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PROBLEMS IN THE ECONOMIC INTERPRETATION OF PIG FEEDING EXPERIMENTS

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SUMMARY

Problems in the economic interpretation of feeding trials intended to be of use to farmers are considered. It is suggested that regression analysis is more useful as an analytical technique in such trials than is analysis of variance and problems concerned with selection of an appropriate regression equation are discussed.

Reference is made to data from a trial involving whey and meal feeding of pigs.

THIS paper will consider the question: "Given a set of data on feed inputs and animal growth, how can this information best be arranged to facilitate making profitable feeding decisions in a similar environment?"

In particular, the paper deals with the feeding of whey and meal, over a period of time, to pigs weighing more than 40 lb to raise their weights to about 140 lb. This problem has been studied in considerable detail by Townsley (1963) and many of the ideas presented here were first developed by him.

PROFITABLE FEEDING DECISIONS

In general, a pig farmer will need to decide the level of nutrition and farrowing dates for his sows, and the feeding policy to weaning, in addition to the feeding schedule for pigs from 40 lb to sale.

In order that the problem is not enlarged too much, attention will be confined to the case of a farmer with fixed commitments to take a given number of 40 lb pigs on specified dates, and is concerned simply with how these should be fed, and when sold, to maximize profits. Considerations of interest and taxation will be ignored for the purposes of the present exposition.

The farmer will typically have available adequate housing space for the pigs he has contracted to take. He will have an unlimited supply of meal, although at a price which is liable to vary throughout the year, and a supply of whey which varies from day to day. The whey will usually be available free, or at a fixed price, with the requirement that the total available quantity be used. The selling price for baconers and porkers will also vary from week to week.

In this situation, it is obvious that the farmer's profits will be at a maximum when the value of pigs sold exceeds the cost of meal fed by the maximum amount. The maximum profit which can be achieved depends, of course, on the amounts of whey available to the farmer. In attempting to maximize profits, the farmer can control the weight and age at which he sells his pigs by altering the proportion and absolute amounts of whey and meal fed in each time period.

A feeding trial which provides information on the effect of feeding rates on growth of pigs will, if properly interpreted, allow the farmer to make improved feeding decisions, and hence increase his profit. A feeding trial which, because either of design or interpretation, does not provide any new information on the relationship between proportion and quantity of feeds fed, and rates of gain (on a week-by-week basis) cannot even conceptually help farmers to increase the profits from their feeding operations.

A variety of assumptions may be made as to the amount of information which is available, in advance, on the values of the prices of pig meat and meal and the quantities of whey available each week. Even if these prices and quantities were known with certainty, however, there would still be the problem of estimating the relationship between the farmer-controlled variables of whey and meal fed, and the selling weight of his pigs.

It should be emphasized that it is only if the feeding trial provides the farmer with additional information on the relationship between the feeds he has available and the final weight of his pigs for sale, can it be of any assistance to him in deciding how he should feed his pigs.

It may perhaps be helpful to distinguish between *feeding trials* and *nutrition experiments*. This distinction might be stated as follows:

Feeding trials are designed to estimate the gross observed relationship between feeds and animal production.

Nutrition experiments are designed to explain why the relationships observed in feeding trials occur.

Given this distinction, this paper is concerned only with the interpretation of feeding trials.

ALTERNATIVE MODELS

If the biologically correct feeding function was known, and a method of estimating it, there would be no need to present the following points. Since the writer, at least, does not have this information, it may be worth observing that:

(1) A model (or hypothesized underlying relationship) of growth, may be visualized as relating total feed to total gain; or rate of feeding to rate of gain; or change in rate of feeding to change in rate of gain. Depending on the model chosen, the correct estimation procedure will differ.

(2) Time (or rate of feeding) must enter explicitly, or implicitly, into any satisfactory model of growth.

(3) Where the ration fed may affect the animal's digestive efficiency, as in the case of scours in pigs, the model used must make specific allowance for this effect.

(4) If one is content to study only situations where animals are fed *ad lib.*, the design of experiments and interpretation of results can be simplified.

(5) In many cases, not only is an estimate of the response to feed required, but also information on what rations can be fed. That is, some estimate of stomach capacity may be required.

