EVALUATING THE RETURNS FROM TECHNICAL PROGRESS:

COMPARING DUAL METHODS WITH SURPLUS APPROACHES

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ABSTRACT

Comparison of producer surplus (PS) approaches with definitive measures based on the profit function reveals potential problems with using the PS approach to measure the benefits of some common types of technical change. These problems result from inherent features of the PS methodology. An alternative approach using the *balance of trade* function is shown to avoid these problems and to allow generalization to cases with multiple inputs, multiple outputs and multiple distortions. The measure can be interpreted graphically to aid intuition, and is applied to a small, highly distorted economy using a simple model solved on a spreadsheet.

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EVALUATING THE RETURNS FROM TECHNICAL PROGRESS: COMPARING DUAL TECHNIQUES WITH SURPLUS APPROACHES

Over twenty years ago, Duncan and Tisdell (1971) showed that in a competitive industry such as agriculture the form of a technical change can have major implications for its welfare benefits. The fundamental insight that the form of technical change has important implications for its welfare consequences has subsequently been widely acknowledged and used, and a number of studies of agricultural research benefits have extended Duncan and Tisdell's results to a broader set of market and policy conditions.[1] From this literature, it seems clear that the choice of the specification of technical change often has a major bearing on the measures of welfare consequences. Any conclusions are specific to the particular specification of technical change, and the results of any analysis based on only one specification of technical change cannot be generalized. This point is relevant both for theoretical studies, that have arbitrarily chosen certain specifications of the type of technical change (often for analytical convenience), as well as for many empirical studies, generating rates of return to research, that invariably have chosen a particular type of research-induced supply shift.

While Duncan and Tisdell were careful to specify technical change in terms of its effects on costs, much of the subsequent literature has specified different technological changes in terms of shifts in single supply curves.[2] Studies have tended to use either parallel or proportional shifts in supply curves, representing unspecified types of reduction in the underlying cost structures of production. Given the theoretical restrictions that the parameters of a model of a production technology must satisfy, such *ad hoc* representations are clearly incomplete.[3]

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[1]Early contributions were made by Scobie (1976), Jarrett and Lindner (1977), Sarhangi, Logan, Duncan and Hagan (1977), Lindner and Jarrett (1978), Lindner and Jarrett (1980) and Rose (1980), among others. Norton and Davis (1981) reviewed that literature. More recent studies—including Edwards and Freebairn (1981, 1984), Gardner (1988), de Gorter, Nielson and Rausser (1992), Murphy, Furtan and Schmitz (1992), and Voon and Edwards (1992), among others—are reviewed and summarized by Alston, Norton and Pardey (1994).

[2]As discussed by Alston, Norton and Pardey (1994), parallel supply shifts have been used with linear supply curves while proportional supply shifts have been used with linear or constant elasticity functions; the choice has been dictated almost entirely by analytical convenience, given a prior choice of functional form for supply.

[3]For example, given the theoretical requirement that supply curves be homogeneous of degree zero in prices, it is not possible to change the own-price elasticity of supply without adjusting one or more cross-price elasticities.

Our purpose in this paper is twofold. Firstly, we want to reinforce the Duncan-Tisdell point that the form of technical change can have an important influence on the welfare benefits that it yields to both producers and the economy as a whole. Secondly, we would like to explore the implications of going beyond the now traditional categorization of technical changes in terms of their effects on a single supply curve. The alternative we propose is to specify technical changes in terms of their effects on the entire production system, either directly, or in its dual representation (i.e., in terms of the cost function or profit function and the associated systems of factor demand and output supply functions). In this paper, we explore the implications of using this approach, rather than the conventional measures based on producer surplus, and to the insights which can be obtained into the sources of benefits from research.

In much of the literature on technical change, producer surplus measures are used as though they provide definitive estimates of the direct benefits of technical change. It is important to remember, however, that the rationale for using producer surplus is to provide a measure of producer profits or rent. This can be done more directly by specifying a profit function. While some studies using dual approaches to specify profits and the structure of production have specified particular types of technical change (e.g., Binswanger, 1974), the implications of these specifications for producer returns do not appear to have been systematically investigated. If we are to replace *ad hoc* analysis using supply functions with approaches based on duality theory, it is important that the relationships between measures based on producer surplus and measures based on profit functions, and the choices involved with a profit function approach, be well understood.

We first set out the *balance of trade* function as a general approach for evaluating the welfare effects of technical changes. Then we consider the specification of the types of technical change of interest in terms of producer profit functions that represent the production technology and producer behaviour under the hypothesis of competitive profit maximization. For simplicity, and for consistency with the earlier literature, we consider the specific case of a technology represented by a normalized quadratic profit function that yields the linear supply and demand curves emphasized in discussions of research benefits. We compare and contrast the algebraic measures of producer benefits from the profit function with the corresponding single-market producer surplus measures. Numerical examples are provided to illustrate the practical implementation of the profit function approach, and to provide an indication of the order of magnitude of the differences that may arise between it and the conventional producer surplus approach. Finally, we consider the evaluation of welfare change where the technical change results in changes in prices, either because there are nontraded goods, or because the economy is large in world markets.

The Specification of Technical Change

For our purposes, it is convenient to represent production technology using a producer profit function. Changes in this profit function directly provide estimates of the benefits to producers from technical change. The profit function is also a component of the *balance of trade* function used to provide a money metric measure of overall welfare change (e.g., Woodland 1982; Lloyd and Schweinberger 1988; Anderson and Neary 1992). The profit function represents all of the relevant technology and avoids the ambiguities that arise in using *ad hoc* supply curves, where distinctions between average and marginal costs, and between costs and rents have created considerable confusion (see Rose 1980). Depending upon the situation, the profit function may represent technologies with single or multiple outputs and single or multiple inputs, and may include variable and fixed inputs.

In the special case of a small open economy with no nontraded goods, and no trade distortions, the welfare effects of technical change can be evaluated using only the profit function. Where the technical change results in price changes, either because some goods are nontraded or because the country is large in world markets, the effects of these price changes on consumer welfare and on tax revenues must also be taken into account. A *balance of trade* function allowing for these effects is:

$$B = e(p,u) - \pi(p,v,\tau) - (p-p^*) z_p(p,v,\tau,h) \qquad (1)$$

where e (p, u) is the consumer expenditure function for given domestic prices, p and utility level, u; π (p, v, τ) is producer profit for a given endowment of resources, and state of technology represented by τ; p^* is a vector of world prices, z_p is the vector of first derivatives of e - π and, by duality, the vector of net imports; *h* is the utility level at which the net import vector is evaluated.

The utility at which the net trade vector is evaluated may be either the exogenous utility level, u, appearing in the expenditure function, or the actual utility level $h(p, p^*, v, \tau)$ arising with the technical change.[4] If an exogenously fixed utility level is used, the change in the *balance of trade* function represents the amount of compensation that must be paid to the economy from outside in order to maintain a constant level of welfare. If the actual utility level were used, the resulting measure would be a money metric of welfare change (Anderson and Martin 1993). If the exogenous utility term u were held constant at its initial level, the measures would be based on Hicksian compensating variation. If it were held constant at the final level, the measures would be based on Hicksian equivalent variation.

The *balance of trade* function shares the fundamental parameters of the behavioral system, but is separate from it. A behavioral model of supply relations, Marshallian demand equations, market clearing conditions, and (in general equilibrium) income-expenditure conditions can always be used to generate the vectors of quantities and prices needed to evaluate the *balance of trade* function. The *balance of trade* function applies to individual economies, but the behavioral model may contain multiple regions and features such as technology spillovers of the type considered by Davis, Oram and Ryan (1987). While we consider only technical change affecting production (process improvements), the framework could be extended to include

[4] $h(p,p^*, v, \tau) = \{u \mid e(p,u) - \pi(p, v, \tau) - (p-p^*) z_p(p, \tau, u) = 0\}$.

technical change affecting buyers' perceptions of product quality (product improvements) as discussed by Voon and Edwards (1992).

The forms of technical change considered in this paper are exogenous, disembodied technical changes involving various forms of factor or output biases. Three different approaches to specifying such disembodied technical change have been utilized in the literature: (a) the direct incorporation of technical change variables in the function (e.g., Binswanger 1974; Kohli 1991), (b) the use of a distinction between actual and effective quantities and prices, and output- or input-augmenting technical change (e.g., Dixon, Parmenter, Sutton and Vincent 1982), and (c) the use of a varying-parameter specification in which the coefficients of a static model are themselves functions of technical change (e.g., Fulginiti and Perrin 1992). In general form the resulting specifications of producer profit (and hence technology) may be represented as:

$$\text{(a) } \pi = g(p, v, \tau \mid \alpha), \quad \text{(b) } \pi = g(p(\tau), v \mid \alpha), \quad \text{(c) } \pi = g(p, v \mid \alpha(\tau)), \quad (2)$$

where α is a vector of parameters of the profit function and all other variables are as previously defined. The technology may be represented by any of a wide range of dual functional forms that specify the profit function directly, or may be specified in primal form allowing profit to be evaluated indirectly.[5]

These three approaches to the specification of technical change provide great flexibility in incorporating different forms of technical change. As we show below, such approaches can capture the broad types of technical change used in partial-equilibrium models of research benefits, while allowing the restrictions required by economic theory to be satisfied. The general-equilibrium nature of the analysis maintains consistency with the earlier general-equilibrium literature on the evaluation of gains from research and investment (e.g., Bhagwati and Hansen 1973), but allows the analysis to be generalized to situations with any number of inputs and outputs.

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[5]Kohli (1991) discusses a range of possible functional forms.

In the modern theory of shadow pricing, shadow prices for small, exogenous changes in government sector outputs are derived from a form of the *balance of trade* functions (Fane 1991; Drèze and Stern (1987). Thus, our measures of the benefits from technological change might be expected to be close to those obtained by evaluating the changes in output at shadow prices, at least for small changes in technology.

Incorporating Technical Change Variables Directly

The first specification of technical change is well known from the empirical literature on the estimation of flexible functional forms (see Binswanger 1974). Under this approach, the technical change variable(s) enter the profit function in the same way as a quasi-fixed factor would, except that being "public" goods they receive a zero factor return at the level of the firm. In this case, the technical change can be thought of as an increase in the supply of nonrival goods which are provided free to individual producers. Using a normalized quadratic profit function to illustrate this approach, we begin with:[6]

$$\pi/p_o = \alpha_0 + \alpha' P + \tfrac{1}{2} P' A P \qquad (3)$$

where $P = [p' \; v' \; \tau']'$ is a vector of n-1 normalized prices (p) including prices of variable outputs and inputs (where inputs are represented by negative quantities), fixed inputs and outputs (v); and technology variables (τ); $\alpha' = [\alpha_0, \alpha_1, \ldots, \alpha_n]$ is a $1 \times n$ vector of parameters; and A is a matrix of parameters, α_{ij}, comformable with the P vector.

