AN ECONOMIC APPROACH TO MULTIPLE USE

G. ROBINSON GREGORY

~

In almost any discussion of wildland problems one will hear "multiple use" cited as a guiding managerial principle. At times one nearly gets the impression that "multiple use" is a panacea for all problems of public land administration, and an important guide to private property management as well. There has been remarkably little difficulty in gaining general acceptance of the multiple-use idea — the difficulties arise in application. Most people readily concede, for example, that timber production is not the sole function of public forest land — that forage, water, wildlife, and recreation should all be considered in management decisions. But how should the forest administrator decide between these many uses, and (even more difficult) how much managerial effort and cash should be directed toward each use? As an idea, multiple use has met with almost universal acceptance; as a working tool of management, it has had far less success.

This paper has three objectives:

1. To present an economic analysis of the multiple use concept.
2. To review two current approaches to multiple use often presented as being divergent, and show how both are amenable to the suggested analytical approach.
3. To discuss two of the more important problems that must be solved if the suggested approach is to be given empirical content.

---

* The author is George Willis Pack Assistant Professor of Resource Economics, School of Natural Resources, University of Michigan.

AN ECONOMIC FRAMEWORK

Broadly speaking, multiple use of land means using a particular land area to produce more than one good or service. The production of more than one product from the same plant or through use of the same process may be treated under joint-production theory. Wheat and straw, or beef and hides, are frequent text-book examples of joint production. It is believed that this theory can be applied almost directly to the multiple-use problem. Because it lends itself to graphic treatment, the two-product case will be considered first; the generalized multi-product problem will follow.

Suppose a land manager has an area suited to the production of timber and forage. Assuming that the techniques for producing both products are established and available to the land manager, his problem is simply that of deciding whether to produce timber, forage, or some particular combination of the two from the given area. The land area may thus be taken as the fixed factor.

If a graph is constructed with quantity of timber scaled along one axis and quantity of forage along the other, any combination of these two products can be represented by a single point. In Fig. 1, for example, *A* represents a combination of 400 bd. ft. of timber and 400 pounds of forage; *B* a combination of 200 bd. ft. of timber and 2400 pounds of forage. If no management activities were undertaken on the area the combination *C* might result.

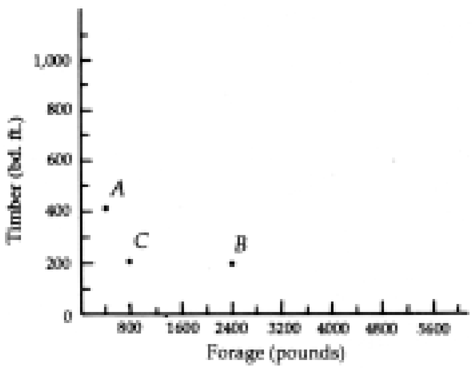

Fig. 1. Any possible output combination of two products can be plotted on a diagram of this type.

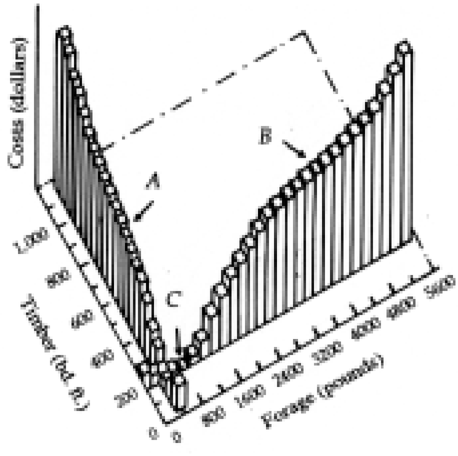

Fig. 2. Costs may be indicated by the height of a column above a plane.