(6) A distinction needs to be drawn between animals' response to a ration after they have adjusted to it and and are "in equilibrium", and their response when the ration represents a major change from their previous regime (*i.e.*, while they are "adjusting" to a new ration).*

Overriding all the above considerations, however, is the need to express the results of feeding trials in functional form (*i.e.*, as equations). This need arises because the farmer requires estimates of growth response for any ration he may want to feed. His interest is certainly not limited to the particular discrete rations which happen to have been fed in particular feeding trials.

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* These points are discussed in greater detail in the original version of this paper, available as Discussion Paper No. 41, Farm Management Department, Massey University.

This in turn means that:

(1) Regression is a much more suitable analytical procedure than the analysis of variance for the interpretation of feeding trials.

(2) It is more important to "scatter" the treatments used in the feeding trial over all combinations likely to be of commercial interest to farmers, than it is to get high (or indeed any) replication of particular treatments.

EXPERIMENTAL CONDITIONS

Confining attention to feeding trials which are intended to help farmers make improved feeding decisions, it is a tautology that unless the experimental condition allows inference to be made about responses under commercial conditions, the feeding trial results cannot be used as they were intended. This is a tautology which applies irrespective of the treatment used, or the type of analysis employed.

This proposition means that, in such feeding trials, the experimentalist must justify every difference between the conditions used experimentally, and commercial conditions. Undoubtedly, the ideal arrangement would be for experimental results to be obtained in exactly the commercial environment in which they were intended to be used.

From the commercial pig producer's point of view, it would be of little use to be told: "In a carefully-controlled environment, small additions of X will increase the rate of growth, but it is not known whether this result would apply in an uncontrolled environment of commercial pig production." It is of little use to be told that: "When fed to pigs individually, this ration gave response Y, but it is not known whether the same response would be obtained if the ration was fed to a pen of pigs, owing to the competition among pigs."

The argument that: "For feeding trials, a carefully-controlled environment is needed to enable the identification of effects which would not show themselves under commercial conditions", fails to explain why effects which do not show themselves under commercial conditions should be of interest.

In short, if feeding trial data are collected under conditions which differ markedly from those used in commercial production, the results are likely to misrepresent the response which would be observed by commercial producers; and any manipulation of the data would consequently give correspondingly suspect results.

ANALYSIS OF VARIANCE

Superficially, it might appear appropriate to use an analysis of variance to estimate whether the feeding treatments have produced a satisfactory significant effect.

The null-hypothesis in the analysis of variance, however, is that a particular treatment effect *has no effect.* But in dealing with major nutrients, there is no doubt that the treatments have *some* effects. Thus, if the analysis of variance indicates the treatment effects are "not significant", the correct interpretation is not that "the treatment has no effect" but rather that "this experiment has insufficient replication and/or insufficient spacing between treatments to show significance at the 5% level". That is, knowing that major nutrients do affect the rate of growth, it does not make much sense to submit a null-hypothesis that there is no effect. Non-significance would not lead to the conclusion that changes in major nutrients do not affect rate of growth or efficiency of feed conversion, or the like.

Worse still, even if a "significant effect" is proved, owing to a particular feed, this is not useful information until it is known whether the effect on growth is sufficiently marked to make it profitable to use more of the feed.

The condition that there is *some* response to the feed (*i.e.*, the rejection of the null-hypothesis of "no effect") is a necessary, but not a sufficient condition, for proving that it is worth increasing the amount of feed used. That is, in feeding trials the interest is not so much in finding whether nutrients have an effect, as in estimating as accurately as possible what their effect is. For this purpose, regression analysis is much more appropriate than the analysis of variance.

DESIGN OF FEEDING TRIALS

The above discussion suggests a number of almost trite rules about the design of successful feeding trials. These may be listed as follows:

(1) The objective of the experiment should be clearly defined.

(2) The experimental conditions (or environment) should be such that the objective in (1) is achieved.

(3) The design of the treatments (*i.e.*, the rations fed) should allow the objective in (1) to be achieved.

On occasions, feeding trials may be initiated without the objective being defined in terms of (at least) the following questions:

(1) For what sort of decision is the experiment meant to provide information?
(2) Who will make this decision?
(3) What information is currently available to the decision-maker?
(4) In what form will the results need to be presented for the decision-maker to be able to use them?

As one example of the need to be sure that the results of a feeding trial will be useful to somebody, the usefulness of providing results in terms of the liveweight of pigs might be considered. If farmers had no way of estimating liveweight, it is obvious that they would be unable to use the experimental results. In this situation, the research worker has the alternative of publishing results in terms of liveweight, and advocating that farmers get scales or sufficient experience to be able to guess liveweight, or of using some other index of liveweight such as "girth" or "length from withers to tail".

