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Perceived Productivity, Forgone Future Farm Fruitfulness and Rural Research Resource Rationalization

INTRODUCTION

Conventional productivity measures may account for only part of the inputs used in, or output from, agricultural production. On the input side, the stock of natural resources is rarely included fully in the productivity calculus, and sometimes a significant element of measured productivity growth may be attributed to a faster rate of exploitation of a non-renewable natural resource. On the output side, externalities such as environmental amenities are typically ignored.

For instance, land clearing and the introduction of improved pasture and inorganic fertilizers in the Australian grazing industry allowed a higher stocking rate and greater output of food and fibre products during the past 100 years. But the same innovations have also led to increased rates of soil erosion, soil compaction and impermeability, soil acidification and dryland salinity, and a reduction in the long-term carrying capacity of the land. A productivity measure that accounted for the reduced stock of natural resources (forgone future farm fruitfulness) associated with the greater rate of measured output would indicate a lower productivity gain, if not a productivity loss, due to what many have perceived as the great breakthrough in Australian pastoral history.[1] Rosaasen and Lokken (1994) document a similar experience in the Canadian prairies where, they argue, the land has been 'mined' as a consequence of government policies and programmes. They suggest that too little attention has been paid to natural resource preservation in decisions about developing western Canada.[2] Of course, not all land degradation has a productivity consequence and some types of development can lead to increased long-term productive potential; the issue is whether such effects have been taken properly into account.[3]

On the output side, we typically exclude unpriced outputs from productivity calculations. Environmental amenities associated with agriculture (or alternative uses of land such as forestry) are occasionally important, and changes in the product mix or the technology of production might involve a reduction or

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an increase in the quantities of positive externalities provided as environmental amenities. Of course, externalities from agriculture might be positive (for example, pollination of crops; reduction of pest populations) or negative (for example, air and water pollution; increased natural resistance by pests). The important point is that changes in technology may involve changes in these unmeasured outputs leading to over- or understatement of the growth in output using conventional measures.

These arguments connect closely to work by Schultz and Griliches on productivity measurement and interpretation. Almost 40 years ago, Schultz (1956, p. 758) wrote: 'The analytical task, as I see it, is to re-establish a strong and satisfactory linkage between input and output over time. In our efforts to do this, we would do well to place before us and keep in mind the characteristics of an *ideal input–output* formula for this purpose. It would be one where *output over inputs* ... stayed at or close to one. The closer we come to a one-to-one relationship in our formulation, the more complete would be our (economic) explanation'.[4]

In this paper we argue that there has been a tendency to develop and adopt technologies that result in a faster rate of exploitation of the unmeasured natural resource stock, and which involve larger quantities of harmful externalities, so that our conventional measures have tended to overstate output growth and to understate input growth, both errors leading to overstatement of the growth of more narrowly defined total factor productivity. For similar reasons, rates of return to research may have been overstated and, while we have no doubt that public-sector agricultural research has often paid handsome dividends and will continue to do so, more accurate measures of the benefits might lead to a different research mix and a higher overall social pay-off. We illustrate the ideas using simple diagrams. We suggest an alternative way to think about agricultural research, technical change and productivity, and offer some preliminary thoughts about ways to improve empirical work directed towards productivity assessment and for research evaluation and priority setting.

PERCEIVED PRODUCTIVITY

A conventional productivity index is a measure of output dividend by a measure of inputs. A *partial* factor productivity (*PFP*) index divides the index of total output (Q) by an index of the quantity of a particular input, or input aggregate, (X_i):

$$PFP_i = \frac{Q}{X_i}.$$

Changes in *PFP* may arise from changes in technology (r) or changes in other (unmeasured) inputs (X_j) given a production function defined by:

$$Q = f(X_1, X_2, \ldots, X_n; r).$$

A *multi-factor* productivity (*MFP*) index accounts for a sub-set, m of the n inputs, dividing the index of output by an input index given by $X^M = m\ (X_1, \ldots, X_m)$:

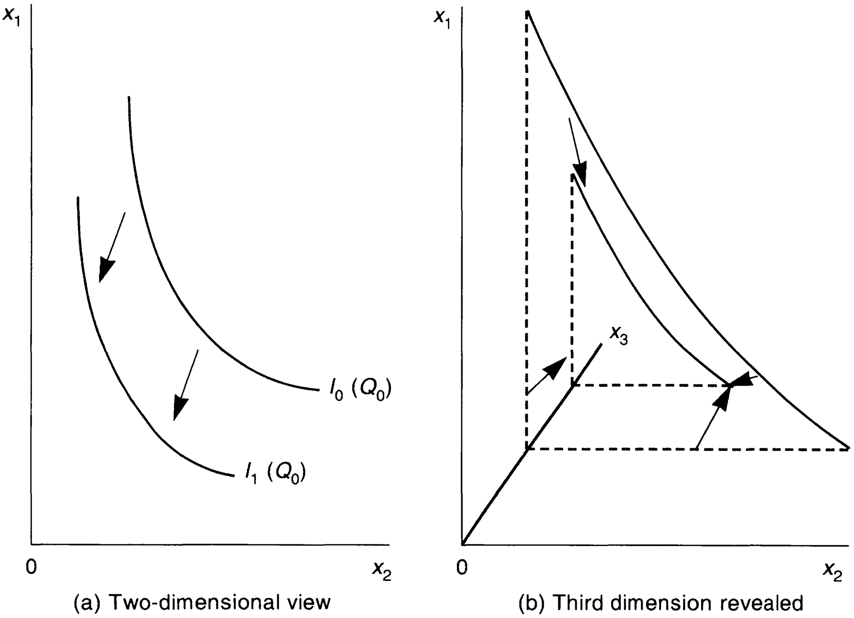
$$MFP^M = \frac{Q}{X^M}.$$

This omits fewer inputs that the *PFP* measure but only changes the degree of the problem of interpreting productivity measures where some inputs are omitted; it does not eliminate that problem. A truer measure of changes in productivity attributable to changes in technology is given when *all* inputs are properly accounted for; that is, all inputs are included and ideal index number procedures are used so that index number problems are minimized. A *total factor* productivity *TFP* index includes an index of all n inputs used in production, X^n:

$$TFP = MFP^N = \frac{Q}{X^N}.$$

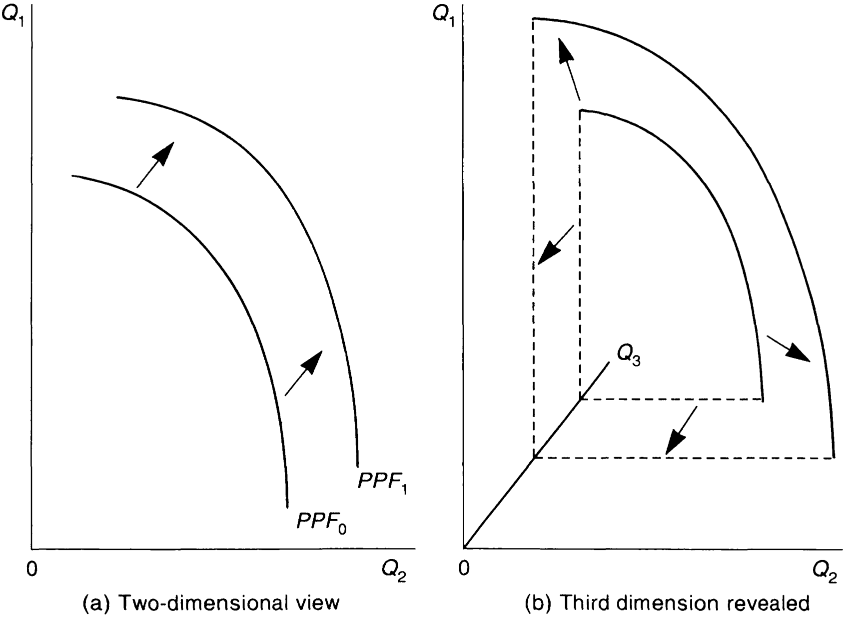
This *TFP* index accounts for the effects of changes in quantities of inputs, though there may still be measurement problems arising from not properly accounting for changes in input quality, for instance.[5] When problems relating to the measurement of included inputs and outputs are eliminated, changes in measured *TFP* may be taken to reflect changes in technology. But what causes such changes? Schultz (1956) and Griliches (1963) suggested that technological change (including increases in farmers' human capital and some other input quality changes) may be thought of as a consequence of expenditures by someone on 'other' inputs (such as education and research and development). Hence, when the latter are included in a more general specification of the production function, the ideal input–output ratio is always unity; all output changes are now attributable to measured input changes and there is no productivity growth. On this view, a conventional *TFP* index that does not include certain 'other' inputs that affect production is incomplete, and should more correctly be termed an *MFP* index in recognition of that fact. Indeed, all of the empirical so-called *TFP* indexes in the literature are almost surely misnamed (and thereby often misinterpreted) in that some inputs have been excluded.

