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RESEARCH BENEFITS REVISITED

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This paper explains why various formulae used in the literature to calculate level and distribution of annual research benefits yield different results. After reviewing the differences in assumptions used by different authors to develop their respective formulae, the paper concludes by presenting alternative formulae which are more generally applicable than those previously available.

INTRODUCTION

In a recent entertaining note in this journal, Scobie [16] drew attention to the current state of confusion surrounding the measurement and distribution of research benefits. In particular, he addressed himself to the question as to the relative gains accruing to producers and consumers and cited the measurement formulae from four studies. These studies were Akino and Hayami [1], Hertford and Schmitz [13], Ardila [2] and Ramalho de Castro and Schuh [6]. Scobie did little more than demonstrate that these formulae may yield different results. In fact, he unwittingly added to the confusion, since the formula that he ascribes to the de Castro and Schuh publication unfortunately does not appear in that reference.

In an article which has not received the recognition it deserves, Duncan and Tisdell [8] explained how the distribution of research benefits between producers and consumers depends on the nature of the supply curve shift, and on the elasticity of demand for the commodity produced. Differences in assumptions about the nature of the shift in the supply curve resulting from diffusion of a research generated innovation explain, in a general way, some of the different results presented by Scobie but a more specific explanation is needed if the above noted confusion is to be even partly resolved. The purpose of this note is to provide such an explanation, and to note some other reasons for the different results obtained by applying different formulae. Attention is also drawn to some sources of confusion in the earlier formulae advanced by Griliches [12] and Peterson [15]. The note concludes with discussion on general formulae developed by the authors.

REASONS FOR MEASUREMENT DIFFERENCES

Scobie points out that there are perhaps other formulae in the literature which would have further added to the confusion. With this we can only agree. The derivation of formulae for measuring research benefits has by now an ancient lineage. The pioneering study was of course that

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of Griliches [11] on hybrid corn, and this was elaborated by Peterson [15] in a study of returns from poultry research. Latter-day contenders—apart from the ones mentioned by Scobie [16]—for the measurement stakes would also need to include Ayer and Schuh [3], and the formula used by Dalrymple [5] in evaluating the benefits of the Green Revolution. All of these formulae purport to measure gross annual research benefits (GARB), which is defined as the total annual social benefit to society from adoption of a process innovation developed by research. In addition, many studies developed formulae to measure the components of GARB, namely the producer and consumer surplus. The relative sizes of these two surpluses will determine the distribution of benefits which is relevant to the policy decision as to who should pay for the research.

None of the confusion arises from different views about the areas which should be measured. There is general agreement that GARB is measured by the area below the demand curve and between the two supply curves in Figure 1—S_1 with the innovation and S_0 without it, (i.e., area $A_0M_0M_1A_1$). Consumer surplus is measured by the quadrilateral area to the left of the demand curve and between the two equilibrium prices (i.e., area $P_0M_0M_1P_1$ in Figure 1). Since GARB is the sum of producer

