Table 12).

## *Risk Aversion*

If the producer is a risk averter, he can follow one of the nonforce molted actions ($a_4$, $a_5$, or $a_7$) to maximize his expected utility,

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[26] The actions producing minimum values were included to add emphasis to the fact that the action that maximized expected utility, assuming risk preference, invariably minimized expected utility, assuming risk aversion, and vice versa.

the particular action chosen being the function of the in-lay period (Table 12). Thus, where the planning period commences at any one of the in-lay periods 2 through 6, he can follow action $a_7$ (annual replacement) and for the other in-lay periods he can follow either $a_4$ or $a_5$ to maximize his expected utility. The force molted action $a_{28}$ minimized the producer's expected utility.

### *Risk Indifference*

If the producer is indifferent to risk, his expected utility is simply a function of the expected net income from an action. In this case the producer can maximize his expected utility by following action $a_{37}$ (two molts over the two-year planning period).

## SUMMARY AND CONCLUSIONS

The economic and technological changes that have occurred in the commercial poultry industry have resulted in the industry feeling the effects of what might be termed a cost-price squeeze. Increasing production costs in conjunction with a decreasing demand for eggs and culled birds probably have catalyzed technological innovation (e.g., controlled environment housing). These changes have, in turn, resulted in lower product prices and hastened the exit of nonadaptive high-cost producers from the industry.

In an effort to make more efficient short-run use of the most important factor of production (the laying bird), attention has been focused on the economic feasibility of replacement policies involving the use of extended laying cycles and force molting programs as alternatives to annual replacement policies.

The literature on the subject of programming of production in commercial egg laying operations has concentrated mainly on the determination of optimum replacement policies without inclusion of force molting alternatives. With few exceptions, the work to date has concentrated on the problem of determining optimum flock replacement policies under conditions of certainty. Programming methods have been applied to obtain diverse solutions to this problem. The replacement problem facing the commercial producer under conditions of uncertainty has received some attention in the literature, but here again no consideration has been given to the possible inclusion of force molting policies in the producer's set of alternatives. The analyses of data from recent force molting trials have provided some information on the economics of force molting and the role of extended laying cycles in commercial egg production, but no attempt has been made to incorporate all available information into a single study.

This study had the following objectives:

1. To develop a methodological procedure for studying the replacement problem under certainty when the set of producer's alternative actions included several force molting actions. The choice criterion was assumed to be maximizing net revenue. The problem was formulated initially as a decision problem under certainty, to illustrate the relevant factors and interrelationships and to study the choice of optimum actions for a wide range of price, cost, and production conditions. Emphasis was placed on determining the economic conditions which might result in the introduction of a force molting program into the producer's optimum replacement policy.

2. To study the replacement problem under conditions of uncertainty, including the stochastic nature of price, cost, and production variables. The choice criterion was maximizing expected utility. Estimates of the moments of the distributions of such variables as egg prices, egg production, feed consumption, and flock mortality were made. These estimates, together with information on the form of the producer's utility function, were used to show how the producer's choice of optimum action could be effected under conditions of uncertainty.

**Certainty analysis.** The certainty analysis was carried out by using a simple enumerative procedure. Fifty-four alternative actions, spanning an assumed two-year planning period, were included in the set A. Using a simple economic model, the net revenues accruing to each action in A were estimated for a wide range of price, cost, and production conditions. A ranking procedure then was used to delineate a small subset $\alpha$ of actions to be studied under conditions of uncertainty.

The results of the certainty analysis showed:

✓ With a mean egg price over the planning period greater or equal to 32.0 cents per dozen, and the cost of a replacement pullet at \$1.50 or less, an annual replacement policy was optimum. With replacement costs of \$1.60 to \$1.70, the levels of feed costs and cull prices became critical in deciding between force molting and non-force molting actions. The analysis showed that a 0.2 cent per pound increase in the cost of layer ration could result in the optimum policy changing from an annual replacement policy to one requiring a force molting program.

✓ With mean egg prices of less than 25.5 cents per dozen, unless the producer can purchase pullet replacements for less than \$1.40, a force molting action, with either 3, 2, or 1 force molts over the two-year planning period would be optimum, the choice of action being a function of the in-lay period.

✓ With mean egg prices at a level of 25 to 29 cents per dozen, a low replacement cost of \$1.20 to \$1.30 favored annual replacement.

