AGRICULTURAL PRODUCTION RESPONSE AND COST STRUCTURES: COST REDUCTION AND OUTPUT INCREASING LINKAGES FOR RESEARCH IMPACTS

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1. INTRODUCTION

The most commonly accepted methodologies for evaluating the impact of research use a shift in the commodity supply function as the basis for their analysis. A number of studies have used a horizontal shift in the supply as a measure of the potential impact of research. Others have used a vertical shift in the supply to estimate this impact. Limited attention has been given to which of these, if either, is more appropriate and when. More importantly consideration has not been given to the potential implications of this choice and whether certain precautions should be born in mind, depending on the measure used. Many project level evaluations implicitly use a horizontal supply shift without considering the importance of the issues involved. Often, the yield increase from experimental trails is used as a proxy for the final horizontal shift in the aggregate supply. It is important to establish what additional implicit assumptions might be being made in these choices and how these may influence the results obtained. To achieve this it is necessary to establish the relationship between the underlying production function, the associated cost functions and then the aggregated supply function.

The aim of this paper is to provide an initial basis for establishing the relationship between and shortcomings of these two potential measures. It begins by highlighting the main points from some past studies. This is followed by a simple diagrammatical presentation of several response and cost function situations to provide a preliminary basis for identifying the important issues. Some conclusions for future research evaluation studies and work in this area are then highlighted.

2. AN OVERVIEW OF PREVIOUS STUDIES

2.1 Introduction

Many past studies have recognised the importance of a shift in the supply of a commodity as a measure of the impact of research. Several of these have discussed a range of options for mathematically representing this shift in an aggregate supply function. However, few studies have focused on the importance of understanding the theoretical linkages underlying these possible shifts. Nor on the possible implications of these linkages for guiding the estimation of the size of the supply shift for applied studies.

This section provides a brief overview of some of these studies and uses them to highlight some of the important issues which need to be considered in choosing the type of supply shift to adopt. The resulting discussion provides the basis for the final section of the paper which develops a preliminary analysis of some production function and cost function linkages which can be important.

2.2 The Adoption of Vertical or Horizontal Shifts in Past Studies

Norton and Davis (1981), in reviewing many past research evaluation studies, highlighted the variability between studies in the choice of the type of supply shift used to represent the impact of research. They noted that Shultz (1953), in probably the first study in this area, used a vertical shift in the aggregate agricultural supply function to estimate the returns to past agricultural research. His vertical shift was an estimate of the reduction in input costs required to produce existing production relative to input costs if the technical change had not occurred. The next major contribution by Griliches (1958), however, used several approaches including a horizontal supply shift to estimate the impact of corn research. There have been a large number of studies since these and a range of supply shifts have been employed. Most have used either an estimate of cost reduction at the pre-research output level, that is, the vertical shift, or an estimate of the increase in output at the pre-research price level, that is, the horizontal shift. However, other shifts have also been used. Peterson (1967), for example, used a variation of a horizontal shift. That is, he used a shift parameter based on the before and after research output level, except output levels were estimated allowing for changes in the price due to demand effects rather than holding the price fixed as in most other studies. As with several other studies the supply shift was measured as a shift to the left, that is, as if the technology was removed rather than introduced.

Akino and Hayami (1975) used a horizontal supply shift to assess rice research in Japan. They approximated the shift in the aggregate supply by estimating the shift in the underlying rice production function. They suggested that the relationship can be approximated by :

$$h = (1+e_s)g \qquad \ldots\ldots \qquad (1)$$

where :

- h is the proportional horizontal shift in the aggregate supply. That is the rate of increase in output due to research with the commodity price held constant.
- e_s is the own price supply elasticity.
- g is the rate of shift in the production function. That is, the rate of increase in output after research if the same level of inputs are used.

The derivation of this relationship was not presented but they noted that it assumes factor neutral technical change (and, although not stated, assumes a constant elasticity - in their case Cobb Douglas - production function). They used percentage yield changes from experiment station comparative yield tests to estimate this shift in the production function.

The analysis of research generated supply shifts by Lindner and Jarrett (1978) and the subsequent debate by Rose (1980), Wise and Fell (1980) and Lindner and Jarrett (1980), although not specifically addressing the issues of interest here, emphasised the importance of considering the specific cost impacts of research. Most of the debate emphasised the importance of measuring and understanding the cost reduction effects of research, that is, the vertical shift in the supply function.

Edwards and Freebairn (1982) highlighted the importance of using the vertical shift or reduction in unit cost as the measure of research impact. They first showed that the relationship between the vertical and horizontal shift in the aggregate supply function is given by (p201):

$$k = h/e_s \qquad \ldots\ldots \qquad (2)$$

where :

- k is the proportionate reduction in the unit cost of production with pre-research costs as the base.
- h is (as in equation (2)) the proportionate increase in production with the pre-research production as the base.
- e_s is the own price elasticity of supply.

With this relationship they then demonstrated, using an application for weed control research, that the estimates of the economic surplus gains from research are very sensitive to the supply elasticity estimates if the impact is first measured as a horizontal shift in the supply. Since reliable estimates of these elasticities are often difficult to obtain they conclude (as did Lindner and Jarrett (1978)) that it is preferable to use a cost analysis and therefore vertical supply shift to estimate the impact of research.