By Hotelling's lemma, differentiating the profit function with respect to the output prices yields the output supply and (negative) input demand functions. For the quadratic function represented in equation (3), this will result in the technology variables entering the output supply

[6]Shumway, Jegasothy and Alexander (1987) discuss the normalized quadratic function in detail. The normalized quadratic profit function presented here includes the widely used Generalized McFadden estimating form as a special case (Diewert and Wales 1987).

and input demand functions as linear shift variables. The output supply or input demand function for any non-numeraire good is:[7]

$$x_i = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} p_j + \sum_{k=1}^{q} \alpha_{ik} v_k + \sum_{h=1}^{s} \alpha_{ih} \tau_h \tag{4}$$

The specification represented by equation (4) allows only for parallel shifts in the output supply or input demand equations, since the effect of a change in any τ_h on x_i does not depend on either output or price. For a single technical change (i.e., a change in a particular τ_h parameter), the change in the *i*th supply function will involve only one term (i.e., $\alpha_{ih}\Delta\tau_h$). In terms of its effect on the supply curve for a single output, this technical change is represented by the move from S_1 to S_2 in Figure 1, which is reproduced from Duncan and Tisdell's Figure 1 (1971, p. 127). This form of technical change is often contrasted with a proportional supply shift in the quantity direction, such as that represented by the move from S_0 to S_1, which Lindner and Jarrett (1978) termed a *pivotal* shift in order to distinguish it from a proportional shift in the price direction.

(FIGURE 1 ABOUT HERE)

A Taylor-series expansion around the initial value of the profit function, defined by equation (3) yields an exact expression for the change in profit resulting from an increase in τ_h when its only effect is on one output level. This expression is:

$$\Delta\pi / p_o = \sum_{i=1}^{s} p_i \alpha_{ih} \Delta\tau_h = \sum_{i=1}^{s} p_i \Delta x_i. \tag{5}$$

[7]The quantity (output or input) of the numeraire good can be determined by Walras' Law from the level of profit attained--it is not independently determined. Since the behavioral functions are homogeneous of degree zero in prices, there are only n-1 independent relative prices.

For `a technical change that causes a parallel shift in only one supply function, that for commodity i, only one element of this summation will be nonzero.[8] Further, this first-order term captures all of the effects of the technical change, there are no higher-order effects to be considered.[9] This technical change also has a very simple geometric interpretation since the change in the α_{ih} term is the magnitude of the horizontal shift in the supply curve for good i.

Interpreting the effects of this technical change geometrically, we see that in this case of a parallel shift in the supply curve for good i only, the gain in net revenue can be expressed very simply as the price of good i times the shift in the supply curve, or as $p_i\alpha_{ih}\Delta\tau_h = p_i\Delta x_i$. In Figure 2 (panel a or panel b), this gain is represented by the rectangle q_0abq_1 (which is equivalent to the parallelogram *abdc*). This result is an interesting one with powerful intuitive appeal: it implies that a technical change that increases the output of good i by Δx_i units, without affecting the output of any other good or the required level of any input, will increase profits by $p_i\Delta x_i$. The resulting measure is equivalent to the "approximation" to gross annual research benefits (GARB) used by Griliches (1958), when demand is perfectly elastic, as is assumed here.

(FIGURE 2 ABOUT HERE)

This simple result from the profit function approach may differ from the result provided by the conventional producer surplus approach, depending upon the elasticity of supply. First, consider the case of *inelastic* supply (panel a in Figure 2), where the linear supply curve has a positive intercept on the quantity axis (i.e., a positive quantity of good i is produced at a zero price). In this case, the producer surplus approach yields the same result as direct evaluation of the profit function. Because an *inelastic* linear supply function has implausible implications when the function is extrapolated back to the axes, some users of the producer surplus approach

[8]Given the definition of the functional form, in this case there are no adding-up effects that require corresponding shifts in other commodity supplies or factor demands. In some other situations it might not be possible to define a theoretically consistent technical change that shifts only one supply function.

[9]The quadratic term involving τ_h in the profit function (i.e., since τ_h is being treated as an argument of the function, like one of the prices or fixed factors) drops out from the summation in equation (4) since $\alpha_{hh} = 0$.

have been concerned about the interpretation of producer surplus measures. Some *ad hoc* solutions have been offered, but these amount essentially to rejecting the combination of the linear functional form and elasticities less than one.[10] The issue of functional form is pervasive. Different functional forms might avoid this particular problem but introduce others. For instance, constant elasticity supply functions pass through the origin and imply, implausibly, that positive output will be supplied at prices near zero.[11]

An *elastic* linear supply function (panel b in Figure 2) is more plausible at output levels near zero than either an inelastic linear supply function or a constant elasticity supply function, since it implies a positive shut-down price (i.e., a price at which zero quantity would be produced). The producer surplus approach yields an estimate of the gains from producer surplus equal to *abef* in this case compared with the profit function measure equal to area *abdc*. The difference between the measure obtained from direct use of the profit function and the producer surplus measure arises because the producer surplus measure is truncated at the price axis. The profit function admits negative quantities of the commodity. The producer surplus measure allows only non-negative quantities and this difference in maintained assumptions is the fundamental source of differences between the measures obtained.

The profit function approach can be adapted to deal with cost-reducing technical change. To do this, it is first necessary to specify the output of good i as quasi-fixed, and hence as an element of the ν vector in the profit function. Differentiation of the profit function with respect to this element then yields the supply price needed to give rise to any specified level of output, w_i. This equation may be written, following equation (4), as:

[10]For instance, Rose (1980) and Lindner and Jarrett (1978, 1980) discussed kinking linear supply functions at the initial equilibrium quantity or price in order to avoid having a negative intercept on the price axis.

[11]An alternative type of supply function has been proposed by Lynam and Jones (1987), which nests the linear and constant elasticity models as special cases. It is a "constant-elasticity" form but displaced from the origin so that it cuts the price axis at a positive price: $x = \beta(P - \alpha)^{\epsilon}$. This type of model has been used in relation to measuring research benefits by Alston and Martin (1993).

$$\frac{w_i}{p_o} = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} p_* + \sum_{k=1}^{q} \alpha_{ik} v_k + \sum_{h=1}^{s} \alpha_{ih} \tau_h \tag{6}$$

Where the technical change reduces the supply price of only one output, then a Taylor Series expansion around the initial value of the profit function yields an expression for the change in profit

$$\Delta \pi / p_o = \alpha_{ih} v_i \Delta \tau_h = v_i \cdot \Delta (\frac{w_i}{p_o}) \tag{5'}$$

The profit function based measure given in equation (5') corresponds to the area *agfe* in Figure 3(a). By contrast, the producer surplus area is *abdc*. Since the triangles *abg* and *cdh* are identical, it is clear that the profit function measure is larger than the producer surplus measure. This is despite the fact that the profit function-based measure ignores the benefits associated with the additional output resulting from the shift from S to S' (i.e., area *abg*). The producer surplus approach is again smaller than the profit function measure because of the truncation of the supply curve at a zero quantity. The *ad hoc* approach of kinking the supply curve at point a would allow the additional area (*cdfe*) to be picked up in the producer surplus measure (e.g., Rose 1980).

The unitary elasticity case depicted in Figure 3(b) is interesting in that both approaches give the same results in this case. The area *acOd* representing the profit function measure equals the area *abfO* used with the producer surplus approach. In this case, the area below the axis counted by the profit-based measure (*dfO*) corresponds exactly with the area *abc* included in the producer surplus measure but excluded from the profit function measure.

(FIGURE 3 ABOUT HERE)

In the final case of an elastic supply curve presented in Figure 3(b), the profit function based measure is given by *aced*, while the producer surplus measure is *abed*. In this case, the producer surplus measure is unambigiously larger, since it includes the benefits associated with additional output (area *abc*).

To provide a feel for the magnitude of the likely differences between the profit function based measures and the producer surplus measures for both the output-increasing and cost-reducing technical change, we estimate the changes in producer profits and producer surplus for output increasing and cost-reducing supply shifts for initial supply elasticities of 0.5, 1.0, and 2.0. The results are presented in Table 1.

Table 1: Additive Shift in the Supply Curve, Percentage Gain

	Output Increasing Shift (10%) a/		Cost Reducing Shift (10%) b/	
Elasticity	π Gain (%)	PS Gain (%)	π Gain (%)	PS Gain (%)
0.5	10	10	10	5
1.0	10	10	10	10
2.0	10	5.025	10	11

a/ A 10% increase from initial output level.
b/ A uniform reduction in marginal cost equal to 10 pct of initial price.

With supply elasticities of 0.5 and 1.0, and a horizontal shift of the supply curve, the profit function measure and the PS measure are identical. However, with an elasticity of 2.0, the producer surplus measure is approximately half the profit function based measure (for an infinitesimal change, it would be exactly half because of the truncation of the supply curve at the price axis). For a cost reducing technical change (vertical supply shift), the producer surplus measure is half the profit function measure when the elasticity is 0.5. With a unitary elasticity, the two measures are the same. With an elasticity of 2.0, the producer surplus measure is slightly larger, because of the addition of the triangle of welfare gains, *abc* in Figure 3(c).

A striking feature of the table is the constancy of the estimated gains in producer profit. With the profit function measures, only the first order welfare gain is measured and the welfare gain corresponds to that used by Griliches (1958). For a given research-induced supply shift, the quantitative importance of the difference between the profit function measure and the producer surplus measure depends only on the elasticity of supply in the neighborhood of initial output. If the elasticity of supply is less than one, the measures are identical.

The choice of measure depends heavily upon the problem at hand. If a horizontal supply shift is believed appropriate, the profit function measure generates results that seem more plausible than the producer surplus measures in the case where they differ, (i.e., where the elasticity of supply is greater than unity). As previously noted, the profit function measure implies that a ten percent increase in output, with no other adjustments, will yield an increase in profits equal to ten percent of gross revenues.

The case of a cost reducing technical change is less favorable to the profit function approach with output levels exogenous because the resulting measure of profit changes does not allow for an induced change in outputs. Thus, the profit function measure omits a welfare triangle that would be relevant if output is not fixed. The producer surplus measure obviates this problem but, in the case of an inelastic supply curve, omits a first order term related to the hypothetical amount of output supplied at a zero price. If the parallel shift is intended to represent a uniform cost reduction on all units of output, then the profit function measure holding output fixed would be first-order superior with a supply elasticity of unity or less and second-order inferior with an elasticity greater than unity. The profit function measure allowing output to vary would be first-order superior in every case.

For a technical change that causes a parallel shift in the supply curve, the profit function approach with output endogenous (i.e., a horizontal supply shift) appears to have a great deal to commend it in situations where output is not controlled. This specification directly represents the effects of a technical change that increases output by a constant amount at all prices. Simply multiplying by the slope of the supply curve will convert a constant reduction in the marginal costs of production (a parallel vertical shift of the supply function) into a corresponding horizontal shift of the supply function. The resulting measure of the change in profit captures the gains from the induced increase in output, which are missed when output is treated as exogenous, and sidesteps the problems resulting from the truncation of the producer surplus measure at the origin. Of course, if output is truly exogenous because of an output quota, then the specification with exogenous output is most appropriate.

Output- or Input-Augmenting Technical Change

Another specification that has been used widely to model technical change is the distinction between actual and effective quantities and prices utilized by Dixon *et al.* (1982). Under this approach, technical change is thought of as something that increases the *effective* quantity of a good associated with a given physical quantity. An important feature of this specification is that there is a corresponding change in the effective price of the good. An increase in the effective quantity of an output provided by each physical unit will raise the effective price relative to the price of the physical units.[12] While care is needed in defining appropriate effective quantity and price variables, this approach does not alter the behavioral parameters of the model, ensuring that they continue to satisfy any theoretical restrictions imposed in their original construction. Further, the specification has the intuitively appealing feature that improvement in technology stimulates output in two ways: firstly through a productivity effect which increases output for a given level of inputs and, secondly, through an increase in competitiveness which draws additional resources from other activities.

