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Activity Analysis: Bridging the Gap between Production Economics Theory and Practical Farm Management Procedures

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This paper is addressed to the traditional problem of demonstrating the relevance of production theory to management-oriented people. Activity analysis, it is argued, is the most appropriate pedagogic framework within which to commence either a production economics or a farm management course. Production economics theory has not been widely accepted as a useful method for the analysis of practical management problems. The theory has been traditionally presented in terms of continuous functions which assume away the question of technical efficiency. Activity analysis, *in its general form*, is a more comprehensive approach to the theory of production than the conventional neo-classical production function approach since activity analysis explicitly incorporates technical efficiency considerations. The failure of general agricultural economists to demonstrate appropriately the relevance of production theory has encouraged a sub-discipline of farm management dedicated to real-world management problems in agriculture. The basic procedures developed by the farm management sub-discipline (virtually independent of production theory) and now in common use, have a strong affinity with activity analysis. The traditional gap between production theory and applied farm management can, therefore, be bridged by approaching the theory from the activity analysis viewpoint.

Conventional production economics theory has been of virtually no assistance "to men of affairs for the practical solution of their economic and business problems" (Dorfman 1953, p. 797). It is our belief that this statement is especially true in relation to farming, where physical and financial ratios, including gross margins,[1] continue to be the basis of most management decisions made by farmers. Physical input–output ratios, gross margins analysis, simple budgeting and other derived forms of budgeting are the practical farm management procedures referred to throughout the paper. A dichotomy has developed between these "traditional" practical procedures and conventional production economics theory (Williams 1969; Musgrave 1976; Candler and Sargent 1962; Blagburn 1962; Burns 1966; Crabtree 1978). In our view, this dichotomy largely breaks down when both traditional farm management procedures and the conventional economic theory of production are seen as outgrowths of

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[1] A "gross margin" is the difference between gross revenue and direct (variable) costs. For more details see section 2 of the paper.

the activity analysis framework.[2] The simple physical activity description is the basic building block for practical farm management procedures *and* for production economics theory.[3] Within the framework of activity analysis, the production theory becomes more relevant for practice and the practical procedures can be seen to be rooted in theory. That is, theory and practice come together. This is not entirely so, however, because conventional theory abstracts from an important problem in farming—that of technical efficiency. By explicitly considering technical efficiency as well as all the conventional production economic concepts, activity analysis represents, not only a more practical approach to theory, but also a more powerful one.

In 1953, King stated that: "This technique (activity analysis) may require some re-orientation of our production economics courses in order to take full advantage of the information which it provides" (p. 833). Yet of the plethora of micro-economic texts available, only a few have presented production economics from an activity analysis viewpoint (*e.g.*, Naylor and Vernon 1969; Brownlee and Buttrick 1968; Quirk 1976; Lancaster 1969; Upton 1976). Perhaps this very short list of books reflects a general lack of appreciation of the power of the activity analysis approach. The book by Upton is an agricultural economics text and he presents production economics from *both* the activity analysis and conventional viewpoint (in separate chapters). Although Upton's book represents a big step in the right direction, he makes no comprehensive statement as to the added power of the activity analysis approach and readers are left to grapple with this question themselves (see the review by Dumsday 1977). It is our objective to make such a comprehensive statement, highlighting the greater practical relevance for farm management of production economics theory when presented in the activity analysis framework. At the same time activity analysis can be used to show how the traditional practical tools of farm management can be linked to economic theory. Thus activity analysis can bridge the gap between theory and practice.[4]

1 Activity Analysis and Production Economics

The elements of activity analysis were first set out more than a century ago by Walras in relation to general equilibrium theory. Dorfman (1953, p. 797–798) effectively defined activity analysis as "nothing but a reformulation of the standard economic problem" with the objective of determining "the optimal levels of productive processes (activities) in given circumstances". Unfortunately, the tendency has been to obscure the methodological concepts of activity analysis by always associating the theoretical framework with the solution procedures (in particular linear programming), thereby distracting attention from the power and generality of the activity analysis approach

[2] For one of the earliest and best methodological expositions of activity analysis, see Dorfman (1953).

[3] "A process (or an activity) is a specific method for performing an economic task" (Dorfman 1953, p. 798).

[4] Several readers of earlier drafts of this article indicated that they viewed production economics theory only as a "framework for thinking" or as a "means of developing concepts". Indeed, the authors themselves have formerly used this response to students of farm management who asked: "Why are we learning production economics theory?" The activity analysis approach gives the theory a direct practical relevance without sacrificing any of the theoretical framework.

to the theory of production (Dorfman, Samuelson and Solow 1958). While there is no necessity for a complete re-statement of the theory of the firm from the activity analysis viewpoint, certain of the basic ideas must be repeated here: first, to demonstrate how the practical activity budget is rooted in economic theory; but more importantly, to launch the discussion concerning the greater practical relevance of the activity analysis approach.

By definition, an activity or process is a unique way of combining the necessary inputs to produce a given output or combination of outputs. In order to be able to diagram an activity, activities using only 2 inputs will be discussed below. Consequently some realism is lost. It should be borne in mind that these activities are analogous to the more detailed activities of traditional farm management procedures. Activity A requires that two inputs, land and seed be combined in the ratio 1:10, and A_1 uses 1 ha of land combined with 10 kg of seed to produce 1 tonne of wheat [see Figure 1 (a) and 1 (b)]. If twice the level of inputs were used, the activity would be operating at A_2 which may produce 2 tonnes of wheat (as in this example) but this assumption is not essential to the general argument. Points A_3 and A_4 represent the same activity using 3 and 4 times the original complement of resources respectively. If the resources are continuously divisible as with land and seed in the case of activity A, then a line beginning at the origin and passing through A_1, A_2, A_3 and A_4 is the locus of activity A. (This would be a broken line or a series of points if some activity levels were not physically feasible.)

