Total Factor Productivity as a Measure of Weak Sustainability [1]

Marthin Nanere and Iain Fraser[2]

Abstract

Analysis of agricultural production generally ignores the undesirable outputs (such as soil erosion) that are jointly produced with desirable, marketable outputs. In this paper we present preliminary TFP results incorporating national level data for off-site damage costs for soil erosion for broadacre agriculture between 1953 and 1994. Following the approach introduced by Repetto *et al.* (1996) our revised TFP estimates provide interesting results. When we assume that damage costs per ton of soil erosion are constant our TFP estimates are higher than estimates omitting the undesirable output. This result can be explained by the fact that the rate of soil erosion grew slower than output increased or the rate of soil erosion declined and agricultural output remained constant. Defining weak sustainability (i.e., allowing substitution between natural and human capital) as non-declining TFP our results indicate that Australian broadacre agriculture is sustainable. Note our results are only preliminary because there are other externalities that we do not include in the analysis and the existing soil erosion damage cost data is very weak.

Key words: undesirable outputs, total factor productivity, non-declining TFP.

Address for correspondence:
School of Business
Faculty of Law and Management
La Trobe University
Shepparton, Victoria 3630
Australia

E-mail:
m.nanere@latrobe.edu.au
i.fraser@latrobe.edu.au

---

[1]Contributed paper, 45th Annual Australian Agriculture and Resource Economics Society Conference, Adelaide, South Australia, January 22-25, 2001.
[2]PhD student and Senior Lecturer, School of Business, La Trobe University, Shepparton and Bundoora, Victoria. We are grateful to Dr. John Mullen for providing the broadacre data.

Total Factor Productivity as a Measure of Weak Sustainability

1. Introduction

This paper concentrates on the public view of resource management in Australian broadacre agriculture. We will look at the case study of broadacre agriculture from the period of 1953 to 1994. The first part of this paper focuses on the importance of productivity growth and the nature of conventional productivity measurement, followed with the theory of incorporating the environmental undesirable outputs into the productivity measurement along with the weaknesses of the conventional TFP approaches. We then provide the TFP-related studies in Australian agriculture. In the second part of this paper an attempt is made to conduct an empirical work to environmentally adjust the TFP for broadacre agriculture at macro or national level. The paper ends with the policy implications and summary.

2. The Importance of Productivity Growth

In general, productivity can be measured in two ways. While labour productivity measures output per worker, total (multi) factor productivity, a broader indicator, measures the productive efficiency of labour, capital, and other inputs in combination. Either way productivity is a key indicator of technological and organisational efficiency.

The productivity growth rate over time indicates how fast real income can rise. For example, if the availability of goods and services were limited entirely by the gradual increase in labour force and capital stock, then our living standards today would not be as high as they are.

Productivity growth also affects the fortunes of farms or firms and even countries. For example, if Australia productivity growth lags behind that of other countries, this may imply that to compete in international markets, real wage levels in Australia must also rise more slowly. These effects will eventually affect the individual farms or firms.

Table 1: Total Factor Productivity of International Business Sector (average annual percentage change, 1960-1997)

Country	1960-1973	1973-1979	1979-1997
Australia	2.0	1.0	0.9
US	1.9	0.1	0.7
Japan	4.9	0.7	0.9
Germany	2.6	1.8	1.2
France	3.7	1.6	1.3
Italy	4.4	2.0	1.1
United Kingdom	2.6	0.5	1.1
Canada	1.1	-0.1	-0.5
Rest OECD[1]	3.1	1.2	1.4

Source: OECD Economic Outlook 64, December 1998.
[1] Austria, Belgium, Denmark, Finland, Greece, Ireland, Netherlands, Norway, Portugal, Spain, Switzerland.

This is why productivity growth rates are important to observe. The marked decline in the Australian productivity growth rate first observed in the 1970s. After a decade of rapidly increasing prosperity, this decline cast doubt on the economy ability to provide rising living standards. Productivity growth in Australia has been below levels recorded in some countries (see Table 1). Productivity growth in Australia remained relatively weak during the 1979-97 period, being surpassed by Germany, France, Italy and UK.

In other country particularly like the United State, this productivity slowdown has prompted many studies that sought to identify the cause and provide a basis for corrective relevant policies. A series of study by Aschauer (1989), Fischer (1988) and Baily (1986) summarised that payoffs to Research and Development expenditures had declined, reductions in public spending on core infrastructure had affected private productivity gains, and the growing importance of the service industries made productivity improvements increasingly difficult to measure. Despite suspicions, however, no one was strongly convicted (Munnell, 1990).

It was generally accepted that three shocks to the economy were important (Gollop and Swinand, 1998). The first was the oil shock of the 1970s leading to productivity levels being declined worldwide. The sudden rise in prices may have caused many energy-inefficient factories uneconomic, resulting in machinery being scrapped prematurely or severely underutilised, lowering the productivity of the capital stock. The second shock was felt in the 1970s as the baby boomers came of age and women's labour participation rates increased. The large number of inexperienced labour into the workforce may have depressed labour productivity (Baily, 1986).

The last shock was environmental regulation. It has been argued that cost of complying with environmental regulations (such as Environment Protection Act 1970, Litter Act 1987, Pollution of Waters by oil and noxious substances Act 1986 in Australia, and Clean Air Act and Clean Water Act in USA enacted in the early 1970s) required industries to divert investment toward the installations of costly abatement technologies and increased production costs.

Behind efforts to weaken environmental law or their enforcement lies the belief that such regulations impose costly burdens on the economy, stifling innovation and lowering productivity (Repetto *et al.* 1996).

Whether firms control pollution because of environmental regulation or for some other reasons, the introduction of pollution abatement process will involve changes in the production process. Jorgensen and Wilcoxen (1990) identified three different response types of environmental regulations. Firstly, the firm may substitute less polluting inputs for more polluting ones. Secondly, the firm may change the production process to reduce emissions. Thirdly, the firm may invest in pollution abatement devices. Naturally, these various measures may be adapted simultaneously. In the literature, the first two measures are known as ‘pollution prevention’ methods, and the third as an ‘end-of-pipe’ measure.

Depending on the ease of substitutability of inputs, switching to less polluting inputs or cleaner inputs may be the least disruptive of the above three possible responses of the firm, because it does not necessarily require as extensive a reorganisation of the production process as do the second and third responses. A high degree of substitutability between inputs implies low costs of environmental regulation, and vice versa.

The second response to pollution control is the process change involving the redesign of production methods to reduce emissions. Such internal process changes may have either a positive or negative effect on production of the ‘good’ output (Kneese and Bower, 1968; Barbera and McConnell, 1990). For example, the internal process change may require more input for a given level of good output, thus having a negative impact on productivity. However, it has also been suggested that increasingly stringent environmental regulation may cause more capital turnover and hence modernisation, so that the net effect may be increased productivity growth (Meyers and Nakamura, 1980).

The third response to pollution control is to invest in abatement technology, ie, in the use of special devices to treat wastes generated. End-of-pipe abatement is often the choice for existing firms that have to meet newly imposed standards (Jorgensen and Wilcoxen, 1990). This type of investment in external treatment imposes a direct cost on the industry and thus raises the total input costs for a given level of output. The net impact of environmental regulations or pollution control on firms production performance depends on which of the above effects dominates and on what the returns are from being able to satisfy consumer’ preferences, such as ‘green values’.

According to Repetto *et al.* (1996), the conclusion that environmental regulations have reduced the rate of productivity growth is an artefact of a basic flaw in the way productivity is measured. That is, a methodology that counts the cost of environmental protection but ignores the cost of environmental degradation. This problem in productivity measurement has led to serious misunderstanding about the effects of environmental policies on the economy and to distortions in the policy-making process.