Technical change of this nature may come about in many ways, such as an improvement in the physical quality of the good, or from improved information or management that allows the good to be utilized more efficiently. Using this approach, the relationship between physical

[12]An example may help illustrate this approach. Suppose we have data on actual quantities of grain harvested and on actual prices paid at the silo. With the actual quantity harvested and the actual price at the silo remaining constant, an increase in the efficiency of post-harvest transport and storage will increase the quantity delivered to the silo (the effective quantity) and increase the effective price of a bushel of output (the price paid to producers).

and effective quantities of a particular good (i.e., input or output), x_i, can be represented by $x_i = x_i^*.\tau_i^e$, where x_i is the actual quantity of the good, x_i^* is the effective quantity of the good, and τ_i^e is the index of output-augmenting or input-augmenting technical change for good i. The corresponding relationship between actual and effective prices is $p_i = p_i^*/\tau_i^e$, where p_i^* is the effective price of the good; p_i is the actual price and τ_i^e is the augmentation factor. When x_i is an input, input-saving technical advance is represented by a decline in τ_i^e, which reduces the physical quantity of the input required for one effective unit and also lowers the effective price relative to the actual price. When x_i is an output, an increase in τ_i^e represents output-augmenting technical change: an increase raises the physical quantity associated with a given effective quantity and raises the effective price for a given actual price.

Under this specification of technical change, producers are represented as optimizing over effective quantities and prices, rather than actual quantities and prices. This causes changes in the quantities of goods chosen, and hence in the revenues generated. Once the quantities have been chosen, however, the revenues may be calculated by simple multiplication using either the actual or the effective quantities and prices since the τ_i^e terms will cancel when p_i^* and q_i^* are multiplied together.

The profit function incorporating technical change is defined by replacing the variables in equation (3) with the corresponding effective values of those variables, and eliminating the terms involving the direct technical change variables, as can be seen in equation (3').

$$\pi/p_o = \alpha_0 + \alpha' P^* + \tfrac{1}{2} P^{*\prime} A P^* , \qquad (3')$$

where $P^* = [p^{*\prime} \ v^{*\prime}]'$. Considering, for simplicity, technical change affecting only the variable output quantities x, and the corresponding prices, p, output supply or input demand is:

$$x_i^* = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} p_j^* + \sum_{k=1}^{q} \alpha_{ik} v_k , \qquad (7)$$

where the x_i^* and p_i^* variables are as defined above. Substituting the definitions of p^* and x^* into equation (7) yields a behavioral function in the actual price and quantity variables:

$$x_i = \tau_i^e \left[\alpha_i + \sum_{j=1}^{n} \alpha_{ij} (p_j \tau_j^e) + \sum_{k=1}^{q} \alpha_{ik} v_k \right] . \tag{8}$$

From inspection of equation (8), it is clear that a technical advance of this form for commodity i involves two proportional shifts: one resulting from multiplication of some or all of the price variables by τ_i^e (a proportional shift in the price direction), and one resulting from multiplication of the entire term in parentheses by τ_i^e (a proportional shift in the quantity direction). A combination of this type of shift in the supply curve and a parallel shift of the type considered in the previous section could be used to generate a pivotal shift like that represented by the move from S_0 to S_1 in Figure 1.

A second-order Taylor-Series expansion will exactly capture the benefits of this form of the technical change given the quadratic form for the profit function. The resulting expression for the welfare effects of technical change is:

$$\Delta\pi / p_o = p_i \left[\alpha_i + \sum_{j=1}^{n} \alpha_{ij} p_j^* + \sum_{k=1}^{g} \alpha_{ik} v_k \right] \Delta\tau_i^e + \left[\tfrac{1}{2}\alpha_{ii} p_i^2\right](\Delta\tau_i^e)^2 \tag{9}$$

Assuming τ_i^e is initially unity, substituting equation (8) into (9) yields:

$$\begin{aligned} \Delta\pi / p_o &= p_i x_i^0 \Delta\tau_i^e + \tfrac{1}{2}\alpha_{ii}\left[p_i \Delta\tau_i^e\right]^2 \\ &= p_i x_i^0 \Delta\tau_i^e \left[1 + \tfrac{1}{2}\epsilon_i^0 \Delta\tau_i^e\right] \end{aligned} \tag{9'}$$

where $\epsilon_i^0 = (\alpha_{ii} p_i / x_i^0)$ is the elasticity of supply of good i at the initial price p_i and quantity x_i^0.

The first term on the right-hand side of the first line of equation (9') can be thought of as representing the welfare effect of the direct increase in the actual output of good i, that is the increase in output that is brought about purely by the increase in productivity, without any reduction in the output of other commodities. The second term (a second-order term) measures the net welfare gain that results from increases in output of good i achieved by reducing the output of other goods.

Interestingly, the first-order term in equation (9′), representing the benefits from an output-augmenting technical change, is the same as that given in equation (5) for the case of a horizontal supply shift: it is equal to $p_i \Delta x_i$ in both cases. This particular result has potentially very important practical implications -- the measured benefit from a given percentage technical change is, to a first-order approximation, the same for the two main types of technical change being analyzed. Note, however, that a ten percent output augmenting technical change will yield an increase in output that is larger than ten percent, with the difference depending upon the supply elasticity.

As we demonstrate in Appendix A, the change in profit indicated by equation (9) is equal to the change in producer surplus irrespective of whether the supply curve is elastic or inelastic. Thus, for this type of technical change, the two measures are equal even when the producer surplus measure is truncated at the price axis but the profit function measure is not. A geometric interpretation allows us to compare the producer benefit measure from the profit function with the producer surplus measure. With the producer surplus approach, the welfare change is measured by the area *abdc* plus the area *bde* (i.e., area *abec*) in Figure 4. In contrast, the measure of welfare change resulting from the profit function approach is given by the parallelogram *fdeg* plus the triangle *cdh*.

The profit function measure allows an intuitively appealing decomposition of the benefits from technical change. The area *fdeg* measures the value of the direct increase in output, from *d* to *e*, resulting from the technical change. The rotation of the supply curve from S_1 to S_2 was, after all, due to a multiplicative shift in this supply curve with no consequent reduction in any other supply curve. The area *cdh* measures the net gain in profit which results from the increase in the effective price of good i. Since this component of the increase in output of good i (the increase from c to d in Figure 4) requires a reduction in the output of other goods, it stands to reason that the welfare gain associated with this increase in output should be substantially less than for the component of output increase which is a "free" good.

The decomposition of welfare change provided by the profit function approach raises serious questions about the use of the producer surplus methodology to distinguish between the welfare effects of *ad hoc* parallel and pivotal shifts in supply curves. The pure productivity effect represented by the shift from S_1 to S_2 is a pivotal shift in the supply curve but, as is clear from use of the profit function, yields a benefit measured by area *degf*. By contrast, the pure competitiveness effect represented by the move from S_0 to S_1 is more than a pivotal shift of the supply curve, but yields only a second-order welfare benefit. On this interpretation, it does not seem adequate to specify a technical change as an *ad hoc* shift in a supply function. Some pivotal shifts may have larger welfare gains than parallel shifts with the same effect on output. What seems to be needed is a return to focussing the effects of the technical change on the underlying technology or cost structure--the approach originally suggested by Duncan and Tisdell (1971).

A Varying Parameter Approach

The first two specifications of technical change (direct incorporation approach and the actual/effective distinction approach) allow parallel and pivotal shifts respectively in individual supply curves to be obtained. A third specification of technical change allows all of the parameters of the profit function, potentially, to depend upon the state of technology. In some senses this approach encompasses the other two. For instance, the parallel supply shifts generated by technical change variables incorporated directly in the supply functions can be generated equivalently by treating the intercept parameters (the α_i's) as linear functions of technology variables (e.g., $\alpha_i = \alpha_{i0} + \Sigma_h \alpha_{ih} \tau_h$). Taking this view, all of the above discussion of directly incorporated supply shift variables applies equally to varying parameter approaches. Indeed, the two previous approaches could be implemented in this way (i.e., in a linear supply function the analyst could have in mind either a change of the intercept or an additional argument when including a time trend variable or a technology variable).

The varying parameter approach is relatively flexible in that the intercept parameters could be nonlinear functions of technology variables. In addition, the slope parameters (i.e., the α_{ij}'s) could also be linear or nonlinear functions of technology variables. Indeed, the pivotal and proportional supply shifts in the conventional models clearly have been regarded by many in terms of changes in the parameters of supply functions. Here the potential pitfalls of the varying parameter approach become apparent. We wish to permit the parameters to vary only in ways that allow the modified parameters to continue to satisfy theoretical restrictions. With intercept changes, in most models there are not any problems. However, with slope changes it can be diffficult to preserve symmetry and homogeneity restrictions. It might be possible to satisfy all of the restrictions in such a specification only at a particular point in the data. In the light of these considerations, we defer detailed discussion of the potentially more general varying parameter approaches for future work.

Defining the Supply Function and Welfare Measures Consistently

Which measure (and therefore which set of assumptions) is better? The profit function measure, given that the profit function is well defined, seems unassailable. Producer surplus attempts to approximate changes in profit. But our profit functions are defined over the domain of positive prices, allowing for negative quantities in the case of elastic supply. For some intermediate goods, this may literally be true: at a sufficiently low price, it may pay to cease producing the good and to purchase it instead. More generally, however, it is important to recall that technical change does not literally involve extrapolation back to a zero price. It is the local approximation near the actual level of output that is critical to the performance of a profit function.

The profit function is, after all, the definitive specification. Producer surplus measure are justified (Just, Hueth and Schmitz, 1980) by their ability, under some circumstances, to yield estimates of changes in profits or rents. In the remainder of this section, we consider the multiple output/multiple input case to see the nature of the difficulties that arise in applying producer surplus measures of changes in profit.

The truncation of supply at the origin, as implied by the producer surplus measures, can be justified only if the commodity in question, commodity i, is a *necessary* output or input (Just, Hueth and Schmitz 1982, p. 341). This specification implies that, at the price consistent with zero output (input) of good i—the shut-down price, $\hat{p}_i$—the quantities of all other inputs and outputs are also zero, making profits zero. Integrating over the price of good i from its shut-down price, $\hat{p}_i$, to the market price, p_i, yields a producer surplus measure that is also an exact measure of profit. As Just, Hueth and Schmitz (1982, p. 342) note, the equality between a single-market producer surplus measure and multimarket profits will not hold if quantities of any of the other outputs or inputs are non-zero when the output of good i is zero.

