ECONOMIC THEORY AND SHEEP-CATTLE COMBINATIONS*

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This paper deals with the problem of determining the optimum combination of sheep and beef cattle on grazing properties. A major difficulty is that iso-cost functions (production possibility curves) for sheep and cattle are unstable and difficult to estimate because of sheep-cattle-pasture interaction. After discussion of theoretical difficulties consideration is given to practical approaches, based on the iso-cost function concept, which might provide graziers with useful guide-lines. Evidence is presented which suggests that the substitution rate between sheep and cattle with respect to pasture is not constant, and probably varies with stocking rate.

Introduction

Where more than one type of livestock graze the same pasture, be they sheep and cattle, as is common in southern Australia,[2] or domesticated and wild animals (e.g cattle and deer),[3] the decision-maker is faced with the practical problem of manipulating an extremely complex biological production system to achieve his desired objectives.

This article deals with the problem of obtaining useful empirical information about the tradeoffs between sheep and beef cattle grazing common pasture.[4] We restrict our attention to the problem of profit maximization under certainty.[5] First we briefly review the static economic model of two-product production as presented in production economics texts and consider its applicability to the sheep-cattle-pasture system. Second, we summarize major conclusions about the sheep-cattle-pasture relationship drawn from experiments and farm surveys where sheep and

* This paper is based on a study of 42 grazing properties in the Western District of Victoria, presented as a M.Agr.Sc. thesis to the University of Melbourne.[1]

** The authors wish to thank Professor F. H. Gruen of the Australian National University for valuable comments on an earlier draft of this paper. Any errors or omissions are solely the responsibility of the authors.

[1] Wills, I. R., *Beef-Cattle Production in the Western District of Victoria—Technical and Economic Relationships between Beef Cattle and Sheep.* Unpublished M.Sc.Agr. Thesis, Faculty of Agriculture, Melbourne University, October, 1965.

[2] Bureau of Agricultural Economics, *Beef Cattle on Australian Sheep Properties,* Occasional Paper No. 8, Canberra, January, 1972.

[3] See, for example, Pearse, P. H., 'An Economic Approach to the Problem of Range Competition between Cattle and Game', *East African Forestry and Agricultural Journal,* Vol. 33, Special Issue, June, 1968, pp. 84-88 and Pearse, P. H., 'Toward a Theory of Multiple Use: The Case of Recreation Versus Agriculture', *Natural Resources Journal,* Vol. 9, No. 4, October, 1969, pp. 561-575.

[4] In this paper 'common grazing' or 'mixed grazing' means running sheep and cattle together in the one paddock for at least part of a defined production period.

[5] For a discussion of other factors affecting sheep-cattle combinations, see Wills, I. R. and Lloyd, A. G., *Beef Cattle Production in the Western District of Victoria,* Agricultural Economics Report No. 3, Faculty of Agriculture, Melbourne University, August, 1968.

cattle have grazed common pasture. Third, we consider some pragmatic criteria based on economic theory which would provide guidance to graziers in choosing sheep-cattle combinations.

Reality versus the Theory

Where sheep and cattle are run on common pasture we have a dynamic biological production system with each of the three living components of the system, the sheep, the cattle and the pasture, continuously affecting the others. For example, the grazing of the sheep affects the characteristics of the pasture and the availability of pasture to the cattle. As a result, given numbers of sheep and cattle grazed together will perform differently than when grazed separately on the same area, and the difference will be a function of time. Figure 1 gives a very simple schematic representation of the system, assuming minimal external intervention.[6]