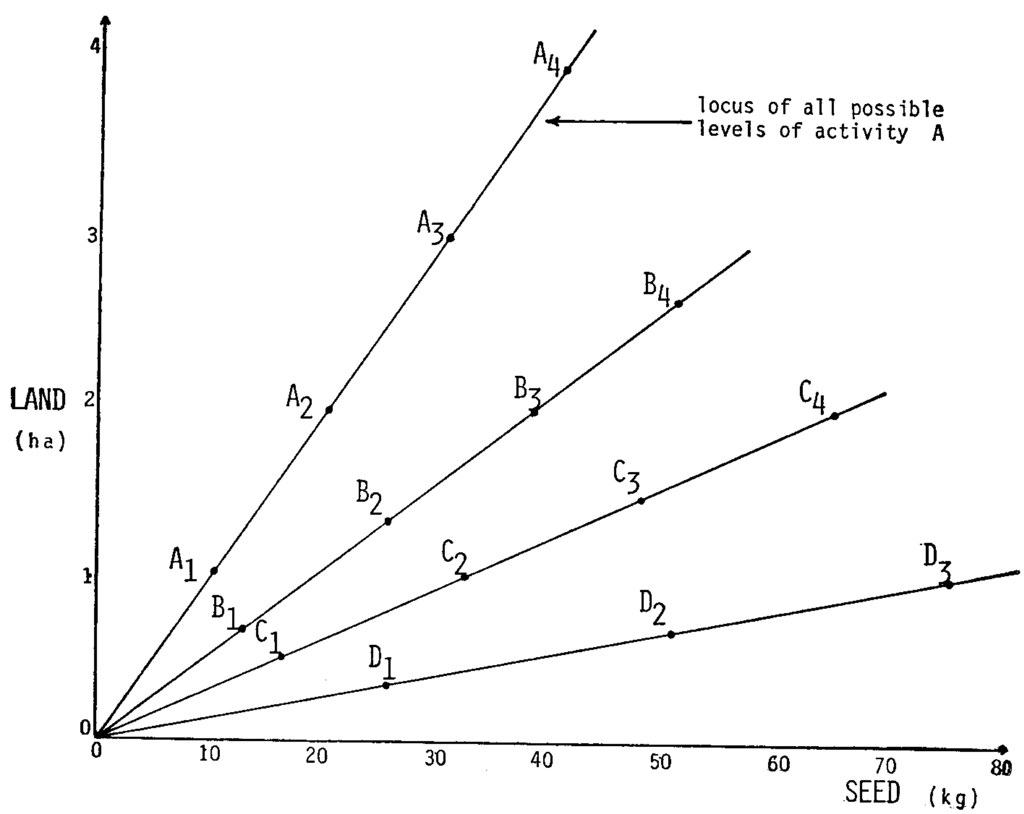

Figure 1 (a): *Activity Rays in Factor/Factor Space*

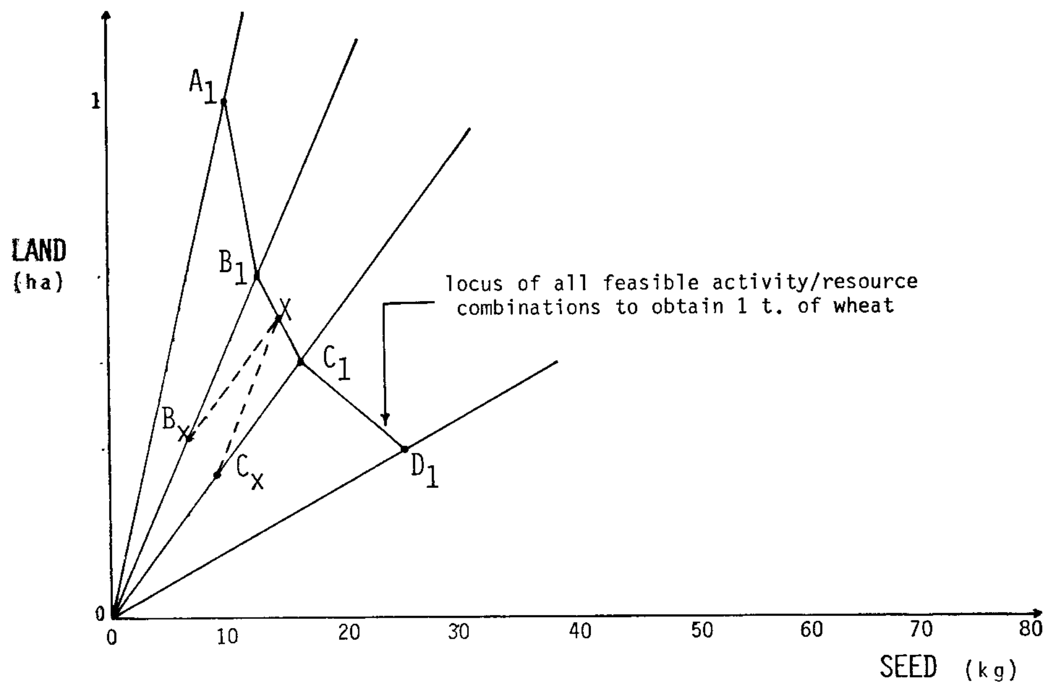

Figure 1 (b): *Activity Rays and an Iso-product Line*

Of course, 1 tonne of wheat could be produced by a combination of land and seed not represented by activity *A*. Consider an activity *B* which uses 0.66 ha of land and 12.5 kg of seed to produce 1 tonne of wheat (point B_1). As with activity *A*, the second activity can be represented by a line passing through the origin. Points B_1, B_2, B_3 and B_4 represent the resource combinations required using activity *B* to achieve an output of 1, 2, 3 and 4 tonnes of wheat respectively. We can extend the discussion by introducing activities *C* and *D* as depicted in Figure 1. The line joining A_1, B_1, C_1 and D_1 is analogous to the iso-product curve familiar from the traditional presentation of input/input relationships. The important distinction to be made between Figure 1 and the conventional input/input diagram is that the various input combinations are achieved, not directly by assuming we can substitute more of one factor for less of another, but indirectly by using more of one activity and less of another. For example, suppose it was desired to combine resources in the ratio represented by point *X* in Figure 1 (b). We could conceivably start at point B_1 and move towards point *X* by diverting resources from activity *B* to activity *C*, or vice versa. At point *X* we would be operating activity *B* at level B_X and activity *C* at level C_X (Dorfman 1953, p. 805).