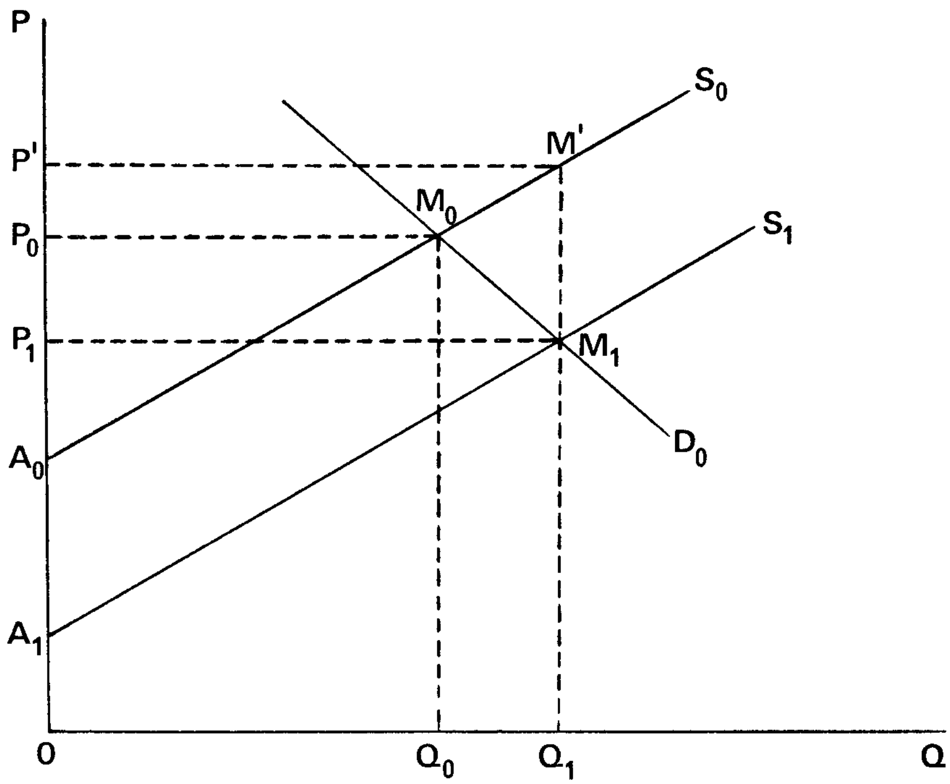

FIGURE 1

and consumer surplus, producer surplus is most easily defined as the difference between GARB and consumer surplus. Because producer surplus can be treated as a residual, most of the discussion in this paper focuses on the reasons for differences in the measurement of GARB, and to a lesser extent on reasons for differences in the formulae used to calculate consumer surplus.

Most writers in this area who use the concept of social surplus rely on the theoretical underpinnings outlined in Currie, Murphy and Schmitz [4]. "The literature on the long run supply curve of a perfectly competitive industry is vast . . . There is widespread agreement that it does represent the average costs of each firm in the industry" [4, p. 757]. In the classic Ricardian case of a fixed supply of land, the "supply curve is then a long run average cost curve including rent to land and a long run marginal cost curve excluding rent to land" [4, p. 757). Our discussion in this note is based on this interpretation of the long run supply curve.

Unfortunately, this concept of the supply curve is unlikely to coincide with the supply curve estimated by econometric techniques, and which by implication is the supply curve used in the formulae developed to date. The principal reason is that econometric estimation of supply curves has to be based on values of price and quantity which equilibrate demand and supply. As a result, estimated elasticity of supply is only likely to be a reasonably good approximation for that segment of the supply curve which is in the vicinity of market clearing equilibria. On the other hand, the shape and position of the entire supply curve back to its intercept with the vertical axis can influence the measured value of GARB, and of producer surplus also.

To overcome this difficulty, other authors have made either implicit or explicit assumptions about the form of the supply curve. For instance, Griliches [11] ignored actual supply elasticities and simply assumed that supply was either perfectly elastic, or perfectly inelastic. The two formulae he derived were:

$$\text{Loss 1} = kP_1Q_1(1 - \tfrac{1}{2}kn)$$

for the case of an infinitely elastic supply curve, or constant long run average costs, and

$$\text{Loss 2} = kP_1Q_1(1 + \tfrac{1}{2}kn),$$

subsequently corrected by Griliches [12] to give

$$\text{Loss 2} = kP_1Q_1\left(1 + \tfrac{1}{2}\frac{k}{n}\right)$$

for the case of a completely inelastic supply curve where k is the proportionate change in average production costs, n is the absolute value of the price elasticity of demand for corn, and P_1 and Q_1 are the equilibrium price and quantity respectively, after the introduction of the innovation. The use of the Loss terminology relates to the fact that Griliches and Peterson both evaluated research benefits by asking the question, "What would be the social loss if the innovation were to disappear?".

Griliches recognized the approximations involved in his formulae, but justified his approach by stating that these "two estimates bracket estimates implied by assuming other intermediate supply elasticities" [11, p. 422]. While intuitively reasonable, it will be proved below that this assumption is not generally valid.

Other authors, such as Peterson, have assumed a general mathematical form for the supply curve, and then used econometrically estimated values of elasticity of supply to define the actual supply curve to be used in the formulae. Apart from the abovenoted difficulties caused by applying a parameter value which is only locally valid over the entire range of the supply curve, this approach can involve assumptions which imply irrational behaviour by producers. For instance, both Ayer and Schuh [3] and Akino and Hayami [1] assume without any supporting evidence that the with- and without-innovation supply functions both go through the origin, which implies non-zero output at all positive prices, no matter how small. Hertford and Schmitz [13] also assume that the pre-innovation supply function goes through the origin, but the post-innovation supply function apparently is assumed to shift to the right with an intercept on the quantity axis. Extrapolating the supply function backwards implies that positive output will be forthcoming at negative prices, which is clearly illogical, given the view of the long-run nature of the supply curve.