But if there is a management problem, it can be assumed that something is to be done, hence costs will be incurred. To bring these costs into the picture necessitates use of a third dimension. If the forage and timber scales are plotted on a horizontal plane, costs can be represented by the height above this plane. In Fig. 2 a few of the infinite number of possible timber–forage combinations are shown, with the height of the column indicating production costs. If *C* is again the combination achieved without managerial activity, then costs would necessarily rise in any direction from this point. Only the increased yields, however, are economically significant.

By connecting all those columns of equal height (in effect, by constructing a contour map of Fig. 2.) a set of curves similar to the solid lines in Fig. 3. will be generated. Each curve represents all the combinations of timber and forage that can be produced at some given cost, hence are called “iso-cost” curves. While an infinite number of these curves could be drawn, only a few are illustrated. The shape of the individual curves, as well as the pattern of the entire curve family, would be expected to differ for every area. An illustration of this will be given later.

So far only production costs have been treated. Management aims, however, to maximize net revenue, and to achieve this objective revenues must be introduced. The

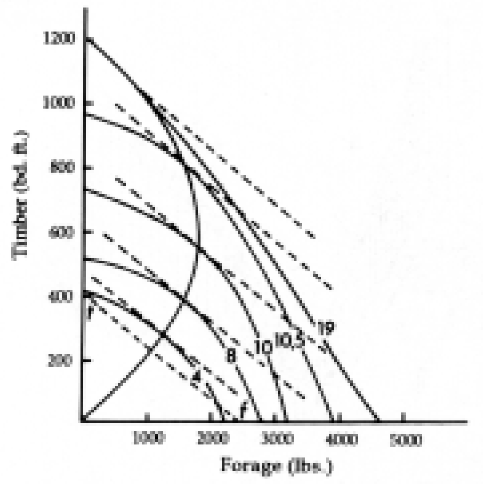

Fig 3. Iso-cost curves (—) identify all product combinations that can be produced at equal cost. Iso-revenue curves identify all product combinations that will yield equal revenues. The expansion path, through points of tangency, locate a series of product combinations that should be considered by the land manager.

approach is directly analogous to that taken with costs, though less complicated, If any point on the timber axis is selected, conversion to dollar values can be readily accomplished by multiplying the volume by the unit market price.

For example, if the market price of stumpage were $20 per M.B.M., 400 bd. ft. would be worth $8 (point *t* in Fig.3). The quantity of forage worth an identical amount at its current market price can be similarly calculated and located on the forage scale. In the present example a forage price of $6.67 per ton was assumed. Eight dollars worth of forage would therefore be 2400 lbs. (point *f*.) By connecting these two points all possible combinations of timber and forage producing $8 in revenue will be identified, for all will necessarily lie on this line.[1] Once this line has been located the entire family of iso-revenue curves is established, for all such lines will be parallel.

[1] This is true for timber and forage, since no area being analyzed in this fashion would be large enough to produce quantities that might significantly affect the price of either product. With other products this might not be true. In this latter case the iso-revenue lines would be curved, and their location would necessitate knowledge of the product demand functions.

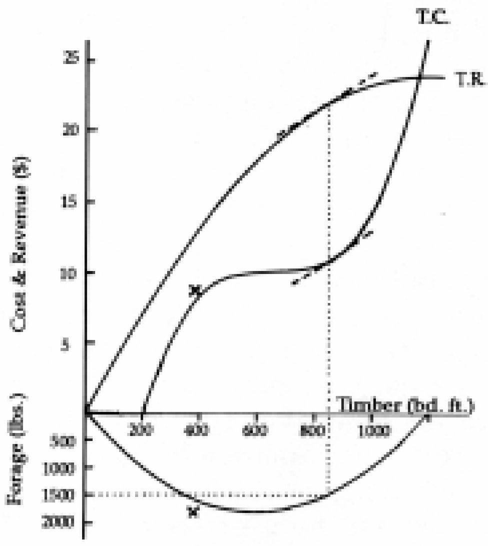

Fig 4. Solution of the two-product case. Total cost (TC) and total revenue (TR) curves in upper part of figure are directly related to the product combinations identified by the expansion path in the figure's lower portion.