Now consider Figures 2 (a) and 2 (b), the first of which is essentially a reproduction of the basic detail in Figure 1 (b). If we hold land constant at 1 ha, each activity will not only combine a different quantity of seed with the 1 ha of land, but also each activity will yield a different level cf output from the 1 ha of land. The horizontal line *LL* serves to identify the relevant points in Figure 2 (a). These points (all with the subscript *F*) can be mapped into input/output space as in Figure 2 (b) to obtain a conventionally shaped production function. In this case the function is only defined over the range A_F to D_F. Although any point on the line A_F to D_F in Figure 2 (b) can be obtained by combining 2 activities, it is not possible to operate outside this range of seed-input levels.

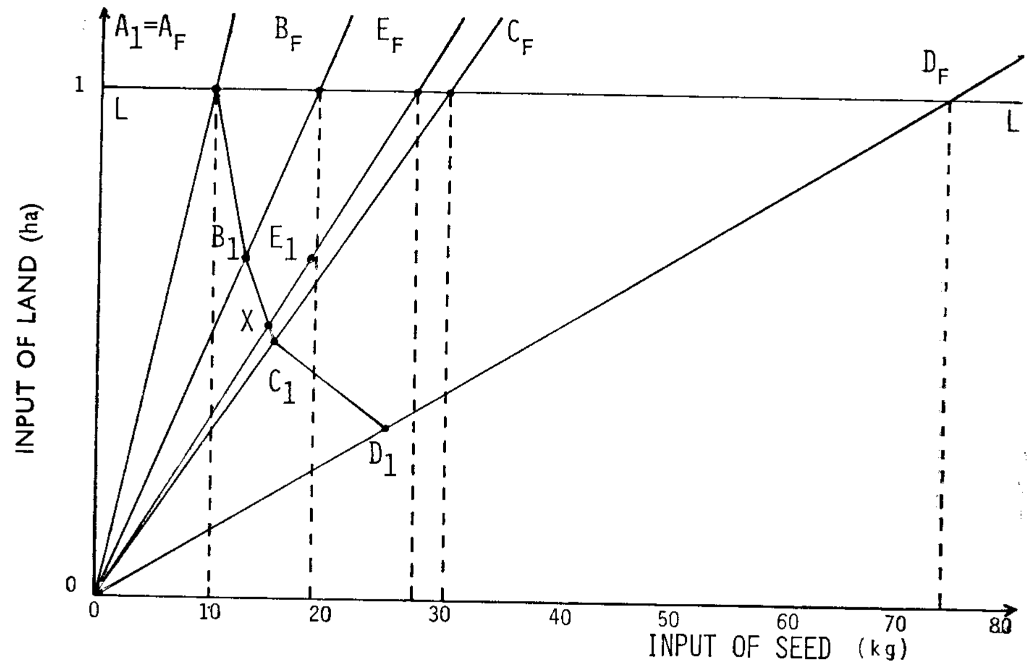

Figure 2 (a): *Activity Analysis and the Law of Variable Proportions*

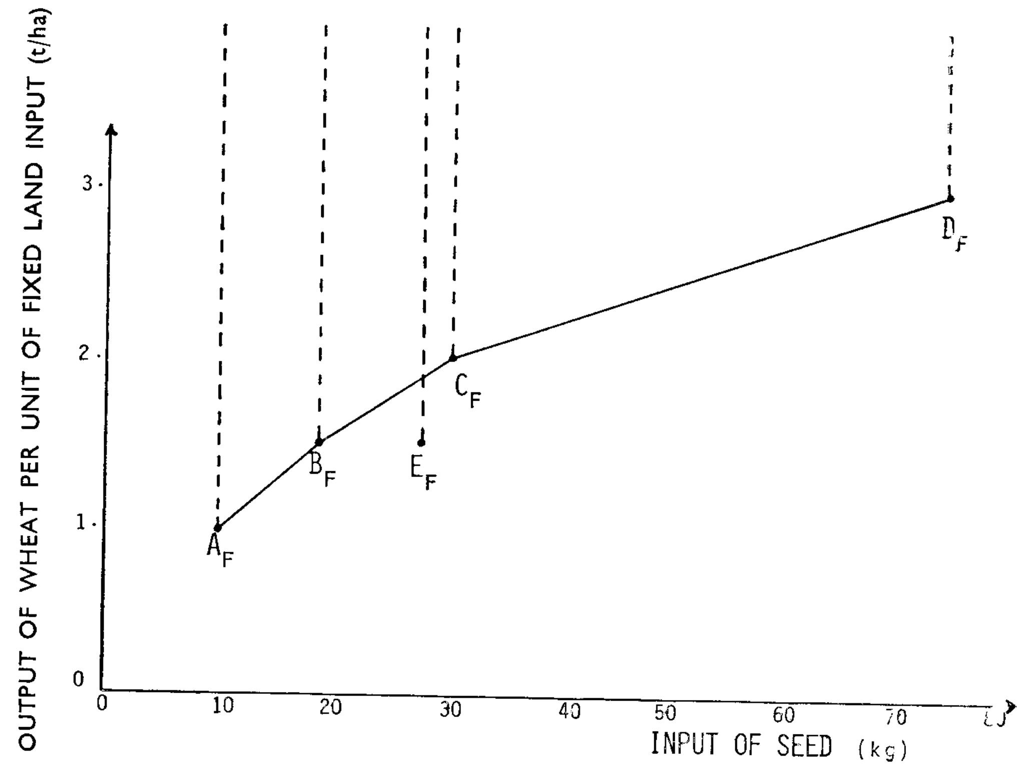

Figure 2 (b): *Activity Analysis in Factor/Product Space*

The third basic theoretical production relationship is output/output. In Figure 3, two activities producing two different products (wheat and barley) are represented. The two activities compete for the available land, labour and machinery hours. The line $A_W A_B$, therefore, represents all the maximum combinations of wheat and barley which are feasible given the amount of land available. The lines $B_W B_B$ and $C_W C_B$ represent available labour and machinery hours.