In past literature on the measurement of research benefits, even less attention has been paid to the critical role that the nature of the supply shift occupies in the distribution of research benefits. As already noted, the one outstanding exception is the study by Duncan and Tisdell [8] which showed diagrammatically that the distribution of research benefits between producers and consumers *does* depend on the nature of the shift in the supply curve, as well as on the elasticity of demand for the product. In particular, they showed that when demand is inelastic, returns from research to producers will be negative if research reduces the cost of marginal production more than for inframarginal production.

However, while virtually all studies have included elasticity of demand as a parameter to be specified in applying the formulae, it has been equally common to predetermine the nature of the supply shift by the type of assumptions made in the derivation of the formulae. For example, if a perfectly elastic supply curve is assumed, as in the cases of Griliches' formula for Loss 1 and of Ardila's formula for producer surplus, then the with-innovation supply curve *must* be parallel to the without-innovation supply curve. On the other hand, in the studies by Ayer and Schuh, and Akino and Hayami, among others, it was assumed that adoption of a process innovation would simply shift the supply curve to the right by an equi-proportionate amount at all levels of price. That is, if $Q = f(P)$ without the innovation, then $Q = (1 + x) f(P)$ with the innovation, where x is the proportionate increase in output. This is obviously a special case of the situation where inframarginal reductions in long-run average cost are less than at the margin, and elsewhere has been labelled a pivotal shift.

Not surprisingly, Akino and Hayami's empirical results, and Scobie's further verification of those results, simply support Duncan and Tisdell's theoretical analysis. In the autarky case, the elasticity of demand was assumed by Akino and Hayami to have an absolute value of 0.2, and producers were always disadvantaged—i.e., producers' surplus fell—although the increase in consumer surplus offset this fall. It was only in the open economy case with infinitely elastic demand that producer surplus increased. In this case, increased producers' surplus is coincident with increased total social benefits. Evenson, Flores and Hayami [10] using the same pivotal supply shift as Akino and Hayami arrive at the same conclusion. Their Table 10 shows that for rice research, producers' surplus is always negative. Therefore, the conclusions of both studies about the distributive effects of research, given the nature of their postulated shift in the supply function, are sensitive only to their estimates of the demand elasticity.

The formulae used by Ayer and Schuh contain further differences, because in addition to a pivotal supply shift, it was also assumed that product supply was a function of price in the previous period rather than current price.

Apart from the nature of the supply shift as an influence on the measurement of research benefits, authors also differ as to whether the new technology should be treated as a vertical or horizontal shift in the supply function. This difference in treatment alone cannot explain the difference in formulae. The treatment of research as generating a horizontal shift in the supply curve emphasizes the yield increasing effects of innovations, but ignores, or at least de-emphasizes, their impact on production costs. If the estimate of the magnitude of the shift of the supply curve is based solely on the yield-increasing effect of the innovation, then the formulae are likely to produce seriously biased estimates of research benefits. This appears to be the case with the formula used by Dalrymple to estimate GARB for the Green Revolution. The formula is,

$$B = PQK\,(1 + K/2E_D)\,(1 - [(1 - E_D)^2 E_S/(E_D - E_S)])$$

where B = gross annual benefits

P = price of product

Q = quantity of product

K = shift of supply curve owing to research and is equivalent to the ratio of the yield from high yielding varieties to that from traditional varieties.

E_D and E_S are the price elasticities of demand and supply.

The Green Revolution technology clearly did shift the supply function through its yield effect, but in contrast to the hybrid corn technology, the high yielding wheat and rice varieties did require complementary inputs such as fertilizer, tube wells, insecticides, etc., which would have added, probably substantially, to costs. Consequently, the supply function shift would have been considerably less than that implied by the yield effect considered in Dalrymple's formula.

In our view, the treatment of effective research as lowering the average costs of firms in the industry, that is, a vertical shift in all of the relevant cost functions, makes more sense. It has the further benefit of communicating with scientists as to the impact of their research on the cost structure of firms, and the impact of the change in technology on new firms entering and old firms leaving the industry.

