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EVALUATION OF POSTHARVEST RESEARCH : RESULTS FOR AN APPLICATION TO TROPICAL FRUIT RESEARCH PROJECTS AND SOME FURTHER METHODOLOGICAL ISSUES

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1. INTRODUCTION

As most economies develop there is an important trend to specialisation in the production of most activities. Associated with this trend is the increased importance of trade. This trade occurs usually within a country to begin with but eventually becomes international as well. In most economies the agricultural sector plays a major role in the early stages of the development process. As domestic and international trade in agricultural products expand, increased importance is placed on the postharvest sector, in the form of, for example, assembly, transport, storage, grading and processing of produce.

As the demand for postharvest sector products and services expands there are increased incentives to improve the technologies available in this sector. Research is an important source of these improved technologies. Since many postharvest activities are undertaken by private businesses and many of the technologies used in this sector can be patented, the private sector often plays an important role in providing this postharvest research effort. However, there is still a range of production constraints which is only likely to be resolved through public sector supported research. The results from these types of research are not appropriable by those undertaking the research and, therefore, the private sector may under-invest in these areas. This paper assumes a case has been established for public sector funding of postharvest research and the question is how do decision-makers ensure that these funds are allocated effectively?

Increasingly, public research institutions are placing more importance on efforts to evaluate the impact of the research they fund. The information generated by these evaluations has been found to make several important contributions. These include:

- it provides a useful basis for supporting cases for continued and increased government funding of research;

- it provides information which can support decision-making within research institutions; and often, if undertaken with constructive interaction between economists and technical scientists, it can improve the nature and focus of the research projects.

Evaluation of farm level research was first undertaken in the 1950s and a now considerable set of these evaluations has been completed for a range of commodities and countries. Evaluation of postharvest research has only received attention during the last 10 years.

Given the growing interest in postharvest research it seems important to devote some effort to determining what the impact of this type of research has been or is likely to be. This paper attempts to address this area in three ways. First, it provides a brief review of methods for evaluation of agricultural research, especially postharvest research and some of the past attempts to evaluate postharvest research. Second, it summarises the results of a preliminary analysis of 6 collaborative postharvest tropical fruit research projects which have been funded during the past 10 years by the Australian Centre for International Agricultural Research (ACIAR). A model which suits evaluation of these particular postharvest tropical fruit research projects is chosen and the implications of the preliminary results from its application are discussed. Finally, some suggestions for expanding the methodology are considered. These suggestions arose from issues which were raised during the evaluation of the 6 projects.

2. METHODS FOR EVALUATING POSTHARVEST RESEARCH AND SOME PAST APPLICATIONS

2.1 A Brief Overview of the Development of Methods for Evaluation of Research

Development of methods for the evaluation of agricultural research began with the early work by Schultz (1953) and Griliches (1958). This early work focused on farm level research activity and projects. A review of these farm level evaluation methods is given in, for example, Norton and Davis (1981). Summaries of the returns from research estimated by some of these studies have been summarised in, for example, Ruttan (1982, pp242-6). Many of the early evaluations were undertaken by economists outside the research organisation where the research was undertaken. Recently there has been an increased emphasis by research institutions to generate these evaluations to support decision-making. Examples are Davis and Ryan (1993), GRDC (1992) and Johnston et al. (1992).

It was not until the early 1980s that attention was focused on the need to consider postharvest separately from farm level research. Freebairn et al. (1982) first raised the issue of the need to consider a revised, although theoretically related, form of methodology to estimate the returns to postharvest or, as they called it, market service sector research. This initial paper has generated significant interest in this area. Although the model Freebairn et al. (1982) developed was an important improvement on the temptation to simply use the retail value of the increase in output as the benefits to research, it was soon found that the question of the impact of and benefits from postharvest research can be quite complex. Developments by Alston and Scobie (1983), Freebairn et al. (1983) and Holloway (1989) have been important. Alston (1991) provides a comprehensive review of research evaluation methodology which includes and places in perspective postharvest research.

Perhaps one of the more critical implications which has come from these developments is the potential importance of the distribution of the gains from postharvest research. With farm level research it is generally accepted that if the results of research are applicable to a farmer or group of farmers and they adopt the resultant technology then those farmers, at least, will always gain from the research. This is not to say that some farmers will not lose from research. The farm level analyses have shown that if the technologies are not appropriate to a group or groups of farmers and if the research impact causes a fall in the product price (which is likely to occur in most circumstances) then these farmers can be worse off with the research rather than if it had not been undertaken. On the other hand, the above postharvest focused studies have shown that it is quite possible for all farmers to lose from the impact of postharvest research on the commodity they produce. This will not always be the case. However, it has been shown that the types of conditions required for this result are found in some circumstances. The important result can be summarised as: while society generally will gain from most successful farm level and postharvest research, in some cases some groups (especially perhaps farmers) might be worse-off due to the research.