To explore the conditions under which this condition will hold, it is useful to write the system of independent supply/demand equations for the non-numeraire goods defined by equation (4) in matrix form as:

$$X = \alpha + A\,p + B\,\nu + C\,\tau \qquad (10)$$

The shut-down price of any individual commodity depends on the values of all other commodity prices and technology. The shut-down prices are jointly determined. Assuming the A matrix is non-singular, there will only be one set of relative prices at which output (or input) of *all* n-1 non-numeraire commodities will be zero.[13] This set of shut-down prices can be obtained by setting the X vector to zero and solving the resulting system of equations to obtain:

$$\hat{p} = -A^{-1}\,[\alpha + B\,\nu + C\,\tau] \qquad (11)$$

A unique solution will generally exist for equation (11). Since all of the other n-2 relative prices are being held constant in the analysis, they must begin at the shut-down values that satisfy (11) for the producer surplus measure to equal total profit. But, in equation (11) it

[13]This solution does not immediately ensure that output of the numeraire commodity is zero. It will generally be necessary to add an additional "state of technology" variable to ensure that output of the numeraire commodity is zero when all of the other quantities are zero.

can also be seen that a technical change that causes a parallel shift in any one linear supply curve will generally imply a change in all of the shut-down prices associated with a zero quantity of all outputs and inputs. Thus a different set of shut-down prices is necessary to satisfy the requirements for producer surplus to be a valid measure of profit before and after the technical change being evaluated. The further problem then arises that we want to hold the other prices constant while allowing technology to change. It would be possible to maintain all of the shut-down prices but one constant, while varying the technology, so that the producer surplus methodology could continue to be used. However, this would require solving for changes in up to n-2 additional technical change variables, or n-2 free coefficients in the C matrix. While this adjustment can "save" the producer surplus approach it does so only by changing the question: it relates to a fundamentally different technical change experiment in which not just one, but all, of the supply curves shift.

The more typical study assumes only one supply curve shifts and that all other supply curves are unaffected (or irrelevant). The above arguments imply that the single-market producer surplus measures in such studies may mis-state the welfare consequences of a parallel shift in one linear supply curve, when that curve is drawn from a system of such equations. This implies that the very popular approach of using producer surplus to evaluate the welfare consequences of a parallel shift in one supply curve alone is theoretically questionable.

When the Technical Change Causes Prices to Change

Where technical changes leave all prices unchanged, as in the case of a small country with all goods traded, then the complete welfare effects of the change can be evaluated using the profit function alone. When the technical change causes prices to change, as in a country which is large in world trade for at least one commodity or where the prices of nontraded goods are affected, the welfare effects of induced price changes must be taken into account.

To understand the effects of price changes on the *balance of trade function*, it is probably easiest to begin with the case where the country is large enough to cause changes in world prices. A second order Taylor series expansion of equation (1) in prices can be used to provide an approximation of the welfare effects of these price changes which lends itself to an intuitive, graphical interpretation. Assuming initially that changes in world prices are fully transmitted into the domestic economy, the resulting change in the *balance of trade* is:

$$B_1 - B_0 = [z_p - (p-p^*)z_{pp}](p_1^* - p_0^*) - \frac{1}{2}(p_1^* - p_0^*)z_{pp}(p_1^* - p_0^*) \qquad (12)$$

where z_{pp} is the vector of second derivatives of $(e-\pi)$ and all other terms are as defined in equation (1). If the initial tariff level were zero, equation (12) would contain only two terms. The first of these terms, $z_p(p_1^*-p_0^*)$, measures the terms of trade loss (or gain) resulting from an increase (or decline) in world prices for imports. The second, quadratic, term measures the extent to which a terms of trade loss is diminished by the substitution of domestically produced goods for more expensive imported goods, or the diversion of goods previously exported to domestic markets. For a single price change, this quadratic term is the Harberger triangle familiar from analyses of the effects of tariff or terms of trade changes in the absence of distortions.

With a nonzero tariff, the second term within the square brackets must also be considered. This term is the change in the trade vector induced by the complete set of trade distortions. The sum of the two terms in the square brackets is the pattern of trade which would have prevailed in the absence of the trade distortions. In a linear world, it is this trade pattern exclusively that determines the income effects of changes in the terms of trade (Tyers and Falvey 1989; Alston and Martin 1994).

As an aid to understanding, the effects of a decline in the world price of a single distorted good from p_0^* to p_1^* are depicted in Figure 5 using the version of the *balance of trade function* with utility held exogenous in the net import function (z_p). The three terms in equation (12) correspond to three areas in the diagram. The first term in equation (12), the terms of trade effect $z_p(p_1^*-p_0^*)$ is represented by the area *fdhg* in Figure 5. The second term, the induced tariff revenue effect, is represented by the area *bced*. The third term, the substitution effect, is represented by area *ab*˜. If the compensation measure is being used, the net import demand function in Figure 5 incorporates the compensated consumer demand rather than the Marshallian demand curve used (theoretically incorrectly) with the surplus approach.

When there is more than one distortion in the economy, the welfare effects of a commodity price change are not confined to its own market, but spill over into all distorted markets for commodities that are substitutes for or complements with the affected commodity. Figure 6 depicts the case of a distortion in a related market which results in a gap between the domestic and the world price of the related good. Assuming that technical change lowers the price of the directly affected commodity, and that this commodity is a net substitute (in production and/or consumption), the consequence is to reduce the net import demand for the related commodity. The net import demand shifts leftward, from z_p^0 to z_p^1. Since each unit of this good has a greater value inside the country than its international price, changes in the quantity imported have welfare implications. The effect on the welfare measure, B, are given by the change in the net trade volume times the size of the import tariff. In Figure 6, this is represented by the area *abdc*.

Where the good of direct interest is nontraded, not all of the components of welfare change identified above need to be considered. The pure terms of trade effect identified in Figure 5 is, of course, irrelevant since net trade in nontraded goods is inherently zero. Similarly, there is no induced revenue effect resulting from changes in the volume of trade in nontraded goods. There is no need to consider a Harberger triangle associated with changes in the level of net trade since the net trade position for these goods remains zero. Only the induced changes in tariff revenues associated with changes in the volume of net trade of other goods need to be considered. However, these indirect effects are first order, and may be significant in some cases.

An Illustrative Application—Trade Distorting Policies With and Without Nontraded Goods

The following example of a hypothetical, highly-distorted, small, open economy—based on Martin and Alston (1994)—shows that the approach can be implemented with little information beyond that required for conventional, graphical approaches. The model is of a very simple economy, with three sectors: cocoa, rice, and other. Technical change increases productivity by a fixed percentage in either rice or cocoa, or in both cocoa and rice.

Basic data on the structure of this hypothetical economy are presented in Table 2. Each of the three production sectors has the same volume of output (100 units) and the same value of output at world prices ($1,000). However, there is an export tax of 50% on the export of cocoa, which reduces the value of output at domestic prices to $500. In contrast, there is an import duty of 50% on rice, which raises the domestic value of production to $1500. The remaining sector of the economy is assumed to be undistorted. Total income from production is $3000 and trade taxes raise revenues of an additional $1000, allowing total expenditure of $4000. While three goods are produced, cocoa is not consumed domestically, so only two consumption goods are included. With only three sectors on the production side of the economy, information on only three independent elasticities is needed to specify the production structure completely at a particular point. The own-price elasticities of supply at the initial production point are set to unity, and the cross-price elasticity of cocoa output with respect to the price of rice is set to -0.8, making the two crops much more closely related than crops and the residual "other" sector.

National production is represented by a normalized quadratic profit function which is equivalent to the generalized McFadden (Diewert and Wales) functional form in this case. The profit function subsumes the effects of fixed factors and intermediate inputs into the constant terms and is of the form:

$$\pi = a_c p_c^* + a_r p_r^* + a_o p_o^* + \tfrac{1}{2}[b_{cc} p_c^{*2} + 2 b_{cr} p_c^* p_r^* + b_{rr} p_r^{*2}]/p_o^* \tag{13}$$

where p_c^* and p_r^* and p_o^* are the *ef*

effective, nominal, prices of cocoa, rice and other goods, depending upon the actual prices, p, and the level of actual output achieved per effective unit of output. The effective price of good i is defined as $p_i^* = p_i.\tau_i$, where τ_i is an index of technology in the production of good i, set to unity in the base period.

The supply functions are obtained by differentiating equation (13) with respect to the effective prices. For each non-numeraire good, these equations take the form

$$q_i = a_i + b_{ii}(p_i^*/p_o^*) + b_{ij}(p_j^*/p_o^*) \tag{14}$$

for $(j \neq i)$, while for the numeraire good, the supply function is

$$q_o = a_o - \tfrac{1}{2}[b_{cc}(p_c^*/p_o^*)^2 + 2 b_{cr}(p_c^*/p_o^*)(p_r^*/p_o^*) + b_{rr}(p_r^*/p_o^*)^2]. \tag{15}$$

The slopes of the supply functions were inferred from the local elasticities and the relevant base-period price and quantity variables and then the intercepts were obtained by subtraction to calibrate the production system to the base data set. The parameters are presented in table 3 together with the local elasticities from which they were derived.

An Almost Ideal Demand System (*AIDS*) representation (Deaton and Muellbauer) was used on the consumption side. With two goods, only one local price elasticity and one local income elasticity of demand were needed to parameterize the demand system. These elasticities are presented in table 4, together with the parameter estimates for the demand system. Calibration of the demand system began with the familiar AIDS share equations:

$$w_i = \gamma_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln(e/P) \tag{16}$$

where w_i is the value share of good i in consumption spending (i.e., $w_i = p_i x_i/e$ where x_i is the quantity of i consumed), e is total expenditure and P is a price index for total consumption defined as:

$$\ln P = \gamma_N + \sum_{j=1}^{n} \gamma_j \ln p_j + \tfrac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j \tag{17}$$

The value of β_r was first determined for the rice equation given the income elasticity of demand and the expenditure share.[5] The level of P was specified in the base period using Stone's price index; this allowed the γ_{ij} parameters to be determined. In turn, the value of the γ_r parameter was determined to explain the observed expenditure share for rice. Next, the γ_N term in the cost function was calculated by subtraction from the base period value of Stone's index. Finally, the remaining β and γ parameters were inferred using the symmetry, homogeneity and adding-up restrictions. The AIDS expenditure function is:

$$\ln e = \ln P + u\beta_N \prod_{k=1}^{n} p_k^{\beta_k} \tag{18}$$

With u set arbitrarily to 0.5, the one remaining parameter, β_N, could be determined. The final equation needed to complete the model was the income-expenditure condition equating expenditure with production income, plus trade tax revenues and any foreign capital inflow:

$$e - \pi - \sum_{i=1}^{n} (p_i - p_i^w)(x_i - q_i) = 0 . \tag{19}$$

The model consisting of equations (13) through (19) was solved using the *Solver* option in *EXCEL 4.0*, and three technical change experiments were conducted. These experiments involved raising the productivity of (a) cocoa production, (b) rice production, and (c) both rice and cocoa production. In each case, the experiment involved an increase of 10% in the actual output per effective unit of output (e.g., a 10% increase in output/hectare). Such an experiment was chosen because it is a plausible specification of technical change (of a type that can be represented in the translog profit function, see Kohli, p. 105), and because it highlights the potentially important difference between the size of the technical change and the effect on output. The results of the three experiments are reported in the middle section of Table 5.

Considering the **cocoa experiment** first, it is important to note that the 10% increase in productivity increases the output of cocoa by more than 10%. The 21% increase in cocoa output (from 10 to 12.1) reflects both the direct impact of the productivity shock on the output of this sector, and the indirect effect through increased profitability; this technical change leads to resources being drawn from the other sectors. Because their relative profitability is reduced, the output of both rice and other goods actually falls in the cocoa productivity experiment—an effect which is frequently ignored in analyses using single commodity, partial equilibrium treatments. Export tax receipts from cocoa rise directly because of the technology-induced increase in output. Revenues from the rice import duty increase with the increase in the volume of imports. This import growth occurs both because the pull of resources out of rice and into cocoa increases the gap between domestic rice supply and demand, and because an increase in demand is induced by the rise in real income.[6] Profits from total production increase by only $52 with the cocoa experiment because the domestic price of cocoa is depressed by the export tax, and the domestic price of its close substitute in production (rice) is above world parity. The overall welfare gain is $205 using the money metric approach and $171 using the compensation measure much larger than the increase in profits at domestic prices. The difference between the value of output at market prices and its shadow value arises because the increase in output of this repressed sector increases government revenues from taxation both directly and indirectly.