What are the implications for practical productivity measurement? The most important affect interpretation. Carefully constructed partial measures, including *MFP*s of various types, are legitimate indicators of the changes in measured output attributable to changes in the measured and, by subtraction, the unmeasured factors. One challenge is to be sure we attribute this residual to the appropriate unmeasured factors. Analysts have often assumed that the only unmeasured factors in a conventional productivity index are those associated with local agricultural research (and, perhaps, education and extension). Some of the changes in measured productivity might also be due to unmeasured private-sector R&D, economies of scale, international or interregional technology spillovers, or unmeasured input or output quality changes arising from factors other than R&D. They might also be due to unaccounted changes in



(a) Two-dimensional view
(b) Third dimension revealed

FIGURE 1 *Consequences of omitting an input*



(a) Two-dimensional view
(b) Third dimension revealed

FIGURE 2 *Consequences of omitting an output* current service flows from the stock of natural resources, or in that stock itself (omitted inputs) or changes in the supply of environmental amenities or other externalities (omitted outputs), which is the particular focus of this paper.[6]

The omission of relevant inputs or outputs can lead to the illusion of technological change, as Figures 1 and 2 illustrate.[7] Figure 1 represents a single, homogeneous output and multiple inputs. Panel (a) represents a two-dimensional view of production in which we move from isoquant I_0 to I_1, holding output fixed at Q_0, an apparent improvement in productivity. In panel (b), the third dimension is revealed. The saving of inputs X_1 and X_2 in going from I_0 *to* I_1 was due to an increased use of the third input, X_3, along a stable three-dimensional isoquant. A conventional characterization of the two-dimensional perspective is that technology has changed: the isoquant has shifted, and we can quantify that shift as a productivity improvement. But, when it is viewed properly in all its dimensions, there has been no shift of the isoquant, which is stable; only from an overly narrow perspective does it seem that the isoquant is moving.

Figure 2 represents multiple outputs. Panel (a) represents a two-dimensional view of production in which we move from production possibility frontier PPF_0 to PPF_1, an apparent improvement in productivity. In panel (b), the third dimension is revealed. The increase in outputs Q_1 (say, food) and Q_2 (say, fibre) in going from PPF_0 to PPF_1 was simply due to a reduction in output of the third good, Q_3 (say, fauna and flora) along a stable three-dimensional frontier. Again, the appearance of shifting curves, when in fact the curves are stable, is due to an overly narrow perspective.

THE INTERTEMPORAL META-PRODUCTION FUNCTION

The analysis above is static; it deals only with a single production period. An alternative way to use three-dimensional panels in Figures 1 and 2 is to regard the third dimension as referring to inputs or outputs in a future time period. Thus, in panel (1b), the same output today may be achieved with less current inputs but at the expense of what would have been future inputs; in panel (2b), greater output today may be achieved at the expense of future output. But again, productivity has not changed, we have simply chosen different combinations of inputs or outputs along a given (intertemporal) set of production possibilities.