2.2 Past Applications of Postharvest Research Evaluation Methods

The early postharvest research evaluation papers concentrated on developing the methodology. When applications were included they were generally hypothetical rather than relating to a specific research project or outcome. Several subsequent studies have applied the

methodology to specific research issues and in some cases projects. Table 1 provides a brief summary of 14 of these studies. These will not be discussed in detail here. One important feature is the considerable variability in both the evaluation method used and the types of results reported. Only 5 of the 14 provided a complete assessment which included an assessment of the lags from the commencement of the research and the adoption levels and patterns as well as the annual welfare impacts of the research. These five are listed at the top of Table 1 and in the order of the highest to lowest internal rate of return (IRR). The rates of return reported range from 29 to 143% which are similar to the types of returns reported for farm level research. The other studies have reported estimates of the annual welfare gains to the countries indicated from the research. Some of these are estimates of the potential gains rather than those to a specific completed project. There are some very large estimates reported, especially for the livestock sectors. One of the 14 reported negative returns to the project and two found it difficult to apply the available methods to the research project considered.

Care is required in drawing general conclusions from these studies. The methods and format for presentation are not necessarily comparable. Literature reviews especially such as that provided by Alston (1991) have been very useful in guiding the choice of methods for evaluating research. However, so far the methodology classification has been based on only the economic characteristics. During the process of applying research evaluation methods at a project level at ACIAR (and this experience has been confirmed by other institutions) it has been found that it is important to be able to select an evaluation method which best suits the type of research being undertaken, as well as the economic characteristics facing the production of the commodity the research will eventually influence. This is especially important as there appears to be a gap in the literature regarding the most appropriate procedures for estimating the research impact parameters which are included in the economic models. The nature of these parameters will depend on the type of research. Davis (1992) and Davis and Lubulwa (1993) have discussed this issue and suggested several possible research classification areas. They related the methodology classifications, suggested by Alston (1991), to these research area classifications. A summary of the section of the discussions from these papers relevant to postharvest research is provided in Table 2. This emphasises that the type of model is likely to vary with the type of postharvest research.

Davis (1992) allocated ACIAR's postharvest research projects to these groups and found that the majority fell in the wastage reduction group. In addition a categorisation of the sessions based on the papers presented at a recent International Conference on Postharvest Handling of Tropical Fruit held in Chiang Mai, Thailand suggests that a considerable share of current research efforts is focused on this wastage reduction and associated research. This is illustrated in Table 2 (last column).

The recent versions of the multi-regional vertical market models as outlined in Alston (1991) are becoming relatively complex, especially from an economic perspective. Yet procedures for estimating the research impact parameters included in them are not very well developed. Davis (1993) discussed this and suggested a simpler model which focuses on waste reduction at the postharvest level as a possible alternative for this sub-set of postharvest research projects.

Table 1. Summary of some postharvest research evaluation studies

Description	Commodity	Country	Research Type	Net Present Value ($M)	Internal Rate of Return (%)	Benefit Costs Ratio	Comments	Source
Suppression of Grain Dust	Wheat	Australia	Wastage	14.5	143	54:1		GRDC (1992)
Integrated Pesticide Use in Grain Storage	Rice	Malaysia/Philippines/ Australia	Wastage-Storage	24.3	43			Chudleigh (1991)
Stored Grain under Plastic	Rice	South East Asia/Australia	Wastage-Storage	9.2	38			Ryland (1991)
Reduced Amylose in Rice	Rice	Indonesia	Quality	117.0	37		Only annual benefits reported	Unnevehr (1986)
Reduced Amylose in Rice	Rice	Philippines	Quality	227.0	29		Only annual benefits reported	Unnevehr (1986)
Pigmeat Fat Reduction	Pigs	USA	Quality	977.5			Present value of year 5 benefits no research costs	Lemieux and Wohlgenant (1989)
Reduction in Dark-Cutting in Beef	Beef	Australia	Quality	905.0			Potential benefits no research costs	Voon and Edwards (1990a)
Boxed to Tray Ready Beef Processing	Beef	USA	Processing	845.6			Annual impact no research costs included	Mullen et al. (1988)
Increased Protein Content in Wheat	Wheat	Australia	Quality	447.0			Potential benefits no research costs	Voon and Edwards (1990b)
Reduced Backfat Depth in Pigs	Pigs	Australia	Quality	66.0			Potential benefits no research costs	Voon and Edwards (1990c)
Wool Carding Improvement (Sirocard)	Wool	Australia	Processing	21.9			Benefits only no research costs included	Mullen and Alston (1990)
Component Pricing and Grading	Soybeans	USA	Grading/ Quality	-12.6			Annual impact no research costs included	Updaw (1980)
Wheat Quality for Middle East	Wheat	Australia/Middle East	Quality	?			Qualitative assessment only	GRDC (1992)
Safe Storage of Oilseeds	Rapeseed	Australia	Wastage-Storage	$5/t			Impact per tonne only assessed	GRDC (1992)