Many of the empirical studies are of an *ex post* nature, i.e., they ask the question "what would be the losses if this innovation were to disappear?", rather than *ex ante*, i.e., asking the question "what are the likely gains from an innovation which effectively lowers the cost functions of firms?" In our view, an *ex ante* evaluation is what is needed to assist with the allocation of research resources rather than an *ex post* one. The *ex ante*, *ex post* dichotomy makes no fundamental difference to the formulae, but does explain why some formulae are expressed in terms of without-innovation values for prices and quantities (P_0, Q_0), while those based on *ex post* analysis utilise with-innovation levels of prices and quantities (P_1, Q_1).

To summarize, all previous studies have employed formulae which lack generality because they are based on specific and different assumptions about the nature of the shift in the supply curve resulting from the diffusion of a process innovation. These differences in assumed type of supply shift are the most important reason for differences in the formulae developed to measure research benefits. Other reasons include different assumptions about the shape and position of the supply curve, and about lags in supply response. Cases also exist of errors in estimation of the size of the supply shift, and even logical errors in the derivation of the formulae from a given set of assumptions. In the next section, the two first and best known formulae to measure GARB are discussed in more detail to illustrate why they can produce biased estimates.

AN ANALYSIS OF TWO WELL-KNOWN FORMULAE

Griliches' formula for a conservative measure of research benefits (i.e., assuming a perfectly elastic supply function) is given by:

$$kP_1Q_1(1 - \tfrac{1}{2}kn)$$

According to Griliches, using this formula to calculate GARB gives a result which is a lower bound to the range of possible values. The special case of a perfectly inelastic demand curve and a proportionate shift in the supply curve illustrated in Figure 2 will be used to demonstrate that this claim is not generally valid. Furthermore, it will be shown that this formula can both underestimate *and* overestimate the actual value of GARB when supply is in fact less than perfectly elastic. Griliches' assumption that without hybrid corn, the supply curve would have been proportionately higher at all levels of output is retained. The reason why an innovation such as hybrid corn is likely to result in a proportionate rather than a parallel shift, when the curve is less than perfectly elastic, is due to the fact that percentage increase in yields from using hybrid corn is relatively constant in all areas.