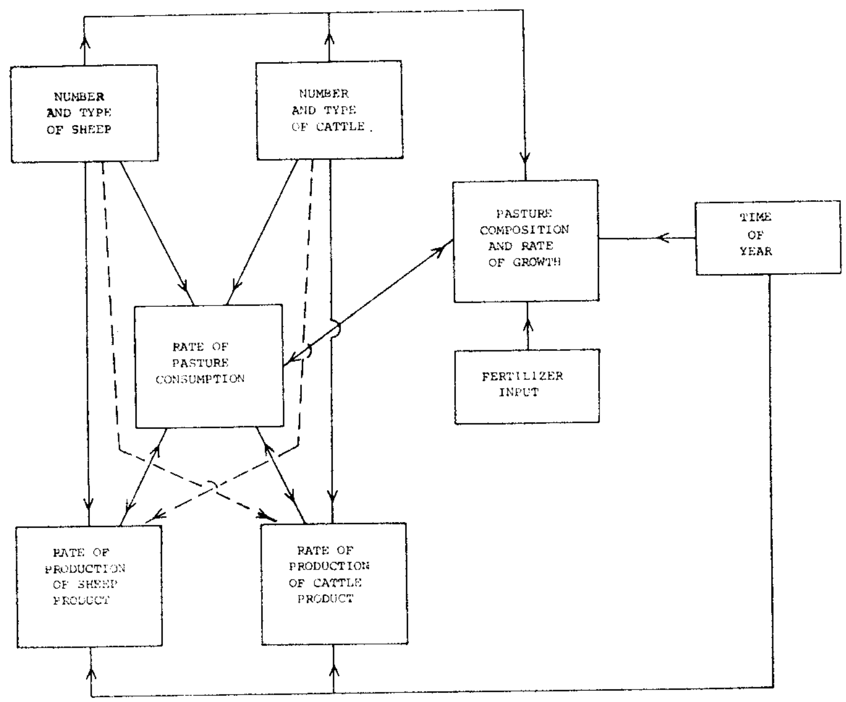

FIGURE 1—A Simplified Representation of the Sheep Cattle-Pasture Grazing System (relationships operating within a single time period).

Turning to economic theory, the simplest form of multiple-product production involves two independent production processes and a single variable input. The production functions can be combined to obtain an iso-resource function which specifies the product combinations obtained by reallocating a fixed quantity of the variable input between the two

[6] The model depicted in Figure 1 is a modified version of the grazing model previously presented in Dillon, J. L. and Burley, H. T., 'A Note on the Economics of Grazing and its Experimental Investigation', *Australian Journal of Agricultural Economics*, Vol. 5, No. 2, December, 1961, pp. 123-132. See also Dillon, J. L. *The Analysis of Response in Crop and Livestock Production*, Pergamon Press, Oxford, 1968, pp. 90-101.

processes.[7] The iso-resource function (also called the production possibility curve) is completely specified by the two production functions and the quantity of the variable input available.

In the case of two independent production processes and two or more variable inputs the derivation of the iso-resource function is more complex. In addition to reallocating the shared inputs between the two processes it is necessary to have least-cost combinations of inputs in each process.[8] In this case the iso-resource function (now more usefully thought of as an iso-cost function, since different inputs can only be aggregated in value terms) is dependent not only on the two production functions and the quantity of shared inputs, but also on the prices of the shared inputs and the possibilities for making transfers of funds between input categories.[9]

The requirement for least-cost combinations of inputs in each production process makes it impossible to estimate iso-cost functions directly using data from multi-enterprise firms, even if the processes involved are independent. Since observed input combinations will vary for a given product combination, the estimated iso-cost functions must lie within the true production possibility frontier, because variations from the optimum input combination can only lower output.[10]

Now to return to the case of sheep and cattle grazing common pasture. Not only is it impossible to estimate an iso-cost function directly using data from multi-enterprise farms, but interdependence between the two production processes introduces additional problems. In the sheep-cattle grazing system it is neither logical nor practical to ignore important interactions between the sheep, the cattle and the pasture. Referring back to Figure 1, consider the determination of the rate of production of sheep product as represented in the diagram. Production of sheep product depends directly on the number of sheep grazed, the time of year and the rate of pasture consumption by the sheep. However, since the sheep and cattle share the pasture, it also depends indirectly on the number of cattle grazed and the rate of consumption of pasture by cattle and the effects of this grazing on pasture production and composition within the same time period. Clearly in this case independent sheep and cattle production functions do not exist, therefore it is impossible to derive an iso-cost function in the manner described in the texts.

