Australian Agricultural and Resource Economics Society

43rd Annual Conference

Christchurch, New Zealand January 20 – 22, 1999

USING PRODUCTIVITY MEASUREMENT TO CALCULATE THE BENEFITS OF RESEARCH

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Foreword

Given the continuing need for public sector agencies to improve their resource allocation decision processes, the Victorian Department of Natural Resources and Environment Economics Branch has developed a rigorous system for measuring the impact of research-induced technological change. This can assist decision makers choose between alternative investments, and provide a means of assessing the impact of past research efforts.

This document explains how productivity measurement is an integral part of evaluating agricultural technology-change benefits in the Department's Primary Industry investment assessment framework

Funding for this project has come from the Victorian State Government's Agriculture and Food Initiative.

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Other papers in the Methodology series:

- Beneficiaries and Funding: Selected Strategies (NRE 1998a)
- Explaining the role of CABs in NRE's Primary Industry Investment Assessment Framework (1998b)

Introduction

The Victorian Department of Natural Resources and Environment (NRE) Economics Branch has established an investment assessment system to provide information that will assist the Primary Industries Division to allocate resources. Judicious investment decisions will maximise the agricultural sector's growth, without compromising the environment.

A schematic view of the NRE Economics Branch system is presented in **Appendix 1**. There are two aspects to the system: qualitative and quantitative. The former includes an analysis of beneficiaries and funders (see NRE 1998a). The NRE Economics Branch qualitative analysis assists decision-makers to identify activities that can enhance economic growth. The government can undertake activities that have a net benefit to the public and the private sector does not have incentives to participate because rewards cannot be appropriated by one individual/firm.

The NRE Economics Branch quantitative analysis determines the relative worth of research-induced technology change. There are three main components to the system: Farm level models (or Complex activity budgets [CABs]), the MONASH general equilibrium model and benefit-cost analysis (shown in the top part of the diagram in **Appendix 1**).

This paper explains how the measurement of on-farm productivity change is used in the calculation of agricultural research benefits. As will be shown, productivity-change measurement is the interface between CABs and the MONASH model

Economic Surplus

The NRE Economics Branch quantitative analysis attempts to measure the gross benefits derived from a research-induced technology change. Economic surplus is the standard measure of benefit (*well being*)[1]. A research-induced technological change is a shift of the supply curve downwards (Figure 1)[2]. Every producer is able to produce each unit of output at *lower cost*, due to the new technology.

Figure 1: Supply shift from research-induced technological change
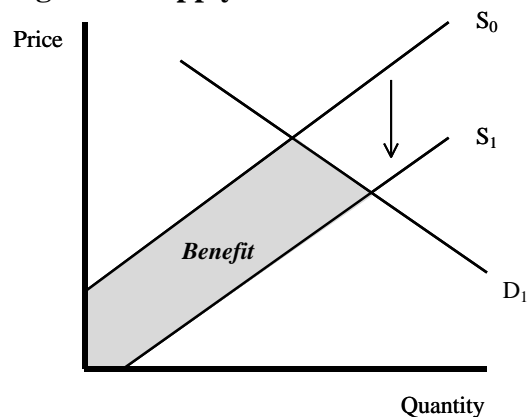
Following Alston *et. al.* (1995), the cost reduction from a technological change is denoted by the letter *k*. The *k* associated with the *first round* of a technology impact, that is, before any alterations to the farming enterprise take place, is denoted k_1. It is the impact that occurs when a technology is adopted, but the *use of (other) inputs remains constant*. Since the purpose behind research is to prompt a change in practices, a more satisfactory description of the technology's impact is one that takes account of the altered producer behaviour. This is measured by k_2, the cost reduction *after input use has changed* (Figure 2, next page).

Consider the case of an improved wheat yield. k_1 measures the cost reduction that occurs when a new seed is used but when, *inter alia*:

- the rotation stays constant, and

- the amount of area planted to wheat stays constant

On the other hand, if the farmer adjusts input use to cater for the new technology—changing rotation so that wheat is included more regularly or increasing the area sown to wheat—then the measured cost reduction would be equal to k_2.