More recently Lynam and Jones (1985) provided a useful discussion of the importance of understanding the production function/cost function linkages for assessing the impact of technical change. They highlight several points which are important for the discussion in this paper. These include:

(i) the production function to horizontal supply shift relationship developed by Akino and Hayami (1975) has several limitations. As discussed above (see equation (1)) the estimate only applies to neutral technical change and a constant elasticity production function. The neutral technical change is an important limitation.

(ii) Considerable care is required in considering the restrictions these production functions impose on the supply and therefore the possible inconsistencies which may arise if elasticity estimates used in equation (1) are taken from studies independent of the research production impact assessments. Combinations of equations (1) and (2) above, which are implied in some studies, would especially potentially suffer this problem.

(iii) Past studies have shown that production functions estimated from part experimental data have provided poor estimates of actual output increases due to research.

In light of these comments and others, relating to modelling supply shifts due to research, they then developed a research evaluation model which includes three shift parameters. The model is:

$$Q = k_1 c [k_2 P - k_3 M]^d \qquad \ldots\ldots \qquad (3)$$

where :

Q is the output of the commodity.

P is the price of the commodity.

c,d are the pre-research supply constants.

k_i are the three supply shift parameters due to research.

Lynam and Jones focus their attention on defining the k's in terms of whether they represent different mathematical forms, for example, parallel, divergent or convergent shifts, rather than clearly indicating their economic interpretation. In fact the k's used can represent both vertical and horizontal supply shifts. This can be confusing especially when the same symbol, k, is used for all possible research impacts.

Given the importance they initially placed on the need to understand the production function/cost function interactions the form of this model is somewhat surprising. When supply functions are derived from underlying production functions the 'constant' terms in the supply function become complex functions of the underlying production function parameters. A neutral technical change which involves a change in the constant terms in the production function will probably have an impact similar to k_1. However, non-neutral technical change will have potentially non-proportional impacts on all the parameters in the supply function. In the case of equation (3) this would involve changes in both c and d. In addition the relationship between the k's in this model and the vertical and horizontal supply shift at some reference price and output has not been established. A combination of the last two points leaves some uncertainty regarding the meaning of and comparability between changes incorporated through each of the k's. For example, it is unclear whether a 20% change in each of the k's is a comparable set of technologies and whether they have a consistent link back to the production function. The critical underlying issue is; how are the k's actually estimated? The authors acknowledge this by '... the model does not resolve the question of appropriate specification of the shift parameters ...' (p.15). Indeed the study presents arbitrarily chosen 20% values for each 'k' in the empirical application. Also in Pachico, Lynam and Jones (1987) only hypothetical values for 'k' were used in applying the model.

Antony and Anderson (1990) also adopted this type of model. Instead of interpreting the three shift parameters in more detail and then estimating them directly they suggest that technical researchers can understand horizontal shifts in aggregate supply functions better than cost reductions and then use the following to estimate the k's:

$$(1+h)Q_o = k_1 c [k_2 P_o - k_3 M]^d \quad ..... \quad (4)$$

where :

h is the technical researchers' estimate of the proportionate shift in the aggregate supply.

Q_o, P_o are the pre-research equilibrium prices and quantities

The authors note that for this equation of three unknowns it is only possible to estimate one of the k's at a time - the rest being set equal to 1. Also though they suggest that k_3 is actually excluded because it gives unacceptable results. Inspection of equation (4) and consideration of the paper's discussion indicates that equation (4) is a substitute for equation (2). Thus it is similar to the horizontal to vertical conversion suggested by Edwards and Freebairn (1982). Care is, however, required to not confuse the k's with the vertical shift at pre-research equilibrium.

Antony and Anderson (1990) suggest, however, that 'h' is equivalent to the shift in the underlying production function, that is, in the terminology of equation (1) they assume h=g. The underlying economic basis for this assumption is not clear. Based on the discussion by Lynam and Jones (1985) and above, however, they implicitly seem to be assuming that (i) the technologies being considered are factor neutral, (ii) the supply elasticity for all commodities considered is zero (see equation (1)), and (iii) that farm based production observations are available to estimate output changes and these are not determined under researcher controlled conditions. Few of these assumptions appear reasonable. Since the Lynam and Jones model they adopt becomes redundant if the supply elasticity is zero, assumption (ii) is difficult to accept. This assumption also implies a special case underlying production function.

In conclusion there has been some discussion of the production function to cost function linkages of technical change in the existing literature. However, there is still a need to give more attention to this issue if the impact of research is to be fully understood and research evaluation studies are to be improved. As noted in Norton and Davis (1981), past studies have often not made it clear whether a vertical or horizontal shift is being used, notation has often been confusing and as a result a substantial range of formulae are available for estimating research benefits. In the next section some implications of this are discussed.

2.3 Important Issues for the Choice of Shift

As indicated in the previous section many past studies have considered several issues relating to research evaluation methodology in the one paper. It is often instructive to separate each of the issues and consider them individually. In terms of the supply shift due to research, two important issues are involved. These include:

(i) At an aggregate supply level is the shape of the shift important?

(ii) Is there a strong basis for suggesting that research impacts are better measured as an output increase or as a cost reduction? That is, a horizontal or vertical shift.