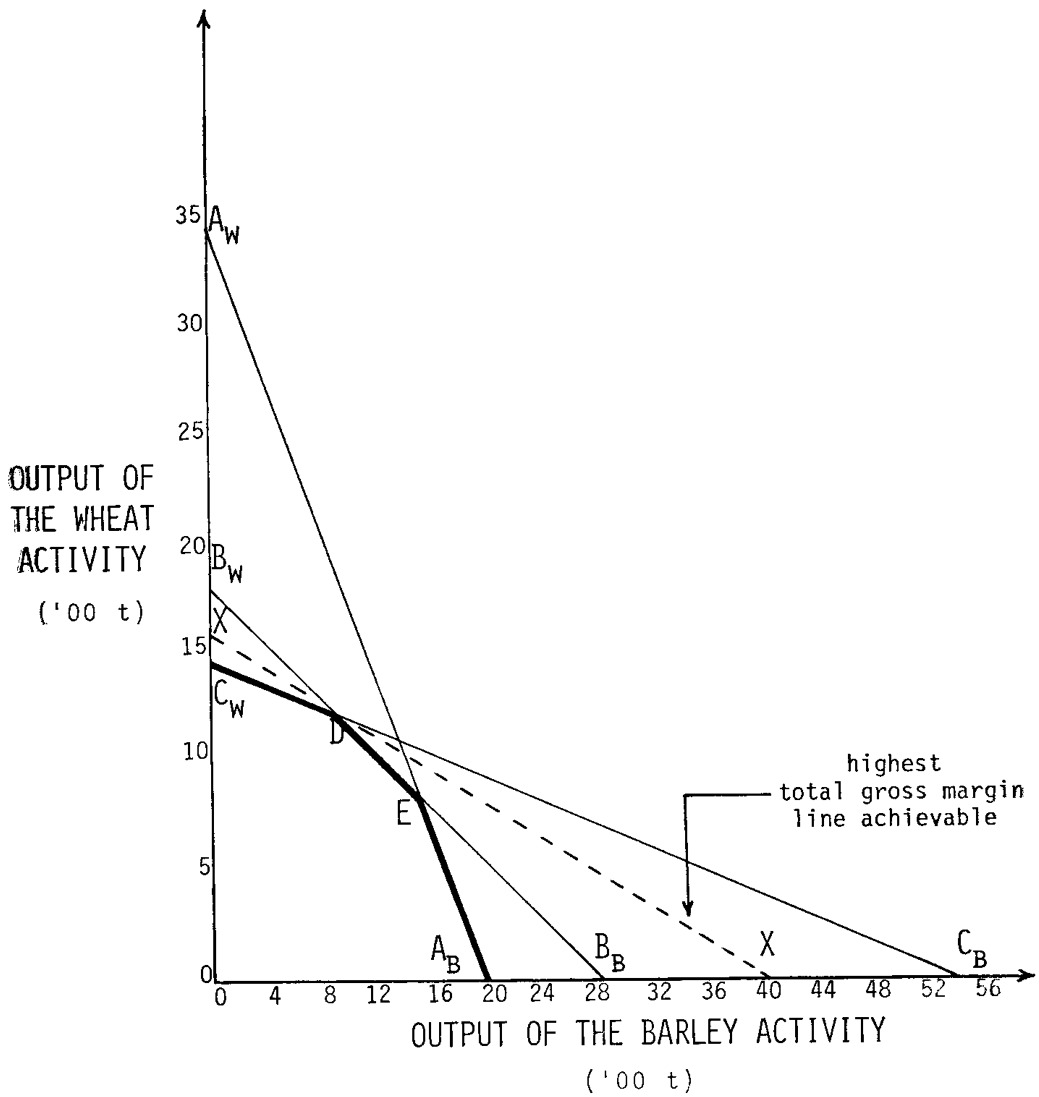

Figure 3: *Activity Analysis in Product/Product Space*

Given the (reasonable) assumption that activity levels must be greater than zero, all *feasible* combinations of the wheat and barley activities must be above and to the right of the origin but on or within the frontier $C_W DEA_B$. In order to choose the optimal combination of activities (and hence resource combination), it is necessary to introduce total gross margin lines into Figure 3. Suppose wheat can be produced using the single activity considered in Figure 3 for a gross margin of $100 per tonne while the barley activity yields a gross margin of $40 per tonne. There will be a whole family of total gross margin lines parallel to XX. The optimal combination of wheat and barley to produce will be the combination which achieves the highest total gross margin. In Figure 3 this combination is represented by point D.

2 Activity Analysis and "Traditional" Farm Management Procedures

Early farm management researchers concentrated on comparative empirical studies using data from farm surveys, case-study farms and financial records (Currie 1956; Jensen 1977). These efforts amounted to little more than accountancy and agricultural arithmetic (Barnard 1977). An excellent and detailed documentation of this early work is available in Case and Williams (1957). They highlight the dichotomy which developed back in 1905 with the publication of Taylor's *Introduction to the Study of Agricultural Economics*, which adopted the more abstract production economics approach. This approach contrasted sharply with the original comparative techniques which relied on economic theory only to a limited extent, if at all. (In addition to references already given, see Bachman 1950; Fellows 1949; Eugene 1950). In recent years, the debate has broadened to encompass other issues, but there is general agreement that a gap does exist between the traditional approach to farm management and the production economics approach, which (at the professional level) has gained in popularity since World War II (Jensen 1977). That this gap has developed is somewhat surprising, since it was the field of agriculture to which the "fathers of economics" turned for examples to illustrate and develop their basic theories (Currie 1956, p. 350).

We claim that at the farm level, the traditional approach remains the norm—that the relevance of production economics is not seen by farmers and indeed, we believe, it is not seen by many students of agricultural economics.

As stated above, the traditional comparative approach to farm management emphasized a variety of discrete physical and financial input/output ratios. Certain of these ratios or indices became widely recognized, particularly in the United Kingdom, as "efficiency indicators" or "farm standards" in the 1940's and 1950's (*e.g.*, Ministry of Agriculture, Fisheries and Food 1963; Queensland Joint Committee 1971). In 1956, Liversage formally defined *one of these efficiency ratios* which he called "gross profit" as the difference between the value of gross output and specific (or variable) costs. This measure is widely used today by farm management specialists, especially in Europe and Australia, and is now known as a "gross margin".