As replacement cost increased, however, a force molting action became optimum at progressively lower total variable cost levels.

- The in-lay period (period of the year when birds began laying) was shown to have a significant influence on the choice of action, due to its effect on the form of the egg price cycle facing the producer over the planning period.
- Of the original 54 actions in A, only 11, four non-force molting and seven force molting actions, were classified as being undominated. These actions were included in the set $\alpha$ to be studied under conditions of uncertainty.
- The ranking procedure used in the certainty analysis showed that for all price, cost, and production conditions studied, the *top five* actions produced net revenue figures which were close to each other. Without any information on the degree of variability of net income for each of these actions, it was not possible to state categorically that the producer's best action would be confined to the optimum action.

**Uncertainty analysis.** The uncertainty analysis began with a definition of the replacement problem as one of choosing between the alternative actions in $\alpha$, given that the expected levels of costs, prices, and production variables which define the state of nature prevailing over the planning period were not known with certainty. This was followed by a discussion of the choice criterion of maximizing expected utility. The expected utility was derived from (1) the moments of the distributions of net income for an action, and (2) the producer's utility function.

In order to derive estimates for the moments of distribution, the sources of producers' income variability were defined. The estimation of the stochastic nature of these variables was discussed. Lack of sufficient reliable information from the force molting trials resulted in several important constraints on the estimation procedures. Because of this, more emphasis was placed on methodological procedure, although it was hoped that the results of the analysis would provide some guide to the producer's optimum replacement policies under conditions of uncertainty.

The results of the uncertainty analysis showed that:

- If the producer had a *risk preference,* he could follow action $a_{28}$ (three force molts after 6, 13, and 19 months of production) to maximize his expected utility.
- If the producer had a *risk aversion,* he could follow one of the non-force molting actions ($a_4$, $a_5$, or $a_7$) to maximize his expected utility. The particular action chosen was shown to be a function of the in-lay period. Thus, where the planning period commenced at one of the in-lay periods 2 through 6, action $a_7$ (annual replacement) was the

optimum action. For all other in-lay periods, action $a_4$ or $a_5$ could be followed.

If the producer was *indifferent to risk,* he could follow action $a_{37}$ (two force molts after 9 and 19 months of production) to maximize his expected utility.

On the basis of these results, it would seem that the future importance of force molting policies in commercial egg production depends on the producer's inherent attitudes toward risk. Historical evidence indicates that force molting policies have not found wide application. This could be due to the lack of reliable information or, more significantly, to an inherent risk aversion on the part of poultry producers which has resulted in the traditional choice of non-force molted actions.

In conclusion, this study has succeeded in defining several problem areas for future research. On the basis of available information, it is concluded that force molting policies can provide alternatives to traditional annual replacement policies, but recommendations for their use in commercial egg production must be based on consideration of producers' attitudes toward risk.

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# APPENDIX A

## Revenue and Costs

Let price, cost, and production variables be defined in terms of the i^th^ action in A.

$$\pi_i = TR_i - (LD_i + TCF_i + FC_i)$$

where:

$\pi_i$ = net revenue accruing to the $a_i$ action in A over the length of the planning period N,
$TR_i$ = total revenue from egg sales,
$LD_i$ = flock depreciation (the difference between the cost of the flock at point-of-lay and its salvage value when culled),
$TCF_i$ = total feed cost, and
$FC_i$ = fixed costs.

### *Production Variables*

Let $L_i$ = the number of laying flock replacements made over the length of the planning period.
$q_{gni}$ = the number of dozen eggs laid per hen-month in the $g^{th}$ grade in the $n^{th}$ stage of production;

where:

g = 1 designates small AA grade eggs,
g = 2 designates medium AA grade eggs,
g = 3 designates large B grade eggs,
g = 4 designates large A grade eggs,
g = 5 designates large AA grade eggs,
g = 6 designates extra large AA grade eggs,
g = 7 designates jumbo AA grade eggs,
g = 8 designates reject and commercial grade eggs, and

$$q_{gni} = Q_{ni} \cdot GD_{gni}$$

where

$GD_{gni}$ = percentage of total hen-month egg production laid in the $g^{th}$ grade in the $n^{th}$ stage of production,[1] and
$Q_{ni}$ = total hen-month egg production in the $n^{th}$ stage of production.[2]

$$= \sum_{g=1}^{8} q_{gni}.$$

---

[1] Note that: $GD_{gni} = f(GD_{gjk}) = f(s_{jk})$, where $GD_{gjk}$ = percentage of total hen-month egg production laid in the $g^{th}$ grade in the $s_{jk}{}^{th}$ state of production.