In the **rice experiment**, the pattern of output effects is similar to that in the cocoa experiment, with rice output going up by more than 10%, and output in both other activities declining. In this case, however, profitability at domestic prices increases by $158, more than three times as much as in the case of cocoa. However, the tariff revenue effects are both negative in this case. The increase in the supply of rice lowers imports of rice and hence reduces revenues from the rice import tariff. In addition, resources are drawn away from cocoa, leading to a reduction in export tax revenues on cocoa. The overall effect on welfare is very small, with an equivalent variation of only $15 using the money metric and $13 using the compensation measure, because the gains in production income are so strongly offset by the declines in government tax revenues.

The third, cocoa and rice, experiment is included both to illustrate the ease with which such combined experiments can be performed in this framework, and to highlight the fact that the results of the combined changes (a benefit of $211 using the money metric measure and $177 using the compensation measure) are not simply the sum of the effects of the two experiments. Because, the position of the supply curve for an individual commodity is affected by the profitability of other commodities, it is not valid simply to sum the effects (Rose, 1980). In this example, the total effect was similar to the sum of the parts, but the discrepancy may be larger in other cases.

In the three experiments reported above, the compensation measure of equivalent variation can be approximated very closely using an approach from the cost-benefit literature. Since all three goods are assumed to be tradeable, and the country is small, the gains from technical change can be estimated by evaluating all of the changes in output at world prices, which are the applicable shadow prices.[14] The profit function is needed to estimate the full set of inter-related changes in output, but it is not necessary to fully specify the other components of the *balance of trade* function.

The simplication of using constant world prices to evaluate the benefits of research is not available if world prices change, or even if the domestic prices of nontraded goods change. Even for a small country, the shadow price of output is not simply the world price when there are nontraded goods. As we demonstrated previously, changes in the price of nontraded goods will have effects through their impact on tariff revenues in other markets. Since nontraded goods are prevalent, this issue is potentially important for capturing the benefits from research. To illustrate this effect, we repeated each of the experiments performed above with the "other" good specified as nontraded. The results, presented in the last three columns of Table 5, provide a number of interesting contrasts.

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[14]We are grateful to Anne Krueger for this suggestion.

The presence of a nontraded good has implications that are familiar from the "Dutch disease" literature. Notably, the price of nontraded goods rises in response both to the pull of resources away from the sector, and the spending effects created by the increase in income when productivity rises in the traded goods industries. The combined effects result in a real appreciation (rise in the price of the nontraded goods) of between 5 and 10 percent in the experiments considered. The presence of a nontraded good increases the welfare benefits of technical change substantially in the stylized experiments considered.

The crucial effect for welfare is the change in the volume of imports subject to distortions. For the cocoa experiments, the presence of a nontraded good substantially raises imports of rice as demand switches from the nontraded good and relative prices cause output transformation from rice to the nontraded good. In the rice experiment, rice imports increase relative to the case with all goods traded. The reasons are the same as in the cocoa case, the real appreciation pulls productive resources out of the import-competing rice sector and shifts demand towards it.

These results are not meant to imply that the presence of nontraded goods will always increase the benefits from research. Clearly, it is possible that the rise in price of nontraded goods would attract resources out of export industries and increase the consumption of exportables to a degree sufficient to cause an overall reduction in the welfare gains from research. The results do, however, successfully illustrate the fact that the presence of nontraded goods can have powerful impact on the results and may need to be taken into account. Nontraded goods also cause the breakdown of the simple shadow price rule of "evaluate at world prices". However, the simple modeling framework used in this paper provides a tractable alternative framework for evaluation.

Conclusion

In an earlier paper (Martin and Alston 1994) we advocated and demonstrated the use of a *balance of trade* or *trade expenditure function* approach to evaluate the benefits of research.

The objective of this paper was to explore the implications of the modern, dual approach in greater detail by analyzing the implications of particular types of cost-reducing technical change and contrasting the results with those obtained from traditional producer surplus techniques.

In this paper, we have analyzed the implications of alternative specifications of technical change. We first focused on the profit function component of the *balance of trade* function, evaluating the effects of selected types of technical change and comparing them with the results from producer surplus analysis. For clarity and comparability, we used linear supply functions and the corresponding normalized quadratic profit functions, using exact Taylor-Series expansions to provide graphical representations which facilitate interpretation.

In all cases considered, the profit function measures provided definitive and intuitively appealing measures of changes in producer net revenues. In several cases, the results obtained from the producer surplus approach were the same. However, in a number of important cases, the producer surplus measures were misleading because of the truncation of conventional supply curves at the vertical axis.

A very clear-cut difference between the two approaches occurred with a parallel shift in one supply curve that is locally price elastic. For a technical change that raised output of one good by 10 percent, with no other change in input or output levels, the change in profit was 10 percent of the initial value of output for this good--a result that is clearly correct given the formulation of the problem. Using producer surplus measures, the estimated change is smaller by an amount depending on the elasticity of supply. With an elasticity of 2.0, the benefits are underestimated by 50 percent because of the truncation of the supply curve at the origin.

When technical change is of an output-augmenting kind, the profit function based measures and the producer surplus measures provide identical results in the single output case. The profit function approach, however, provides an illuminating decomposition of the benefits into a component due to a pure productivity effect with given resources and a competitiveness effect, which does not depend on the supply elasticity associated with the transfer of resources from other activities. The pure productivity effect is first-order in magnitude and equal to the benefits from a parallel supply shift even though it produces a proportional shift of the supply curve and a much smaller gain in producer surplus. The competitiveness effect, which depends on the supply elasticity, is second order in magnitude, implying that accurate knowledge of the supply elasticity is less important than might be implied by the producer surplus approach.

When there are distortions, and when technical change causes changes in world prices or in the price of nontraded goods, the profit function alone does not provide a full assessment of welfare changes. In this situation, welfare changes because of changes in the terms of trade, because of changes in tariff revenues, and because of substitution in responses to price changes. A Taylor-Series expansion allows these welfare changes to be decomposed into components that have an intuitively appealing graphical interpretation.

The practicability of the *balance of trade* approach is demonstrated using a small model solved in a spreadsheet to assess the effects of single and multiple technical changes. The approach allows technical change to be specified directly in terms of the underlying behavioral parameters so that all interactions are taken into account and to take into account endogenous changes in the price of nontraded goods.

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Table 2: Basic Data for a Stylized Economy

	Production Income	Domestic Price (p)	Output Quantity (q)	World Price	Consumption Expenditure	Tariff/Tax Revenue	Exports at World Prices	Imports at World Prices
Cocoa	500	50	10	100	0	500	1000	0
Rice	1500	150	10	100	3000	500	0	1000
Other	1000	100	10	100	1000	0	0	0
Total	3000				4000	1000	1000	1000

Table 3: Local Elasticities and Parameters of the Normalized Quadratic Profit Function

	Independent Elasticities		Quadratic Profit Function Parameters		
	Cocoa	Rice	Intercepts (a_i)	Cocoa Slopes (b_{ci})	Rice Slopes (b_{ri})
Cocoa	1	-	8.0	20	$-5.\dot{3}$
Rice	-0.8	1	$2.\dot{6}$	$-5.\dot{3}$	$6.\dot{6}$
Other	-0.2	-	-	-	-

Table 4: Marshallian Elasticities and the Parameters of the AIDS Demand System

				γ_{ij}	
	Rice Demand	β	γ_i	Rice	Other
Rice	-1	-0.25	1.76	-0.399	0.399
Other	0.33	0.25	-0.76	0.399	-0.399
Income	0.67				
N	-	7.49	-0.38		

Table 5: Results of the Technical Change Experiments

		All Goods Traded			"Other" Nontraded		
	Base	Cocoa Productivity	Rice Productivity	Both Productivity	Cocoa Productivity	Rice Productivity	Both Productivity
<u>Output</u>							
Cocoa	10	12.1	9.2	11.2	11.9	9.1	11.0
Rice	10	9.7	12.1	11.8	9.4	11.6	11.0
Other	10	9.9	8.8	8.7	10.5	9.6	10.0
<u>Profit</u>	3000	3052	3158	3206	3104	3208	3301
Demand							
Rice	20	20.7	20.05	20.7	21.3	20.8	22.0
Other	10	11.0	10.1	11.1	10.5	9.6	10.0
<u>Trade Tax Revenues</u>							
Cocoa	500	605	460	561	597	457	550
Rice	500	547	398	444	597	457	550
<u>"Other" Good</u>							
Net Imports	0	1.2	1.2	2.3	0	0	0
Price	100	100	100	100	105	105	110
<u>Equivalent Variation</u>							
Money Metric	0	205	15	211	243	67	293
Compensation	0	171	131	177	190	43	218