Thus the question, "In what form will the results need to be presented for the decision-maker to be able to use them?" is absolutely vital.

When experimental results need to be applicable under commercial conditions which may be of low standard, there may seem to be a conflict between the need to obtain experimental results under comparable conditions, and the research workers' desire to get results of the maximum statistical significance.* The point, however, is that commercial producers need information on treatment effects which will have a measureable effect under commercial conditions.

Given the particular model to be used in the regression anaylsis of trial results, it is a simple matter to check that the treatment layout will allow the estimation of the desired regression coefficients. It is a rather more complicated matter to estimate how the standard errors of these estimates will vary depending on the design. The writer

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* Statistical significance can be increased by reducing the variability of environmental conditions. But if this reduction is pushed to a point where the applicability of the results to commercial conditions comes into question, then the experimentalist may have thrown the baby out with the bath water.

cannot add anything to the seminal work of Box (1949, 1958), Box and Wilson (1951), Box and Hunter (1954, 1957) and Box and Draper (1959) on this topic.

It is, however, pertinent to refer to the distinction between an animal's response to a particular ration, when the pig has fully adjusted to the ration, and the hysteresis effect (or asymetrical lagged effects) which may occur when rations are changed. This would suggest that future pig feeding experiments could well involve pigs being put on a sequence of different rations. The pig might be kept on each ration for five weeks. The data from the first week on a new ration would be analysed separately from the data from the second to fifth weeks. The difference between these two functions might provide some light on the extent to which a change in ration does affect the rate of growth.

Finally, it might be worth pointing out the advantage of defining feeding treatments in terms of the age of pigs rather than of their weight. If feeding treatment is defined in terms of the weight of the pig, errors in the measurement of weight can cause a change in the ration fed, and treatments come to depend on measurement errors in previous time periods.

NUMERICAL EXAMPLE

Using data collected in a feeding trial conducted at the Massey Research Piggery in 1960, Townsley (1963) has calculated a regression of the weekly growth on meal and whey fed. An analysis of variance showed that both the linear and quadratic terms are significant. Since the individual terms within the linear and quadratic groupings are not orthogonal, it is not possible to calculate their individual significance in the analysis of variance. The standard errors of the regression coefficients may be used with a t-test to estimate the significance of individual coefficients.

For a pig weighing 135 lb at the beginning of a week, the weight gain per week can be expressed in terms of meal and whey fed, as:

$$\begin{aligned} wt_i = & -8.66345 + 0.626355\, m_j + 0.95945\, wh_j \\ & -0.00497\, m_j^2 - 0.0153\, wh_j^2 - 0.00439\, m_j wh_i \end{aligned}$$

where wt_i, wh_i and m_i are, respectively, the weight gain per week, and the whey and meal fed during the week.

This equation is obtained by substituting $wt_{j-1} = 135$ in the equation in Table IX from Townsley, 1963 (p. 108). This table is reproduced here as Table 1.

TABLE 1: WEEKLY INCREMENTAL MODEL, WHEY IN D.M. SECOND ORDER POLYNOMIAL*

Term	Regression Coefficient	t-test Lenient Criterion 481 d.f.
Constant	-0.608	—
wt_{i-1}	-0.648×10^{-1}	2.69 **
m_i	0.630	3.48 ***
$wh_{D.M.i}$	0.788	6.49 ***
wt_{i-1}^2	0.380×10^{-1}	0.28 NS
m_i^2	-0.497×10^{-2}	0.53 NS
$wh_{D.M.i}^2$	-0.153×10^{-1}	2.77 **
$wt_{i-1}\ m_i$	-0.270×10^{-1}	0.02 NS
$wt_{i-1}\ wh_{D.M.i}$	0.127×10^{-2}	0.86 NS
$m_i\ wh_{D.M.i}$	-0.439×10^{-2}	0.67 NS

$R^2 = 0.5902$; NS = Not Significant at 10% level
** = Significant at 1% level
*** = Significant at 0.1% level.
* Table IX, Townsley (1963), p. 108.