In theory, if inputs are aggregated in value terms, iso-cost functions for sheep and cattle grazing common pasture exist, but since the sheep-cattle ratio affects pasture production, composition and utilization, the

[7] For example, see Heady, E. O., *Economics of Agricultural Production and Resource Use*, Prentice-Hall, Englewood Cliffs, N.J., 1952, pp. 204-214.

[8] Duloy, J. H., 'Simultaneous-Equations Bias and Agricultural Production Function Estimation', *Australian Journal of Agricultural Economics*, Vol. 8, No. 2, December, 1964, pp. 161-168. Also see Carlson, Sune, *A Study on the Pure Theory of Production*, Kelley and Millman, New York, 1956, pp. 84-88.

[9] This point is made in Duloy, J. H., 'The Allocation of Resources in the Australian Sheep Industry', (unpublished Ph.D. Dissertation, University of Sydney, 1963), p. 18. Note that some inputs which may be fixed for the firm (e.g. labour in the case of a sheep-cattle grazing operation) may be allocated to the production of either product. The value of the resources embodied in such inputs is not transferable to other input categories.

[10] See Duloy, 'Simultaneous-Equations Bias and Agricultural Production Function Estimation', *op. cit.*, p. 167.

characteristics of the pasture and the animals involved will change along the functions. Further, since the position and shape of each iso-cost function depends on the initial characteristics of the pasture and the animals, the function is itself dependent on the initial sheep-cattle ratio. Thus for a given total value of shared inputs there is not just a single iso-cost function, as is the case where the production processes are independent, but a number of iso-cost functions, each stemming from a different initial sheep-cattle ratio. In terms of the functions shown in Figure 2, any attempt to move along the curve by altering the sheep-cattle ratio will involve a shift to a new curve.[11] The degree of shift will depend on the rate of movement along the curve (the time period involved) as well as the amount of movement (the change in the sheep-cattle ratio).

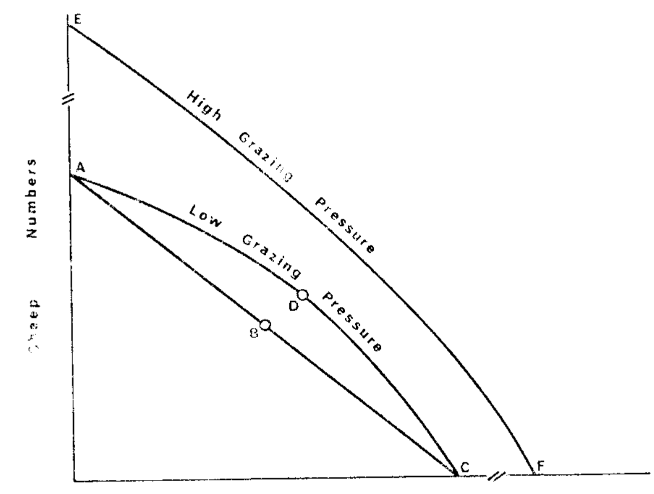

FIGURE 2—Substitution Curves for Beef—Sheep (Hypothetical).

Thus it appears that if it were possible to conduct a mixed grazing experiment to identify various points on a sheep-cattle iso-cost function, the resulting function might not be generally applicable to commercial grazing operations, which are characterized by a variety of grazing management techniques and sheep-cattle ratios. And of course changing seasonal conditions will also shift the iso-cost function, thus further reducing the usefulness of an experimentally-determined function.

The system depicted in Figure 1 could logically be described by a system of simultaneous equations which would allow for interaction between inputs and products within a single time period, along the lines of the model suggested by Dillon and Burley.[12] In the present case,

[11] Starting with a homogeneous pasture, points A, D and C in Figure 2 are meaningful descriptions of the output resulting from three alternative sets of inputs over a given time period. But if, at the end of this period, the grazier is considering moving along the curve from one of these points to another, there is no reason to believe that the resulting product combination will be on the initial curve, since pasture production and composition will have changed during the initial time period.