The choice of which costs to measure and value and which to ignore influences our perception of what is worth doing, and so infiltrates public and private decisions.

2.1 What is Conventional Productivity Measurement?

Conventional productivity measures are usually expressed in terms of output per hour worked, a simple or partial measure of labour productivity. However, a more sophisticated measure that distinguishes among many different categories of labour has been used recently. It is computed as a ratio of an index of outputs weighted by their respective market prices to an index of various categories of labour services weighted by their respective employment costs. After adjustment for inflation, the change in this index over time is taken as the measure of labour productivity growth.

For this reason, Bureau Statistics both in US and Australia have introduced a broader measure of total factor productivity (or multi factor productivity) to measure the efficiency with which all inputs, capital, materials and labour are used. This indicator includes capital and materials used in production in the index of inputs along with labour. Each of these factors of production is made up of constituent inputs weighted by their respective costs to the firm. If industries exhibit constant returns to scale and input markets are competitive, the contribution that the increasing use of each factor makes to the growth rate of output can be determined.

Many studies have been conducted to improve the methodology and the data used to calculate the productivity indicators. The measurement of labour inputs now distinguishes between categories of labour whose effect on productivity differs because of educational attainment or accumulated experience. The measurement of capital services takes account of the age and relative efficiency of plant and machinery. Finally, the measurement of output has been improved by distinguishing quality improvements along with quantitative increases in the output of goods and services.

Despite of the progress, many difficulties remain. Measuring output is still problematic in service industries, such as the legal profession and banking, where the nature of the end product is hard to define, or may change from year to year. On the methodological side, the index used may imply unrealistic assumptions about the production process. Despite these remaining problems, in most respects productivity measurement has become more sophisticated and informative over the last two decades. Unfortunately, in dealing with environmental protection issues, productivity measurement has produced a misleading productivity indicator.

2.2 Environmental Protection's Impact on Productivity

Based on current measure of productivity, it can inevitably be shown that environmental protection reduces productivity growth. Even though this argument is reinforced by extensive empirical work, it can be argued that it is not necessarily correct. Environmental regulations have induced firms to reduce emissions by altering production processes, mainly by installing pollution-abatement equipment (e.g., exhaust gas srubbers and wastewater treatment plants). Purchasing inputs whose main function is to reduce pollution has raised input costs with no corresponding increase in marketed outputs. Thus, because the productivity measure gives industries no credit for reducing emissions, however damaging it is, measured productivity has been depressed.

Only if steps taken to reduce emissions actually reduce production costs or raise the value of marketed output sufficiently would environmental protection measures rise productivity as currently measured. Smith (1998) summarised that reductions in pollution should count as increasing productivity rates only if the absolute magnitude of the marginal disutility of pollution (measured in monetary units) exceeds the marginal abatement cost.

If the opposite is true (i.e., the magnitude of the marginal disutility is less than the marginal abatement cost) then reductions in pollution should reduce the rate of total factor productivity increase.

Most of the studies conducted in the past such as Robinson (1995), Fare, Grosskopf and Pasurka (1986) and Gollop and Roberts (1983) concluded that the response to environmental regulation has impeded productivity growth. Whether intended or not, the inevitable consequences of this consensus has been to strengthen the impression that environmental protection hinders economic growth and reduces living standards. However, this argument is not necessarily acceptable. A more reasonable definition would lead to different conclusions and arguments, as we are going to show in this paper.

3. Conceptual Issues in Conventional Total Factor Productivity

Generally speaking the productivity measure used mostly rests on an incomplete picture of industrial processes. In principle, industries transform marketed inputs into marketed outputs. These transformations conform to physical laws, including the conservation of matter and energy, which dictates that all the raw materials drawn into an industrial process re-emerge in some form. It can be shown that some of the inputs go to product and some to waste streams.

For example, a farm produces not only marketed products, but also non-marketed products such as pollution in the form of soil erosion. The conservation of matter and energy dictates that along with marketed or good outputs, a farm also inevitably generates residual outputs or bad outputs that are potentially damaging when released to the environment.

When industrial production is considered in its entirely like this, it is obvious that in physical terms inputs and outputs must grow at the same rate. The main question is whether industrial processes transform these inputs into outputs of greater value, recognising that some outputs are valuable when sold and that others are damaging when released.

Conventional productivity measures generate differential growth rates for inputs and outputs only by ignoring an entire class of outputs, those that are harmful to society and thus unsalable or non-marketed. The productivity index counts the good output that is produced by the farm but ignores all the other less desirable outputs of the process, even though these undesirable outputs are significant in economic terms. The result leads to an incomplete and misleading indicator of productivity.

Ignoring wastes and residuals or pollution is by no means a trivial omission because they could be huge. These huge flows of unsalable residuals discharged at all stages of the production process generate significant economic costs and environmental impacts. Nonetheless, they are assumed away in measuring productivity growth. As an evaluative measure in relation to natural resource management, the conventional productivity indicator is seriously misleading because environmental protection measures that actually improve economic efficiency can be recorded as lowering productivity.

Despite the fact that the current productivity indicator is misleading, conventional productivity indicators are still currently being used. The main reason is that waste products emitted to the environment, unlike saleable or marketed outputs, do not have market prices. The fact that emissions lack market prices makes estimating their incremental cost to the economy difficult but not impossible.

4. Selected TFP Studies in Australian Agriculture

(add a bit more intro in here) One of the first analyses of the Australian agriculture sector's productivity growth rate was Lawrence and McKay (1980). They calculated Tornqvist quantity indices of outputs and inputs over the 1952-53 to 1976-77 period, from Australian Sheep Industry Survey Data. Multi factor productivity (MFP) in the sheep industry was estimated to have increased by 2.9 per cent per annum during this twenty-five year period. This resulted from an estimated annual rate of increase of 4.4 per cent in total outputs and/or 1.5 per cent in total inputs. The advancement and deferment of inputs and seasonal conditions affecting outputs were found to have been important causes of short run fluctuations in productivity around the underlying trend productivity increase.

Males *et al.* (1990) estimated productivity growth in the braodacre industries and found it to have grown by 2.2 per cent per year over the period 1971-72 to 1988-89. They also split agriculture's MFP growth into different enterprise-types. Crops grew at 5.5 per cent, mixed crops and livestock at 2.4, sheep at 0.2, beef at 0.1 and sheep-beef at 2.4.

Mullen and Cox (1995) measured productivity growth in broadacre agriculture between 1952 and 1987-88. They used ABARE survey data that included producers with more than 200 sheep[3] and found the average rate of growth for Australia was 2.3 per cent per year.

Mullen *et al.* (1995) estimated that total factor productivity growth averaged 2.7 per cent per year over seventeen year time period between 1977-78 and 1993-94. They found that most of this growth was due to high productivity in the cropping sector of 4.6 per cent. South Australia and Western Australia had the highest productivity of all the states, 4.1 and 3.3 per cent respectively. This was attributed to the fact that a higher proportion of their agricultural production comes from cropping, the best productivity performer. Victoria's productivity growth was broadly consistent with the Australian results, cropping and mixed farming showed relatively strong MFP, whilst sheep specialists' performance was poor.

Strappazzon *et al.*(1996) examined several measures of productivity growth in Australian broadacre agriculture for the period 1977-78 to 1993-94[4]. They found that annual productivity growth lay in the bound between 2.3 and 3 per cent.

---

[3] The earliest available data on agricultural inputs and outputs were collected on farms that held greater than 200 sheep. Therefore, in order to be consistent throughout the time, the authors maintained this benchmark.
[4] The authors used the Paasche, Laspeyres, Tornqvist Theil and Fisher Indices, and the Chavas and Cox non parametric productivity measure.