[2] Note that: $Q_{ni} = f(Q_{jk}) = f(s_{jk})$ where $Q_{jk}$ = hen-month egg production in the $s_{jk}{}^{th}$ state of production.

### *Mortality*

Let $M_i^1$ = percentage flock mortality over the first year of the planning period,

$M_i^2$ = percentage flock mortality over the second year of the planning period,

$p_{ni}$ = the accumulative flock mortality up to and including the n*th* stage of production

$= V \cdot m_{ni}$

where

$V$ = initial flock size (number of birds in present state $s_{1,0}$) and

$m_{ni}$ = accumulative percentage flock mortality up to and including the n*th* stage of production.[3]

### *Production Function*

The production function is:

$$Q_{ni} = f(Y_{ni}, X_{1ni}, X_{2ni} \mid X_3, X_4, \cdots, X_n)$$

where:

$Y_{ni}$ = hen-month feed consumption in the n*th* stage of production,[4]

$X_{1ni}$ = number of months in-lay,

$X_{2ni}$ = a dummy variable to account for the effects of the force molting treatment on egg production, and

$X_3, X_4, \cdots, X_n$ = fixed parameters which include breed characteristics, climatic conditions, and management factors such as housing, lighting, and degree of environmental control.

### *Production Parameters*

Let $W$ = the weight of a culled bird, and

$V$ = initial flock size (number of birds present in state $s_{1,0}$).

**Output prices.**

Let $P_{gt}$ = producer prices for eggs in the g*th* grade in the t*th* month of the year, $t = 1, 2, \cdots, 13$, and

$P^c$ = salvage price per pound liveweight for culled birds.

**Input prices.**

Let $C^r$ = cost of a point-of-lay pullet, and

$P^f$ = cost of layer ration per pound.

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[3] Note that: $m_{ni} = f(m_{jk}) = f(s_{jk})$, where $m_{jk}$ = the percentage flock mortality over the $s_{jk}$*th* state of production.

[4] $Y_{ni} = f(Z_1, Z_2 \cdots, Z_1)$ where $Z_1, Z_2, \cdots, Z_n$ describe the feed mix in terms of such variables as protein, mineral, and vitamin content, digestible protein, starch levels, and starch/protein ratios.

**Other costs.**[5]

Let $C^c$ = per bird cost of cleaning out the laying unit at the end of the planning period, and

$C^t$ = per bird cost of transferring a point-of-lay pullet into the laying unit.

### *Cost and Revenue Equations*

With these definitions, the following cost and revenue equations can be defined:

$$\pi_i = TR_i - (LD_i + TCF_i + FC_i)$$

where:

$$TR_i = \sum_{n=1}^{N} (V - p_{ni})(q_{gni} \cdot P_{gt}),$$

$$LD_i = L_i \cdot V(C^r - (1 - (M_i^1 + M_i^2) / 100) P^c \cdot W),$$

$$TCF_i = \sum_{n=1}^{N} (V - p_{ni}) (Y_{ni} \cdot P^f), \text{ and}$$

$$FC_i = V(L_i \cdot C^t + C^c).$$

Thus, it follows that the net revenue equation, in terms of the variables and parameters defined above, is:

$$\pi_i = \sum_{n=1}^{N} (V - p_{ni})(q_{gni} \cdot P_{gt} - Y_{ni} \cdot P^f)$$
$$- L_i \cdot V[(C^r - (1 - (M_i^1 + M_i^2) / 100) P^c \cdot W) + C^t + C^c / L_i]$$

$$i = 1,2, \cdots, 54$$
$$n = 1,2, \cdots, 26$$
$$g = 1,2, \cdots, 7$$
$$t = 1,2, \cdots, 13.$$

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[5] Other costs such as labor, equipment depreciation, and interest charges were regarded as fixed in the short run, and were not considered.