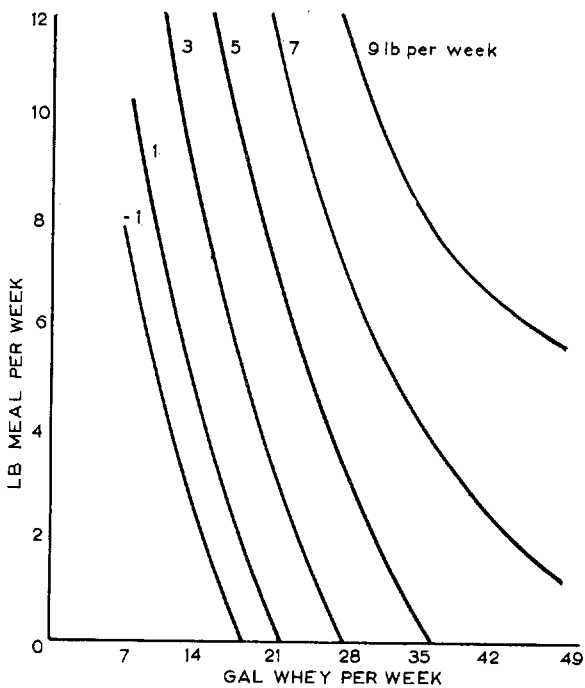

Fig. 1: Growth isoquants for combinations of meal and whey fed to 135 lb pig.

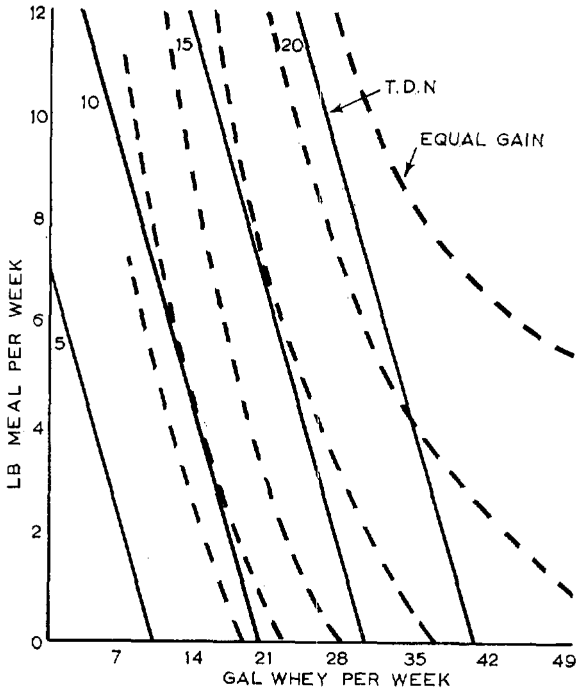

Fig. 2: T.D.N. in combinations of meal and whey fed to 135 lb pig resulting in equal growth.

Figure 1 gives the growth isoquants (lines joining points of equal growth) for combinations of meal and whey fed to a 135 lb pig. Similar diagrams can be calculated for other weights, and the marginal productivities of meal and whey, and their marginal rates of substitution can, of course, be calculated.*

Curves joining combinations of meal and whey with equal T.D.N. have been superimposed on the growth isoquants in Fig. 2. It can be seen at once that T.D.N. intake is not in any way a good index of pig growth in this experiment.

Contours for equal efficiency of feed conversion have been drawn in Fig. 3. In this case, efficiency of feed conversion is defined as follows:

$$\text{Efficiency} = \frac{\text{Gain in liveweight per week}}{\text{T.D.N. consumed in the week}}$$

* Tables for these values are available in Discussion Paper No. 29, Farm Management Department, Massey University.

It is clear from Fig. 3 that maximization of efficiency of feed conversion, in the sense defined above, would not necessarily lead to maximization of profits, and both maxima occur outside the range of the feeding trial.