In comparison to other OECD countries, Australia's agricultural productivity performance has been strong. The OECD (1995) compared OECD countries' agricultural productivity using past studies' results, and by performing their own calculations. They state that in the last few decades "Australian agricultural productivity growth has been among highest in OECD countries".

Even though there has been a vast number of productivity studies conducted in Australia, none of them has clearly incorporated the effect of externalities and considered the role of productivity measurement in relation to sustainable development from a social welfare perspective.

5. The Inclusions of Social Benefits

Most of the studies considering environmental externalities take no account of the social benefits that accrue to society as a result of the improvements in the environment. From a simple accounting perspective it seems unclear why we include the deductions on the input side but not include the additional benefits on the output side. In a recent analysis of natural resource industries in the US, Parry (1997) explicitly excludes non-market effects from his calculations noting that this means that the results cannot be interpreted from a broader social welfare perspective. The resulting impact of environmental compliance cost upon various industries is therefore the same as Ball *et al.* find, TFP measures are revised downward. These adjustments to conventional TFP values are fine if the focus of the analysis is not productivity gains from a social welfare perspective. An appealing study that includes the benefits of pollution reduction in TFP calculations was provided by Repetto *et al.* (1996,1997). In their study Repetto *et al.* adjusted conventional TFP calculations to take account of reduced environmental externalities. Several industries including agriculture are examined and conventional TFP calculations are compared to the adjusted figures. In relation to agriculture, Repetto *et al.* looked at the benefits resulting from the reduction in soil erosion. They expressed erosion damages as a share in total agricultural output. They derived the value of the erosion from the literature on damage function estimation estimated by Ribaudo (1989). The main result of this study is that the TFP estimates are generally revised upward. This reflects the fact that the social benefits of pollution reduction are included in the TFP measure.

Most of the index number approaches depend upon either the estimation of pollutant shadow prices from abatement expenditure by producers (for example, as in the study by Pittman, 1983) or on the external damage value estimates (for example, as in the case of Repetto *et al.* study). Although estimates of abatement costs are more readily obtainable, using them to value emissions will misrepresent efficiency gains from environmental protection unless firms are already controlling emissions optimally. Estimating abatement cost is likely to become less and less practical because it is increasingly difficult to differentiate between "productive" and pollution abatement expenditures on capital or other inputs. On the other hand, pollution damage estimates are not without weaknesses and unlikely to be available on a yearly basis. The limitation, however, is that the accuracy and transferability across region and time periods of non-market valuations of pollution damages are similarly open to question. More details on the inclusion of social benefits will be discussed in the next section.

6. The Significance of Repetto's Approach

The basic concept of environmental economics, which recognises that there are no markets for most effluents discharged into the environment, is presented in Figure 1. In this figure, two curves represent the costs of pollution damage and the costs of pollution abatement at different levels of emissions. The marginal damage curve (MD) measures the damage in monetary terms caused by the last (or marginal) unit of pollution. Though expressed in monetary terms, these non-market damages might include illness among the exposed populations, degradation of natural resources that makes them less valuable to users, damages to buildings and materials from exposure to pollutants, and other environmental impacts.

The marginal abatement cost curve (MA) shows the costs to the firm of removing the final unit of pollution. This cost varies according to the initial level of emissions. At high emission levels, the cost of removing a unit of pollution should be low, or even negative, if the firm can save materials or reduce costs through housekeeping improvements. If the firm is currently doing little or nothing to reduce pollution, relatively cheap and easy abatement options are likely to be available. However, as overall emissions levels are reduced, it becomes harder and more expensive to make further reductions. The MA curve reflects the extra input costs to the firm of various abatement options, assuming it will implement the least expensive ones first. The efficient amount of emission reduction occurs at the intersection of the two curves, where the marginal damage costs equal the marginal abatement costs. At higher levels of emissions, the costs of reducing pollution by a unit (equal to MA) are lower than the damage costs associated with this unit (equal to MD). Hence, efficiency increases if this unit of pollution is removed. If emissions levels are removed further, the higher costs of removing these units are not justified by the small reduction in damages. Emissions reduction is efficient when the incremental costs of pollution control are equal to the incremental costs of pollution damage.

Referring to the same figure, consider a farm or firm that generates E_2 emissions in producing its marketed output. The diagram shows a situation in which emissions are so high that both emissions and input costs can be reduced simultaneously. Using conventional productivity accounting, a reduction from E_2 to E_1 would be considered as productivity increase corresponding to area D, the total input cost saving. However, this still understates the true efficiency gain because it ignores the reduction in environmental damage as a result of lower emissions, equal to area C.

Moreover, further emission reductions from E_1 to E^*, which could maximise efficiency, would cause conventionally measured productivity to fall by an amount equal to area B because the firm incurs abatement costs with no increase in sales revenues. Despite this reduction in measured productivity, economic efficiency actually would increase by an amount equal to area A, the amount by which the avoided costs of environmental damages or the incremental costs of environmental damage exceed abatement costs or the incremental costs of pollution control.

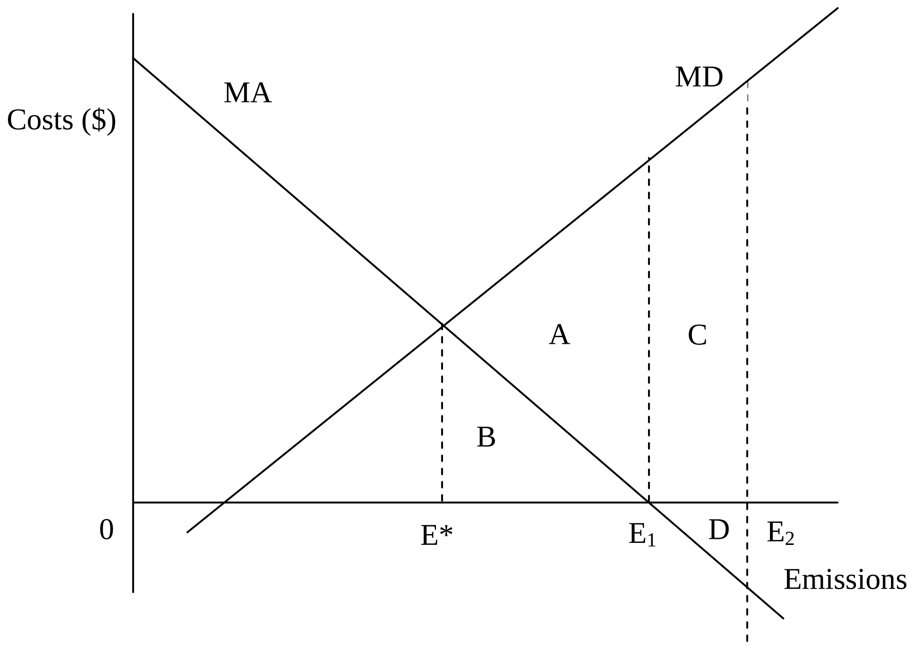

Figure 1: Efficient Pollution Abatement

The conventional methodology used to derive the TFP index can be extended to take account of industrial waste products. Emissions are simply considered joint outputs of the industrial process and are included in the output index with weights determined by their marginal damage costs (as opposed to marginal abatement costs).