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[1] For a more complete exposition about Economic Surplus and related concepts see Alston *et. al.* (1995)
[2] For an explanation of demand and supply, see Tisdell (1972)

Figure 2: k_1 versus k_2

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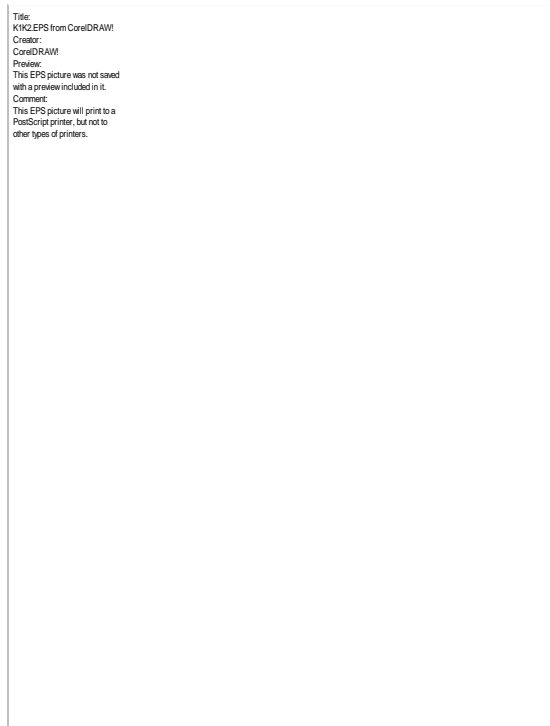
Productivity

The Economics Branch uses CABs to analyse the effect of technological changes (or *shocks*) on farm[3]. CABs are an ideal way to hone in on k_2. Since they represent farming enterprises, CABs will substitute towards relatively cheaper inputs, and produce a relatively more profitable output. After this substitution has occurred, k_2 can be measured.

Practically, k_2 is found by measuring the change in *productivity*. Basically, productivity change is the difference between the rate of output and input growth. Productivity change is a physical concept; it is concerned with the *quantity* of outputs and inputs.

The process of measuring productivity change using CABs involves running two different scenarios: the base-case, or the without new technology, scenario; and the 'with new technology' scenario. The 'with' scenario is determined by translating technology into an appropriate parameter adjustment. For example, the promotion of better fertiliser use to increase pasture production can be translated into a greater volume of dry-matter production per hectare—a variable that can be directly altered in a CAB.

With a given *state of technology*, productivity varies as output increases[4]. In order to avoid productivity variations due to changes in the level of output, the NRE Economics Branch holds the CAB level of output constant in the 'with' scenario. Therefore, the *measured productivity changes reflect a reduced use of inputs*.

CABs use a measure of profit, specifically gross margin, as their objective function. In order to proxy a constant level of *physical* output, total revenue is held constant in the

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[3] For a simple description of CABs, see NRE (1998b)

[4] This is due to the assumption of diminishing marginal product when there are fixed factors. See, for example, Tisdell (1972).

'with new technology' case. In other words, the CAB must find the mix of inputs and outputs that will maximise gross margin, and take account of the fact that the state of technology has altered—a new parameter value, like increased dry matter per hectare, is embedded in the CAB's database.

The magnitude of a research shock will depend on the significance of 'improved inputs'. An improved input is one that is directly affected by research. For example, consider a beef production system. If a research shock affects pasture production by x per cent, then pasture is the improved input. If pasture is a large proportion of total costs, the on-farm productivity impact will be relatively large. Conversely, if there is an x per cent improvement in stock trading efficiency, which is a small proportion of total costs, there will be a relatively small on-farm productivity improvement.

Index Numbers

Productivity can be measured in various ways however one of the simplest, and therefore most popular, is via index numbers.

In the simplest case, where there is only a single output and input, productivity is easily calculated as the rate of growth in the former minus the latter. However, since there are many outputs and inputs in most farming systems, a *productivity index* is used to measure the change from a research-induced technological shock. This allows a multitude of outputs like wheat, barley and wool, or factors like land, labour and capital to be *aggregated* into a single quantity index.

A quantity index measures the movement of all (say) outputs, and weights each according to their significance. Usually, 'significance' is gauged by using prices in combination with quantities. If a relatively expensive (highly priced) output, which is made in relatively large volumes, rises it will drag the overall quantity index in the same direction. A price index is analogous but with quantities used as weights.

Since measurement of productivity change uses information from two time periods there is an issue about the appropriate weights: should first (base) period, second period, or average prices be used? The Economics Branch uses a Fisher index (see below), which uses information on prices from both periods, and weights them geometrically (see **Appendix 2**).

Although there are a range of indices available, Diewert (1992) argues strongly in favour of the Fisher index relative to alternatives such as the Tornqvist-Theil. This conclusion is drawn after analysing indices using a "test" approach and an "economic" approach. The test approach involves logical or accounting tests which index numbers should satisfy. The economic approach analyses which indices conform to basic theorems about economic agents' behaviour. Diewert finds that the Fisher index satisfies all 20 tests in the former and the appropriate theorems in the latter.