With both iso-cost and iso-revenue curves determined, the task of isolating the most desirable combination of products can be narrowed a great deal. The manager will of necessity operate at some point on an iso-cost curve, since these curves include all possible product combinations.[2] For any given production cost he will want to assure the return of the highest possible revenue. The manager can be visualized, therefore as moving *along* an iso-cost curve until the highest revenue is obtained. This will be achieved only when the point of tangency between the iso-cost and iso-revenue curves is reached, for at no other point can he realize so high a revenue with the chosen expenditure. Hence a line connecting these points of tangency (the "expansion path") will delineate all those combinations of timber and forage that the land manager should consider.

The final step consists of identifying which of the combinations on the expansion path will maximize net revenues from the area. The solution is illustrated in Figure 4. The lower part of the diagram consists of the expansion path

[2] Bear in mind that only a few of the iso-cost curves are illustrated in Fig. 3.

that was previously constructed.[3] The upper half reproduces the traditional curves of economic theory — total cost and total revenue. The only difference between this upper set of curves and those developed in usual profit maximization theory lies in their applicability to a production combination rather than to a single product. The total cost and total revenue curves are derived from, hence directly related to, the expansion path in the lower portion — they are functions of both product outputs. The cost of producing (for example) the product combination X in Fig. 4 (380 bd. ft. of lumber and 1550 lbs. of forage) can be read directly from the total cost curve, and is identified by X'(8 dollars). Since the objective is to maximize returns from the area, the proper combination of timber and forage will be that one which achieves the greatest positive difference between total cost and total revenue. This difference will be maximized where the slopes of the total cost and total revenue are equal — where marginal cost equals marginal revenue — and is shown in Fig. 4 as being approximately 850 bd. ft. of timber and 1500 pounds of forage.[4]

Because geometry is limited to portrayal of three dimensions the development has thus far been restricted to multiple use involving only two products. Yet in practice the problem is seldom so restricted. Multiple use of public lands frequently involves consideration of timber , forage, wildlife, water, recreation, and other goods or services. To extend the approach to these more complex (but more real) problems, mathematics must be substituted for geometry. The same two-product case will be used, and changes necessitated by additional products indicated as the development proceeds.

The technical production possibilities depicted in Figure 1 can be expressed mathematically by a set of production functions. If more than one product is to be produced from the given area, then it can be assumed that at some point the output of one product will influence the output of another. Hence, in addition to the input variables com-

[3] The expansion path, together with the two axes, has simply been rotated 90 degrees to the right.

[4] It will occur to any forester that the possibility of growing this particular combination is somewhat remote. It was decided in this case, however, to sacrifice reality for simplicity of illustration.

monly associated with the production function for each product, the output of each of the other products must also be entered as a variable. In the timber and forage case we might have, for example:

$$Q_t = f\left(x_1, x_2, x_3, \ldots x_n ; Q_f\right)$$
$$Q_f = f\left(x_1, x_2, x_3, \ldots x_n ; Q_t\right)$$

as the generalized production functions, with Q_t and Q_f representing the outputs of timber and forage, and x_1, x_2, $x_3 \ldots x_n$ the inputs of variable services required. A separate production function will be required for each product, so there will be as many equations as products being considered. No entry need be made for the land, since this is taken as the fixed factor.

The steps through which costs and revenues were introduced (illustrated by Figures 2 and 3) seem desirable graphically but may be bypassed in the mathematical solution. Total cost of producing any particular combination can be derived as a summation of the various input costs and ultimately expressed as a function of the output of the several products, just as indicated in the upper part of Figure 4. This equation[5] can be expressed generally as $TC = f(Q_t, Q_f)$. Additional products will necessitate additional output variables, but no further complication is introduced at this point by increasing the number of products.

Similarly, the total revenue curve can be translated into a function of the output of the two products.