[12] Dillon and Burley, *op. cit.*; Dillon, *op. cit.*, pp. 66-68 and pp. 90-101.

the grazing system depicted in Figure 1 translates into the following set of four simultaneous equations:

(1) Pasture Composition $= f_1$ (Rate of pasture consumption, No. and type of sheep, No. and type of cattle, Fertilizer Input, Time of year)

(2) Rate of Pasture Consumption $= f_2$ (Pasture composition and rate of growth, No. and type of sheep, No. and type of cattle, Rate of production of sheep product, Rate of production of cattle product)

(3) Rate of Production of Sheep Product $= f_3$ (No. and type of sheep, Rate of pasture consumption, Time of year)

(4) Rate of Production of Cattle Product $= f_4$ (No. and type of cattle, Rate of pasture consumption, Time of year)

While a simultaneous-equations model such as equations 1-4 above will provide a logical description of the sheep-cattle-pasture system, empirical estimates of the relationships in such a model are unobtainable in practice for a number of reasons: first, knowledge of the biological interactions within the system is incomplete; second, even if we know how the system works, we may not be able to measure some of the important variables involved and finally, as Dillon points out, such a system is likely to be under-identified, i.e., contain too many variables whose values are determined within the system.[13] In the circumstances, it appears that the simultaneous-equations format is most useful as a basis for simulation models which can be used to help us to learn more about the mechanism of sheep-cattle grazing systems.[14]

The Sheep-Cattle-Pasture Relationship in Practice

Information about the sheep-cattle-pasture relationship is available from experiments and from farm surveys.[15] The first conclusion to be drawn from this data is that different sheep-cattle combinations applied to the same pasture will result in a non-linear substitution relationship

[13] Dillon, *op. cit.*, p. 97.

[14] For a discussion of simulation techniques applied to grazing systems see Wright, A. and Dent, J. B., 'The Application of Simulation Techniques to the Study of Grazing Systems', *Australian Journal of Agricultural Economics*, Vol. 13, No. 2, December, 1969, pp. 144-153.

[15] Experimental results are reported by Cook, C. W., 'Common Use of Summer Range by Sheep and Cattle', *Journal of Range Management*, Vol. 7, No. 1, January, 1954, pp. 10-13; Culpin, S., Evans, W. M. R. and Francis, A. L., 'An Experiment on Mixed Stocking of Pasture', *Experimental Husbandry*, No. 10, 1964, pp. 29-38; Van Keuren, R. W. and Parker, C. F., 'Grazing Sheep and Cattle Together', *Ohio Report on Research and Development*, Vol. 52, No. 1, January-February, 1967, pp. 12-13; Hamilton, D. and Bath, J. G., 'Performance of Sheep and Cattle Grazed Separately and Together', *Experimental Agriculture and Animal Husbandry*, Vol. 10, No. 42, February 1970, pp. 19-26; Bennett, D., Morley, F. M. W., Clark, C. W. and Dudzinski, M. L., 'The Effect of Grazing Cattle and Sheep Together', *Experimental Agriculture and Animal Husbandry*, Vol. 10, No. 47, December, 1970, pp. 694-709. Survey results are reported in Campbell, K. O. and Musgrave, W. F., *Economic Aspects of the Association of Beef Cattle with Sheep in South-Eastern Australia*, Department of Agricultural Economics, University of Sydney, Research Bulletin No. 3, 1958, and Wills, *op. cit.*, Chapter 7.

between sheep output and cattle output with respect to a fixed area of pasture. Experimental results indicate that this non-linearity stems at least partly from the different grazing habits and preferences of sheep and cattle.[16] As a result of these differences there are two effects of mixed grazing; the immediate effect of increased pasture utilization and the long-term effect of a better pasture composition (preferred species are less likely to be 'eaten out'). The observed grazing preferences cause increasing marginal rates of substitution between sheep and cattle with respect to pasture, i.e., a substitution relationship such as ADC in Figure 2.[17] That farmers recognize this is shown by the fact that most graziers surveyed in southern Australia report that a major reason for running cattle on grazing properties is to 'control' rank pasture growth or undesirable species such as tussocks which sheep are reluctant to eat.[18]