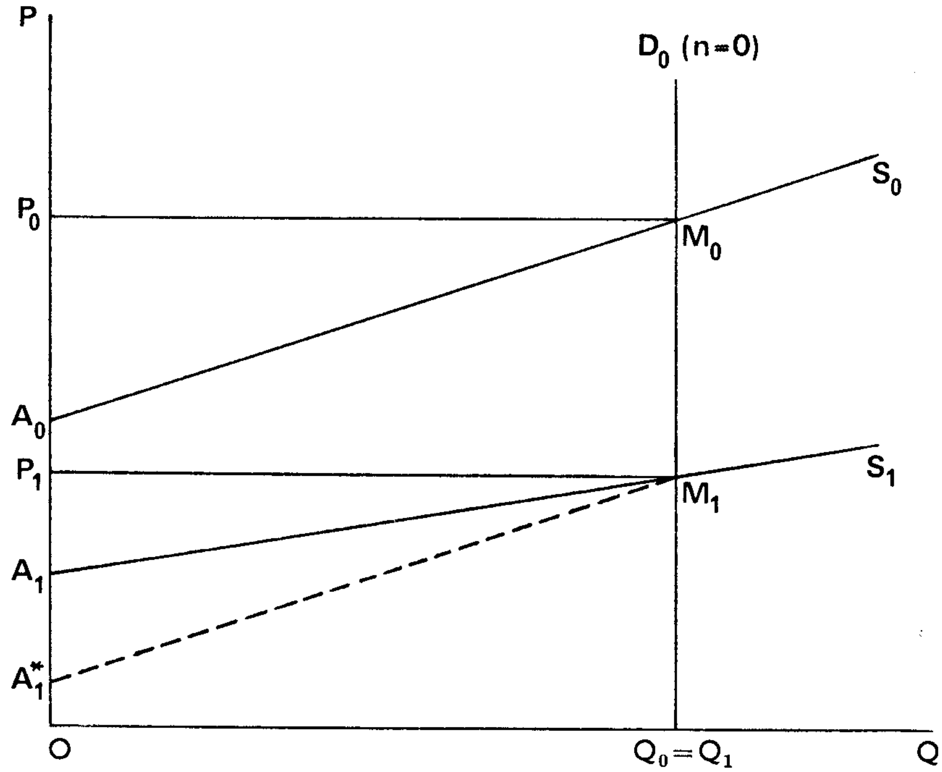

FIGURE 2

It is clear from Griliches' formula that research benefits could in principle be negative. For large k and large absolute values of n we could have $\frac{1}{2}kn > 1$. Alternatively, when demand is perfectly inelastic, Griliches' formula reduces to kP_1Q_1, which measures the area $P_0M_0M_1P_1$ in Figure 2. A fundamental theorem in Euclidian geometry, known as the Law of Parallelograms, states that the area of a parallelogram is equal to that of a rectangle with the same base and altitude [7]. According to this theorem, the area $P_0M_0M_1P_1$ is equal to the area $A_0M_0M_1A_1{}^*$ (*see* Figure 2). Since the area $A_0M_0M_1A_1{}^*$ would represent the level of research benefits for a parallel downward shift of the supply curve, the formula above will overestimate these benefits (by the area $A_1M_1A_1{}^*$ in Figure 2) whenever the absolute fall in average production costs at the margin is greater than the inframarginal reduction in these costs *as long as demand is perfectly inelastic.*

A different case when neither demand nor supply are either perfectly inelastic or elastic is depicted in Figure 1. Specifically, it is assumed that

S_1 is parallel to S_O, and that the vertical distance between the supply curves is measured by kP_1.[1] For this case, Griliches' formula $kP_1Q_1(1 - \frac{1}{2}kn)$ can be shown to underestimate the correct area $A_0M_0M_1A_1$ as follows:

$$kP_1Q_1(1 - \tfrac{1}{2}kn) = kP_1Q_1 - kP_1Q_1(\tfrac{1}{2}\,kn)$$

The first part, kP_1Q_1, measures the area $P'M'M_1P_1$ which by the Law of Parallelograms equals the area $A_0M'M_1A_1$.

Substituting for n at P_1, Q_1 in the second part, where $n = \dfrac{Q_1 - Q_0}{P_0 - P_1} \cdot \dfrac{P_1}{Q_1}$, gives:

$$kP_1Q_1(\tfrac{1}{2}kn) = kP_1Q_1\left[\tfrac{1}{2}k\frac{Q_1 - Q_0}{Q_1} \cdot \frac{P_1}{P_0 - P_1}\right]$$

$$= \tfrac{1}{2}kP_1\,[Q_1 - Q_0]\left[\frac{kP_1}{P_0 - P_1}\right].$$

But $\frac{1}{2}kP_1(Q_1 - Q_0)$ is the area of the triangle $M'M_0M_1$

and $kP_1 = P' - P_1 = (P' - P_0) + (P_0 - P_1)$

so $kP_1Q_1(\frac{1}{2}kn) =$ area of triangle $M'M_0M_1\left[1 + \dfrac{P' - P_0}{P_0 - P_1}\right]$.

Now the correct area to be measured $= A_0M_0M_1A_1$

$= A_0M'M_1A_1 - M'M_0M_1$

which is greater than the area measured by $kP_1Q_1(1 - \frac{1}{2}kn)$, in fact, by the amount [area of $M'M_0M_1$] $[P' - P_0]/[P_0 - P_1]$.

More generally, this underestimation of research benefits by the formula when demand is relatively elastic and the shift in the supply function is a parallel one will be counteracted by the tendency of the formula to overestimate benefits when the supply function shift is divergent. Clearly the nature of the shift is critical in measuring the level and distribution of benefits.

Peterson attempted to derive a more general formula for the measurement of GARB, but unfortunately there appear to be a number of errors in the derivation of his formula. Peterson's basic diagram is shown in Figure 3. The first error concerns the treatment of the variable K which is used by Peterson to describe the shift in the supply function. K is described verbally as "the percentage decrease in the supply function of poultry products that would occur should the new inputs used by poultry farmers to obtain greater efficiency suddenly disappear" [15, p. 657]. In the analysis however, it would appear that K is defined as the change in the equilibrium quantity of output if the innovation disappeared,

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[1] Obviously in this case k must be interpreted as the proportionate reduction in costs at output level Q_1 only.