Fisher himself argued for the use of (in his terms) the *ideal* index number formula using two tests: factor and time reversal. The time reversal test argues that an index number formula should be invariant to the base period; if quantity is measured as doubling from period one to two, measurement from period two to one should show quantity halving.

The factor reversal test ensures if both a price and quantity index were calculated, then their product would equal the value ratio[5].

In order to use index numbers for measuring the change in farm-level productivity from a technology change, information on prices and quantities—for both inputs and outputs—is collated. This is done for both the 'without' and 'with' scenarios.

Quantity indices, such as the Fisher index used by the NRE Economics Branch, are unresponsive to relative price changes[6]. If this were not the case, measured productivity would change due to relative prices. The state of technology does not alter when relative prices change so this would be misleading. This also means that output-quality changes cannot be modelled by using a simple price change in the 'with' scenario (see below).

Productivity is important because output and income can be viewed as synonymous. Therefore, more output per unit input means more income. Even though income is not the only source of well being, it is an important one, and it is often correlated to other measures such as education and life expectancy (Industry Commission 1997b).

The Industry Commission found that productivity was the major determinant of changes in Australia's real income per person over the 1964-65 to 1995-96 period. It contributed 65 per cent whereas the second most important factor, capital deepening (more capital per person), contributed 36 per cent. Demographic change and labour force participation contributed nine per cent.

Research That Affects Output Quality

Star (1974) notes that indices can be used to gauge the effects of quality change. When relatively disaggregated data are used in an index formula, then better quality products that receive higher prices are given more weight. This was the approach taken by Pardey and Craig (1996) to measure US agriculture's productivity growth from 1949-91.

The impact of research that alters output quality can be analysed in the NRE Economics Branch system using two methods.

Firstly, the outputs in CABs can be broken down into traits that are relatively desirable and therefore highly priced. For example, the dairy CAB includes three components to the output 'milk': protein, fat and water. Since a litre of milk is priced according to its composition of these three things, then the CAB can *directly* gauge the effect of altering (say) an increased protein percentage—milk quality change.

Secondly, the productivity improvement from a quality change can be measured *outside of the CAB*, by altering the composition of output in the index number formula directly. For example, with regards to CABs modelling cropping activity, outputs are numerous, including wheat, barley, canola, bean types and wool, sheep meat, etc. Further, the quality of a wheat crop will be part good management, part good luck (seasonal conditions play a role)[7]. Farmers make planting decisions based on judgement and probability, using a hybrid price—which is blend of high and low quality wheat in such and such a proportion—as their decision node. Therefore, pricing all the different outputs—like high versus low quality wheat—and using them as part of the farmer's decision set in a CAB is not realistic.

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[5] For a more thorough explanation, see Fisher's (1923) seminal book.
[6] For a more complete discussion of Divisia indices, see Alston *et. al.* (1995)
[7] Wheat quality is determined by, *inter alia,* protein concentration.

Altering wheat quality in the index calculation can be done by splitting the product into two: one high-, and other low-, priced. The 'with' scenario would then hold the volume of wheat constant, but shift a higher proportion towards that which is relatively expensive.

The MONASH Model

To make decisions about resource allocation, senior managers require industries to be compared in like units. For example, it would be inappropriate to present the different percentage changes from technology shocks across research projects; knowing that pasture production improves dairy farm productivity *x* per cent, and beef *y* per cent does not have any implications for resource allocation. Rather, the value of a productivity change, in dollars, needs to be determined[8].

The benefits to the state economy, or industry, from an *x* per cent on-farm productivity improvement will (usually) be commensurate with industry size. Further, agricultural industries compete for resources so if (say) dairying expands, the land required must necessarily mean that there is less available for other industries.

The MONASH model takes account of the complex linkages across industries. It models the *Australian* economy, and contains 112 industries, 6 regions and up to 283 labour-force occupations. Apart from having the results published in, *inter alia, The International Journal of Forecasting* (Adams *et al.* 1994), the model has been used by the Industry Commission (1997a) and for a range of other consultancies.