The second conclusion of significance for choosing sheep-cattle combinations is that as the 'grazing pressure'[19] on the pasture increases, increasing pasture scarcity relative to the animals' feed requirements forces the two species to become more competitive with respect to pasture. Hence the benefit of increased pasture utilization from mixed grazing is reduced. Further it appears that since sheep are able to graze shorter pasture than cattle, sheep obtain a larger proportion of the fresh pasture growth at high grazing pressures.[20] The curve E F in Figure 2 suggests the range of substitution rates with respect to pasture which might be found at higher grazing pressures. In addition to being near-linear, its gradient implies that the rate of substitution of sheep for cattle is higher at high grazing pressures, reflecting the superior grazing ability of the sheep under these conditions. The increased competition at higher grazing pressures shows up in the fact that most graziers consider that their cattle compete for pasture with their sheep during the autumn-winter, when grazing pressure is high, although cattle are generally considered supplementary or complementary to sheep at other times of the year.[21]

The third and fourth conclusions, for which there is some evidence from surveys, are that sheep and beef cattle do not compete for labour during some periods of the year and that beef cattle generally require less labour per unit of net return than sheep.[22]

[16] For example, see Cook, *op. cit.* and Bennett, Morley, Clark and Dudzinski, *op. cit.*

[17] On this point see Hopkin, J. A., 'Economic Criteria for Determining Optimum Use of Summer Range by Sheep and Cattle', *Journal of Range Management*, Vol. 7, No. 4, July, 1954, pp. 170-175.

[18] See Campbell and Musgrave, *op. cit.* and Wills, *op. cit., pp.* 177-180. It follows that published feeding standards ('livestock equivalents') based on pen feeding experiments are poor guides for choosing sheep-cattle combinations on pasture, on which point see Wills and Lloyd, *op. cit.*, pp. 19-21.

[19] Defined as the ratio of livestock feed requirements to feed available.

[20] Culpin, Evans and Francis, *op. cit.*, and Bennett, Morley, Clark and Dudzinski, *op. cit.*

[21] See Campbell and Musgrave, *op. cit.* and Wills, *op. cit.*, Chapter 7.

[22] See Bureau of Agricultural Economics, *Riverina Continuous Farm Study*, 1957-1958 and 1958-1959 *Annual Reports*, Canberra; Bureau of Agricultural Economics, *Beef Cattle on Australian Sheep Properties, op. cit.*, pp. 19-21, and Wills, *op. cit.*, Chapter 7.

Most graziers probably experience shortages of both feed and labour at particular times in a normal year. In these circumstances the iso-cost concept appeals because an iso-cost framework can comprehend the advantages and disadvantages of each sheep-cattle combination with respect to feed, labour and other shared inputs, as long as input prices are known.

Possible Pragmatic Criteria

Despite the difficulties discussed in the first section of this article, the empirical studies of Campbell and Musgrave and of Hopkin demonstrate that the iso-resource or iso-cost concept provides a useful vehicle for summarizing the broad effects of sheep-cattle-pasture interaction at different sheep-cattle combinations and grazing intensities. Furthermore, application of the concept to existing experimental and survey results gives rise to some decision rules which should be useful to graziers.[23] But can it be used to go beyond these broad prescriptions and make reasonably precise decisions on sheep-cattle combinations in particular situations? In the remainder of this paper we discuss empirical models based upon the iso-resource or iso-cost concept. Although these models only approximate true iso-cost functions, and are subject to the same instability problems, they appear to offer useful bases for further experimentation aimed at exploring tradeoffs between sheep and cattle on pasture. For example, experiments along these lines might provide information about changes in slope (biological 'corner points') as we move along an approximate iso-cost function at high grazing pressures. Even though sheep-cattle grazing experiments are expensive, trial-and-error experimentation by large numbers of graziers operating at relatively high grazing pressures can hardly be less so.