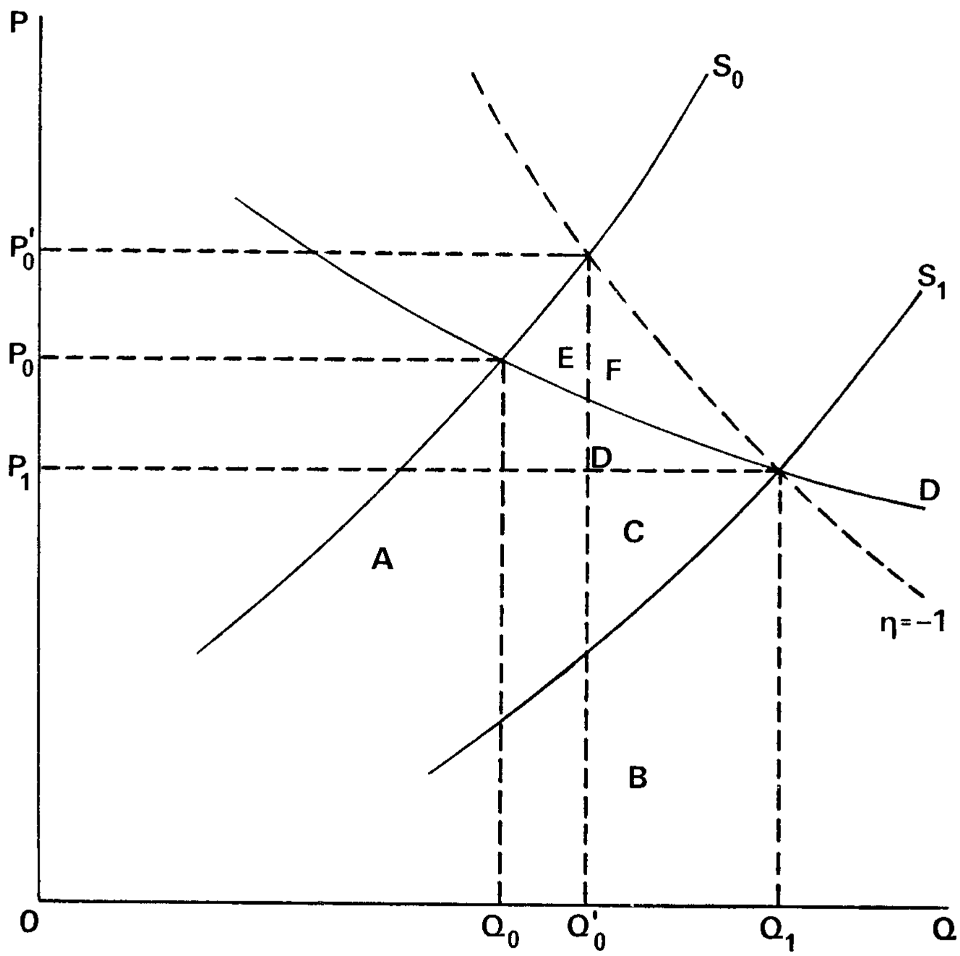

FIGURE 3

expressed as a proportion of the equilibrium level of output produced with the innovation, i.e., $K = (Q_1 - Q'_0)/Q_1$ in Figure 3. This definition of K implies a horizontal, as opposed to the more traditional vertical shift of the supply curve. More importantly, it understates the extent of the shift since it includes the effect of the equilibrating process involving both supply and demand. This approach makes it more difficult to interpret the effect of agricultural research *per se* on the supply function, and would require the further education of scientists into the mysteries of supply and demand elasticities.

A second error in Peterson concerns the assertion "area $A + C + D + E + F$ is approximately equal to area $B + C + D + F$" [15, p. 657, fn.1]. It is difficult to show why this statement is wrong using Peterson's diagram because of the ambiguity caused by not extending the supply curves back to the vertical axis. Therefore the more precise diagram is Figure 1, which represents the special case of a parallel shift in the supply curve and where the demand curve is specified to be unitary arc elastic will be used. It will be shown that as the two areas are markedly unequal in this special case, it follows that they cannot, in general, be even approximately equal. First, note that Peterson's areas $A + C + D + E + F$ and $B + C + D + F$ correspond in Figure 1 to areas $A_0M_0M_1A_1$ and $Q_0M_0M_1Q_1$ respectively. Given that demand is unitary elastic, it follows that the area $Q_0M_0M_1Q_1 = P_0M_0M_1P_1$. On the other hand, area $A_0M'M_1A_1$ = area $P'M'M_1P_1$ by the Law of Parallelograms, so area $A_0M_0M_1A_1$ = area $P'M'M_1P_1$ − area $M_0M'M_1$ which clearly exceeds area $P_0M_0M_1P_1$, by the area $P'M'M_0P_0$.