In the MONASH model, technological improvements are modelled by reference to the production function:

$$Y_j = F_j(\frac{X_{1j}}{A_{1j}}, \frac{X_{2j}}{A_{2j}}, ..., \frac{X_{gj}}{A_{gj}}, \frac{X_{lab1,j}}{A_{lab,j}}, \frac{X_{cap,j}}{A_{cap,j}}, \frac{X_{land,j}}{A_{land,j}})$$

where: Y_j is the output of industry *j*, X_{ij} to X_{gj} are inputs of materials; $X_{lab,j}$, $X_{cap,j}$ and $X_{land,j}$ are inputs of primary factors (labour, capital and land); and the *A*s are technology coefficients. A five per cent improvement in the use of (say) capital is modelled by reducing the $A_{cap,j}$ coefficient by five per cent. A five per cent improvement in the use of all inputs requires reducing all *A*s; the same output can be produced with five per cent less inputs. This is consistent with the approach at the farm level (explained above).

To analyse the effect of a five per cent industry-specific productivity improvement to the Australian economy, two scenarios are run: (i) a control or base case and (ii) a simulation that includes a five per cent productivity improvement (Centre of Policy Studies 1998)[9]. Differences between variables—such as Australian real wages, Australian GDP and Victorian gross state product—are then compared in the two scenarios for the year 2006-07. The relevant industries to NRE, for which results are derived in MONASH, are given in **Appendix 3**.

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[8]Note that the MONASH model will calculate the income change from a productivity improvement, not the change in producer and consumer surplus. Alston *et. al.* (1995) discuss the issues associated with calculating economic surplus in a multi-output setting.

[9] The productivity improvement can be run for labour, land, capital or materials separately, or in any combination.

Results from the MONASH model are approximately linear; the value of a five per cent change is approximately half of a ten per cent one. Therefore, its results can be used as the basis for deriving *gross* benefits from any research shock. For example, the south west makes up 29 per cent of Victorian dairy production (Australian Dairy Corporation 1997). A ***preliminary estimate*** on the worth of a five per cent productivity improvement in dairy is $105 million (Centre of Policy Studies 1998). Therefore, a research shock in the south west that improves on-farm productivity by 2 per cent is worth, *in gross terms*:

0.29*(0.02/0.05)*$105.3 million = $12.21 million.

In many cases, agricultural enterprises have many outputs. For example, a mixed livestock-crop enterprise may produce wheat, barley, canola, wool and sheep-meat. In these circumstances, the impact of a research-induced shock to any one aspect of the farm, for example, a wheat yield increase, will be spread across all outputs. Therefore, aggregation of the impact on farm occurs across all outputs. For example, a one per cent wheat yield impact that raises on-farm productivity by half a per cent is applied to the MONASH result for wheat, barley, canola, wool and sheep meat.

The numbers that are calculated by linking CABs and MONASH via productivity-change estimates are *gross* estimates on the worth of research. In order to make decisions for investment purposes, full benefit cost analysis, using assumptions about technology adoption and probabilities of success are required.

Summary

The NRE Economics Branch has developed, and uses, a novel approach to evaluating the benefits from a research-induced productivity change. Firstly, Farm-level models (CABs) are used to calculate the on-farm productivity change. Relevant model parameters, which reflect the change in technology, are altered to gauge input and output changes, including substitutions towards relatively profitable activities.

Secondly, the on-farm productivity change is measured via an indexing procedure. Specifically, the Fisher index is used due to its desirable traits; satisfaction of the factor and time reversal tests.

Lastly, the value of on-farm productivity change to the economy is gauged using the MONASH general equilibrium model of the Australian economy. A one-shot productivity improvement is modelled in MONASH, and its value (in terms of real income) ascertained, using a ten-period simulation. This allows economy-wide interactions to take place. The value of a research-induced change to producers can also be gauged by using the change in producer production, rather than Victorian income. This would be the appropriate figure for rural industry corporations to consider when assessing the relative worth of research projects.

The quantitative component of the NRE Economics Branch investment assessment framework improves government's decision making . This increases wealth of both the agricultural sector, and the Victorian economy generally. The framework can also be used to value the benefits of past research efforts. These capabilities are essential in a climate of intensive public scrutiny of government spending.