Figure 1. Pivotal and Parallel Supply Shifts

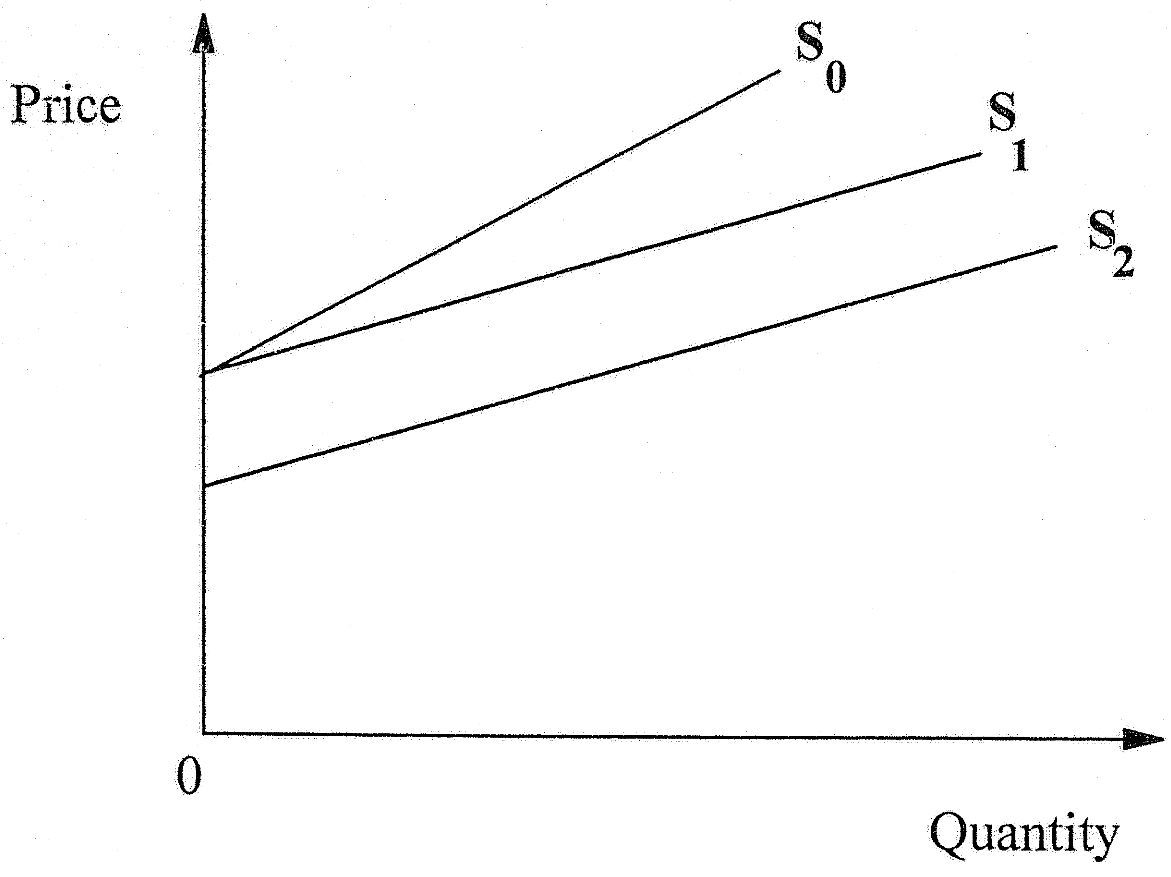
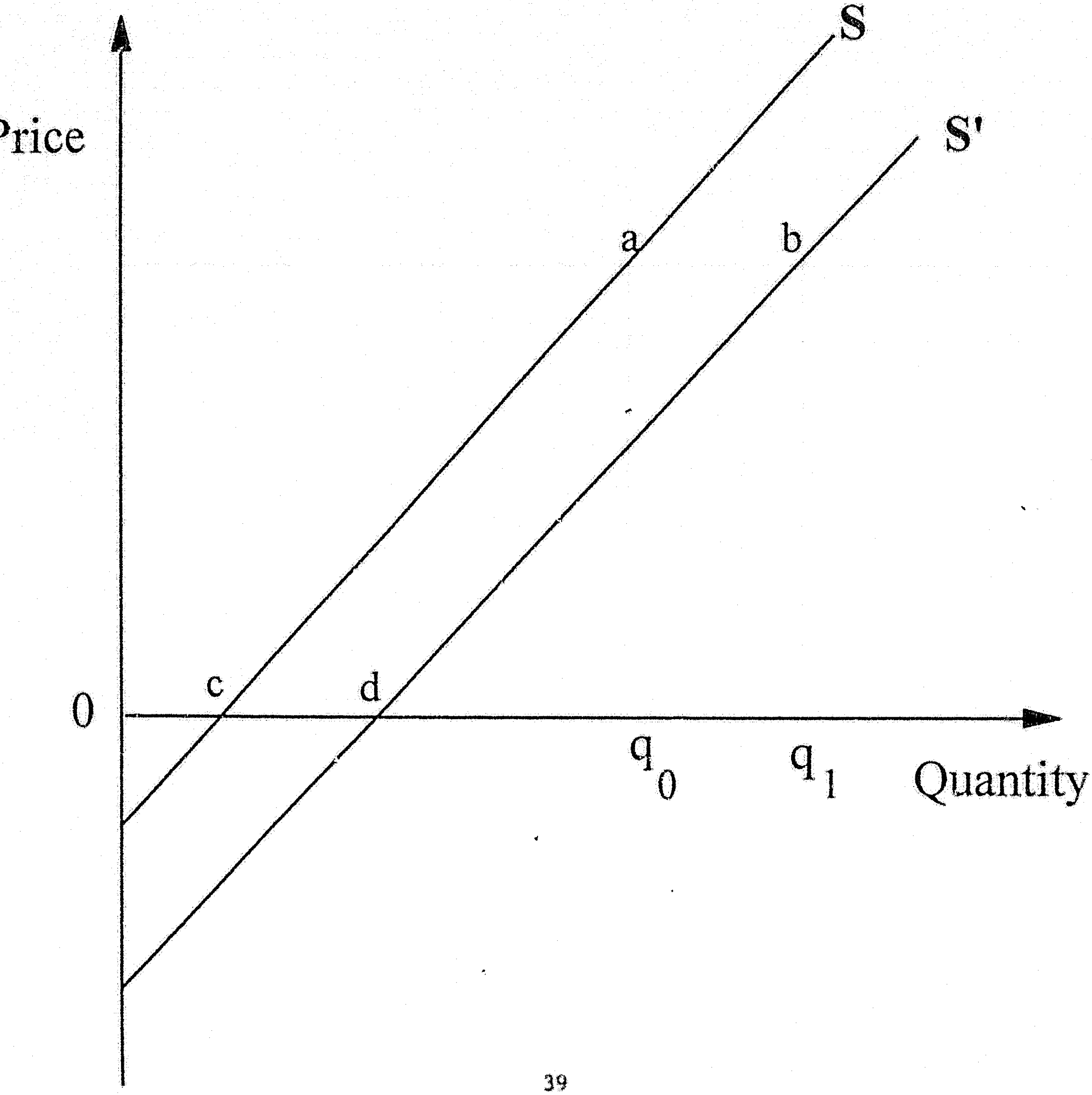