GENERAL FORMULAE

The formulae discussed above differ mainly because the different authors have made different assumptions about the nature of the supply shift. It is possible to develop alternative formulae which are perfectly general in nature so long as the simplifying assumptions of linear supply and demand curves are permitted. In a forthcoming article in the *American Journal of Agricultural Economics* [14], we have developed such formulae and have illustrated the magnitude of the possible biases in measuring research benefits when research workers in this area uncritically apply formulae which have been developed by others, and which postulate particular types of shifts of the supply function.

In Figure 4, the social benefits of research are measured by the rectilinear area $A_1M_1M_0A_0$ which, given the linearity assumptions made, can be decomposed into the areas of a series of triangles. In general, this area can be measured by the rule of cross-multiplication (*see* Durrant and Kingston [9]), which relies on the co-ordinates of the points A_1, M_1, M_0, A_0, A_1 expressed in an anti-clockwise direction. The co-ordinates are O, A_1; Q_1, P_1; Q_0, P_0; O, A_0; and O, A_1 respectively. The area $A_1M_1M_0A_0$ is given by

$$\tfrac{1}{2}[O\text{x}P_1 + P_0\text{x}Q_1 + Q_0\text{x}A_0 + O\text{x}A_1 - O\text{x}A_0 - O\text{x}P_0 - P_1\text{x}Q_0 - Q_1\text{x}A_1]$$

which equals (1)

$$\text{Total benefit} = \tfrac{1}{2}[P_0Q_1 - P_1Q_0 + Q_0A_0 - Q_1A_1] \quad (2)$$

The same procedure can be used to derive the following equation (3) for calculating the size of consumer surplus, reprsented in Figure 4 by the area $P_0M_0M_1P_1$.

$$\text{Consumer benefit} = \tfrac{1}{2}[P_0Q_1 - P_1Q_0 + P_0Q_0 - P_1Q_1] \quad (3)$$

If equation (3) is subtracted from equation (2), a measure of producer benefit is obtained. This is

$$\text{Producer benefit} = \tfrac{1}{2}[Q_0A_0 - Q_1A_1 - P_0Q_0 + P_1Q_1] \quad (4)$$

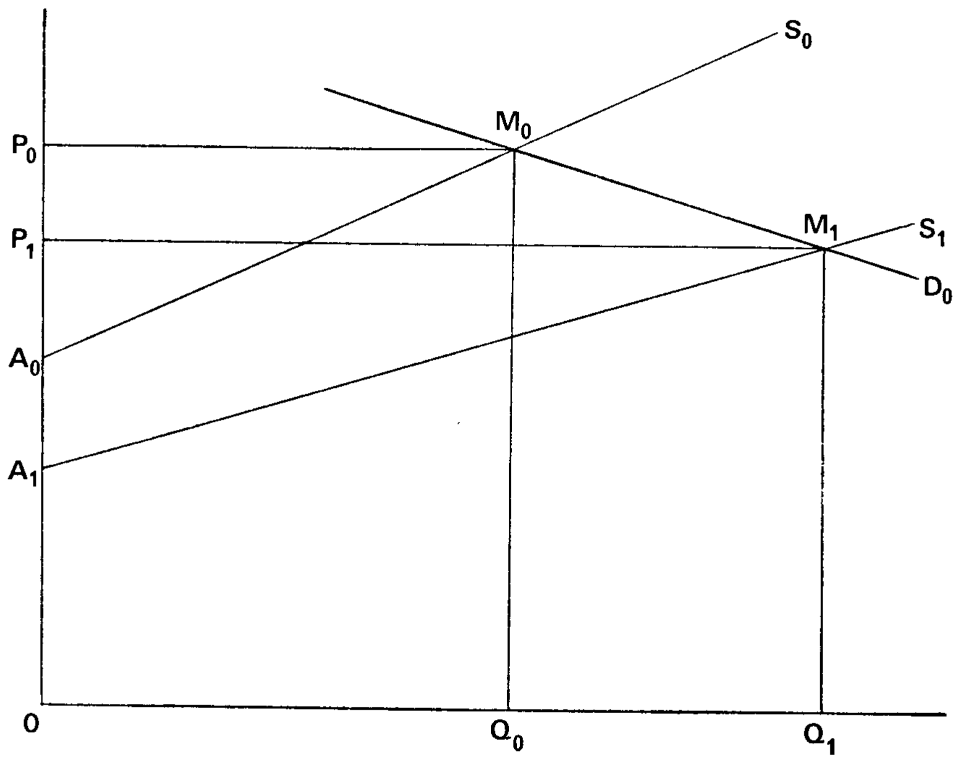

FIGURE 4

Within the assumptions made, equations (2), (3) and (4) are general results,[2] the application of which requires a knowledge of the original equilibrium price and quantity P_0, Q_0; the new equilibrium price and quantity P_1, Q_1; and values for A_0 and A_1. We do not underestimate