Following Repetto *et al.*(1996), the TFP indices estimated by the ABS and US Bureau of Labor Statistics are based on an assumed production function of the form as follows:

$$Q(t) = A(t).f\left[K(t), M(t), L(t)\right] \qquad (1)$$

where $Q(t)$ stands for real output in year t; $K(t)$, $M(t)$ and $L(t)$ represent capital, material and labour inputs, respectively; and $A(t)$ is a productivity index. From this function the rate of productivity change index can be estimated as:

$$\frac{A^{'}(t)}{A} = \frac{Q^{'}(t)}{Q} - \left[\frac{s_k K^{'}(t)}{K} + \frac{s_m M^{'}(t)}{M} + \frac{s_l L^{'}(t)}{L}\right] \qquad (2)$$

where the primed quantities represent rates of change with respect to time. In other words, the rate of productivity change is defined as the difference between the growth rate of the output index and the growth rate of the input index. In turn, the input index is derived by weighting each factor of production by the proportional change in output that results from a small change in that input alone (technically, the output elasticity). These weights are denoted by s_k, s_m and s_l. If there is perfect competition in both the input factor markets and the output markets and there are constant returns to scale, these weights are equal to the shares of the individual factors in total costs and, consequently, add up to one.

Environmental residuals can be incorporated into the framework by defining total output, *W*, as the aggregation of marketed output, *Q*, and emissions, *E*. Total output then exhibits a rate of growth equal to:

$$\frac{W'(t)}{W} = \frac{s_q Q'(t)}{Q} + \frac{s_e E'(t)}{E} \tag{3}$$

According to this formula, the rate of change of total output is equal to a weighted average of the growth of output and growth of emissions. The weights are equal to the shares of output and emissions in the total value of output. Because emissions are damaging, they have a negative value rather than a benefit and so have negative shadow prices. Qualitatively, their impact on productivity is the same as that of input costs.

If A^* is defined as the productivity index for the joint output function, *W*, then the growth rate of A^* is:

$$\frac{A^{*'}(t)}{A^*} = \frac{s_q Q'(t)}{Q} + \frac{s_e E'(t)}{E} - \left[\frac{s_k K'(t)}{K} + \frac{s_m M'(t)}{M} + \frac{s_l L'(t)}{L}\right] \tag{4}$$

Comparing (2) with (4) gives:

$$\frac{A^{*'}(t)}{A^*} = \frac{A'(t)}{A} + s_e\left[\frac{E'(t)}{E} - \frac{Q'(t)}{Q}\right] \tag{5}$$

where:

s_e is the weight of pollution damages in total output;

E' is the change in pollution damages;

E is the level of pollution damages;

Q' is the change in the value of marketed output;

Q is the value of marketed output.

Equation (5) shows how the two productivity indicators are related. Because s_e is negative, whenever emissions grow more slowly than output, the new productivity index will increase more rapidly than the conventional index. Moreover, if output increases or stays constant, any decline in emissions will lead to a faster rate of productivity growth than that measured by the conventional index. Should emissions increase more rapidly than marketed outputs, however, the conventional index will overstate the productivity growth rate. In other words, the revised methodology takes into account a source of productivity growth that the conventional methodology completely misses: a more rapid growth in the value of total output due to a shift toward highly valued marketable products and away from negatively valued waste products. Undoubtedly, this is as valid and potentially important efficiency gains as any other.

Calculating the new productivity measure requires an estimate of s_e, the share of emissions in total output. In turn, s_e is determined by both the quantity of emissions and its shadow price, which represents the total economic damages another unit of emissions would do. Damages can be of many different kinds: increased illness, reduced recreational opportunities, impairment of materials, and ecological impacts. These damages are estimated by various techniques that have been the subject of extensive research and refinement over the last 20 years (Freeman, 1993).

The wide confidence limits, in which damage values are usually expressed arise partly from the complexity of the underlying physical and biological processes, each of which can be described only within some margin of error. Further variation stems from differences in valuation methodologies used in various studies. Moreover, damages from a unit of emissions will vary substantially, depending on timing and location, the hydrological and meteorological conditions around the emissions source, the size of the population affected, and other factors. Although damage studies have been carried out in many locations, extrapolating the results to other places or generalising to larger areas also creates room for inaccuracy. Despite their imprecision, the strongest justification for drawing on estimates of emissions damages is simply that pollution imposes real economic costs.

7. A Case Study in Broadacre Agriculture

Broadacre agriculture has been an important source of economic growth in Australia. An important component of government policy in agriculture has been to foster economic growth by investment in research and extension programs. In an attempt to monitor the performance of agriculture with respect to other industries and the agricultural sectors of other countries there have been a series of studies of productivity growth.

Total factor productivity (TFP) estimates for Australian agriculture have traditionally been measured by using the Tornqvist-Theil index procedure. Two well known examples are Lawrence and McKay (1980) and Males *et al.* (1990). The former analysed productivity for farms in the sheep industry using ABARE survey data from 1952-53 to 1976-77. They found productivity growth to average 2.9% per annum. The latter analysed productivity for all broadacre farms from 1977-78 to 1988-89 and found an annual 2.2% rate of productivity growth.

The following are the productivity analysis results from the broadacre data in the period 1952-53 to 1993-94.

Table 2: Output, Input and TFP Index[5] of Broadacre Farms (1953-1994)

Year	Output Index	Input Index	TFP Index
1953	1	1	1
1954	1.0229	1.0095	1.0133
1955	1.0512	1.0157	1.035
1956	1.109	1.0421	1.0642
1957	1.1208	1.0803	1.0375
1958	1.1476	1.1492	0.9986
1959	1.3037	1.1349	1.1488
1960	1.3306	1.1597	1.1474
1961	1.4722	1.1929	1.2341
1962	1.5563	1.2277	1.2677
1963	1.6835	1.2608	1.3352
1964	1.745	1.294	1.3485
1965	1.8551	1.3235	1.4017
1966	1.6077	1.2802	1.2558
1967	1.9738	1.316	1.4998
1968	1.8983	1.3323	1.4249
1969	2.4984	1.4312	1.7457
1970	2.3156	1.4448	1.6028
1971	2.6803	1.4189	1.889
1972	2.8555	1.5346	1.8607
1973	1.9481	1.5766	1.2356
1974	2.1838	1.6713	1.3066
1975	2.0322	1.3407	1.5157
1976	2.0067	1.3872	1.4466
1977	2.2682	1.4749	1.5378
1978	2.2836	1.6081	1.4201
1979	2.6824	1.5721	1.7063
1980	2.6786	1.6988	1.5768
1981	2.2875	1.5094	1.5155
1982	2.714	1.6011	1.6951
1983	2.2681	1.5999	1.4176
1984	3.21	1.5598	2.058
1985	3.216	1.5214	2.1139
1986	3.3275	1.6037	2.0749
1987	3.4357	1.6869	2.0367
1988	3.111	1.5992	1.9453
1989	3.3435	1.711	1.9541
1990	3.5744	1.7088	2.0918
1991	3.5717	1.7263	2.0689
1992	3.6358	1.7986	2.0215
1993	4.0243	1.7662	2.2785
1994	4.6644	1.8718	2.4919

[5] The indices for outputs, inputs and TFP calculated using TFPIP have been set to one in the first year.

Table 3: Contribution of growth in total factor productivity and input use to growth in output

Period	Trend growth in output % pa	Trend growth in input % pa	Trend growth in TFP % pa	Contribution of TFP to output growth %
1953 to 1994	3.2	1.3	1.9	59.4
1953 to 1962	5.0	2.4	2.6	52
1963 to 1972	6.2	2.0	4.2	67.7
1973 to 1982	3.4	0.6	2.7	79.4
1983 to 1994	3.0	1.8	1.2	40
1953 to 1973	5.0	2.2	2.8	56
1974 to 1994	3.6	1.0	2.7	75

Trend growth rate, over the number of periods, of output, input and TFP can be found by regressing the natural logarithm of these variables against time and a constant term. Trend output growth rates for the three indices and the contribution of TFP to output growth are presented in Table 3 for the whole period and (four sub-periods or two sub-periods).