In the rest of this paper we will put aside the first issue. In the past this has involved discussing parallel versus non-parallel shifts, linear versus non-linear functional forms etc. Several authors still seem to want to continue this debate by using geometric/mathematical manipulations of supply functions. Others, however, have accepted the main conclusions which stemmed from the Lindner and Jarrett (1978, 1980) and Rose (1980) debate. These include "... The only realistic strategy is to assume that the supply shift is parallel." (Rose (1980, p.837)) and "... this would involve subdividing the production area into homogeneous regions in terms of the impact of the innovation in question on yield and production costs. Within each region, a parallel shift could be presumed without risk of serious error." (Lindner and Jarrett (1980, p.844)). The clear message from these points is that disaggregation is preferable to mathematical manipulation of the aggregate supply to resolve this issue.

With respect to the second issue Rose (1980, p.837) also concluded "... for most innovations, the best information available may be a cost-reduction estimate for a single point on the supply curve". Despite conclusions such as this many research evaluation studies, especially at a project level, still use an estimate of the production increase as their base for measuring research benefits. It seems important therefore to consider this issue further.

Two sub-issues are important:

(a) Does it matter whether the production increase of cost reduction is measured as the shift due to technical change?

(b) How is either measure estimated? Does the answer to this provide some guidance for empirical applications?

In principle if both shifts can be measured accurately it should not matter which is used. However, since accuracy can rarely be guaranteed, the discussion in section 2.2 leads to the conclusion that cost reduction estimates are less likely to compound and possibly exaggerate any errors which might occur. The following indicate the basis for this conclusion:

. Research benefits based on estimates of the output increase are more sensitive to supply elasticity estimates. Equation (2) highlights this point.

. Related to the elasticity sensitivity is the sensitivity to the pre-research price level chosen. Equation (2) is expressed in terms of proportional changes. The vertical shift, although in principle referring to a cost reduction, in fact, is implicitly estimated as a proportion of the pre-research price. If equilibrium conditions apply and a cost analysis indicates that this price does, in fact, equal the current cost (marginal and perhaps average) then estimates will not be biased. However, if a price is chosen which includes off-farm costs, for example, transport services, then errors can occur. Since many exogenous (to the research) factors can influence prices the possibility for errors in this transposition is high.

. As highlighted by equation (2) (which is not a general case) most formulae for estimating benefits, based on horizontal shifts, can result, implicitly, in cost reductions of greater than 100%. Since some technologies can achieve substantial yield increases and low supply elasticities are often observed, this situation is likely to arise often, if simple horizontal shift estimates are used.

With respect to how each shift might be estimated, it is important to look more closely at the production function impact of the potential new technology to provide an indication of the implications for a shift in the cost function and therefore supply. Some of the previous studies discussed above have considered various aspects of these linkages. In the next section several diagrammatical illustrations are developed to highlight some additional points.

Prior to this, however, it is useful to standardise the notation used to represent the different shifts. In the rest of this paper the following notation will be used:

k, K — is used to represent the unit cost reduction due to research, that is, the vertical shift in the supply. Lower case letters denote the proportional change compared with the pre-research situation. Upper case letters refer to the absolute value of the cost decrease.

h, H — is the change in output in the supply environment. This is the horizontal change in output levels at the pre-research price. Again lower case is the proportional and upper case the absolute change.

g, G — is the increase in output due to the research, measured as the change in output at the same level of inputs. Thus it is a vertical shift from the input axis in the production function.

Any further terminology will be added as required.

3. DIAGRAMMATICAL ILLUSTRATIONS OF PRODUCTION AND COST LINKAGE RELATIONSHIPS

3.1 Introduction

To fully appreciate all aspects of the underlying linkages between production, cost and supply functions, a detailed mathematical treatment is required. Often, however, simpler diagrammatical assessments can provide some useful insights. While these assessments are often a better media for emphasising basic relationships, they also can miss important more complex interactions. Those limitations should be kept in mind during the below discussions.

Several situations are illustrated in this section. These include, first, a simple single output, single input production case. Most information used to assess research impacts is generated from the research itself or the researcher's expectations of the potential impact. Much of this information is usually generated with strict controls on most production inputs. This tends to be he case even when farm level technology trials are conducted. A two input case is used to illustrate the possible impact fixing certain input levels might have on shift estimates. The implications of factor biased technical change is also considered. Finally, since research trials can often ignore the increased uses of some inputs, the factor biased technical change case is used to determine how shift estimates based on production level research information might be affected.

3.2 Single Output and Single Input Linkages

Figure 1 illustrates one way of representing the underlying production function, total cost function and marginal cost (supply) function. Figure 1(a) is the inverted conventional single output, single input production function. The mirror image of the traditional associated total cost function is given in figure 1(b). Here some level of fixed cost is included. With a single input the total cost is an input price scaling of the production function with fixed costs added. As is usually the case the marginal and average cost functions are drawn in figure 1(c) with a scaled up monetary axis. The (firm) supply is given as the discontinuous function in figure 1( ) which is the marginal cost curve above the minimum average total cost and then horizontal at that price.

The before research functions are identified with a 'o' subscript. Equilibrium output and input levels are found by applying the optimising conditions in any one of the three segments. Thus with a fixed output price, Pq, equilibrium output is Q_o which has associated input use of X_{10} and total cost C_o.