Figure 2. Gains in Profits from a Parallel Supply Shift

(a) Inelastic supply



igure 2. Gains in Profits from a Parallel Supply Shift

(b) Elastic Supply

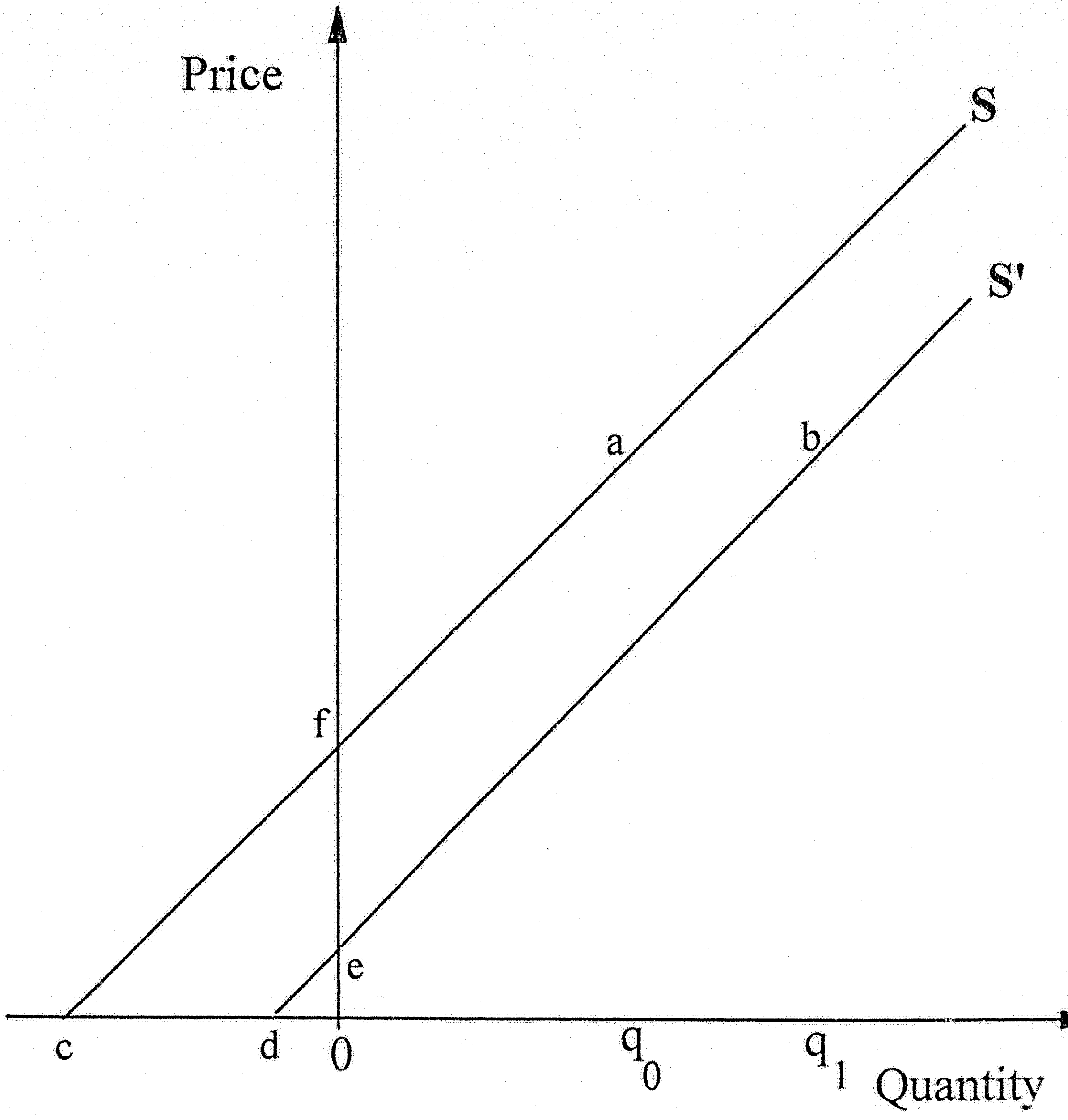


Figure 3. Gains in Profit from a Parallel Cost Reduction

(a) Inelastic Supply

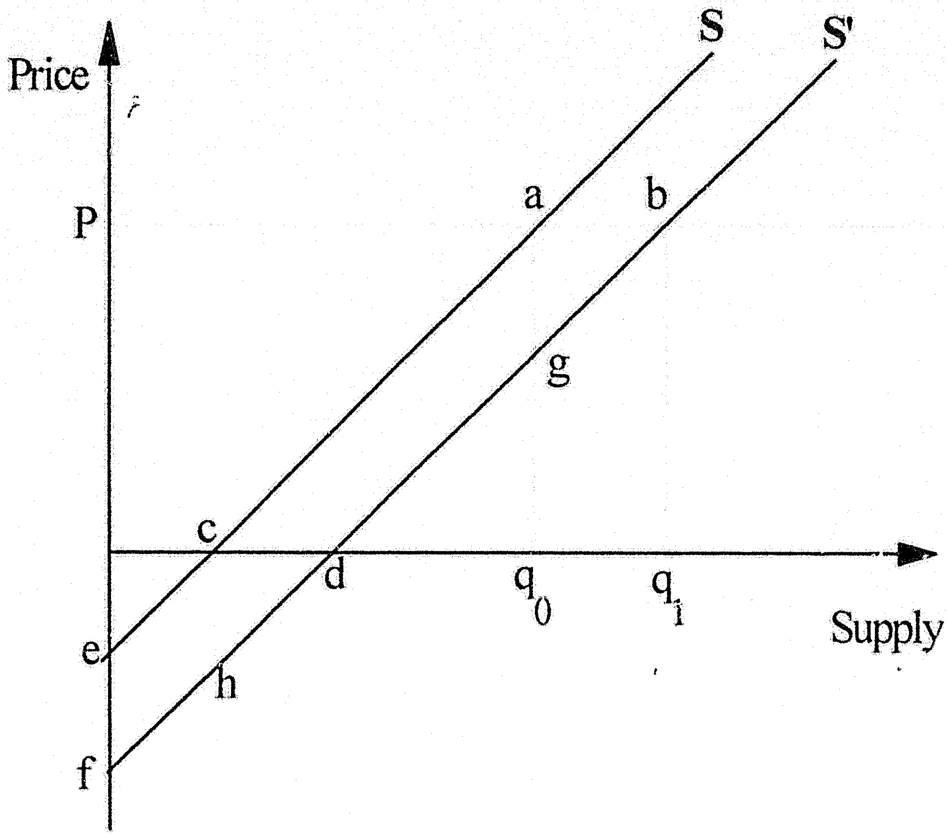


Figure 3. Gains in Profit from a Parallel Cost Reduction

(b) Unitary Elasticity

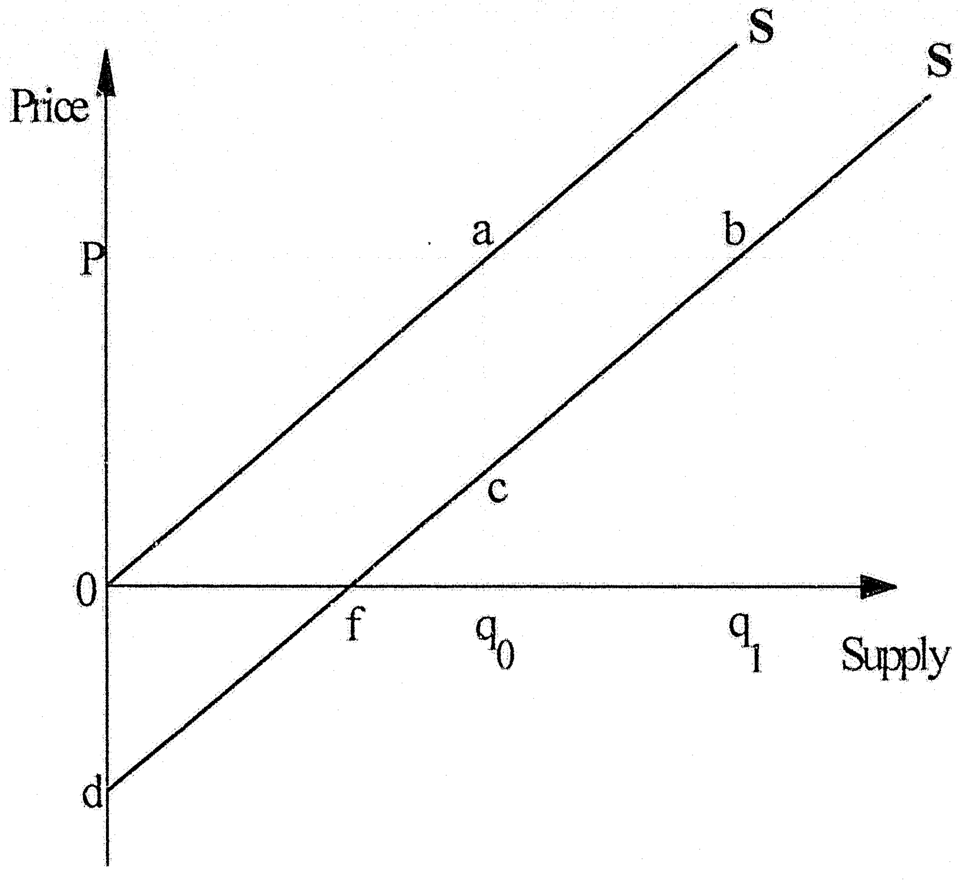


Figure 3. Gains in Profit from a Parallel Cost Reduction

(c) Elastic Supply

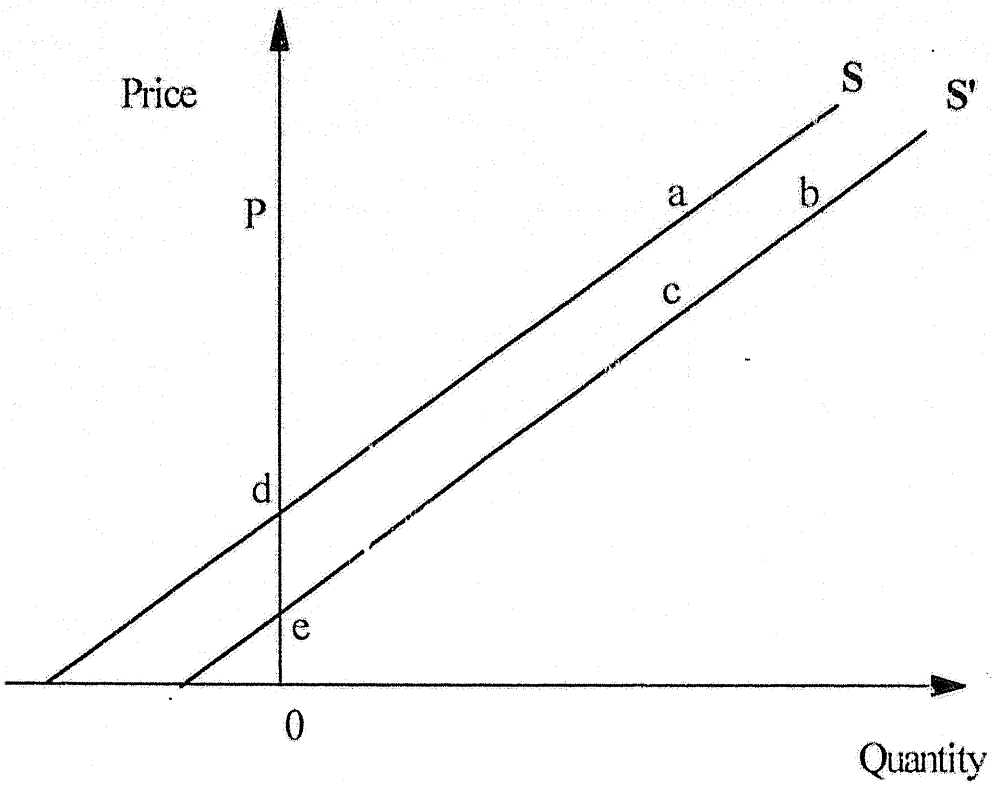


Figure 4. Output-Augmenting Technical Change

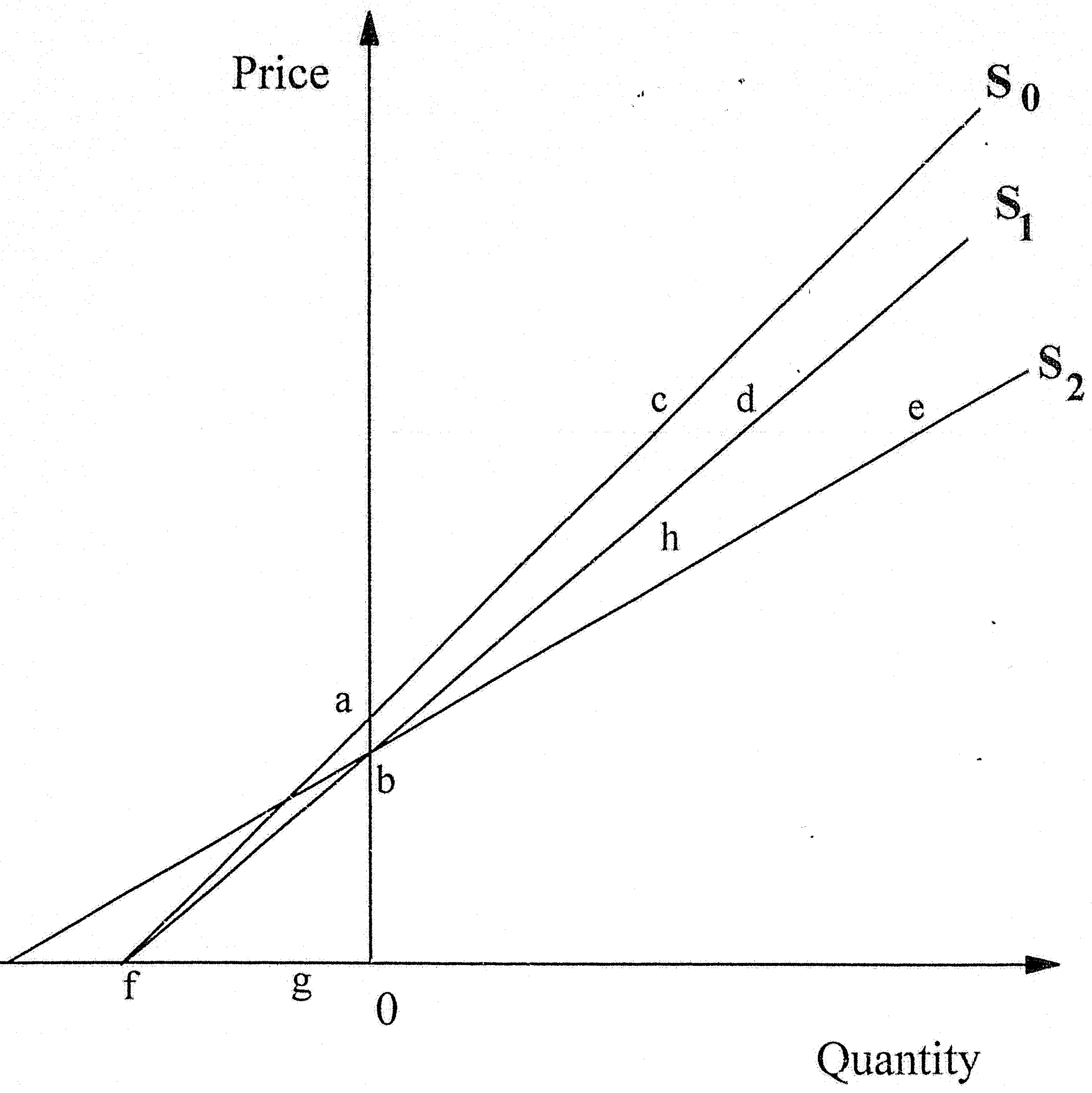


Figure 5. Effects of a Change in Price on Welfare

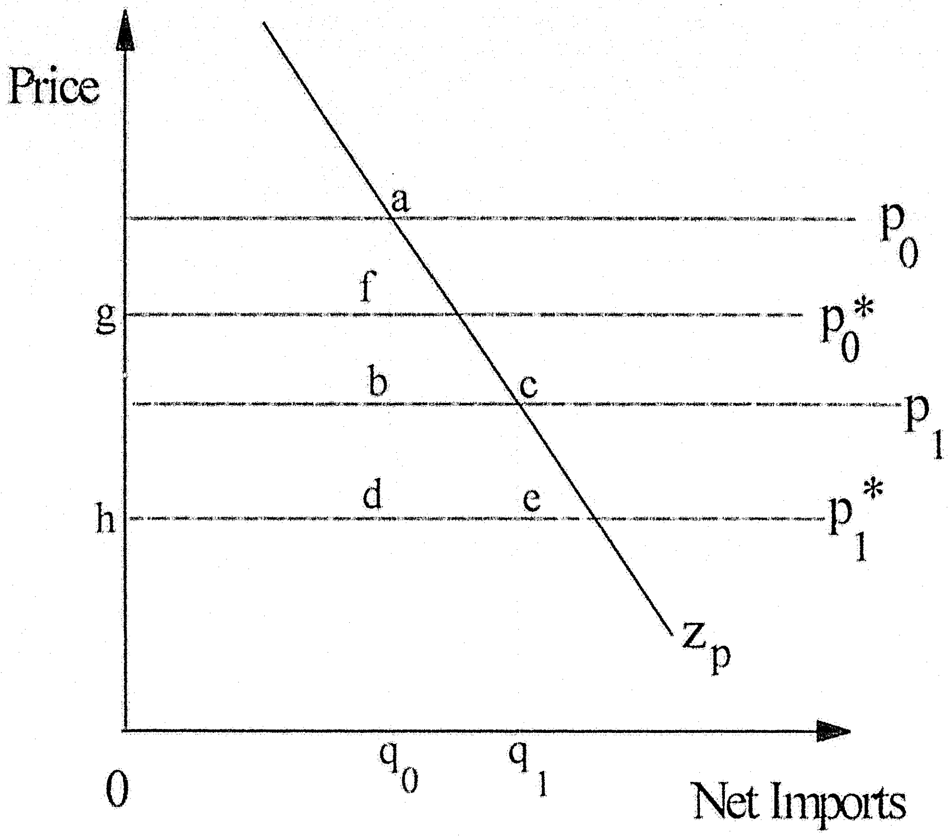
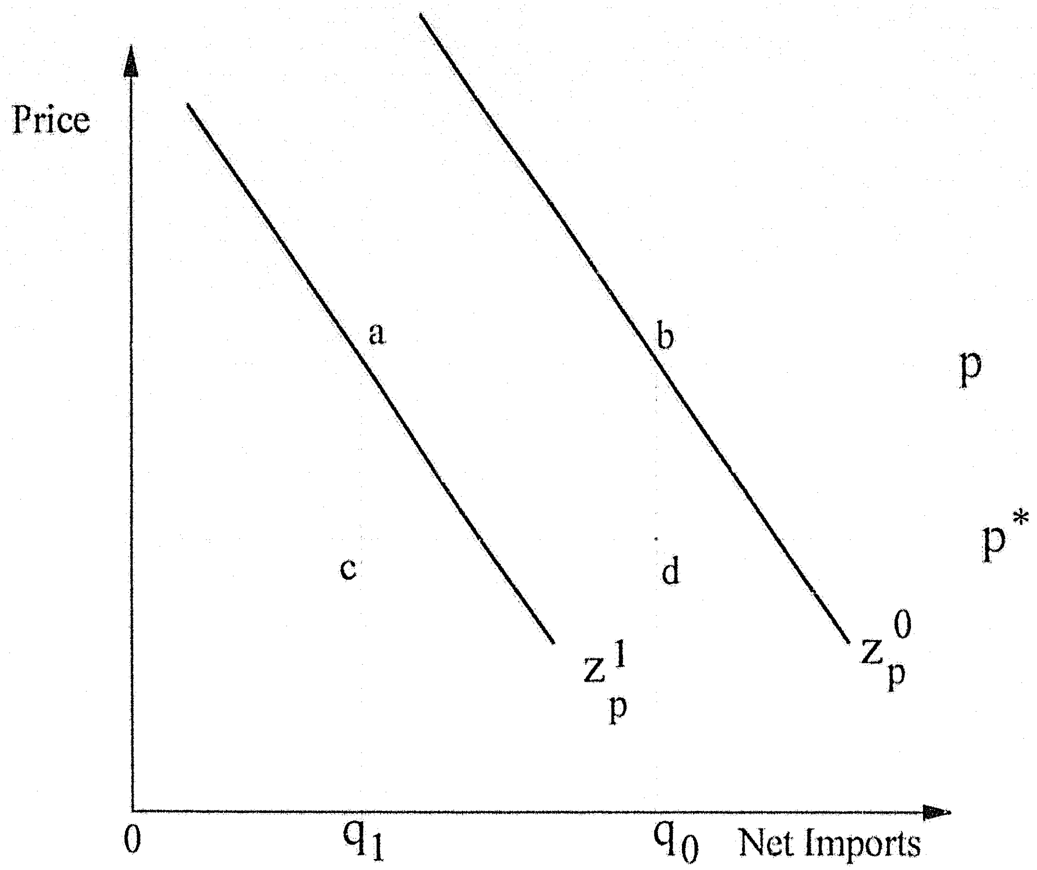


Figure 6. Effects of a Tariff in a Related Market



Appendix A
Changes in Producer Surplus and Changes in Profit from "Augmenting" Technical Change in a Normalized Quadratic Profit Function

A.1 Change in Profit

Assume a normalized quadratic profit function with a commodity of interest (x, with price p) and the numeraire (with price w), with augmenting technical change represented by τ, with $p^* = \tau p$ and $x^* = x/\tau$. The normalized profit function is:

$$\frac{\pi}{w} = \alpha_0 + \alpha_1 \frac{p^*}{w} + \frac{1}{2}\left[\frac{p^*}{w}\right]^2 \text{ or}$$
$$\pi = \alpha_0 w + \alpha_1 \frac{p^*}{w} + \frac{1}{2}\left[\frac{p^{*2}}{w}\right] = \alpha_0 w + \alpha_1 \frac{\tau p}{w} + \frac{1}{2}\frac{\tau^2 p^2}{w}. \tag{1}$$

Using Hotelling's Lemma, the supply function for x is defined as:

$$x = \frac{\partial \pi}{\partial p} = \alpha_1 \tau + \alpha_{11}\tau^2 \frac{p}{w} = \left[\alpha_1 + \alpha_{11}\tau\frac{p}{w}\right]\tau. \tag{2}$$

Similarly, differentiating the profit function with respect to τ:

$$x = \frac{\partial \pi}{\partial \tau} = \alpha_1 p + \alpha_{11}\tau\frac{p^2}{w} = \left[\alpha_1 + \alpha_{11}\tau\frac{p}{w}\right]p = \frac{x}{\tau}p. \tag{3}$$

The second derivative of the profit function with respect to the technology index is:

$$\frac{\partial^2 \pi}{\partial \tau^2} = \alpha_{11}\frac{p^2}{w}. \tag{4}$$

A second-order Taylor Series approximation to the change in profit due to technical change is:

$$\Delta\pi = \frac{\partial \pi}{\partial \tau}\Delta\tau + \frac{1}{2}\frac{\partial^2 \pi}{\partial \tau^2}(\Delta\tau)^2 = \frac{x}{\tau}p\Delta\tau + \frac{1}{2}\alpha_{11}\frac{p^2}{w}(\Delta\tau)^2. \tag{5}$$

Defining $w = 1$ and the inital values as $\tau_0 = 1$ so that $p_0^* = p_0$ and $x_0^* = x_0$,

$$\Delta\pi = x_0 p\Delta\tau + \frac{1}{2}\alpha_{11}p^2(\Delta\tau)^2 = p\Delta\tau\left[x_0 + \frac{1}{2}\alpha_{11}p\Delta\tau\right]. \tag{6}$$

A.2 Change in Producer Surplus—Elastic Supply

From equation (2), setting $w = 1$, the supply function for x is defined as:

$$x = \frac{\partial \pi}{\partial p} = \alpha_1 \tau + \alpha_{11} \tau^2 \frac{p}{w} = \left[\alpha_1 + \alpha_{11} \tau \frac{p}{w}\right] \tau . \tag{7}$$

The intercept of the supply function on the price axis is $\beta = - \alpha_1/\alpha_{11}\tau$. Initially, when $\tau = \tau_0 = 1$, $\beta = \beta_0 = - \alpha_1/\alpha_{11}$. After technology changes, when $\tau = \tau_1$, $\beta = \beta_1 = - \alpha_1/\alpha_{11}\tau_1$.