Indeed, we can conceive of an *intertemporal meta-production function* as a dynamic relationship that defines all of the current and future production and consumption possibilities. By choosing the mix of current consumption, production and investment, we determine which sub-set of opportunities is available for the next period and beyond. In particular, research and other capital investments involve a choice to consume or produce less in the current period in order to be able to produce and consume more later. Conversely, a faster rate of current consumption of non-renewable resources is a decision to produce and consume more now and less later. On the *static* meta-production function, we select a particular technology and input combination from a menu of available alternatives; on the *intertemporal* meta-production function we choose a time path of technologies and flows of production, consumption and investment. Clearly, this involves some serious abstractions from reality, perhaps the most important being the presumption that all of the outcomes from alternative capital investments, in research in particular, for the entire future are known. Adding unavoidable uncertainty makes the problem harder, but the main ideas provided by the more abstract model are largely unaffected.[8]

Utilizing the ideas of Schultz (1956) and Griliches (1963), the intertemporal meta-production function is the stable multi-period relationship that reflects the entire set of (maximized) production possibilities, along which the output–input ratio is constant.[9] Corresponding to this production function there would be a multi-period measure of total factor productivity that would involve aggregating all outputs and all inputs over all time. In keeping with the arguments above, if that indexing procedure has been done correctly, the intertemporal total factor productivity index would always be unity.

This intertemporal view of *TFP* is consistent with the notion that there are fundamental laws of nature that can be revealed, but not revised, by investing in R&D and human capital accumulation. The intertemporal meta-production function is simply the envelope of all currently known and unknown (but unchanging) production possibilities.[10] The false appearance of greater current productivity might arise if a poor job is done of accounting for associated changes in future outputs and inputs. In particular, the normal, single-period *TFP* measures implicitly assume all future input and output quantities are constant (or at least independent of current quantities).

Unmeasured inputs and outputs in conventional productivity measures may or may not be associated with market failures. For instance, the fact that conventional productivity measures do not take account of the effects of farmers' current actions on their farms' future fertility should not be taken to mean that there is a market failure. There is no reason to presume, as a matter of course, that these effects are misunderstood or ignored by farmers in making decisions, even if they are ignored by economists. There is much more evidence that farmers are rational, while economists and their models may not be, than the converse. It may be privately and socially optimal for farmers to speed up the rate of consumption of their stocks of farm fertility, with an associated increase in conventionally measured (short-run) productivity, under some conditions. On the other hand, some unmeasured outputs in conventional productivity indexes are surely associated with market failures, and these unmeasured outputs are often linked with public goods and externalities. This arises more clearly in circumstances where property rights are ill-defined than in cases where farmers choose to degrade their own land. But in some cases farmers (and others) are ignorant of the size and nature of the long-run effects of certain production practices. Such ignorance may be thought of as a micro-level analogue of the more comprehensive technological uncertainty discussed above, that may well involve uncertain and essentially irreversible risks to the natural resource base.

RESEARCH RETURNS REVISITED

The systematic misstatement of productivity due to the omission of relevant effects on future or current inputs and outputs is likely to have contributed to corresponding errors in the rates of returns to research computed using either those productivity indexes or the quantity and price indexes used in their construction. In addition, some special problems may be encountered when those measurement problems also involve externalities and market failures.

The literature on research benefit measurement contains little about the treatment of research benefits in the presence of externalities associated with production, and even less about externalities that may be affected by research. Alston *et al.* (1994) made some preliminary observations about the issue, relating it to the general question of measuring research benefits in the presence of more general market distortions. Figure 3 represents the market for a commodity, the production of which entails a negative externality. Initially consumption and production of Q_0 at price P_0 is determined by the intersection of supply (according to marginal private costs, *MPC*) and demand *D*. There is an externality of *E* per unit associated with production, which is the difference between marginal social cost *MSC* and *MPC*. In Figure 3, technology may change so as (1) to reduce marginal private cost with no effect on the external-