The introduction of a new technology will shift the production function from Pf_o to Pf_1 in figure 1(a) at the previous input level, X_{10}, the increase in output is the distance between the two production functions measured along the horizontal quantity axis, Q. By the definition in the previous section this is 'G'. With a single input environment and no change in input price the total cost function will shift in a similar fashion to TC_1. Similarly the marginal and average cost functions will change to MC_1 and AC_1. However, since the marginal product has now increased at the previous equilibrium input level, input use will increase to restore equilibrium. This results in a further increment in output to Q_1, which is also the equilibrium supply with the new technology. Therefore Q_1-Q_o = H which is greater than G.

This representation can be used to highlight some important aspects of possible estimation of the supply shifts. The production function 'horizontal' shift at pre-research equilibrium is given by G (in fact for some functional forms and neutral technical change the proportional shift, g, will be the same for all not just the equilibrium, input levels). Transformation of this G to H, the horizontal supply shift, however, requires reasonably accurate knowledge of the underlying production function parameters. This was highlighted by Lynam and Jones (1985) and also by Akino and Hayami (1975) in equation (1). If elasticities estimated for other purposes are simply adopted the reliability of conversion of G to H is questionable. The implications of Antony and Anderson's (1990) assumption that G=H can also be seen from this diagrammatical illustration. For this to apply a linear production, total cost and therefore perfectly elastic marginal cost must apply.

To achieve accurate estimates of K full knowledge of production parameters are also required. However, reasonable approximations can, in most circumstances, be derived using:

(i) the estimate of total costs (or unit costs) before and after technical change at the original output but lower input levels,

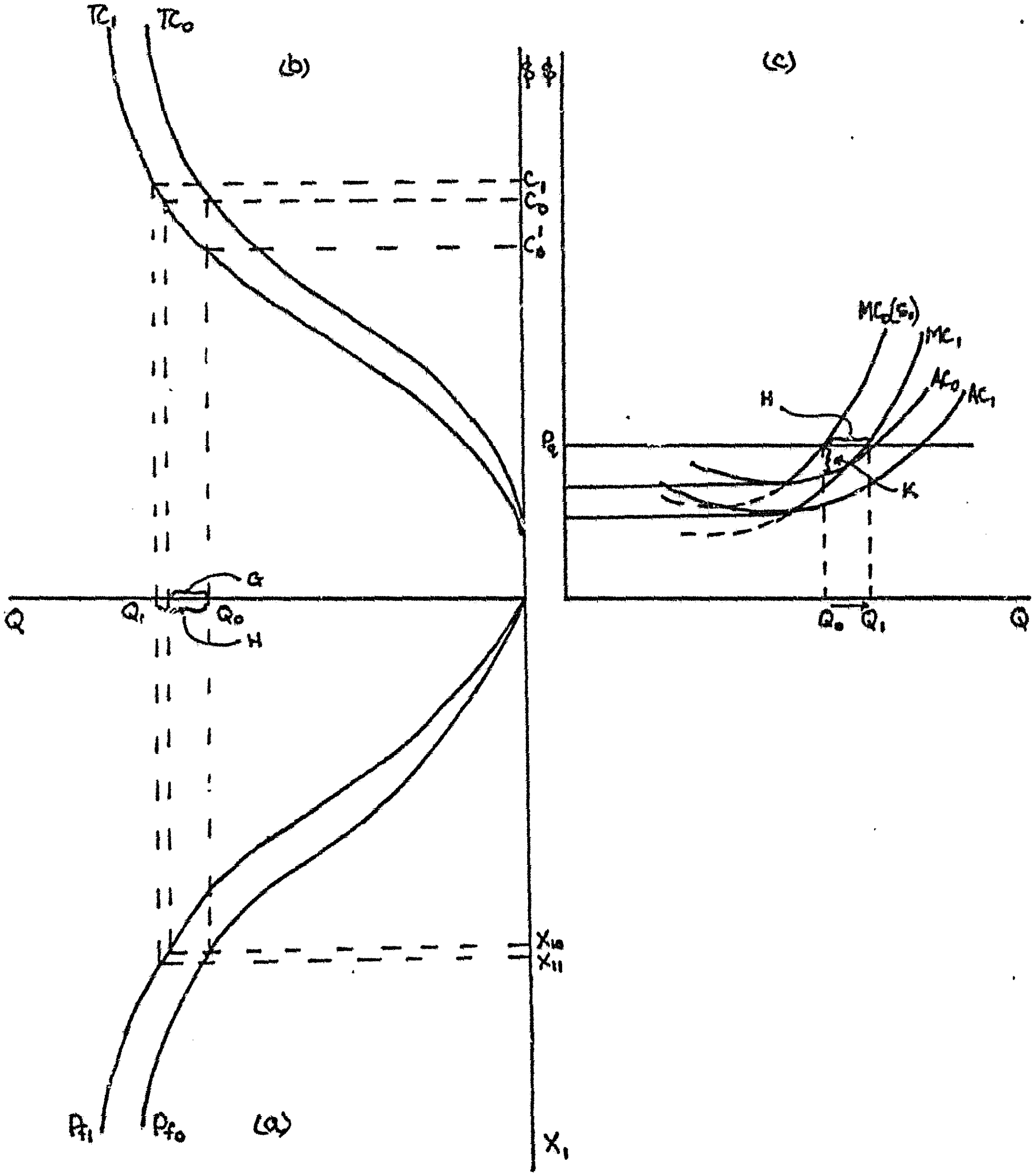

Figure 1 : Technical Change Linkages in A Single Output. Single Input Environment.