Initially the emphasis was on collecting farm data and calculating historical gross margins for comparison with both other farms and district standards. This diagnostic approach was even incorporated into a number of computerized record-keeping systems developed in the 1960's. However, as Mauldon and Schapper (1970) point out, the mechanical application of the gross margin formula to historical data is fraught with danger. The modern approach has moved away from the mechanical manipulation of historical records to the careful definition and synthesis of activities as the first step towards rational forward planning (Rickards and McConnell 1967; Barnard and Nix 1973). Activity budgeting, as this technique has become known, consists of spelling out in physical and financial terms a specific way of producing a given product or combination of products. Once the physical structure of the activity has been defined in terms of inputs and outputs, this information can be combined with expected input and output prices to determine the expected pay-off for the activity. The term gross margin is commonly used to describe this pay-off, but any one activity budget can be used to obtain a large number of different, but related, gross margins depending upon how the unit of the activity is defined and what prices and costs are assumed.

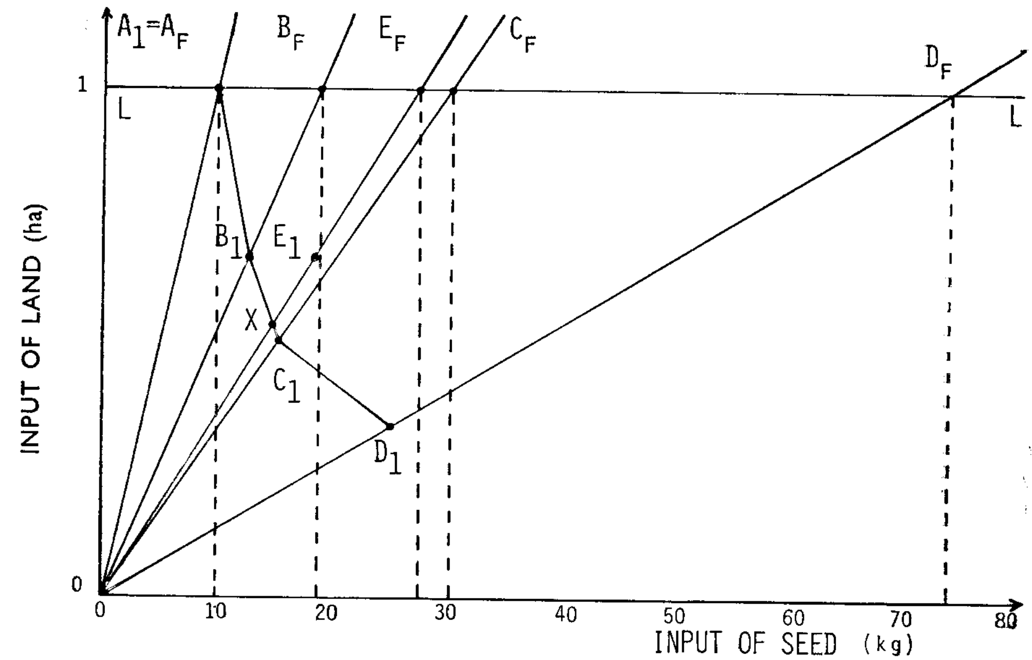

Figure 2 (a): *Activity Analysis and the Law of Variable Proportions*

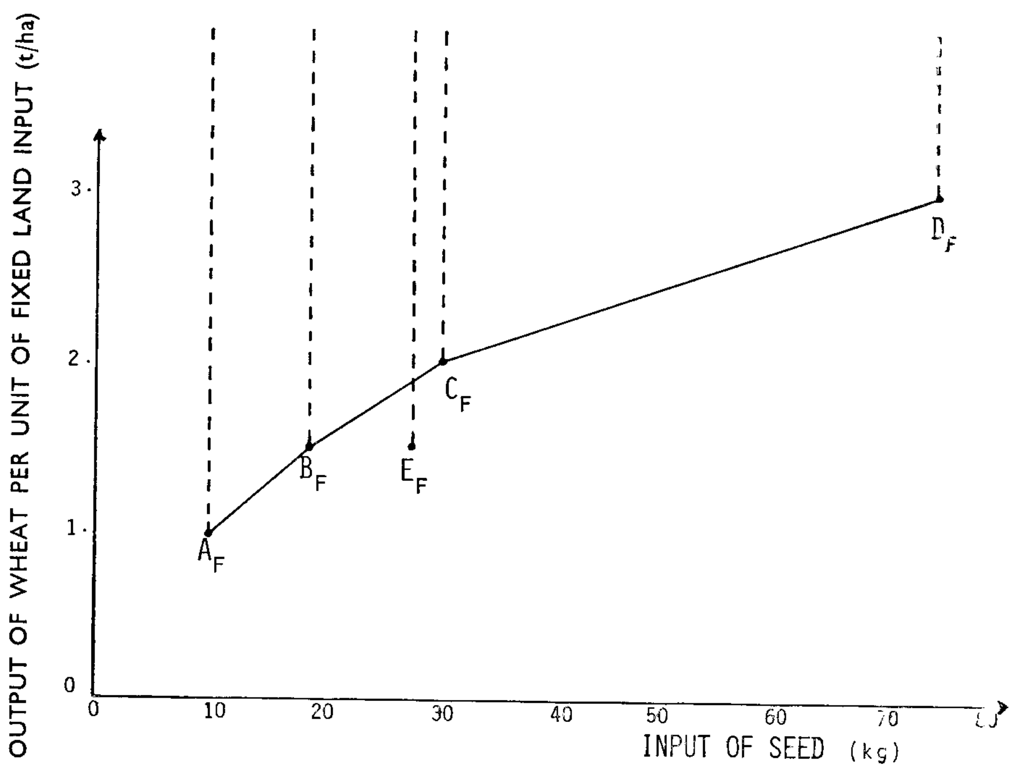

Figure 2 (b): *Activity Analysis in Factor/Product Space*

The third basic theoretical production relationship is output/output. In Figure 3, two activities producing two different products (wheat and barley) are represented. The two activities compete for the available land, labour and the point E_F, 1 ha of land will be combined with 27.5 kg of seed to produce 1.5 tonnes of wheat. Point E_F in Figure 2 (a) can be mapped into Figure 2 (b) and is located below the production function defined by the other 4 activities. In the activity analysis framework, activity E is dismissed as technically inefficient, since point X (a combination of activities B and C) uses less of both input in producing the same output as point E_1.