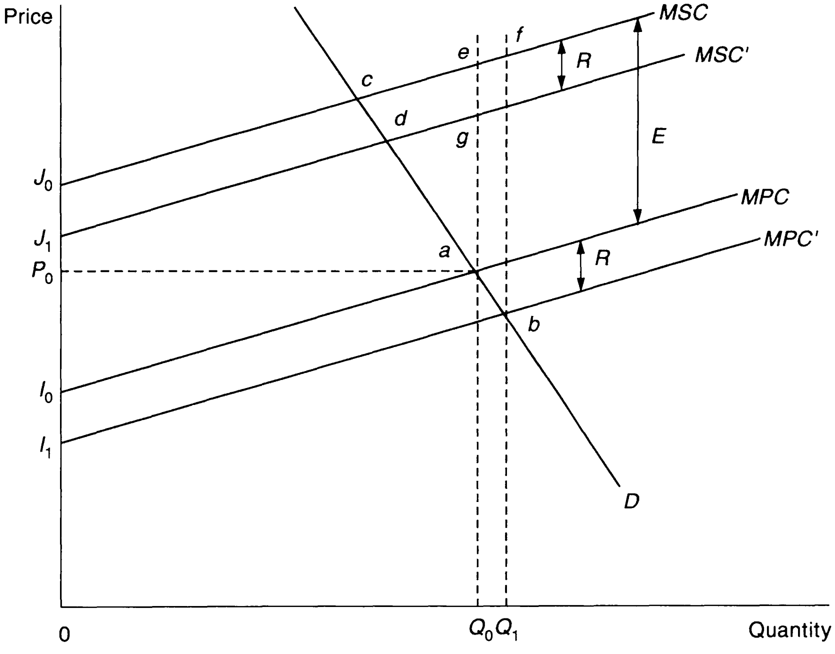


FIGURE 3 *Research benefits with an externality*

ity (that is, *MPC* shifts by *–R* per unit to *MPC′* and *MSC* shifts, by the same amount, to *MSC′*); (2) to reduce marginal private cost with an equivalent increase in the externality effect so that marginal social cost is unchanged (that is, *MPC* to *MPC′*; *MSC* unaffected); or (3) to reduce marginal social cost by reducing the externality effect so that marginal private cost is unchanged (that is, *MSC* to *MSC′*; *MPC* unaffected). Of course, there are other possibilities involving unequal changes in both private and social costs. Conventional measures of research benefits using standard (private) productivity measures would find that cases (1) and (2) were equal (which they are from the private perspective of producers and consumers, but are not when the externality is taken into account) and that the third case was inferior, with no benefits.

Since the curves are drawn as linear and shifting in parallel, the welfare effects can be shown using simple geometry. In cases (1) and (2) the private benefit is equal to area I_0abI_1, while in case (3) it is zero. Net social welfare increases by area J_0cdJ_1 in case (1) when private and social costs change by an equal amount and the deadweight cost of the externality is unaffected; it decreases by area *efba* in case (2), the increase in deadweight costs due to the externality when social costs do not change and output increases from Q_0 to Q_1. Social welfare increases by the largest amount of all, area J_0egJ_1, in case (3) when research reduces the externality but does not affect production. Thus the ranking of the three types of technological change from a social welfare perspective is entirely different from the ranking from a private (producer and consumer perspective. Specifically, the rankings are as shown in Table 1.

The same point can be illustrated algebraically, in an approach similar to that used by Alston and Martin (1994) to measure research benefits in the presence of price-policy distortions. Define the deadweight cost due to externalities, *D*, as the difference between net social benefits from production and consumption, W^s, and net private benefits from production and consumption (producer surplus plus consumer surplus), W^p, so that

$$W^s = W^p - \Delta D.$$

Then express the equation in first difference form to represent the effects of a discrete change in technology.

$$\Delta W^s = \Delta W^p - \Delta D.$$

TABLE 1 *Private and social rankings of different types of technical change*

	MSC	*MPC*	Private	Social
Case (1)	*–R*	*–R*	1	2
Case (2)		*–R*	1	3
Case (3)	*–R*		3	1

Thus the social benefit from a given change in technology is equal to the private benefit minus the effect of the change in technology on the deadweight cost of the externalities.

Private-sector investors will be relatively uninterested in research that leads to technical changes of type (3) (with no private benefits but benefits to society from reduced externalities) and quite interested in changes of type (2) (with some private benefits but net social costs). In the particular case shown in Figure 3 and Table 1, the private-sector ranking of projects is very different from the social ranking. Thus, while there may be a tendency for the private sector to underinvest from society's viewpoint in agricultural research in general (for well known reasons), there will be an even greater tendency to underinvest in technological changes that involve mitigation of externalities. There may also be a tendency to overinvest (at least to invest relatively intensively) in technologies that achieve private benefits partly through the creation of externalities. For example, it would be expected that pesticide-intensive production practices that might pollute air or groundwater would be more actively researched by chemical companies than the use of biological controls.