(ii) the same costs and the G estimate (remember this is still the single input case).

This confirms the conclusion by, for example, Rose (1980) that the best information available is a cost-reduction estimate.

3.3 Single Output and Two Input Linkages

Two situations will be illustrated in the two input environment. Most research effort involves production information based on holding many inputs fixed. Experimental design and the research project objectives require this restriction. Even when technologies are trialed in farm fields or environments those conducting the trials are required to control and fix many input levels. The first situation illustrated assumes all input levels are allowed to vary. The two dimension production is then determined by the expansion path which depends on input prices as well as technical parameters. The second situation illustrated considers one fixed input and the other variable. The possible impact of this on the estimates of production function shift information is discussed.

3.3.1 Two Variable Inputs Case

Figure 2 repeats the functions given in figure 1. An extra quadrant is added to represent a two input situation. Figure 2(d) then represents the conventional factor-factor diagram with a mapping of isoquants. For a given set of input prices, and assuming these remain fixed before and after the technology is developed, the efficient input combinations for each output level are given by the expansion path.

As shown in figure 2(a) and (d) the expansion path can be mapped onto a single input production function diagram to give an "efficient" production plane. This can be linked to the total cost function as in figure 1, however, this linkage is now no longer a simple input price scaling of the production function. Instead it is now dependent on both input prices and the substitutability between them as indicated by figure 2(d).

Factor neutral technical change can be represented by a shift toward the origin of the isoquants. If the isoquants in figure 2(d) are relabelled to represent this, the shift in the production function in figure 2(a) is given. The linkages are the same as in figure 1 with the shifts of G, H and K being basically the same. An important difference, however, being that the equilibrium output level is now determined by optimum conditions which include the prices of two inputs and their marginal products. The slopes of the total cost function are more complex and equilibrium is usually determined in figure 2(b) or (c) rather than figure 2(a), since the latter applies to only one input.

A change in relative input prices can be represented in figure 2. The expansion path in figure 2 (d) will shift thus causing a shift in most of the other components of figure 2. Note that if these input price changes are independent of the research, then the impact of the research, is still similar to that shown in figure 2. The difference being that the "pre-research" positions of the curves and equilibrium will be different.