Using Fisher Index, TFP in broadacre farms was estimated to have increased by 1.9 per cent per annum over the 1953 to 1994 period. This resulted from an estimated annual rate of increase of 3.2 per cent in total outputs and/or 1.3 per cent in total inputs.

Trend output growth for the period 1953 to 1994 was 3.2 per cent per year with total factor productivity contributing 59.4 per cent of the growth. Between 1953 and 1962, trend growth was 5.0 per cent a year with TFP growth accounting for 52 per cent of this. For the last two decades Broadacre agriculture's productivity growth fell from 2.8 to 2.7 per cent. TFP growth was thus contributing more than 70 per cent to output growth as it more than offset the reduction in input use.

The input, output and soil erosion data for Australian broadacre agriculture span from 1953 to 1994. The data represents an average farm and are taken from the Australian Bureau of Agricultural Resource's and Environment (ABARE) annual surveys of broadacre industries. These surveys are designed and samples selected on the basis of a framework provided by the Australian Bureau of Statistics (ABS), which consists of an annual listing of key characteristics and industry information for all agricultural establishments in Australia. This information is obtained by the ABS from data obtained in its Agricultural Census carried out in March of each year.

Information is collected from farmers by, face to face and telephone interviews. Each item has a value and a quantity component. If quantity variables are not available, they are calculated by deflating survey data by the appropriate ABARE prices paid and received indices (ABARE, 1998).

A small number of representative farms in a particular industry are used to produce the survey estimates. The differences between these estimates and the estimates that would have been obtained if the information had been collected from a census of all farms, are called sampling errors. The data also includes non-sampling errors. These are such things as not being able to contact certain types of farms; the respondent may provide inaccurate information or may differ from non-respondents in a variable being surveyed. ABARE attempts to minimise non-sampling errors and to publicise the magnitude of the sampling errors.

The industries included in the broadacre agriculture are provided as follows. The broad-acre industry is broadly defined as comprising the farming industries that produce meat, crops and wool. Broadacre industries include five separate industries.

1. Wheat and other crops industry: farms engaged mainly in growing cereal grains, coarse grains, oilseeds and pulses.

2. Mixed livestock-crops industry: farms engaged mainly in running sheep or beef cattle and growing cereal grains, coarse grains, oilseeds and/or pulses.

3. Sheep industry: farms engaged mainly in running sheep.

4. Beef industry: farms engaged mainly in running beef cattle.

5. Sheep-beef industry: farms engaged mainly in running sheep and beef cattle.

The broadacre data consists of the inputs and outputs of the representative farm for each industry, region and state. Also included are other variables considered relevant to the study of agricultural enterprises. Data is available over a forty two-year period from 1953-54 to 1994-95.

7.1 Broadacre Outputs

Outputs consist of eleven items, which can be split into four major groups, namely crops, livestock sales, wool and other income.

Crops

Crops are split into wheat, barley, oats, grain sorghum, oilseeds and other crops. The value variable for wheat is the quantity harvested (in tonnes) multiplied by the Australian Wheat Board's average net return for that year's pool. For other grains and crops, the value variable is net receipts in that year. The quantity variable for each of the grains is the quantity harvested (in tonnes). For the other crops, it is receipts deflated by the prices received index for crops.

Livestock Sales

This category is split into sheep, lamb, beef and other livestock. For beef and sheep, the value variable is sales minus positive operating gains. For other livestock and lambs the value variable is sales. The quantity variable for sheep, lamb and other are derived from quantity of sales deflated by the respective index for each item. For slaughtered beef the quantity variable is the quantity of beef sold deflated by the beef prices received index.

Wool

The value variable for wool is simply wool receipts at the farm gate and the quantity variable is the amount of wool shorn (in kilograms).

Other Farm Income

The value variable is receipts and the quantity variable is receipts deflated by the farm sector prices received index.

7.1.1 Output Trends

The output indices along with the shares and rates of growth[6] for crop outputs, livestock outputs, wool and other outputs are presented in Table 4.

[6] Trend growth rate can be calculated either as rate of change concept or chained logarithmic changes. The logarithmic changes is considered as a close discrete approximation to rate of change concept for a continuous change. The difference between the two is quite remarkable if the changes are large enough. Conceptually productivity measurement is built on the rate of change concept, but for discrete yearly data, logarithmic change is used in the computation of output and input indices. In practice trend growth rate can be computed by regressing the natural logarithm of the interested variables against time and a constant.

Table 4: Australian Broadacre Output Quantity Index, 1953-1994

Year	Crop Outputs		Livestock Output		Wool		Other Output	
	Average Share	Index	Average Share	Index	Average Share	Index	Average Share	Index
1953		100		100		100		100
1954	0.26	107	0.22	92	0.24	100	0.27	111
1955	0.20	85	0.24	100	0.25	104	0.31	127
1956	0.22	97	0.26	114	0.26	116	0.26	113
1957	0.18	79	0.28	123	0.28	125	0.26	113
1958	0.15	69	0.26	116	0.27	122	0.32	142
1959	0.24	126	0.25	130	0.26	133	0.24	126
1960	0.21	111	0.27	140	0.27	142	0.25	132
1961	0.27	157	0.27	155	0.24	137	0.23	131
1962	0.24	149	0.27	162	0.24	145	0.25	155
1963	0.29	193	0.26	174	0.22	142	0.23	151
1964	0.29	201	0.26	181	0.22	154	0.22	150
1965	0.31	224	0.23	171	0.21	155	0.25	182
1966	0.25	156	0.24	153	0.22	139	0.29	180
1967	0.35	273	0.21	166	0.20	154	0.24	192
1968	0.24	181	0.24	177	0.21	152	0.31	230
1969	0.37	371	0.22	217	0.17	167	0.24	236
1970	0.31	278	0.25	228	0.19	175	0.25	221
1971	0.24	239	0.24	241	0.17	170	0.36	361
1972	0.27	291	0.26	284	0.16	173	0.31	331
1973	0.26	197	0.35	263	0.21	159	0.18	137
1974	0.36	316	0.29	257	0.20	174	0.15	128
1975	0.39	320	0.28	228	0.20	165	0.13	103
1976	0.41	338	0.30	248	0.21	172	0.08	68
1977	0.39	347	0.28	245	0.18	161	0.15	131
1978	0.34	312	0.34	306	0.19	173	0.13	114.4
1979	0.47	514	0.26	280	0.15	161	0.12	127
1980	0.47	513	0.26	286	0.17	186	0.10	112
1981	0.42	387	0.27	243	0.18	163	0.14	125
1982	0.49	539	0.23	249	0.16	171	0.13	145
1983	0.37	339	0.27	247	0.20	187	0.15	141
1984	0.51	665	0.20	257	0.14	186	0.15	191
1985	0.48	626	0.22	286	0.16	204	0.14	183
1986	0.44	572	0.22	293	0.16	208	0.18	232
1987	0.45	603	0.21	287	0.16	223	0.18	241
1988	0.40	484	0.25	303	0.17	208	0.17	209
1989	0.42	556	0.25	335	0.17	223	0.15	203
1990	0.41	565	0.24	335	0.18	253	0.17	236
1991	0.42	582	0.21	284	0.19	266	0.18	253
1992	0.43	599	0.22	302	0.17	233	0.19	264
1993	0.49	754	0.18	280	0.14	225	0.19	295
1994	0.51	916	0.18	321	0.13	233	0.19	335
	Annual Growth Rates							
1953-1973		6.58		5.04		2.60		4.69
1974-1994		4.20		1.21		2.26		6.09
1953-1994		5.42		2.80		1.84		1.51

The broadacre farmers in Australia increased crop outputs, livestock and other output by approximately nine times, three times and three times respectively, with rate of growth of 5.42 percent, 2.80 percent and 1.51 percent annually compared to 1.84 percent growth rate by wool output for the sample period of 1953 to 1994. Over the full period, the growth in Australian broadacre's output was contributed to a large extent by crop outputs, other outputs followed by wool output and livestock to a lesser extent.