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[2] Griliches' measure of the loss associated with the disappearance of the innovation, and derived by assuming a perfectly elastic supply curve, is $kP_1Q_1[1 - \frac{1}{2}kn]$, where k is the proportionate shift in the supply function given by $k = \frac{P_0 - P_1}{P}$ and n is the absolute value of the elasticity of demand.

Evaluating this elasticity at P_1Q_1 gives $n = \frac{\Delta Q}{\Delta P} \cdot \frac{P_1}{Q_1} = \frac{Q_1 - Q_0}{P_1 - P_0} \cdot \frac{P_1}{Q_1}$

If we substitute for k and n in Griliches' measure, then equation (3) is obtained. Note that in Griliches' special case $A_0 = P_0$ and $A_1 = P_1$, so equation (3) is also the same as equation (2).

the difficulties of measuring the relevant variables in this formulation, but would argue that these formulae force researchers to be explicit about all of the assumptions which have to be made. Furthermore, because of its general nature, it should reduce some of the confusion engendered by the proliferation of alternate formulae based on different assumptions about the nature of the supply shift.

REFERENCES

[1] AKINO, M. and Y. HAYAMI, "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development", *Amer. J. Agr. Econ.*, 57 (1975): 1–10.

[2] ARDILA, V. JORGE, "Rentabilidad Social de las Inversiones en Investigacion de Arroz en Colombia", Unpub. M.Sc. thesis, Universidad Nacional (ICA), Bogota, Colombia, 1973.

[3] AYER, H. W. and G. E. SCHUH, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil", *Amer. J. Agr. Econ.*, 54 (1972): 557–69.

[4] CURRIE, J. M., J. A. MURPHY and A. SCHMITZ, "The Concept of Economic Surplus and its Use in Economic Analysis", *Econ. J.*, 81 (1971): 741–99.

[5] DALRYMPLE, DANA, "Impact of Research on Wheat and Rice Production" in T. M. Arndt et al. (eds). *Resource Allocation and Productivity in National and International Research.* Minneapolis, University of Minnesota Press, 1976.

[6] DE CASTRO, RAMALHO, J. P. and G. E. SCHUH, "An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study", in T. M. Arndt et al. (eds). *Resource Allocation and Productivity in National and International Agricultural Research.* Minneapolis: University of Minnesota Press, 1976.

[7] DODGE, CLAYTON W., *Euclidean Geometry and Transformations*, Addison-Wesley, Massachusetts, U.S.A., 1972.

[8] DUNCAN, R. and C. TISDELL, "Research and Technical Progress: The Returns to Producers". *The Econ. Record.*, 47 (1971): 124–29.

[9] DURRANT, J. E. and H. R. KINGSTON, *A New Analytic Geometry*, Macmillan, 1946.

[10] EVENSON, R. E., P. M. FLORES and Y. HAYAMI, "Costs and Returns to Rice Research", Resource Paper No. 11, International Rice Research Institute, Los Banos, Philippines, Mimeo, 1976.

[11] GRILICHES, ZVI, "Research Costs and Social Returns: Hybrid Corn and Related Innovations". *J. Pol. Econ.* (1958): 419–31.

[12] GRILICHES, ZVI, "Research Costs and Social Returns: Hybrid Corn and Related Innovations" in Nathan Rosenberg (ed.). *The Economics of Technological Change*, Penguin, 1971.

[13] HERTFORD, REED and A. SCHMITZ, "Measuring Economic Returns to Agricultural Research", California Agricultural Experiment Station, Unpub. Paper, 1975.

[14] LINDNER, R. K. and F. G. JARRETT, "Supply Shifts and the Size of Research Benefits". *Amer. J. Agr. Econ.* (forthcoming).

[15] PETERSON, WILLIS L., "Return to Poultry Research in the United States". *J. of Farm Econ.* 49 (1967): 656–69.

[16] SCOBIE, GRANT M., "Who Benefits from Agricultural Research?", this *Review*, 44 (1976): 197–202.