In many multiple product cases the possible combinations will be limited by technical considerations. It seems probable that in most situations the expansion path could be determined without resort to a complex production function analysis. In any event once the expansion path has been determined, the product combinations can be treated as a single new product, and total revenue and total cost curves derived. The total revenue curves illustrated in Fig. 4, for example, can be expressed by equation

---

[5] From this same equation the family of iso-cost curves may be derived. Considerable insight is gained by a careful analysis of these cost relationships, but since it is not necessary for the final solution, the full development is not presented here.

$$TR = 4X - 0.167X^2$$

Similarly, the total cost curve is described by the expression

$$TC = -20 + 13.75X - 2.083X^2 + 0.105X^3$$

In both equations, while the product combination (X) is identified by the timber part of the output (in hundreds of bd. ft.) it is nevertheless a combined variable. To illustrate: the total revenue that can be realized from the combination of 500 bd. ft. of timber and 1750 lbs. of forage (on the expansion path) can be determined by substituting 5 for X in the total revenue equation and will be

$$TR = 4(5) - 0.167(25) = \$15.83$$

This same result can be obtained by adding the revenues from each product:

500 bd. ft. of timber at $20 per M	=	$10.00
1750 lbs. of forage at $6.67 per ton	=	$ 5.83
		$15.83

From the total cost equation it is seen (again by substituting 5 for X) that the total cost of producing this same combination will be $9.80.

$$TC = -20 + 13.75(5) - 2.083(25) + 0.105(125) = \$9.80$$

Where product combinations are highly variable, it will usually be preferable to express both total cost and total revenue as joint functions of the products, rather than by using a combination variable. Derivation of such functions can probably best be accomplished through the production function approach previously outlined.

In the graphic illustration, the product combination maximizing returns was determined by establishing the point at which the total cost and total revenue curves have identical slopes. This is simply another way of expressing the necessary equality of marginal cost and marginal revenue, since the slope of these curves represents the change in cost (or revenue) associated with a corresponding change in output. Mathematically, marginal cost and revenue may be determined by taking the first derivative of the total functions with respect to output.

Since equality of marginal cost and marginal revenue is a necessary condition for profit maximizing, the two marginal expressions can be equated and the profit-maximizing output determined directly.

From the total cost and total revenue equations previously developed, for example, the following two marginal expressions can be derived through differentiation:

$$MC = \frac{dTC}{dX} = 13.75 - 4.166X + 0.315X^2$$

$$MR = \frac{dTR}{dX} = 4 - 0.334X$$

If marginal cost is to equal marginal revenue, then

$$13.75 - 4.166X + 0.315X^2 = 4 - 0.334X$$

which simplifies to

$$0.315X^2 - 3.832X + 9.75 = 0$$

Solving this by means of the quadratic formula, it is seen that the desired output combination consists of 854 bd. ft. of timber and the associated 1480 lbs. of forage.[6]

Had joint cost and revenue expressions been derived (as is necessary for a general solution) the marginal functions would be determined by taking partial derivatives of the total functions with respect to each of the products. If, for example, total cost is represented by the generalized expression

[6] Actually, since a quadratic expression was used, there will be two roots which satisfy the equation, and in this case both roots are real. One needs only to subtract costs from revenue, however, to identify which is the profit maximizing combination. In this instance the second root is 3.62, or 362 bd. ft. of timber. From the equation, *TC* at this output is $7.46, and *TR* = $12.29. Net revenue is therefore 12.29–7.46 = $4.83. A similar calculation with the other root (854 bd. ft.) yields a net revenue of 21.98–10.91 = $11.07.

$$TC = f\left(Q_t, Q_f\right)$$

Then the two marginal cost relationships are simply

$$MC = \frac{\partial TC}{\partial Q_t}$$

and

$$MC = \frac{\partial TC}{\partial Q_f}$$

The resulting marginal cost and revenue expression would next be equated, just as in the illustrative case, but now would form an equation system in terms of product outputs. Since the number of unknown product outputs would be equaled by the number of equations, this system could be solved simultaneously to yield the set of product outputs that would maximize net return from the land area under the given cost and revenue situation.