Conventional theory would also regard points such as E_F in Figure 2 (b) as representing technically inefficient resource combinations. However, conventional marginal analysis ignores such points completely. Marginal analysis is concerned only with allocative (price) efficiency in selecting the most profitable point from amongst all the technically efficient points. Before the mathematical form of the production function can be obtained, what has been called the "purely technical problem" has to be solved. Technical efficiency is assumed in conventional marginal analysis which therefore represents a special case of general (non-linear) activity analysis (Dorfman, Samuelson and Solow 1958, p. 202.) because the general activity analysis approach incorporates both technical and allocative efficiency aspects.

In the single-output/two-input case depicted in Figure 2, it is relatively easy to identify activities, such as E_F, which are technically inefficient. However, without the aid of the diagram and the assumption that there are only five feasible activities, the identification of technically efficient activities *and activity combinations* (*e.g.*, the combination which is preferred to activity E in Figure 2) is far from a trivial task, even in this simple case. When two inputs can be used in a potentially infinite number of ways (activities) to create a product, a *given bundle* of the two inputs (*i.e.*, a specific quantity of each) can be used up either by a single activity or by combinations of different activities. To assume a "technically efficient" production function is to assume it is known which activity or combination of activities yields the greatest output from a *given bundle* of resources. The production function "fails to present adequately . . . the consequence of using several activities in parallel" (Dorfman 1951, p. 15), because it abstracts completely from this question. In the real world, where production involves many outputs, many inputs *and* many activities, the identification of technically efficient activities is an enormous problem which cannot justifiably be assumed away.

The problem is especially great in farming, which is not only characterized by multi-inputs and outputs, but where the *timing* of the inputs can crucially affect output. Timing must be regarded as an input and an alteration to timing creates a new activity even if the amounts of other inputs are unaltered. Thus the technical problem is compounded immensely. From the standpoint of farm management, assuming away problems of technical efficiency "is often equivalent to throwing the baby out with the bathwater" (Bachman 1950, p. 1164).

There is a second strong reason for questioning the obsession with allocative efficiency at the expense of technical efficiency. Recent evidence suggests that, in many agricultural situations, profits can be quite inelastic with respect to relatively large changes in the level of variable inputs in the vicinity of the economic optimum (Anderson 1975). Profit insensitivity has been especially well documented in respect of fertilizer production functions. Paradoxically, these have been the functions receiving most attention by farm management economists with a production theory orientation. Profit insensitivity with respect to the degree of allocative efficiency achieved is not restricted to agriculture (Leibenstein 1966).[6] Insofar as the phenomenon is general, then "neoclassical marginalism", which assumes away technical efficiency to focus fully on allocative efficiency, is an elaborate hoax! Certainly there has recently been an upsurge of interest by general economists in technical efficiency (Farrell 1957; Timmer 1970; Shapiro and Müller 1977; Kelly 1977; Leibenstein 1966). This work represents a welcome step back into reality after years of pre-occupation with problems of price efficiency. Technical efficiency might not have been ignored for so long had economists realized how much they were assuming in using production functions (Dorfman, Samuelson and Solow 1958, p. 203).

In contrast, the importance of technical relationships has always been recognized in farm management by means of the traditional efficiency factors, and, more recently via gross margins. Candler and Sargent (1962) were critical of the "lack of theoretical underpinning" in the use of farm standards and efficiency ratios, but accepted their usefulness as measures of technical efficiency (p. 288). What must be recognized, and what this paper tries to clarify, is that farm standards in the form of activity descriptions can fill the dual role as measures of technical efficiency while at the same time being fully integrated with production economic theory via the activity analysis framework.

Another important aspect which can be seen from Figure 2 is that each *technically efficient* activity can be represented by a point on a (conventional) production function or response curve conforming to the law of variable proportions. The fact that each technically efficient activity represents a single point on a production function with only one variable input is of considerable importance. In the usual practical case where the precise nature of the *whole* production surface for a particular product is not known, there may frequently be some evidence relating to the application of varying amounts of one input to a fixed bundle of all other inputs. Under these circumstances the limited data which are available can be utilized to delineate a subset of all the possible activities. These activities should combine the variable input (fertilizer) with the fixed bundle of all other resources (land, labour, seed, machinery hours, and pesticide, for instance) in a technically efficient and economically rational manner. The activities should represent points *on* the response curve *within* the rational zone of production (see Perrin *et al.* for an application of this idea).[7] Simply viewing production activities as being on a response surface may be a powerful practical aid in preventing irrational decisions from being made.

(iii) Consider Figure 3 Again

The analogy with the conventional approach to output/output is clearly very strong. However, from the practical managerial viewpoint, there are two distinct advantages of the activity analysis approach to be considered.

[6] Leibenstein (1977) has carefully distinguished between the concept of technical efficiency and his notion of *X*-efficiency. In the context of family farms where the workers are also the owners and the decision-makers, many of the distinguishing characteristics listed by Leibenstein become less important. Nevertheless, there would appear to be a significant conceptual difference between technical efficiency as discussed in this paper and the broader concept of *X*-efficiency introduced by Leibenstein.

[7] The rational zone of production has been questioned as a valid concept (Johnston and Nelson 1971). Nevertheless, it continues to be used for pedagogic reasons. In this context, the rational zone can e defined by what Candler and Sargent (1962, p. 283–4) call the "technologists' dilemma".

First, managers rarely adjust output combinations every time product price ratios change. (Likewise they do not respond to every change in factor price ratios.) Instead, relative prices may shift significantly before the manager decides to change the output mix. The reason for this behaviour is obvious. Managers do not see themselves as facing the smooth continuous production possibility curve postulated by conventional theory, but rather production possibility curves likely to resemble those presented in Figure 3 where the slope of the total gross margin lines may change significantly (due to changes in input and/or output price ratios) before the optimal activity (resource) combination is altered. Hence, the greater appropriateness and relevance of activity analysis.