Each of the empirical models discussed below would use data from mixed grazing experiments where input characteristics can be held reasonably constant across treatments and accurate measures of output made. The models considered are:

1. Cost surfaces;
2. 'Iso-cost curves';
3. Iso-performance curves.

Cost Surfaces

A cost surface would be obtained by plotting total variable costs[24] against sheep output and cattle output. Although no experiment can cover all possible changes in all the variables invloved in a real sheep-cattle grazing situation, it is practicable to estimate a 'constrained' cost surface in which the set of possible input combinations is limited.[25] Much of our present sketchy knowledge of sheep-cattle substitution on pasture

[23] Wills and Lloyd, *op. cit.*, pp. 18-23. See also Lloyd, A. G., 'The Economics of Cattle-Sheep Combinations', *Farm Management*, Vol. 4, No. 2, June, 1968.

[24] Including costs of inputs fixed for the firm as a whole which can be allocated to the production of either product.

[25] For an example of an attempt to estimate a constrained iso-cost surface, see Wills, *op. cit.* Appendix V, Section II. The experiment is described in Bennett, Morley, Clark and Dudzinski, *op. cit.*

has come from mixed grazing experiments; why not design these experiments with cost-surface estimation in mind? While it is true that the resulting constrained cost surfaces will be valid only for a particular set of input prices, it would be a relatively simple matter to test the stability of calculated sheep-cattle substitution rates with respect to changes in input price ratios.

'Iso-Cost Curves'

If an experiment is designed so that total cost is maintained constant as resources are reallocated between sheep and cattle, an iso-cost function may be obtained directly. As in the case of cost surface estimation, no grazing experiment can include all possible changes in input combinations while maintaining total costs constant. However, a constrained 'iso-cost curve' can be obtained if all inputs not shared between the sheep and the cattle are fixed on a per-sheep or per-beast basis and the experimental substitution rate is set equal to the ratio between the resulting costs per sheep and per beast. For example, where pasture and supplementary feed are shared by sheep and cattle, an experiment of this type could be used to determine a constrained 'iso-cost curve' for both inputs. The quantities of shared inputs (pasture, supplementary feed and fixed inputs such as fencing) would be the same for all treatments (sheep-cattle combinations). All other inputs would be fixed on a per-sheep or per-beast basis and the two animals substituted between treatments according to the ratio of the cost of the set of inputs, including sheep, used solely to produce sheep product to the cost of the set of inputs, including cattle, used solely to produce cattle product.

This approach would focus specifically on the objective of maximizing returns from a fixed total value of inputs. Although the condition of the animals and the pasture would almost certainly differ between treatments along the 'iso-cost curve', this would not reduce the practical value of the experiment as long as the variation remained within limits acceptable to the experimenter. Moreover, although the total supplement fed per treatment would be the same for all treatments, its division between the sheep and the cattle could be determined by the need to maintain the animals in acceptable condition. Note that the derivation of an 'iso-cost curve' does not require that the experimenter decide in advance how much supplementary feed will be used over the production period —this can be altered to accommodate seasonal conditions; it does require that the quantity of supplementary feed used be the same for all sheep-cattle combinations along a given curve.

In addition to controlling the allocation of supplementary feed between the animals, the experimenter could also exercise control over the condition of the animals and the pasture by manipulation of grazing management, a virtually costless input. For example, at various times the cattle might be given 'preferential grazing'. Such adjustments would be consistent with the practice of most graziers who normally run sheep and cattle together.

A constrained iso-cost curve will only be a useful guide to optimum sheep-cattle combinations as long as the relative costs of the sets of variable inputs required for sheep and cattle do not change greatly. Assuming that quantities of supplementary feed are fixed on a per-treatment basis, the major variable cost items which dictate the experimental substitution rate will be livestock interest and replacement costs, shearing, crutching and other specific labour costs and veterinary costs. Of these, only livestock interest and replacement costs appear likely to cause substantial changes in the sheep-cattle cost ratio in the short term. Since these cost ratios are highly correlated with sheep product/cattle product price ratios, the iso-cost curve and price ratio line will tend to move together so as to cause little change in the optimum. In any case, this problem can be met by making pro-rata adjustments of the experimental results or by making adjustments based on the results of other experiments conducted at different levels of grazing pressure.