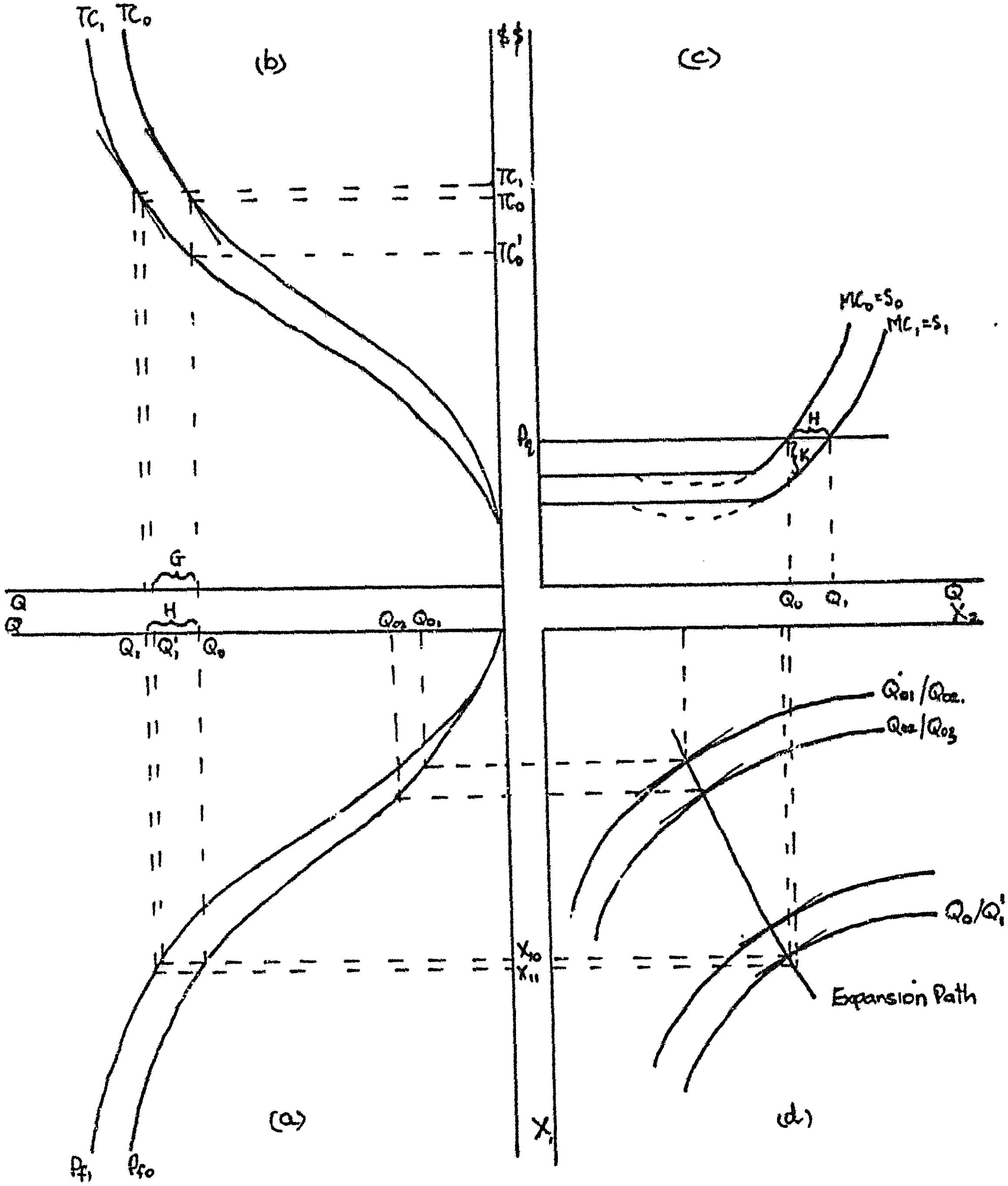

Figure 2 : Technical Change Linkages in A Single Output, Two Input Environment.

3.3.2 One Variable Input, One Fixed Input Case

As indicated above, research results are usually based on experiments and trials which involve holding many inputs fixed. If this information is used as a basis for estimating G to then estimate H and possibly K, it is important to determine whether this constraint on the information is likely to influence the estimates obtained.

Figure 3 illustrates this situation. If input X_2 is fixed at X_{20} output observations would be associated with X_1 input levels along a vertical line from X_{20}, see figure 3(d). If this is mapped into the single factor production function in figure 3(a) (given a set of input prices) fixing one input level results in inefficient production combinations except at the level which intersects the expansion path. Therefore the X_1 based production function associated with fixed X_2 will be as indicated in figure 3(a). That is, less of X_1 is used at lower output levels and more at higher. Clearly the choice of the fixed level of X_2 can be crucial in determining the position of this production function.

The supply (marginal cost) and total cost functions are usually regarded as those associated with actual farm production, therefore, the mapping of the "constrained" versus "efficient" production function onto figure 3(b) is not included. It is assumed that while farmers may adopt the technology they would assess their optimum resource and production situation based on the "efficient" production function. As a result the final supply will not necessarily be affected by the research constraints used to generate production change information.

It is important then to determine whether the research based trial information, if used to calculate the shift in the production function, say $\hat{G}$, will provide an accurate estimate of G. From figure 3(a) it is seen that if the shift in the production function is measured at the pre-research equilibrium input level then there is scope for

$$\hat{G} \neq G.$$

For example, the choice of the fixed input level becomes important, especially whether the level is higher or lower than the efficient equilibrium pre-research level. Since most estimates of G that are derived from research or trial results are measured in relation to one input, eg land, labour, etc, this illustration demonstrates the clear need for care in assuming this information will give an accurate estimate of G or g. On the basis of this illustration either over or under estimation could occur.

3.3.3 Two Input Case with Factor Biased Technical Change

The same type of diagram as figures 2 and 3 can be used to illustrate the influence of biased technical change. In the factor-factor representation in figure 2(d) and 3(d) the positions and shapes of the isoquants can be used to represent a range of possibilities. Depending on the form of the production function appropriate to each case a range of possibilities exist. Brown (1968) discusses several of these possibilities. There are several implications of this, for example, the likelihood that g (the proportional production function shift) will hold for many input levels is reduced. In addition the degree of input bias and the relative prices of