Second, practical managers are almost seeking a constrained optimum. Activity analysis is particularly well-suited to handle this situation, since, as Baumol (1958, p. 840) has pointed out, the side conditions of activity analysis are inequalities of the kind represented in Figure 3. For example, the optimal solution must lie above and to the right of zero but not beyond the line representing the maximum which can be achieved with the available labour. The total amount of labour used in the optimal solution must be no more than the maximum amount available but it may be less than this amount. On the other hand, the side conditions of marginal analysis are equations not inequalities (*e.g.*, MFC = VMP). Although the principle of equi-marginal returns will permit conventional analysis to identify a constrained optimal solution,[8] the activity analysis framework better describes the practical problem by focussing on the quantities of fixed productive factors which are essential data in determining what a firm can or cannot do. In the conventional approach, the same fixed factors are regarded as being somewhat aside from the problem, simply because they are fixed. Insofar as farming is characterized by a high proportion of fixed costs and by a lack of response to price changes, the activity analysis approach is of special *practical* relevance for farming.

4 Concluding Comment

Historically, the neo-classical theory of the firm was developed to explain the behaviour of markets, rather than to prescribe optimum management strategies for individual firms. The neo-classical theory of the firm is essentially outward looking towards the market, in that it emphasizes the response of the firm to market forces. On the other hand the activity approach to representing the production choices faced by the individual firm is inward looking. The emphasis is on representing the situation as managers tend to see it.

The main thrust of this paper has been to demonstrate the role of activity analysis in *linking* the neo-classical theory of production and farm management procedures. As the simple sketch in Figure 4 demonstrates, the concept of an activity can be seen as being *central*, not only to farm management procedures and production theory, but also to linear programming and other mathematical programming techniques. Unfortunately the three areas represented by square boxes in Figure 4 are presented to students (and others) as more-or-less separate entities. While the traditional treatment of linear programming usually includes some mention of the connection between LP and the neo-classical theory of the firm, the emphasis tends to be on solution procedures rather than on the generality of the underlying activity analysis concepts. Likewise, the

[8] In his discussion of the differences in side conditions Baumol (1958) seems to have overlooked this point (p. 840, footnote 6).

usual pedagogic approach to farm management is to begin with the conventional theory of production couched in terms of continuous functions. However, the logical jump from the text-book production function to real-world budgeting is too great for most people.[9] As Crabtree (1978) has pointed out while reviewing one such text, ". . . even the most able farmers or advisers would find little to which they could relate in this text either in terms of felt problems or aids to decision making." Most students, practical farm management extension workers, and practising managers find it extremely difficult to see the relevance of the neo-classical theory to real-world management problems.

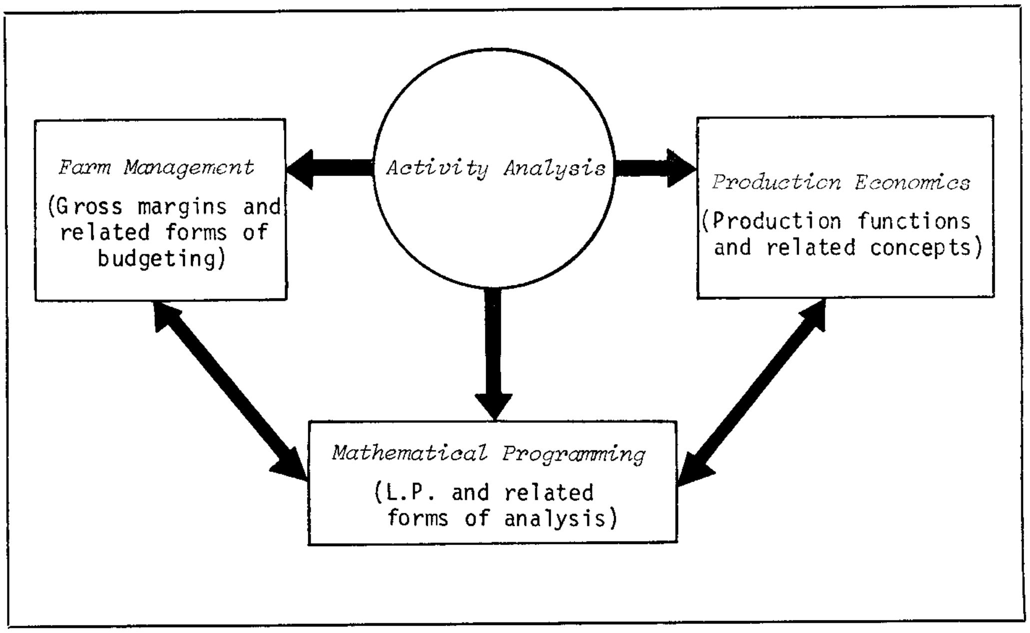

Figure 4: The Central Role of the Activity Concept

On the other hand, management oriented people can recognize the theoretical construct of an activity because it represents production opportunities as they see them, namely as discrete production processes. Our view, therefore, is that the activity concept should be the starting point for exposition in all three areas depicted in Figure 4.[10] Starting with the concept of an activity one can quickly derive and explain the essentials of *both* production economics *and* managerial budgeting procedures (including LP) before the main emphasis is switched to the subject shown on either the right or the left side of Figure 4.

There need be no conceptual gap between production functions and budgets if both are developed from the central activity concept. Approached from this angle, the important principles of production economics take on a new relevance for real-world management, especially farm management.

[9] See Jensen (1977, p. 53) for additional reasons for the farm management/production economics dichotomy.

[10] In emphasizing the generality of the activity analysis approach, it must be remembered that: (a) linear activity rays do not necessarily require constant returns to scale within the activity (*e.g.*, see Quirk 1976). However, if the linear programming solution procedures are to be applied, this requirement *is* necessary; (b) linear activity rays do not imply linear production functions (Figure 2); and (c) activity analysis does not require that activity rays be linear (Dorfman, Samuelson and Solow 1958, p. 203).

References

Anderson, J. R. (1975), "One more or less cheer for optimality," *J. Aust. Inst. Agri. Sci. 41 (3)*: 195–97.