Iso-Performance Curves

Mixed grazing experiments involving a variety of sheep-cattle ratios have generally been set up with a constant sheep-cattle replacement ratio, as represented by the line ABC in Figure 2. In these circumstances, the non-linearity of substitution rates with respect to pasture has revealed itself in the experimental finding that animal performance per head is generally better in the mixed-grazing treatments than in the all-sheep or all-cattle treatments, except at high grazing pressures or in poor seasons.[26] But clearly graziers could take out the benefits of mixed grazing in the form of increased stocking rate rather than improved output per head. At some set of higher stocking rates, such as those represented by the curve ADC in Figure 2, performance per head in mixed grazing treatments would be the same as at A and C. This suggests that it might be useful to define the substitution rate between sheep and cattle with respect to pasture in terms of an iso-performance curve such as ADC, linking sheep-cattle combinations yielding constant output per sheep and per beast.

In estimating an iso-performance curve, as with an 'iso-cost curve', the quantities of shared inputs (e.g. pasture, supplementary feed, fencing) would be the same for all sheep-cattle combinations. Other inputs would be fixed on a per head basis (e.g. shearing, drenching) and their costs deducted from gross returns per head. Constant animal performance would be sought by varying the allocation of supplementary feed between sheep and cattle within treatments, and by varying grazing management. The allocation of supplementary feed and pasture could be guided by frequent measures of performance, such as wool growth and body weight.

The iso-performance curve would be a special type of 'iso-cost curve' in which certain shared inputs would be allocated so as to satisfy the iso-performance constraint and outputs would be measured in the form of the intermediate products, livestock, rather than in terms of wool and meat. Output per head, and therefore gross returns per head, would be held constant for each class of animal. The 'optimum' sheep-cattle combination would be located at the point of tangency between the iso-performance curve and the line representing the ratio of the gross

[26] For example, see Hamilton and Bath, *op. cit.*, and Bennett, Morley, Clark and Dudzinski, *op. cit.* Regression analysis of Rutherglen data for 1964-67 suggested that the all-sheep and all-cattle treatments would have required increases in area of up to 46 per cent to achieve the performance per head reached in the mixed grazing treatments (*Private Communication*, D. Hamilton, Rutherglen Research Station).

margins[27] per head for the sheep and the cattle. The slope of this line would be constant for any iso-performance curve but would vary between curves.

A major advantage of the iso-performance approach is that changing input prices do not affect the iso-performance curve, but merely require recalculation of the gross margins. Furthermore, iso-performance curves, as a pragmatic approach, have the important advantage of being based on the farmers' 'decision units', namely livestock numbers, rather than livestock output.

Variations in seasonal conditions could be accommodated by varying either the level of animal performance or the total supplement fed per treatment, or both. The aim would be to hold animal performance, and if possible total supplementary feed, constant as between treatments, but not necessarily at pre-determined levels. In practice it is unlikely that both animal performance and supplementary feed use would be exactly equal over all treatments along the curve. These departures from constancy could be adjusted statistically, and with little error if they were minor. Performance per head at various grazing pressures, levels of supplement and sheep-cattle ratios would indicate, via regression analysis, the variation in animal numbers which would have been necessary to attain iso-performance.

Concluding Remarks

The shape and position of cost surfaces, 'iso-cost curves' and iso-performance curves would vary with initial sheep-cattle ratios and seasonal conditions. If variations due to varying sheep-cattle ratios were small (as might be the case within the range of sheep-cattle ratios relevant to most graziers), the results in various types of seasons could be weighted by their probability of occurrence, permitting the selection of the sheep-cattle combination which maximized expected profits per acre.

With all three approaches—cost surfaces, 'iso-cost curves' and iso-performance curves, simulation of sheep-cattle grazing systems could contribute greatly to solving the problems of estimation discussed.

None of the three approaches suggested offers a theoretically elegant and practically satisfactory solution to the problem considered. However, they may stimulate economists and agricultural scientists towards giving more attention to an important issue.

[27] i.e., gross return per head, less the cost of inputs held constant on a per head basis. Thus, all of those costs which vary along the curve would be taken into account through the gross margin. The common inputs, pasture, supplementary feed, fencing, etc., are thus treated as 'overheads' which must be deducted from the total gross margin per acre to arrive at profit per acre.