# APPENDIX B

Table 1. Production data relevant to the $s_{jk}$ states of production for the action set A

| | Dozens of eggs produced per hen-month | Hen-month production | Percent production by grade[b] | | | | | | | Feed consump. in pounds | Pounds feed per dozen eggs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Grade ($GD_{gjk}$) | | | | | | | | |
| $s_{jk}$[a] | | ($X_{1jk}$) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | ($Y_{jk}$) | |
| j k | ($Q_{jk}$) | % | | | | | | | | | |
| 1 0 | 1.35 | 58 | 29 | 67 | | | 2 | 1 | 1 | 6.42 | 4.76 |
| 2 0 | 2.01 | 86 | 8 | 70 | | 2 | 17 | 2 | 1 | 7.08 | 5.24 |
| 3 0 | 1.95 | 84 | 2 | 50 | 1 | 8 | 34 | 4 | 1 | 7.03 | 3.61 |
| 4 0 | 2.00 | 86 | 1 | 30 | 1 | 13 | 46 | 9 | | 7.32 | 3.66 |
| 5 0 | 1.88 | 81 | | 21 | 2 | 16 | 47 | 13 | 1 | 7.12 | 3.79 |
| 6 0 | 1.82 | 78 | | 16 | 2 | 18 | 43 | 20 | 1 | 6.78 | 3.72 |
| 7 0 | 1.73 | 74 | | 13 | 1 | 19 | 40 | 25 | 2 | 6.71 | 3.88 |
| 8 0 | 1.74 | 75 | | 9 | 2 | 19 | 33 | 32 | 5 | 7.15 | 4.11 |
| 9 0 | 1.66 | 71 | | 5 | 2 | 17 | 27 | 42 | 7 | 7.12 | 4.29 |
| 10 0 | 1.58 | 68 | | 2 | 3 | 15 | 22 | 48 | 10 | 6.61 | 4.18 |
| 11 0 | 1.52 | 65 | | 2 | 4 | 13 | 19 | 51 | 11 | 6.95 | 4.57 |
| 12 0 | 1.58 | 68 | | 2 | 4 | 12 | 17 | 52 | 13 | 6.46 | 4.09 |
| 13 0 | 1.53 | 66 | | 2 | 5 | 11 | 16 | 54 | 12 | 6.44 | 4.21 |
| 14 0 | 1.43 | 61 | | 2 | 9 | 9 | 13 | 54 | 13 | 6.18 | 4.32 |
| 15 0 | 1.36 | 58 | | 2 | 10 | 8 | 12 | 55 | 13 | 6.29 | 4.63 |
| 16 0 | 1.25 | 54 | | 1 | 10 | 8 | 10 | 55 | 16 | 6.52 | 5.22 |
| 7 5 | 1.32 | 57 | | 13 | 2 | 16 | 43 | 24 | 2 | 4.68 | * |
| 8 5 | 0.21 | ....[c] | | 9 | 1 | 16 | 39 | 33 | 2 | 4.64 | * |
| 9 5 | 1.39 | 60 | | 2 | 1 | 10 | 26 | 51 | 10 | 7.79 | 5.60 |
| 10 5 | 1.88 | 81 | | 2 | 1 | 11 | 26 | 50 | 10 | 7.46 | 3.97 |
| 11 5 | 1.88 | 81 | | 2 | 1 | 13 | 28 | 46 | 10 | 7.65 | 4.07 |
| 12 5 | 1.82 | 78 | | 2 | 2 | 15 | 28 | 48 | 5 | 7.00 | 3.84 |
| 13 5 | 1.76 | 75 | | 2 | 2 | 14 | 28 | 47 | 7 | 6.17 | 3.51 |
| 14 5 | 1.54 | 66 | | 2 | 1 | 14 | 30 | 44 | 9 | 3.00 | * |
| 15 5 | 0.53 | 21 | | 3 | 1 | 11 | 27 | 49 | 9 | 6.14 | * |
| 16 5 | 1.77 | 76 | | 4 | 1 | 11 | 23 | 51 | 10 | 8.07 | 4.56 |
| 17 5 | 1.86 | 80 | | 3 | 1 | 11 | 20 | 54 | 11 | 7.25 | 3.89 |
| 18 5 | 1.79 | 77 | | 2 | 2 | 12 | 20 | 55 | 9 | 7.19 | 4.02 |
| 19 5 | 1.74 | 75 | | 2 | 2 | 12 | 20 | 56 | 8 | 7.10 | 4.08 |
| 20 5 | 1.27 | 54 | | 2 | 2 | 11 | 20 | 57 | 8 | 4.38 | * |
| 21 5 | 0.11 | ....[c] | | 2 | 2 | 11 | 17 | 58 | 10 | 5.06 | * |
| 22 5 | 1.24 | 53 | | 2 | 2 | 10 | 16 | 59 | 11 | 7.74 | 6.24 |
| 23 5 | 1.60 | 69 | | 3 | 2 | 10 | 16 | 57 | 12 | 7.47 | 4.66 |
| 24 5 | 1.68 | 72 | | 3 | 3 | 9 | 14 | 58 | 13 | 6.76 | 4.02 |
| 25 5 | 1.71 | 73 | | 3 | 3 | 9 | 14 | 58 | 13 | 6.84 | 4.00 |
| 26 5 | 1.68 | 72 | | 4 | 4 | 9 | 13 | 56 | 14 | 6.31 | 3.76 |
| 10 4 | 1.48 | 62 | | 2 | 2 | 13 | 25 | 48 | 10 | 6.06 | 4.09 |
| 11 4 | 0.19 | ....[c] | | 2 | 1 | 11 | 22 | 52 | 12 | 4.24 | * |
| 12 4 | 0.84 | 36 | | 1 | | 9 | 20 | 57 | 13 | 6.73 | * |
| 13 4 | 1.89 | 81 | | 1 | | 10 | 20 | 57 | 12 | 7.50 | 3.96 |
| 14 4 | 1.84 | 79 | | 1 | 1 | 10 | 19 | 56 | 13 | 7.02 | 3.81 |
| 15 4 | 1.78 | 76 | | 1 | 2 | 11 | 20 | 55 | 11 | 7.01 | 3.93 |
| 16 4 | 1.78 | 76 | | 1 | 2 | 12 | 20 | 54 | 11 | 7.30 | 4.10 |