The producer surplus before and after the technological change (i.e., for $i = 1$ or 2, respectively) is given by $PS_i = (p - \beta_i)x_i/2$. Thus, the intital producer surplus is:

$$PS_0 = (p - \beta_0)x_0/2 = \left[p + \frac{\alpha_1}{\alpha_{11}}\right] x_0/2 = (\alpha_1 + \alpha_{11} p)^2/2\alpha_{11} . \tag{8}$$

The producer surplus after the technological change is:

$$PS_1 = (p - \beta_1)x_1/2 = \left[p + \frac{\alpha_1}{\alpha_{11}\tau_1}\right] x_1/2 = (\alpha_1 + \alpha_{11} \tau_1 p)^2/2\alpha_{11} . \tag{9}$$

The change in producer surplus due to the change in technology is given by:

$$PS_1 - PS_0 = \left[(\alpha_1 + \alpha_{11}\tau_1 p)^2 - (\alpha_1 + \alpha_{11} p)^2\right]/2\alpha_{11} = \alpha_1 p(\tau_1 - 1) + \tfrac{1}{2}\alpha_{11} p^2(\tau^2 - 1). \tag{10}$$

Using $\tau_1 - 1 = \Delta\tau$, and $(\tau_1^2 - 1) = 2\Delta\tau + (\Delta\tau)^2$, this simplifies to

$$PS_1 - PS_0 = \alpha_1 p \Delta\tau + \alpha_{11} p^2 \Delta\tau + \tfrac{1}{2}\alpha_{11} p^2 (\Delta\tau)^2 = p\Delta\tau\left[x_0 + \tfrac{1}{2}\alpha_{11} p \Delta\tau\right]. \tag{11}$$

This is identical to the measure from the profit function, given in equation (6).

A.3 Change in Producer Surplus—Inelastic Supply

From equation (2), setting $w = 1$, the supply function for x is defined as:

$$x = \frac{\partial \pi}{\partial p} = \alpha_1 \tau + \alpha_{11} \tau^2 \frac{p}{w} = \left[\alpha_1 + \alpha_{11} \tau \frac{p}{w}\right] \tau . \tag{12}$$

The intercept of the supply function on the quantity axis is $\gamma = \alpha_1\tau$. Initially, when $\tau = \tau_0 = 1$, $\gamma = \gamma_0 = -\alpha_1$. After technology changes, when $\tau = \tau_1$, $\gamma = \gamma_1 = -\alpha_1\tau_1$.

The producer surplus before and after the technological change (i.e., for $i = 1$ or 2, respectively) is given by $PS_i = p(x_i + \gamma_i)/2$. Thus, the intital producer surplus is:

$$PS_0 = p(x_0 + \gamma_0)/2 = p(\alpha_1 + \alpha_{11}p + \alpha_1)/2 = p(2\alpha_1 + \alpha_{11}p)/2. \tag{13}$$

The producer surplus after the technological change is:

$$PS_1 = p(x_1 + \gamma_1)/2 = p\left(\alpha_1\tau_1 + \alpha_{11}\tau_1^2 p + \alpha_1\tau_1\right)/2 = p\left(2\alpha_1\tau_1 + \alpha_{11}\tau_1^2 p\right)/2. \tag{14}$$

Let $\tau_1 = 1 + \Delta\tau$, then

$$\begin{aligned} PS_1 &= \tfrac{1}{2}p(1 + \Delta\tau)(2\alpha_1 + \alpha_{11}(1 + \Delta\tau)p) \\ &= \tfrac{1}{2}p(2\alpha_1 + \alpha_{11}p) + \tfrac{1}{2}p^2\alpha_{11}\Delta\tau + \tfrac{1}{2}p(2\alpha_1 + \alpha_{11}p + \alpha_{11}p\Delta\tau)\Delta\tau \\ &= PS_0 + (\alpha_1 + \alpha_{11}p)p\Delta\tau + \tfrac{1}{2}\alpha_{11}p^2(\Delta\tau)^2. \end{aligned} \tag{15}$$

Thus, the change in producer surplus due to the change in technology is given by:

$$PS_1 - PS_0 = \alpha_1 p\Delta\tau + \alpha_{11}p^2\Delta\tau + \tfrac{1}{2}\alpha_{11}p^2(\Delta\tau)^2 = p\Delta\tau\left[x_0 + \tfrac{1}{2}\alpha_{11}p\Delta\tau\right]. \tag{16}$$

This, also, is identical to the measure from the profit function, given in equation (6)