7.1.2 Input Trends

Inputs

Inputs consists of 27 items which can be split into five major groups, namely capital, livestock purchases, labour, materials, and services.

Capital

Capital is divided into land, plant and machinery, structures, and livestock. The value variable for land and livestock (beef cattle and sheep) are the opportunity cost of investing funds in those capital items. These are calculated as the average capital value (that is, the average of opening and closing values) multiplied by a real interest rate. The value variables for plant and structures capital are the opportunity costs plus depreciation.

The quantity variable used for land is the area operated. For beef cattle and sheep is the average of opening and closing numbers. For buildings and plant capital, it is the average value of capital stock deflated by the respective prices paid indices for each.

Livestock purchases

Livestock purchases are split into beef, sheep and other livestock. Their value variables equal purchases plus negative operating gains. The quantity variables for sheep and beef is derived from the respective value variables (above) and respective prices received indices for sheep meats and slaughtered beef. For the relatively small category of other livestock, the quantity variable is derived from the value of purchases and a prices received index for livestock products.

Labour

Labour consists of four items: owner-operator and family labour, hired labour, shearing costs, and stores and rations. The value of the owner operator and family labour input is imputed using weeks worked (collected during the survey) and an award wage. The value of hired labour is wages paid, and the value of shearing and stores and rations are expenditure. The quantity variables for owner operator and family labour and hired labour are weeks worked. Expenditure deflated by a shearing prices paid index is the quantity variable for shearing.

Materials and Services

There are seven items in the materials group: fertiliser, fuel, crop chemicals, livestock materials, seed, fodder, and other materials; and there are seven items in the services group: motor vehicle costs, rates and taxes, miscellaneous livestock costs, administrative costs, repairs, contracts, and other services. For each item in both groups the value item is expenditure. The quantity variables are derived by deflating the expenditure on each by the appropriate prices paid index.

Table 5: Australian Broadacre Input Quantity Index, 1953-1994

Year	Contracts		Services		Research & Management		Labour	
	Average Share	Index	Average Share	Index	Average Share	Index	Average Share	Index
1953	0.125	100	0.125	100	0.125	100	0.125	100
1954	0.127	102	0.104	84	0.142	114	0.125	101
1955	0.130	105	0.102	82	0.131	105	0.127	102
1956	0.127	105	0.103	85	0.125	103	0.125	103
1957	0.122	104	0.108	92	0.126	108	0.125	107
1958	0.116	106	0.109	100	0.130	120	0.127	116
1959	0.121	108	0.114	102	0.118	106	0.127	114
1960	0.119	111	0.113	105	0.126	117	0.122	114
1961	0.116	112	0.112	108	0.131	127	0.116	112
1962	0.120	118	0.113	111	0.132	129	0.114	112
1963	0.122	125	0.113	116	0.135	138	0.112	114
1964	0.101	105	0.122	127	0.150	157	0.107	111
1965	0.136	153	0.118	133	0.153	173	0.101	114
1966	0.108	117	0.113	122	0.155	168	0.103	112
1967	0.159	179	0.123	138	0.158	177	0.100	112
1968	0.135	152	0.115	130	0.151	170	0.098	110
1969	0.171	218	0.105	134	0.137	176	0.088	113
1970	0.141	176	0.106	132	0.136	169	0.091	113
1971	0.102	119	0.105	122	0.129	151	0.095	111
1972	0.122	158	0.105	135	0.126	162	0.086	111
1973	0.103	134	0.106	138	0.158	205	0.081	105
1974	0.136	189	0.120	167	0.171	236	0.083	115
1975	0.110	122	0.134	149	0.150	166	0.098	109
1976	0.105	122	0.131	152	0.146	170	0.094	109
1977	0.109	136	0.114	142	0.160	200	0.096	120
1978	0.102	140	0.110	151	0.138	189	0.088	121
1979	0.158	215	0.111	152	0.158	216	0.088	120
1980	0.186	277	0.116	173	0.160	239	0.086	128
1981	0.127	173	0.147	199	0.169	229	0.093	127
1982	0.138	194	0.154	217	0.168	237	0.092	129
1983	0.116	171	0.154	227	0.150	221	0.086	126
1984	0.140	194	0.157	218	0.163	226	0.092	127
1985	0.116	159	0.166	228	0.168	231	0.092	126
1986	0.131	178	0.148	202	0.154	210	0.093	127
1987	0.118	163	0.141	195	0.157	217	0.093	129
1988	0.150	211	0.129	182	0.169	238	0.087	123
1989	0.143	220	0.137	210	0.170	260	0.083	128
1990	0.123	185	0.139	208	0.174	261	0.092	137
1991	0.101	139	0.146	201	0.149	206	0.095	131
1992	0.105	151	0.143	206	0.160	231	0.089	129
1993	0.116	161	0.152	211	0.168	234	0.083	116
1994	0.127	189	0.140	208	0.173	256	0.076	113
Annual Growth Rates								
1953-1973		2.65		2.54		3.28		0.34
1974-1994		0.60		1.79		1.17		0.43
1953-1994		1.53		2.38		2.22		0.51

Table 5: continued

Year	Livestock		Capital		Land		Plant & Equipment	
	Average Share	Index	Average Share	Index	Average Share	Index	Average Share	Index
1953	0.125	100	0.125	100	0.125	100	0.125	100
1954	0.122	98	0.128	103	0.124	100	0.129	104
1955	0.124	100	0.130	105	0.124	100	0.132	106
1956	0.140	116	0.133	110	0.121	100	0.126	104
1957	0.140	120	0.138	118	0.118	101	0.123	105
1958	0.134	123	0.143	131	0.107	98	0.134	123
1959	0.128	115	0.144	129	0.109	98	0.138	124
1960	0.143	133	0.141	131	0.106	99	0.130	121
1961	0.155	150	0.141	136	0.104	100	0.125	120
1962	0.147	144	0.148	145	0.103	101	0.123	121
1963	0.152	155	0.148	151	0.099	101	0.120	122
1964	0.151	157	0.152	158	0.098	102	0.120	125
1965	0.152	171	0.140	158	0.087	98	0.114	128
1966	0.171	185	0.139	151	0.090	98	0.121	131
1967	0.119	134	0.135	152	0.090	101	0.116	130
1968	0.131	148	0.137	155	0.090	102	0.142	161
1969	0.162	207	0.132	168	0.081	103	0.124	159
1970	0.172	214	0.146	182	0.082	102	0.127	158
1971	0.188	219	0.170	198	0.086	100	0.126	147
1972	0.210	271	0.167	215	0.081	104	0.104	135
1973	0.173	224	0.179	232	0.089	115	0.111	144
1974	0.115	160	0.183	254	0.080	111	0.111	154
1975	0.084	93	0.222	246	0.111	123	0.091	100
1976	0.108	126	0.223	259	0.100	116	0.093	108
1977	0.150	188	0.184	230	0.099	124	0.088	110
1978	0.174	239	0.190	261	0.116	159	0.082	113
1979	0.130	177	0.168	229	0.105	143	0.083	113
1980	0.109	162	0.160	239	0.102	152	0.082	122
1981	0.121	164	0.161	218	0.089	120	0.093	127
1982	0.110	154	0.155	218	0.096	136	0.088	123
1983	0.172	253	0.148	218	0.090	133	0.084	124
1984	0.114	158	0.152	210	0.095	132	0.086	119
1985	0.122	167	0.160	220	0.090	123	0.086	119
1986	0.119	162	0.176	241	0.097	132	0.083	114
1987	0.131	181	0.178	246	0.106	147	0.075	104
1988	0.142	200	0.163	230	0.095	134	0.066	93
1989	0.148	226	0.162	248	0.092	141	0.064	99
1990	0.141	211	0.174	261	0.093	139	0.064	95
1991	0.136	188	0.201	277	0.106	145	0.066	91
1992	0.135	194	0.204	293	0.105	151	0.060	87
1993	0.117	163	0.198	277	0.109	151	0.058	81
1994	0.126	186	0.193	287	0.110	163	0.054	81
Annual Growth Rates								
1953-1973		4.41		3.65		0.29		2.07
1974-1994		1.47		0.70		1.04		-1.96
1953-1994		1.28		2.41		1.24		-0.6

The input indices along with the shares and annual rate of growth for contracts, services, research and management, labour, livestock, capital, land, and plant and equipment are presented in Table 5.