One observation should perhaps be made: throughout the development there has been an implicit assumption of instantaneous production. This assumption is of course unrealistic and was made to avoid introduction of discounted formulas, etc. To relax this assumption requires only that all anticipated costs and revenues be discounted to a common point in time.

CURRENT APPROACHES

Having presented an economic framework for analyzing multiple-use problems the question of how it fits in with current interpretations of the concept might well be raised. Two such interpretations may be distinguished on the basis of area applicability. One group, perhaps best exemplified by G. A. Pearson[7], would apply multiple use to large areas but maintains that managerial subdivisions of the total area should be devoted to specialized uses. Any specific acre, therefore, would be put to a single use — the use to which it was eminently suited — though the area as a whole might be producing a variety of goods and services. The second group, exemplified by Dana[8] and

[7] G. A. Pearson. 1944. Multiple use in forestry. J. For. 42: 243–249.

[8] S. T. Dana. 1943. Multiple use, biology, and economics. (Editorial) J. For. 41: 625-626.

McArdle,[9] would hold that multiple use may require the production of several goods and services from the same acre.

Logically, the Pearson approach requires the land manager to settle upon a "primary" use for each subdivision of the total area. "Secondary" uses would be tolerated only as long as they do not interfere with the primary use. If, for example, it had been decided that a particular area was best suited to timber production, forage production might also be tolerated, but never to the point where income from timber was reduced.

In contrast, the Dana–McArdle approach would hold that the major objective in managing this same tract was to maximize returns from the area, and would further maintain that the combination of forage and timber which would achieve this maximization might entail some sacrifice of timber output.

Admittedly, the contrast between these two approaches has here been emphasized. Under many — perhaps most — current situations both approaches would yield practically the same result. Yet in an economy characterized by an ever-expanding consumption of natural resources it might be expected that differences could increase. Conflicts between land uses are unusual when there is an abundance of land — the real problems arise when expansion of one use means curtailment of another, and land in the United States is being used ever more intensively.

To compare these two approaches, suppose that the land manager is working with areas, each of which is definitely suited to the production of a single product. Possible isocost patterns for two very distinct areas — one eminently suited to timber production, the other to forage production — are illustrated in Figure 5. If the scales on the two diagrams are identical, and if the product price relationship are the same as those used previously, the expansion path in Figure 5A would coincide with the timber axis, and in 5B with the forage axis. This indicates simply that under such conditions any combination of timber and forage will be less profitable than would the single product for which

[9] Richard F. McArdle. 1953. Multiple use — multiple benefits. J. For. 51: 323-325.

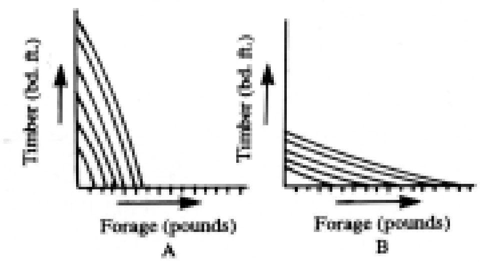

Fig 5. Possible iso-cost patterns for two very different kinds of areas. Area A would favor timber production, Area B forage production.

the area is best suited. In a situation of this type, therefore, the Pearson approach would be entirely justified. It is obvious, however, that it represents only a special case.

If the situation is not as depicted in Figure 5 — if instead it resembles more closely that illustrated by Figure 3 — then the Dana–McArdle approach is necessary if maximum returns are to be achieved. It appears, therefore, that the Pearson approach is not in fundamental conflict with that of the Dana–McArdle school. It is simply a special case in the general problem.