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Appendix 1: Investment Assessment Framework
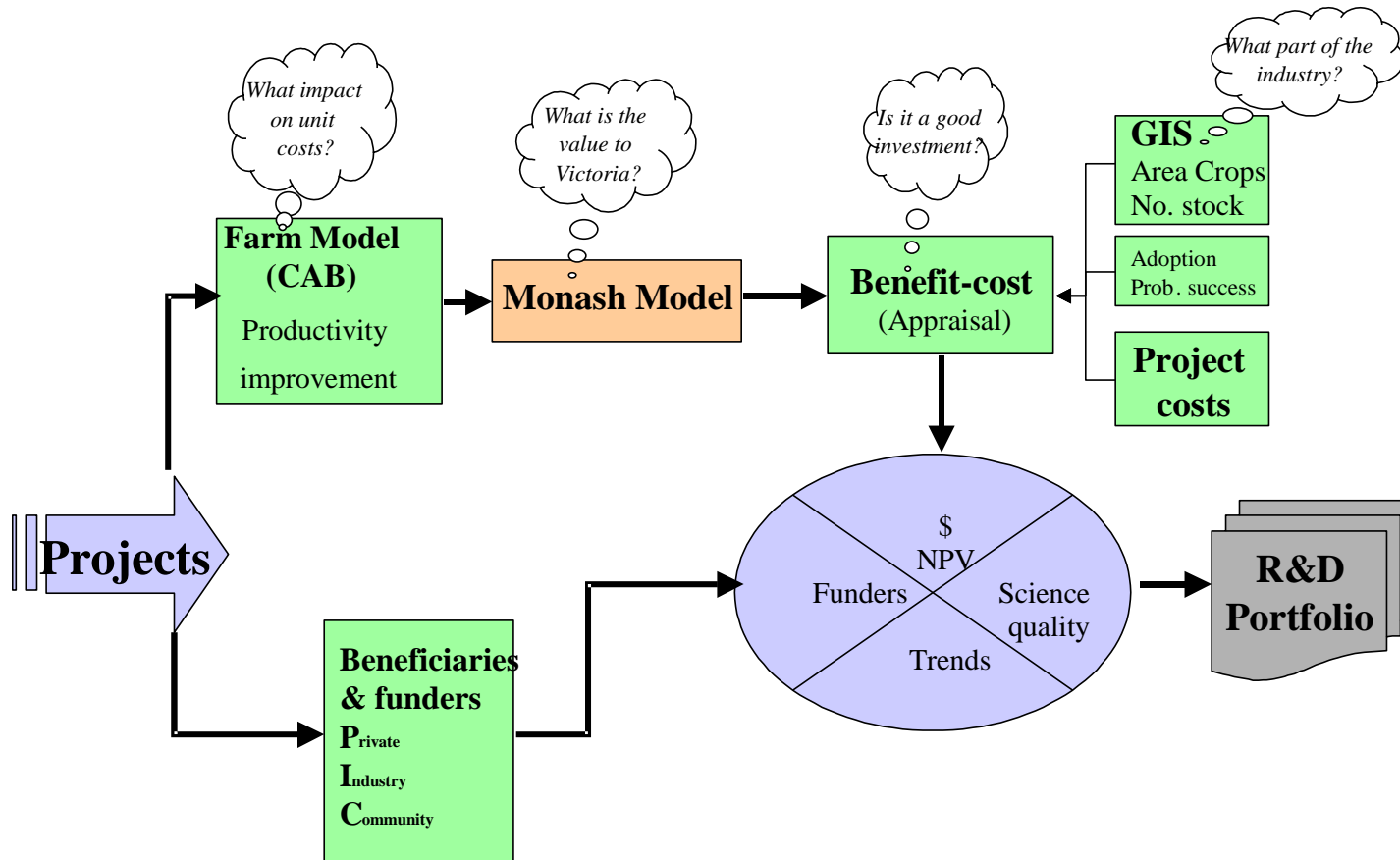
Appendix 2: Mathematical Formula for the Fisher Index

The Fisher index is utilises two other popular formulas: the Laspeyres, and the Paasche.

The Laspeyres quantity index, denoted *La*, is given by:

$$La_t = La_{t-1}(P'_{t-1}X_t / P'_{t-1}X_{t-1})$$

and the Paasche index approximation is denoted *Pa*:

$$Pa_t = Pa_{t-1}(P'_tX_t / P'_tX_{t-1})$$

where $X_t \geq 0$ and $P_t \geq 0$ are (Tx1) vectors of quantities and prices respectively, both at time *t*. The implicit Laspeyres quantity index (the value ratio divided by the price index) is the same as the Paasche direct quantity index and vice versa.

The Fisher index is given by the geometric mean of the two:

$$F_t = (La_t)^{1/2}(Pa_t)^{1/2}$$

Appendix 3: MONASH Model Industries

The industries relevant to resource allocation for the NRE Primary Industries
Division, which are analysed by the MONASH model, are given in Table A3.

Table A3: MONASH Industries

Wool
Sheepmeat
Wheat
Barley
Other Grains
Beef
Milk
Fruit
Vegetables
Poultry
Agricultural Services
Forestry
Fishing
Meat Processing
Milk Processing
Fruit Products