COMPETITIVENESS CONSIDERATIONS

Discussions of competitiveness tend to play down more fundamental economic criteria such as comparative advantage, and to focus on the short run. The issues raised in this paper illustrate the contrast between a narrow focus on short-run competitiveness and a broader view of the longer-run situation. It is possible to become more competitive, for a while, through a semblance of greater productivity by choosing more extractive production patterns and processes, which involve a faster rate of consumption of the fixed stock of natural resources and, perhaps, forgoing current environmental public goods such as clean air or wilderness reserves. While many of these perspectives are obvious, the choice by government of the types of research and development work to undertake, and the types of technology and production mix to encourage, may involve subtle, implicit choices about the long-term sustainability of production choices that are difficult to identify, let alone quantify. Similarly, taking a longer and broader view of competitiveness, a government might choose to encourage a growth path that involves building productive capacity and comparative advantage in directions that account more fully for unpriced natural resources. Such considerations may be regarded as esoteric, for rich nations only to be concerned with, though a case can be made (as illustrated for sub-Saharan Africa by Crosson and Anderson, 1994) that they are even more imperative for less-developed countries.

How do we measure competitiveness or changes in competitiveness? One approach is to use total factor productivity indexes of the types discussed in this paper; but it is important to include all of the relevant current and future inputs and outputs as completely as possible in order to have a measure of competitiveness that more comprehensively reflects social opportunity costs. From a narrow national, or regional, perspective the relevant inputs and outputs would exclude externalities borne by other nations or regions. Even a comprehensive vision of competitiveness that correctly accounts for all local costs might not be fully compatible with global considerations. Obviously, measuring productivity properly cannot eliminate international spillover problems unless a multinational approach is taken. But correct measures remain necessary to achieve local objectives and to understand international effects (Solow, 1992).

PRACTICAL PERSPECTIVES

The ideas in this paper are preliminary and, in many aspects, not ready for practical implementation. The multi-period perspective on the meta-production function may help us to think more clearly about how to interpret single-period productivity measures and measures of research benefits, but it does not offer much prospect of practicable implementation, especially when we add considerations of unavoidable uncertainty. There are, nevertheless, some practical implications that can be applied, at least in principle, in the context of single-period approximations to the multi-period measures.

It is possible, in principle, to augment current-period measures of productivity, and research benefits, with measures of externalities from production as well as estimates of both current service flows from stocks of natural resources, and induced changes in those same stocks (that is, treating resource stocks consumed in production, which represent reduced future service flows, like any other current input). While an accurate assessment of changes in natural resource stocks necessarily involves many intractable multi-period measurement issues one might hope to avoid by using a single-period analysis, an approximation based on available information is likely to be more accurate than assuming that resource stocks are unchanging.

CONCLUDING COMMENTS

Conventional static productivity measures often exclude relevant inputs and outputs. As proposed by Schultz (1956) and Griliches (1963), an ideal productivity index is always equal to one. Conventional productivity growth, then, reflects measurement error relative to the 'ideal index' output growth, due to important factors not being accounted for. Some may be simply a difference between what the farmer knows, and takes into account, and what the economist measures, whereas some may be associated with either positive or (more likely) negative externalities that are disregarded by decision makers, as well as many economists. In either case the productivity index is likely to be misinterpreted, as a measure of increased productive capacity, and will misstate the benefits from a particular omitted variable (such as agricultural R&D) unless care is taken to account fully for the effects of all the other omitted variables, including those associated with natural resources.

Accurate productivity assessment and appropriate policy advice require measures that take better account of the changes in the natural resource stock associated with different agricultural production technologies and product mixes, and that account more clearly for externalities and other market distortions. High rates of return to public-sector agricultural research can be sustained, in developed and developing countries alike, but realizing the potential social pay-off requires closer attention to the environmental factors that have been omitted from analysis in the past.