Table 1 (Continued)

| $s_{jk}$[a] | | Dozens of eggs produced per hen-month | Hen-month production ($X_{1jk}$) | Percent production by grade[b] | | | | | | | Feed consump. in pounds ($Y_{jk}$) | Pounds feed per dozen eggs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Grade ($GD_{gjk}$) | | | | | | | | |
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| j | k | ($Q_{jk}$) | % | | | | | | | | | |
| 17 | 4 | 1.71 | 73 | | 1 | 3 | 12 | 18 | 56 | 10 | 6.92 | 4.05 |
| 18 | 4 | 1.64 | 70 | | 1 | 3 | 12 | 16 | 57 | 11 | 6.79 | 4.14 |
| 19 | 4 | 1.55 | 66 | | 1 | 2 | 12 | 17 | 57 | 11 | 6.83 | 4.41 |
| 20 | 4 | 1.18 | 50 | | | 2 | 12 | 17 | 56 | 13 | 4.43 | * |
| 21 | 4 | 0.11 | ....[c] | | | 1 | 12 | 18 | 56 | 13 | 5.18 | * |
| 22 | 4 | 1.02 | 44 | | | 1 | 11 | 17 | 57 | 14 | 7.41 | 7.26 |
| 23 | 4 | 1.72 | 74 | | | 1 | 11 | 17 | 56 | 15 | 7.69 | 4.47 |
| 24 | 4 | 1.68 | 72 | | | 2 | 10 | 15 | 58 | 15 | 7.18 | 4.27 |
| 25 | 4 | 1.65 | 71 | | | 3 | 9 | 13 | 60 | 15 | 6.91 | 4.18 |
| 26 | 4 | 1.58 | 68 | | | 3 | 8 | 13 | 60 | 15 | 6.43 | 4.08 |
| 13 | 2 | 1.40 | 60 | | 2 | 4 | 11 | 17 | 53 | 13 | 5.77 | 4.12 |
| 14 | 2 | 0.49 | 22 | | 2 | 3 | 9 | 18 | 55 | 13 | 3.13 | * |
| 15 | 2 | 0.60 | 26 | | 1 | 2 | 8 | 15 | 65 | 9 | 6.01 | * |
| 16 | 2 | 1.51 | 65 | | 2 | 1 | 11 | 19 | 54 | 13 | 7.77 | 5.15 |
| 17 | 2 | 1.65 | 71 | | 2 | 2 | 10 | 19 | 53 | 14 | 7.24 | 4.39 |
| 18 | 2 | 1.59 | 68 | | 1 | 2 | 11 | 18 | 52 | 16 | 7.10 | 4.46 |
| 19 | 2 | 1.46 | 63 | | 1 | 3 | 11 | 17 | 52 | 16 | 7.16 | 4.90 |
| 20 | 2 | 1.38 | 59 | | 1 | 3 | 11 | 16 | 51 | 18 | 6.97 | 5.05 |
| 21 | 2 | 1.30 | 56 | | 1 | 4 | 11 | 15 | 50 | 19 | 7.12 | 5.47 |
| 22 | 2 | 1.30 | 56 | | 1 | 5 | 10 | 14 | 50 | 20 | 6.69 | 5.15 |
| 23 | 2 | 1.22 | 52 | | 1 | 5 | 10 | 13 | 50 | 21 | 6.52 | 5.34 |