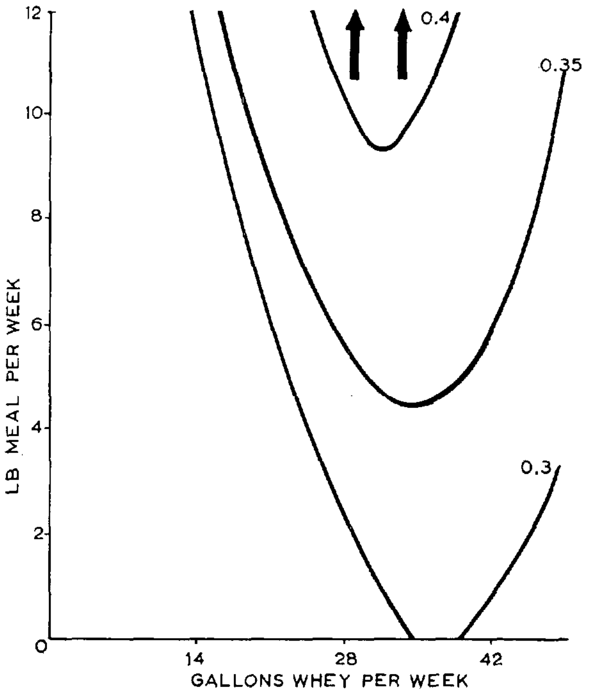

Fig. 3: Contours for equal efficiency of conversion for meal and whey feeding.

USE OF PRODUCTION FUNCTION

Even if the growth equation was known with certainty, and even if these relations were non-stochastic, it would still be difficult to maximize profits, because, as it happens, an appropriate arithmetic procedure has not yet been developed to cope with this.

A problem which can easily be solved, however, assumes that the relative worth of gain in weight of different pigs is known. One can then maximize the value of gain, subject to the amount of whey available in any week.

If, for instance, the pigs on hand are classified into classes on the basis of weighing from 40 to 49.9 lb, from 50 to 59 lb, and so on, up to 170 lb and higher, and if the relative worth of a pound of gain in each class can be stated, then these relative worths may be used to give maximum value of gain in a given week (assuming that the feed response function is known with certainty). It is not reasonable to ask farmers to calculate the exact solution for themselves. They would not understand the analytical statement of the problem and would be quite unable to carry out the calculations even if they did understand what had been asked for. Thus, in practice, it is necessary to settle for a trial and error or iterative approach to the solution of feeding problems by farmers. For a pig of given weight, the optimum ration can be calculated as soon as two ratios which involve weight gain per week, meal and whey fed, or the prices of these are known.

It is possible to present feeding tables in several ways. Probably the most useful way is that when (a) the weight gain wanted for pigs of each weight and (b) the gallons of whey available to replace one pound of meal are known. Given tables of this sort, a "trial and error" approach to the selection of an optimum feeding plan would include the following steps:

(1) Specify "target" weight gains for each weight range of pigs, and a "target" rate of gallons of whey to replace a pound of meal.
(2) Consult the tables to find the appropriate rates of meal and whey to feed.
(3) Multiply the number of pigs in each weight class by the feeding rates, and thus obtain the total meal and whey required each day.
(4) Compare the whey needed, with the whey available. If the available whey equals the required whey, then the target rate in (1) is consistent with the available whey, and hence the solution has been found. If "whey available" exceeds "whey needed", consult (5); if "whey needed" exceeds "whey available", consult (6).
(5) Whey available exceeds whey needed. In this case, it is possible to get a higher rate of gain without feeding more meal, or to get the same rate of gain while reducing the amount of meal fed. Or it is possible to get considerably greater gain while increasing meal and whey fed.

With these possibilities in mind the target rates in (1) can be raised, and the iteration repeated.

If the discrepancy in (4) is small, it may be sufficient to change the target rate of gain for just one class of pigs. If the discrepancy is large, it may be better to change the target rates for all pigs.

(6) Whey available is less than whey needed. In this case, it is necessary to reduce the rate of gain, or to increase the amount of meal fed. Alternatively, both meal and whey fed can be reduced; this will probably result in a marked reduction in the rate of growth.

With these possibilities in mind, the "target" rates in (1) can be revised, and the iteration repeated.

This illustrates the way in which the results of feeding trials can be presented to farmers so that they can feel their way iteratively towards optimum feeding rations.

The validity of feeding tables calculated in the above way will depend on the extent to which the experimental conditions accurately reflect the farm production situation, and the design, or treatments, used in the feeding experiments.

CONCLUSION

This paper has been concerned with feeding trials which are designed to be of use to farmers. For this purpose, it has been suggested that regression is a much more appropriate analytical technique than the analysis of variance, and that environmental conditions in which data are collected can be too well controlled.

Some of the problems involved in the selection of an appropriate regression equation have been touched on. Attention has been drawn to further information on these problems (notably Townsley, 1963, and the original version of this paper). Of necessity, at present, the selection of a regression equation must involve a degree of subjective judgement.

Finally, it has been shown that feeding trial results can be presented in a form in which they could be used by farmers.

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