Figure 5 makes it clear that it is entirely possible for one product to be favored exclusively under one price relationship, but not under another. Similarly, it is to be expected that the optimum product combination will alter (the expansion path will shift) as either cost or revenue relationships change. Furthermore, on some areas it might well happen that two uses that were complementary at one intensity of management might be competitive at another.

QUANTIFICATION PROBLEMS

The reader will undoubtedly have noted that only dollar values were used in developing the framework. Yet quantification in monetary terms is by no means a prerequisite, although some common denominator must exist before value comparisons can be made objectively. So long as the appropriate costs and returns are entered in the analysis, this approach has equally valid application to public or private problems. In the former, one would expect social costs and social returns to be used for the various products — in application to private areas it is probable that only those costs and returns affecting the owner would be entered. Even so, it is obvious that only a framework has been developed. Putting meat on the skeleton will involve a great deal of research in several areas, at least two of which warrant emphasis.

The first concerns all those products which are not usually valued by market transactions. The major stumbling block here is the quantification of non-market-determined values in terms that permit objective comparisons to be drawn. There are many[10] who feel that no attempt should be made to place dollar values on wildlife, scenic views, and the like, yet the troublesome fact persists that in an economy such as ours, things valued in dollar terms often have a distinct competitive advantage. A rocky, lonesome coast line may be "priceless" to the lover of seascapes, but it has little likelihood of keeping its beauty if oil is known to lie beneath the rocks.

The problems inherent in quantifying non-market-determined values lie beyond the scope of this paper, but it seems appropriate to observe that the technique developed in the iso-cost diagram may contribute to determining some of these values. To illustrate: suppose a product with a readily measurable value (such as timber) is placed on one scale, and on the other some less easily valued product (perhaps wildlife). One may still construct iso-cost curves, since these depend upon a purely physical base coupled with determinable *cost* data. The difficulty would seem to lie with constructing iso-revenue lines, for their slope is the very item in question.

But suppose one has an area in which it is believed that the balance between wildlife and timber is approximately correct. The iso-cost curves can be plotted as above and the present point of operation located on one of theses curves. If it is assumed that the present balance is correct, then a line tangent to the iso-cost curve at the present point of operation permits one to identify the "value" of the product. The slope of this tangent will be equal to the ratio of

---

[10] For example, note Robert Marshall's quotation, appearing in Dana's article cited in footnote 8.

the two values, one of which (timber) is readily quantifiable. For example, if the slope were 45 degrees, and 25 dollars´ worth of timber were intercepted on the timber scale, then the quantity of wildlife intercepted on its scale would also be worth 25 dollars. This is, of course, simply an extension of the opportunity-cost concept and does not presume to determine the intrinsic "value" of wildlife which may be "worth" more or less to any single individual, just as a painting or a pair of shoes may be worth more or less than its purchase price to different people. It does, however, identify the value imputed to wildlife by the administrative decisions governing management of the particular tract. *It is the only economic value that wildlife can possess if one considers the balance between the two products to be correct.*

The second area requiring much research concerns determination of the returns to various intensities of management for timber, water, forage, and all the other products of wild land. "Cost and returns" studies made in forestry are steps in the right direction, but these steps must be lengthened a great deal. Isolated case studies will not suffice. It is not enough to know that "forest management pays" or that specific silvicultural practices will pay their way. We need to be able to give far better answers to the question: How much forest management pays most? This necessitates input-output analysis of a far higher order than that undertaken to date. The need for such study seems obvious.

CONCLUSION

In conclusion, it should be stated that, with the possible exception of the technique illustrated in Figure 4, the approach to multiple use which has been presented involves no methodology that might be considered new by a production economist. It is believed, however, that multiple land use has not commonly been recognized as a problem of joint production, and that this approach will be new to most of those working in the field of wildland management research. Furthermore, the approach seems to resolve in an objective fashion some of the confusion attending the multiple-use concept, and it may offer a start toward placing a value on those products some individuals wish to regard as "intangibles".