Bachman, K. L. (1950), "Relation of economic theory to the analysis of empirical data in farm management research," *J. Farm. Eco. 32 (4)*: 1159–68.

Barnard, C. S. (1977), Review of "Crop management economics" by A. Rae, *J. Agr. Eco. 28 (3)*: 322–24.

Barnard, C. S. and Nix, J. S. (1973), *Farm Planning and Control*, Cambridge: Cambridge Univ. Press.

Baumol, W. J. (1958), "Activity analysis in one lesson". *Amer. Eco. Rev. 48 (5)*: 837–73.

Blagburn, C. H. (1962), "Farm standards and the theory of production—a rejoinder", *J. Agr. Eco. 15 (2)*: 291–95.

Brownlee, O. H. and Buttrick, J. A. (1968), *Producer, Consumer and Social Choice*, New York: McGraw-Hill.

Burns, E. O. (1966), "Comparative analysis of farm accounts", *Aust. J. Agr. Eco. 10 (2)*: 169–82.

Candler, W. and Sargent, D. (1962), "Farm standards and the theory of production economics", *J. Agr. Eco. 15 (2)*: 282–90.

Case, H. C. M. and Williams, D. B. (1957), *Fifty Years of Farm Management*, Urbana: University of Illinois Press.

Cocks, K. D. (1964), "Creep budgeting", *Rev. Mkt. Agr. Eco. 32 (3)*: 137–49.

Crabtree, J. R. (1978), Review of "The analysis of response in crop and livestock production" by J. L. Dillon, *Euro. Rev. Agr. Eco. 5 (1)*: 85–87.

Currie, J. R. (1956), "Review of fifty years' farm management research", *J. Agr. Eco. 11 (4)*: 350–60.

Dorfman, R. (1951), *Application of Linear Programming to the Theory of the Firm*, Berkeley, Calif.: Univ. of Calif. Press.

Dorfman, R. (1953), "Mathematical or 'linear' programming: a non-mathematical exposition", *Amer. Eco. Rev. 43 (5)*: 797–825.

Dorfman, R., Samuelson, P. A. and Solow, R. M. (1958), *Linear Programming and Economic Analysis*, New York: McGraw-Hill.

Dumsday, R. G. (1977), Review of "Agricultural production economics and resource use" by M. Upton, *Aust. J. Agr. Eco. 21 (2)*: 143–44.

Eugene, S. (1950), "Relation of economic theory to the analysis of empirical data in farm management research-discussion", *J. Farm. Eco. 32 (4)*: 1120–21.

Farrell, M. J. (1957), "The measurement of productive efficiency", *J. Royal Stat. Soc. (Series A, General) 120 (3)*: 253–81.

Fellows, I. F. (1949), "Developing and applying production functions in farm management", *J. Farm. Eco. 31 (4)*: 1058–64.

Jensen, H. A. (1977), "Farm management and production economics 1946–1970", *A Survey of Agricultural Economics Literature Vol. 1*, ed. L. R. Martin, pp. 3–89. Minneapolis: University of Minnesota Press.

Johnson, R. S. and Nelson, A. G. (1971), "A note on the definition of the economic region of the production function", *Amer. J. Agr. Eco. 53 (1)*: 109–11.

Kelly, P. D. (1977), "A frontier production function approach to measuring technical efficiency in the N.S.W. egg industry", *Quart. Rev. Agr. Eco. 30 (3)*: 254–72.

King, R. A. (1953), "Some applications of activity analysis in agricultural economics", *J. Farm. Eco.* 35 *(5)*: 823–33.

Lancaster, K. (1969), *Introduction to Modern Microeconomics*, Chicago: Rand-McNally, Chapter 4.

Leibenstein, H. (1966), "Allocative efficiency vs *x*-efficiency", *Amer. Eco. Rev. 56* (*3*): 392–415.

Leibenstein, H. (1977), "*X*-efficiency, technical efficiency and incomplete information use: a comment", *Eco. Dev. and Cultural Change 25* (*2*): 311–16.

Liversage, V. (1956), "Accounting for farm planning", *J. Agr. Eco. 11* (*4*): 472–77.

Mauldon, R. G. and Schapper, H. P. (1970), "Random numbers for farmers", *J. Aust. Inst. Agr. Sci. 36* (*4*): 279–84.

Minister of Agriculture, Fisheries and Food (1963), *The Farm as a Business: I. Introduction to Management*, London: HMSO.

Musgrave, W. F. (1976), "Problems of change in Australian agricultural economics", *Aust. J. Agr. Eco. 20* (*2*): 133–43.

Naylor, T. H. (1966), "The theory of the firm: a comparison of marginal analysis and linear programming", *South. Eco. J. 32* (*3*): 263–74.

Naylor, T. H. and Vernon, J. M. (1969), *Microeconomics and Decision Models of the Firm*, New York: Harcourt, Brace and World.

Perrin, R. K., Winkleman, D. L., Moscardi, E. R. and Anderson, J. R. (1976), *From Agronomic Data to Farmer Recommendations*, CIMMYT Information Bull. No. 27. Mexico City: CIMMYT.

Queensland Joint Committee (1971), *Accounting and Planning for Farm Management*, 2nd ed., Brisbane: Qld. DPI.

Quirk, J. P. (1976), *Intermediate Microeconomics*, Chicago: ScienceResearch Associates.

Rickards, P. A. and McConnell, D. J. (1967), *Budgeting, Gross Margins and Programming for Farm Planning*, University of New England Farm Management Guide Book, No. 3. Armidale: UNE.

Shapiro, K. H. and Müller, J. (1977), "Sources of technical efficiency: the roles of modernization and information", *Eco. Dev. and Cultural Change 25* (*2*): 293–310.

Taylor, H. C. (1905), *Introduction to the Study of Agricultural Economics*, New York: Macmillan.

Timmer, C. P. (1970), "On measuring technical efficiency", *Stanford Food Res. Inst. St. 9* (*2*): 99–171.

Upton, M. (1976), *Agricultural Production Economics and Resource Use*, London: Oxford University Press.

Williams, D. B. (1969), "Production economics, farm management and extension", *Am. J. Agr. Eco. 51* (*1*): 57–70.