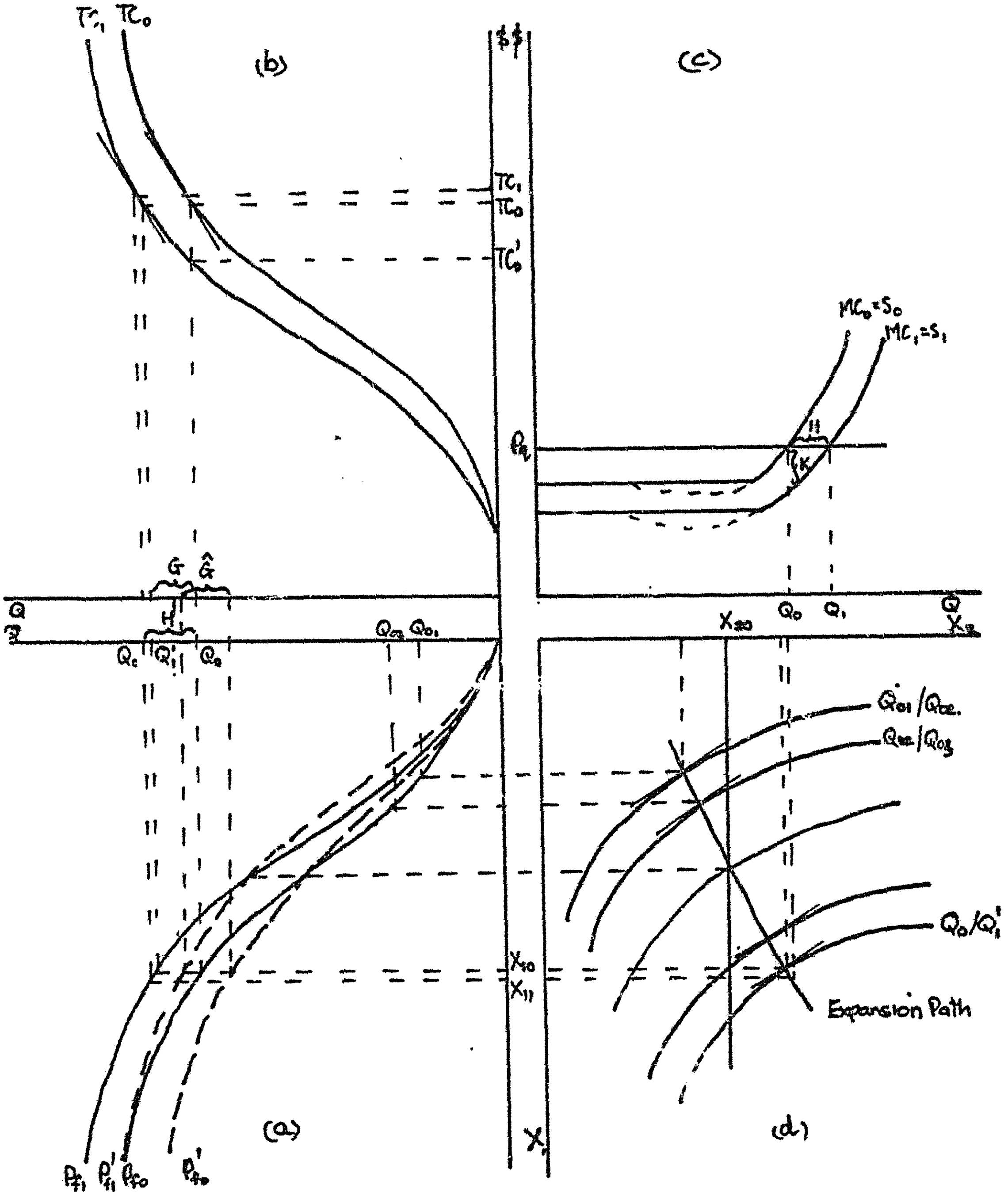

Figure 3 : Technical Change Linkages with Fixed Factors.

inputs may alter the neutral technical change conclusion that H>G. That is, the balancing of changed relative marginal products and different relative input prices could mean equilibrium output levels are lower than the shift at original input levels in the underlying production function. While many studies suggest most research, especially yield increasing research, are factor neutral this may not be the case. For instance, even yield increasing research tends to use relatively more of some inputs to achieve the higher output. An example, often ignored, is the increased labour and machinery required to harvest the increased yield.

3.3.4 Overview

The estimation of H from G has been shown to become more complex if more than a single input is considered; if research generated information has constraints placed on it (which it has to for research to be manageable); and if factor biased technical change is common. Detailed production function parameter information is required to ensure errors are not made. It is not possible to conclude that a systematic bias might result.

Cost reduction estimation of K from total cost information suffers similar problems. However, the current cost base can be used as a good basis for this estimation. Also even a simple cost analysis requires considering likely changes in all input levels, one at a time. Therefore the chance of error seems to be lower.

3.4 Possibility of Missing Information in Research Production Estimates

Most agricultural production systems are complex. Research effort, in most cases, must reduce this complexity before a manageable research project can be defined. In doing this it becomes very likely that information, which might be of importance for farm level decision making, is overlooked. This is not surprising and is accepted as one possible explanation as to why farm level production rarely mirrors that achieved in research or field trials. If this incomplete information is used to estimate the production function shift, which is then used to estimate the supply shift, errors may occur in the research benefit estimates which are obtained.

Figure 4 illustrates a case where it is assumed that research results suggest a neutral technical change which gives a shift from P_{fo} to P'_{f1} in the commodity production function. If, however, it turns out that the research effort did not measure all the labour inputs associated with the new technology, for example, it ignored the additional harvest input required for the higher yield, then the shifts in isoquants given by Q_{11} not Q'_{11} are appropriate. In this case the new output requires more inputs than the research information indicated. Mapping this into figure 4(a) gives a production function P_{f1}, which is below the original estimate. If we define the experimentally based production function shift as F (f for proportional) then we see in this case

$$F > G.$$

The cost linkages are also shown through to the three marginal cost curves MC_o, MC'_1 and MC_1. It can be seen that under this possibility the F estimate could in fact be larger than the correct H value or shift in the final supply. Thus while under some linkage parameter situations using the research based production function shift as a direct estimate of H may