NOTES

[1] For instance, Chisholm (1992, p. 16) reports a 'guesstimate' of the cost to Australia of lost production attributable to land degradation, of $600 million per year (1988–9 dollars). This translates into a loss of $4800 per farm per year from net farm income of $34 281 per farm per year (1988–9 dollars). The facts about the economic consequences of Australian agricultural development this century are still disputed, as indicated by the differing perspectives offered by Chisholm and Dumsday (1987), Cocks (1992) and White (1993), and much scope exists for refining understanding of the processes involved.

[2] In a study of 50 years of Minnesota (USA) corn yields, Cardwell (1982) suggests that, while productivity grew, in terms of measured yields rising from 2010 kg/ha in the pre-1930s to 6290 kg/ha by the early 1980s, there has been progressive erosion of productive potential. He found that the 'long-term negative aspects of changing cultural and management practices ... have highlighted the substitution of inorganic N for organic sources and an estimated 21% loss in yield potential due to loss of soil and organic matter' (Cardwell, 1982, p. 990). This finding might not be representative of the mid-west, or even Minnesota.

[3] Such problems are not confined to developed-country agriculture. Anderson and Thampapillai (1990) review problems of soil conservation in developing countries. Public-sector irrigation projects provide another example. Often projects have involved a comparatively massive injection of government funds, with damage to river systems and associated natural resources, in order to achieve a faster rate of output from the irrigated land over a relatively short period (say, less than 100 years) during which problems of siltification, salinization and desertification progressively erode the measured productivity gains, leading to a possibly permanent or irreversible destruction of productive capacity.

[4] Schultz attributed this idea to Griliches. Indeed, only five years later, Griliches (1961, p. 446) wrote: 'As I understand it, we are interested in "productivity" because we are interested in understanding ... the forces that affect "output" because we hope, ultimately, to be able to affect them for the better. We approach this task first by trying to take into account the "obvious" factors: changes in labor and capital (and other materials if our output measures are gross). We measure these inputs as best we can, aggregate them using some sensible weighting procedure and get a "total input" index. We compare this index with our output index and call any discrepancy "productivity." Crudely speaking then, the "productivity" indexes measure the changes in output that have not been accounted for by the analyst's input measures. It is a measure of our ignorance, of the unknown, and of the magnitude of the task that is still ahead of us. The task is to open this box, whose dimensions we know, and see what is inside of it. Is it return to scale, the "size" of the market, changing market structure, changing quality of inputs, "pure" technological change, or something else besides all that?'

[5] An analogous set of arguments applies to the index of aggregate output:

$$Q = g\,(Q_1, Q_2, \ldots, Q_n, \tau).$$

[6] Several previous studies have raised the issue of productivity measurement and natural resource accounting, including, for example, Lynam and Herdt (1989), Oskam (1991), Solow (1992), Antle and McGuckin (1993), Crosson and Anderson (1993) and Rosaasen and Lokken (1994). Anderson (1993) offers further observations on the related literature on sustainable agricultural systems. The recent work of Ehui and Spencer (1993) provides a concrete example (in this case from Nigeria) of an attempt to include in *TFP* indexes key aspects of the natural resource stocks (although not externalities) in assessment of agricultural productivity changes in African farming systems.

[7] Whether a particular omission is regarded as an omitted input or output is sometimes somewhat arbitrary.

[8] Including uncertainty explicitly in the analysis even of single-period meta-production functions adds considerable complexity (for example, for a discussion of research risk, see Anderson, 1991; Alston *et al.*, 1994, ch. 7). Formal analysis of an intertemporal meta-production function including uncertainty, even in terms of simply eliciting cogent measures of the relevant joint probability specifications, may be intractable.

[9] Of course, an inferior path could be chosen involving technically inefficient combinations of inputs and outputs (that is, the multi-period counterpart of producing at an interior point, below the *PPF*) as a consequence of imperfect knowledge. For now we rule out this possibility.

[10] The image of the technological ship of the future sailing under a conceptual and empirical flag of $TFP = 1$ evokes contingent metaphysical questions such as 'Can life really be so simple?' or 'Is that all there is?' and practical questions such as 'How do we make use of this in measuring productivity and evaluating alternatives?' Answers to these questions are surely needed if we are to get the ship launched, to avert the navigational perils and to keep the vessel afloat beyond this, its maiden voyage.

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