Broadacre farmers in Australia have used more services, research and management, and capital input (2.1, 2.6 and 2.9 fold increase respectively) compared to contracts (1.89), labour (1.1), livestock (1.9) and land (1.6). Almost 20 percent reduction of plant and equipment indicating that fewer plant and equipment constitute the broadacre agriculture sector. For the period 1953 to 1994 the annual growth rate of services, research and management, and capital inputs were above 2 percent compared to an increase of 1.53 percent of contracts, 1.28 percent of livestock and 1.24 percent of land inputs. Plant and equipment showed a rate of decline of 0.6 percent.

7.2 Environmental Impacts of Undesirable Outputs

The record of input growth mentioned in the previous section has had important environmental impacts. Agriculture apart from producing desirable outputs also generates undesirable outputs for example in the form of soil erosion. Research on undesirable outputs has been focused mostly on refining valuation techniques, but very little attention has been given to quantify the magnitudes of environmental pollution in physical quantities. By far the most important and difficult variables to construct are undesirable outputs due to broadacre agriculture production. In the following section we will discuss how we constructed the environmental damage data in physical terms due to agricultural production in the form of soil erosion. Although environmental damage from agriculture takes many forms, the only effects for which economic costs have been estimated satisfactorily are those from sheet and riil erosion[7].

Because a complete time series data for off-farm costs (soil erosion) is not available, the soil erosion data series need to be carefully constructed. The rate of soil erosion data is obtained from the Environment Australia, ERIN unit. This soil erosion data in was predicted by the universal soil loss equation (USLE) specifically designed for Australia, starting from December 1, 1994 to February 28, 1995, and it is the form of ArcInfo GIS. This data is then combined with the broadacre boundary in an attempt to estimate the magnitude of soil erosion in Australia primarily caused by broadacre agriculture production. In order to construct the soil erosion data series, three different rates of soil erosion due to broadacre farm activities were used namely, the average low rate of soil erosion one ton per hectare per year, the average moderate rate of soil erosion 5.42 ton per hectare per year and the average high rate of soil erosion 132.47 ton per hectare per year.

[7] Sheet erosion is the removal of a fairly uniform layer of soil from the land surface by runoff water. Riil erosion is an erosion process in which numerous small channels of only several centimetres in depth are formed, mainly on recently cultivated soils (see Brady and Weil, 1996).

The hectares of broadacre farms were then multiplied by the three different average rate of soil erosion to arrive at an estimate of erosion total per year as required for the total factor productivity analysis.

In calculating TFP, the damage cost estimates from the US were employed because there has been no studies that have estimated the damage costs for soil erosion in Australia. Sensitivity analyses were conducted to see how much or to what extent the damage costs and soil erosion would have impacts on TFP estimates. This would generate important policy implications in the broadacre agriculture in relation to natural resource management in Australia.

Although these estimates are the most comprehensive ones available, they are still incomplete and most likely underestimate the true damage costs, mainly because effects on recreational activities are ignored.

7.3 The Impact of Soil Erosion and Damage Costs on TFP Estimates

The following tables are the preliminary sensitivity analysis results of the Australian broadacre agriculture from 1953 to 1994.

Table 6: The Impact of Low Rate of Soil Erosion and Damage Costs on TFP Estimates from 1953 to 1994 (Average annual percentage change)

Damage Costs Estimate ($/ton)	Conventional TFP	Revised TFP (Constant damage values)	Revised TFP (Damage Values Proportional to GDP)
1.03	2.86	3.24	1.57
1.78	2.86	3.56	2.68
3.57	2.86	4.49	2.83

Table 7: The Impact of Moderate Rate of Soil Erosion and Damage Costs on TFP Estimates from 1953 to 1994 (Average annual percentage change)

Damage Costs Estimate ($/ton)	Conventional TFP	Revised TFP (Constant damage values)	Revised TFP (Damage Values Proportional to GDP)
1.03	2.86	3.06	2.23
1.78	2.86	3.22	2.76
3.57	2.86	3.63	2.84

Table 8: The Impact of High Rate of Soil Erosion and Damage Costs on TFP Estimates from 1953 to 1994 (Average annual percentage change)

Damage Costs Estimate ($/ton)	Conventional TFP	Revised TFP (Constant damage values)	Revised TFP (Damage Values Proportional to GDP)
1.03	2.86	2.91	2.72
1.78	2.86	2.95	2.84
3.57	2.86	3.03	2.86

Table 6 to 8 show when we assume that damage costs per ton of soil erosion are constant our TFP estimates are higher than estimates omitting the undesirable output. This result can be explained by the fact that the rate of soil erosion grew slower than output increased or the rate of soil erosion declined and agricultural output remained constant. Defining weak sustainability (i.e., allowing substitution between natural and human capital) as non-declining TFP our results indicate that Australian broadacre agriculture is sustainable. Note our results are only preliminary because there are other externalities that we do not include in the analysis and the existing soil erosion damage cost data is very weak. In brief summary, the revised methodology takes into account a source of productivity growth that the conventional methodology ignores or misses.

7.4 Policy Implication

The implications for agencies concerned with productivity growth and with environmental protection in the Australian Broadacre industry are obvious. It is important to introduce an unbiased measure of productivity that accurately captures the economic impacts of environmental protection. Such measure would record the costs averted as well as the costs incurred throughout the economy as environmental quality is protected. It would also record more accurately the record of economic progress in environmentally sensitive industries, such as broadacre farms in Australia.

Preparing and maintaining a revised record of productivity growth depends on an adequate information base. The environmental protection agency should make greater effort in developing environmental databases, using them for economic analysis and making them publicly available. This type of protection agency should develop and publish consistent time-series data on land degradation, such as soil erosion and salinity on an industry by industry basis (region by region basis).

Having such time series records of emissions trends would be useful not only for estimating productivity growth, but also for other important purposes. For example, efforts to develop cross-media industry wide pollution reduction plans as alternatives to detailed command and control regulations depend for accountability on reliable environmental performance indicators, especially trends in emissions (pollution).

Protection agency in Australia should also continue to increase the availability of credible estimates of marginal pollution damages, the other essential information needed to revise productivity measures. Protection agency should also continue to fund and carry out research to estimate the marginal costs of pollutants for which current knowledge is lacking or inadequate.

Such information will be highly useful and relevant not only for productivity measurement but also for priority setting in environmental policy, regulatory analysis, and other purposes. This information should also be accessible to researchers outside of government as well.

The productivity measurement should be developed using a revised set productivity growth estimates for pollution-intensive sector using the basic methodology set out in this study. These revised estimates should cover a long period of time (at least 30 to 40 years), to capture the true impact of environmental protection on Australian Broadacre Agriculture productivity. This information should also be updated and published regularly.