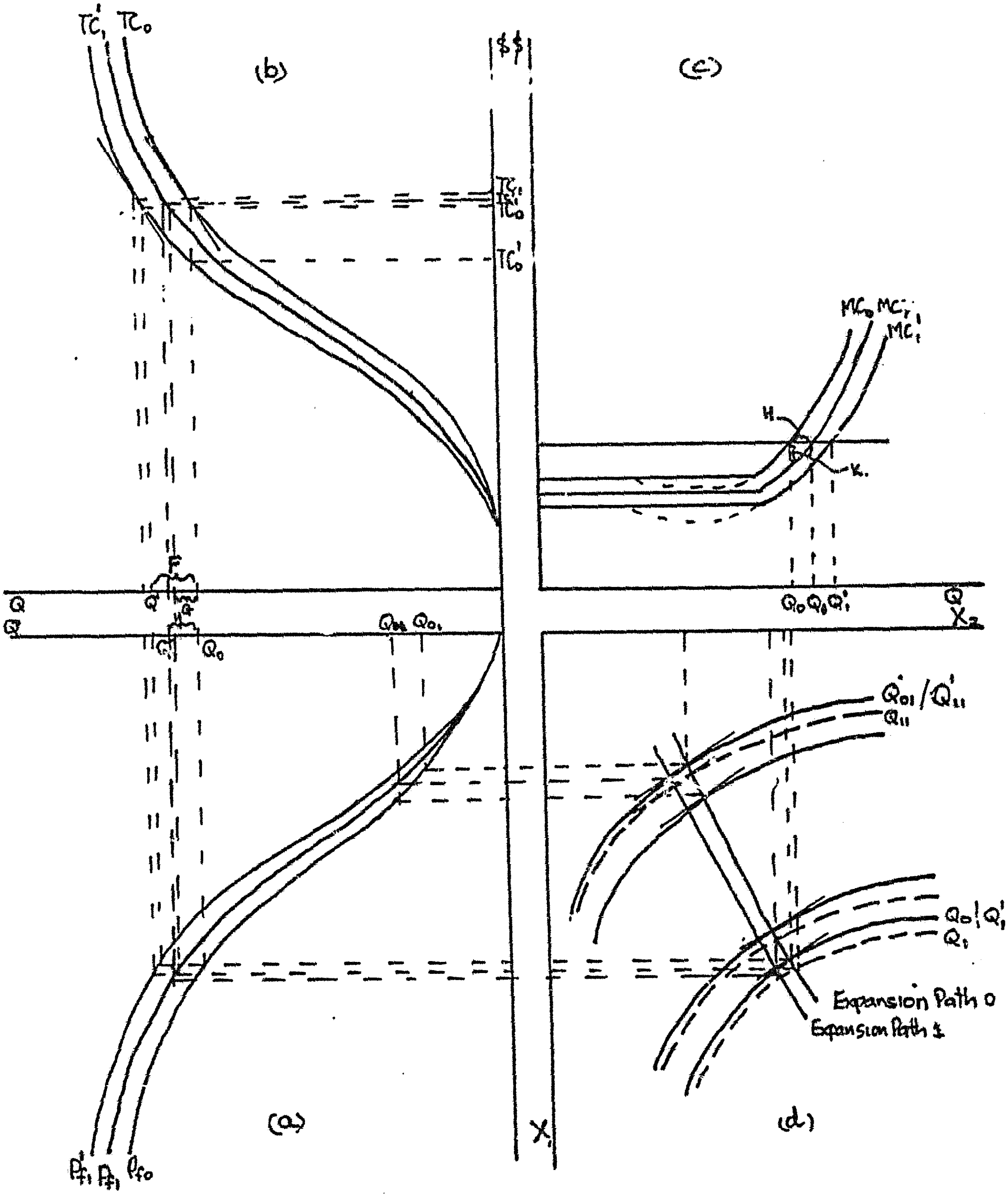

Figure 4 : Illustration of the Possible Impact of Incomplete Input Information.

underestimate H, in other cases using F could result in overestimation. If the linkage conversions are used this overestimation will be compounded.

4. CONCLUSIONS

A brief overview of the research evaluation literature indicates that past studies have used a vertical or horizontal shift in the commodity supply, and even in a few cases a combination of both, to measure the impact of research.

In many studies this choice has been made without giving full consideration to the possible implicit assumptions being made. Quick project level, often called "benefit/cost" type studies, usually implicitly use a horizontal shift and simplistic supply and demand assumption to provide a simple measure of research benefits. Even some studies which explicitly consider supply and demand conditions have chosen the type of shift without considering the full implications of this choice. There is still a tendency for applications to use different terminology and not clearly specify the underlying implications of the shift choice.

The important point highlighted in this paper is that the production function to supply function linkages can be complex, especially if non-neutral technical change is the norm. Since reliable comprehensive estimates of the underlying parameters are rarely available it is concluded that caution is required in using horizontal shifts based on esearch (or researcher controlled trials). Ultimately these estimates need to be adjusted to represent horizontal supply shifts. These adjustments are inevitably made (often implicitly) with parameters not usually estimated as part of the evaluation study. Final benefits estimates are usually then sensitive to these estimates as well as the choice of base level price.

Vertical shift estimates, that is, unit cost reductions, are also dependent on the same production function/cost function linkages and therefore underlying parameters. However, if (even simple) cost analyses are used to approximate the eventual supply shift the scope for error is reduced. Also the understanding of the impact of the technological change is likely to be enhanced. Implicit assumptions can still be made however, this is less likely to occur. The benefits estimates obtained are, in most cases, less sensitive to, often, exogenously determined parameters. This is especially so if it is not assumed that the currently observed commodity price is necessarily equal to the unit cost. In summary the assessment developed in this paper agrees with Rose's (1978, p.837) conclusion that using cost reduction estimates is the best approach.

The preliminary assessment presented here clearly requires further development and refinement before more confident guidelines can be developed. More emphasis on mathematical derivations of the linkage relationships is important. Expansion to include between product substitution adds the important dimension of opportunity costs and product transformation to the cost analysis and output change relationship. Bantilan and Davis (1991) provide a start to this work.

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