Table 2. Summary of possible postharvest research area classifications

Research Classification Area	Type of Evaluation Model (Based on Alston[1991])	Comments	Classification of the session themes in a recent International Postharvest Conference
Post Farm gate			
Wastage Reduction	Multi-regional vertical market model	Wastage reduction version may be a useful simplification	. Harvesting . Diseases & Disorders . Storage . Ripening . Disinfestation
Processing Methods	Multi-regional vertical market, probably factor-biased, model	Private sector relevance could be important since most research gains are appropriable	Processing
Transport	Multi-regional vertical market model	Private sector relevance could be important since most research gains are appropriable	Transportation
Farm & Off-Farm			
Product Quality	Multi-commodity, related in consumption, vertical market model	Care is required if a simple increase in price model is used	Harvesting
New Product	Single or multi-regional, multi-commodity supply shift model	Quantity associated with minimum TAC[(a)] required. Care is required as estimates are subject to more error	
Policy/Regulation	Value of information with saving in dead weight loss model.	Model not well developed and few applications	Regulation
Environmental Issues	Single or multi-regional, multi-commodity supply shift model	Other areas also involve environmental issues	
Human Health	Labour supply shift, demand for health services	Models not well developed or applied	
Institutional Analysis	Value of information with saving in dead weight loss model.	Model not well developed and few applications	Marketing

a: TAC stands for Total Average Cost

2.3 Overview

This section has briefly reviewed research evaluation methods and their application to postharvest research. A summary of past applications indicates that there have not been many evaluations of postharvest research efforts and even with those which have been undertaken there has been minimal consistency in both the approach adopted and the scope of the evaluation. In particular, very few studies have undertaken full evaluations where information such as the research and adoption lags and levels have been incorporated.

In addition attempts to classify several groups of postharvest research efforts into research areas suggest that many of the research projects in this area seem to be focusing on what might be regarded as postharvest wastage reduction issues. It is possible that a wastage reduction evaluation model such as that proposed by Davis (1993) might be the most appropriate methodology for evaluation of these types of projects. At ACIAR it was decided to expand its set of evaluations to include more postharvest research projects and to test the potential usefulness of this wastage reduction evaluation model.

3. AN EVALUATION OF ACIAR'S POSTHARVEST TROPICAL FRUIT RESEARCH PROJECTS

One of ACIAR's 7 research programs is specifically focused on the development of postharvest technologies. During the past 10 years this program has developed and supported projects in a range of postharvest research areas. One of the major thrusts has been the postharvest treatment of tropical fruit. Since there have been few evaluations of tropical fruit research in general this group of projects was selected for evaluation. This section provides a brief summary of these evaluations. A more detailed outline of this work is provided in Lubulwa and Davis (1993).

3.1 A Brief Description of ACIAR's Postharvest Tropical Fruit Projects

During the past 10 years ACIAR has funded 6 collaborative tropical fruit postharvest research projects, 4 have been completed and two are still in progress. Table 3 summarises some of the important commodity and country foci of the projects and the solutions explored. A brief summary of each project is given below.

(i) Use of calcium to inhibit ripening and senescence of fruits (PN8319)

This project investigated whether the process of postharvest application of calcium by vacuum infiltration can be used in Indonesia and Australia to extend storage life of mango, avocado, papaya, guava, melons, rambutans, mangosteen, longans, and lychees at storage temperatures ranging from 25 to 30°C. While Hass avocados did not respond well to calcium infusion, data on Australian Fuerte avocados showed that calcium treatments led to an average shelf life extension of about 3 to 5 days or 32 to 55 per cent over the average shelf life of 9 days for Fuerte without the treatments. However ACIAR (1986) noted that:

> *In Australia, Fuerte is an early variety for which growers get a good price before the better varieties become available. They are therefore interested in*

Table 3. Commodity coverage in ACIAR's[a] postharvest tropical fruit research projects