| 24 | 2 | 1.21 | 52 | | 1 | 7 | 8 | 13 | 49 | 22 | 6.71 | 5.54 |
| 25 | 2 | 1.12 | 48 | | 1 | 8 | 7 | 12 | 50 | 22 | 6.26 | 5.58 |
| 26 | 2 | 1.07 | 46 | | 1 | 10 | 6 | 11 | 51 | 21 | 5.48 | 5.12 |
| 17 | 3 | 0.85 | 36 | | 1 | | 11 | 22 | 53 | 13 | 5.55 | * |
| 18 | 3 | 0.01 | ....[c] | | 1 | 1 | 16 | 16 | 51 | 15 | 4.08 | * |
| 19 | 3 | 1.49 | 64 | | 1 | 3 | 15 | 13 | 52 | 16 | 7.76 | 5.21 |
| 20 | 3 | 1.31 | 56 | | 1 | 3 | 14 | 13 | 52 | 17 | 6.59 | 5.03 |
| 21 | 3 | 1.49 | 64 | | | 4 | 15 | 13 | 51 | 17 | 7.68 | 5.16 |
| 22 | 3 | 1.59 | 68 | | | 2 | 14 | 17 | 50 | 17 | 7.59 | 4.78 |
| 23 | 3 | 1.56 | 67 | | | 3 | 13 | 14 | 52 | 18 | 7.28 | 4.67 |
| 24 | 3 | 1.55 | 66 | | | 3 | 15 | 11 | 52 | 19 | 7.24 | 4.67 |
| 25 | 3 | 1.52 | 65 | | | 3 | 19 | 9 | 50 | 20 | 6.95 | 4.57 |
| 26 | 3 | 1.48 | 63 | | | 4 | 17 | 9 | 49 | 21 | 6.61 | 4.47 |
| 20 | 1 | 1.36 | 58 | | | 5 | 12 | 15 | 57 | 11 | 6.59 | 4.84 |
| 21 | 1 | 1.31 | 56 | | | 6 | 12 | 13 | 56 | 13 | 6.50 | 4.96 |
| 22 | 1 | 1.25 | 54 | | | 9 | 11 | 11 | 55 | 14 | 6.46 | 5.17 |
| 23 | 1 | 1.20 | 52 | | | 10 | 12 | 11 | 52 | 15 | 6.40 | 5.33 |
| 24 | 1 | 1.17 | 50 | | | 12 | 10 | 10 | 52 | 16 | 6.20 | 5.30 |
| 25 | 1 | 1.10 | 47 | | | 14 | 9 | 8 | 51 | 18 | 6.00 | 5.45 |
| 26 | 1 | 0.97 | 42 | | | 16 | 8 | 8 | 51 | 19 | 5.80 | 5.97 |

[a] $s_{jk}$ represents the state of production. The subscript 'j' represents the number of months in-lay, and 'k' represents the force molting treatment.

[b] 1 represents small AA grade eggs; 2, medium AA grade eggs; 3, large B grade eggs; 4, large A grade eggs; 5, large AA grade eggs; 6, extra-large AA grade eggs; and 7, jumbo AA grade eggs.

[c] Indicates hen-month egg production of less than 10 percent.

* Indicates the duration of a force molting period.