Informed discussion of the true impact of environmental protection on the national economy is highly desirable. In the past, discussion has tended to be rather one-sided since the costs of controlling pollution can be quantified and estimated much more readily than the costs of not controlling pollution.

As discussed previously, individual companies are also keenly interested in their own productivity records, and, companies in environmentally sensitive industries are searching for performance metrics and indicators that can adequately reflect their individual progress toward eco-efficiency. The methods used in this analysis can readily be adapted for this purpose. It would measure efficiency gains in the use of conventional inputs, capital and labour as well as raw materials and intermediates. In addition, it would measure progress in reducing emissions and effluents. Estimates of damage costs would have to be particularised to each company's own sites and the composition of its waste streams. Doing so would provide environmental managers with information useful in priority setting. Environmentally progressive companies that begin tracking their own productivity improvements using this basic method will be better able to integrate their environmental and business management practices. This kind of study and analysis can be conducted in further research when more undesirable data is available.

8. Summary

In this paper an attempt to explain how an operational definition of sustainable development could be implemented has been presented based on public point of view. An attempt has been made to adjust our current productivity measurement that completely ignores the concept of economic efficiency. The accepted criterion of efficiency in environmental economics is that the damages averted should exceed the costs incurred. Just by counting only the costs of controlling pollution while ignoring the damages create, the current approach implies that any environmental protection that raises industrial costs reduces productivity regardless how much larger the damage averted. Using the Repetto's approach we have attempted to propose an alternative method for measuring the adjusted productivity growth in broadacre agriculture for at least four decades. This method extends the output index to include both desirable and undesirable output (soil erosion). Marketed products are weighted according to their relative prices, but undesirable output is weighted negatively according to the damages inflicted on the economy by the release of an additional pollution. This method ensures that the benefits of pollution control are captured in the record of productivity growth along with the costs.

9. Bibliography

Aschauver, D.A. 1989. "Is Public Expenditure Productive?. *Journal of Monetary Economics*, 23(2):177-200.

Baily, M.N. 1986. "What Has Happened to Productivity Growth?". *Science,* 234:443-451.

Ball, V.E. 1984. "Output, Input and Productivity Measurement in US Agriculture, 1948-79". *American Journal of Agricultural Economic*, 67:475-486.

Ball, V.E. 1994. "Measuring Agricultural Productivity in US Agriculture". Paper presented at Evaluating Agricultural Research and Productivity in an Era of Resource Scarcity: Symposium sponsored by NC-208, Preceeding edited by W. Burt Sundquist.

Ball, V.E., Lovell, C.A.K., Nehring, R.F. and A. Somwaru. 1994. “Incorporating Undesirable Outputs into Models of Production: An Application to US Agriculture.” *Cahiers D’Economic et Sociologie Rurales,* 31:60-74.

Barbera, A.J. and V.D. McConnell. 1990. “The Impact of Environmental Regulations on Industry Productivity: Direct and Indirect Effects”. *Journal of Environmental Economics and Management*, 18:50-65.

Brady, N.C. and R.Weil. 1996. *The Nature and Properties of Soils.* Upper Saddle River, New Jersey: Prentice-Hall, Inc.

Chisholm, A. and Dumsday, R. 1995. "Environmental Indicators and Land Resource Policy: An Australian Perspective". In Batie, S.B. (ed), *Developing Indicators for Environmental Sustainability: The Nuts and Bolts*, Proceedings of the Resource Policy Consortium Symposium, Washington DC, June 12-13.

Chisholm, A.H. 1992. “Australian Agriculture: A Sustainability Story”. *Australian Journal of Agricultural Economics,* 36:181-190.

Fare, R., Grosskopf, S. and C.Pasurka. 1986. "Effects on Relative Efficiency in Electric Power Generation Due to Environmental Control". *Resources and Energy*, 8:167-184.

Fischer, S. 1988. "Symposium on the Slowdown in Productivity Growth". *Journal of Economic Perspectives*, 2(4):3-7.

Freeman, A.M. 1993. *The Measurement of Environmental and Resource Values: Theory and Methods.* Washington D.C. Resource for the Future.

Gollop, F.M. and M.J. Roberts. 1983. "Environmental Regulations and Productivity Growth: The Case of Fossil-Fueled Electric Power Generation". *Journal of Political Economy*, 91:654-674.

Gollop, F.M. and G.P. Swinand. 1998. "From Total Factor To Total Resource Productivity: An Application To Agriculture". *American Journal of Agricultural Economics*, 80:577-583.

Jorgensen, D. and P.J. Wilcoxen. 1990. "Environmental Regulation and U.S. Economic Growth." *RAND Journal of Economics*, 21(2):314-340.

Kneese, A.V. and B.T. Bower. 1968. *Managing Water Quality: Economics, Technology, Institutions.* Resources for the Future. John Hopkins Press.

Lawrence, D. and L. McKay. 1980. "Inputs, Outputs and Productivity Change in the Australian Sheep Industry". *Australian Journal of Agricultural Economics*, 24(1):46-59.

Males, W.P., Davidson, H., Knopke, P., Loncar, T. and M.J. Roarty. 1990. "Productivity Growth and Developments in Australia".

Meyers, J.G. and L. Nakamura. 1980. "Energy and Pollution Effects on Productivity: A Putty-Clay Approach" in New Developments in Productivity Measurement and Analysis. Kenderick (ed). University of Chicago Press.

Mullen, J.D., Strappazzon, L., Cox, T.L. and Knopke, P. 1995. "Alternative measures of productivity in broadacre agriculture", paper presented to the New England Conference on Efficiency and Productivity, University of New England, November 23-24, 1995.

Mullen, J. D. and Cox,T.L. 1995. "The Returns from Research in Australian Broadacre Agriculture." *Australian Journal of Agricultural Economics,* 39(2): 105-128.

Munnell, A.H. 1990. "Why Has Productivity Growth Declined? Productivity and Public Investment." *New England Economic Review*, 3-22.

OECD. 1995. *Technological Change and Structural Adjustment in OECD Agriculture*. OECD Publications Service, Paris.

Parry, I.W.H. 1997. "Productivity Trends in Natural Resource Industries". *Discussion Paper* 97-39, Resource For the Future, Washington DC.

Pittman, R.W. 1983. "Multilateral Productivity Comparisons with Undesirable Outputs". *Economic Journal,* 93:883-891.

Repetto, R., Rotham, D., Faeth, P. and D. Austin. 1996. *Has Environmental Protection Really Reduced Productivity Growth?* We Need Unbiased Measures. World Resource Institute, Washington DC.

Repetto, R., Rotham, D., Faeth, P. and D. Austin. 1997. "Productivity Measures Miss the Value of Environmental Protection". *Choices,* 4th quarter:16-19.

Ribaudo, M.O. 1989. *Water Quality Benefits from the Conservation Reserve Program.* Agricultural Economic Report No. 606. Washington DC Resources and Technology Division, Economic Research Service, USDA.

Robinson, J.C. 1995. "The Impact of Environmental and Occupational Health Regulation on Productivity Growth in US Manufacturing". *The Yale Journal on Regulation*, 12:346-387.

Smith, V.K. 1998. "Should Pollution Reduction Count as Productivity Gains for Agriculture?". *American Journal of Agricultural Economics,* 80:591-594.

Strappazzon, L., Mullen, J.D and T.L Cox. 1996. “Comparing Measures of Productivity Growth for Australian Broadacre Agriculture. *Working Paper 9605, Economic Branch, Division of Chief Scientist, Agriculture Victoria,* Melbourne.