Project Number Solutions explored in the project	8319 Vacuum infiltration of fruit with calcium	8355 Postharvest technology for bananas	8356 Chemical controls to fruit disease	8844 Cool storage, CA[b] and chemical controls	9313 Non-chemical controls of fruit disease	9105 Edible coatings for shelf life extension
Country focus	Indonesia, Australia	Malaysia, Philippines, Australia	Malaysia, Philippines, Thailand, Australia	Thailand, Australia	Thailand, Australia	Thailand, Australia
Mango	✓		✓	✓	✓	✓
Avocado	✓			✓	✓	✓
Longan			✓	✓	✓	
Lychee			✓	✓	✓	✓
Rambutan				✓	✓	
Mangosteen			✓	✓	✓	
Durian				✓		
Green Coconut			✓	✓		
Papaya	✓					
Banana	✓	✓				

a: ACIAR stands for Australian Centre for International Agricultural Research. The projects were collaboratively funded by ACIAR and participating institutions in Australia and South East Asia.

b: CA stands for controlled atmosphere.

c: A tick indicates that the fruit in question was studied as part of the project, but it does not necessarily imply that the study led to some useful technology for postharvest handling of the fruit. The commodities are not equally applicable to all countries. Details about the fruits which different countries focused on are given in Lubulwa and Davis (1993).

faster ripening using ethylene but are not likely to be interested in delaying ripening with calcium infusion.

The project demonstrated that calcium infiltration could delay ripening in some varieties of avocado in Australia and Indonesia and in some papaya varieties. However for the treatment to have commercial application it was considered that better control of rotting was necessary.

(ii) Postharvest physiology of and technology for bananas in South East Asia (PN8355)

This project was confined to bananas. Research was conducted in Malaysia, Philippines, Thailand and Australia. Commercially viable handling technology for banana was successfully developed (Lizada et al. [1987]). This technology involved better control of ethylene to delay ripening of bananas under modified atmosphere storage, and use of fungicides to control stem-end rot. Four handling trials had proven the technology feasible for the export of bananas from Malaysia and the Philippines by sea to Hong Kong and Japan[1]. ACIAR (1986, p43) reached similar conclusions but noted that there was still a need for research on banana pathology problems in response to modified atmospheres and on low cost ethylene absorbents.

(iii) Chemical controls for fruit disease (PN8356)

Research under this project was conducted between 1983 and 1987 with the aim of investigating postharvest characteristics of mango, longan, lychee and mangosteen in Australia and the South East Asian region. The project demonstrated that during controlled atmosphere storage, a dual treatment of hot water followed by prochloraz was required to control stem end rot, anthracnose and alternaria rot. The project in addition verified the efficacy of hot benomyl and prochloraz sprays for the control of anthracnose with negligible impact on fruit quality, and demonstrated that hot benomyl controlled some types of stem end rot. Postharvest research into other tropical fruits in Thailand under PN8356 produced results indicating that sulphur dioxide fumigation increased the storage life of lychees to at least 90 days. For mangosteen, storage at 5^0C in 5 per cent carbon dioxide and 5 per cent oxygen gave one month storage.

(iv) Cool storage, controlled atmospheres and chemical controls (PN8844)

This project was funded by ACIAR from 1989 to 1992 and focused on mangoes, lychee, longan, rambutans, mangosteen and durian. A review by Alexander (1991) concluded that the project achieved major results in the following areas:

- new technologies with early commercial application particularly in relation to export marketing of longans, lychees, mangoes and durian;

- results of scientific merit, particularly in relation to controlled atmosphere storage of different varieties of mangosteen, rambutan, mango, lychee and longan; the development of harvesting indices for lychee, durian, longan, rambutan and mango; the biology and control of mango stem end rot and other postharvest diseases; and mango sap burn.

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1 See ASEAN Food Handling Newsletter, April 1987, p11.

- the development of sulphur dioxide fumigation technology for the control of postharvest disease in exotic tropical fruits, external browning in trimmed green coconuts and measures to limit lychee and rambutan skin colour loss in storage.

(v) Non-chemical controls for fruit disease (PN9313)

While PN8356 and PN8844 focused on the use of fungicides in the control of tropical fruit disease, PN9313 will study the mechanisms of tropical fruit resistance to disease, and the development of strategies that minimise the use of chemicals in the control of tropical fruit diseases and pathogens. This is partly in response to increased international community pressure for a reduction in the use of postharvest chemicals on fruit. Partly the project is meant to build on pioneering discoveries made within ACIAR PN8844 regarding the infection processes of stem end rot fungi. Potential benefits from this project include the following: watering regimes suitable for stimulation of flowering and reduction in stem end rot losses in tropical fruit (mango, lychee) may be developed. Screening procedures for the selection of stem end rot resistant cultivars may be developed. The results could alleviate reliance on postharvest fungicides (in mangoes) and underpin development of control recommendations for stem end rot of avocado, carambola, mangosteen and rambutan, commodities for which there are no satisfactory stem end rot control measures at present.

(vi) Development of simple edible coatings for the postharvest life extension of fruit (PN9105)

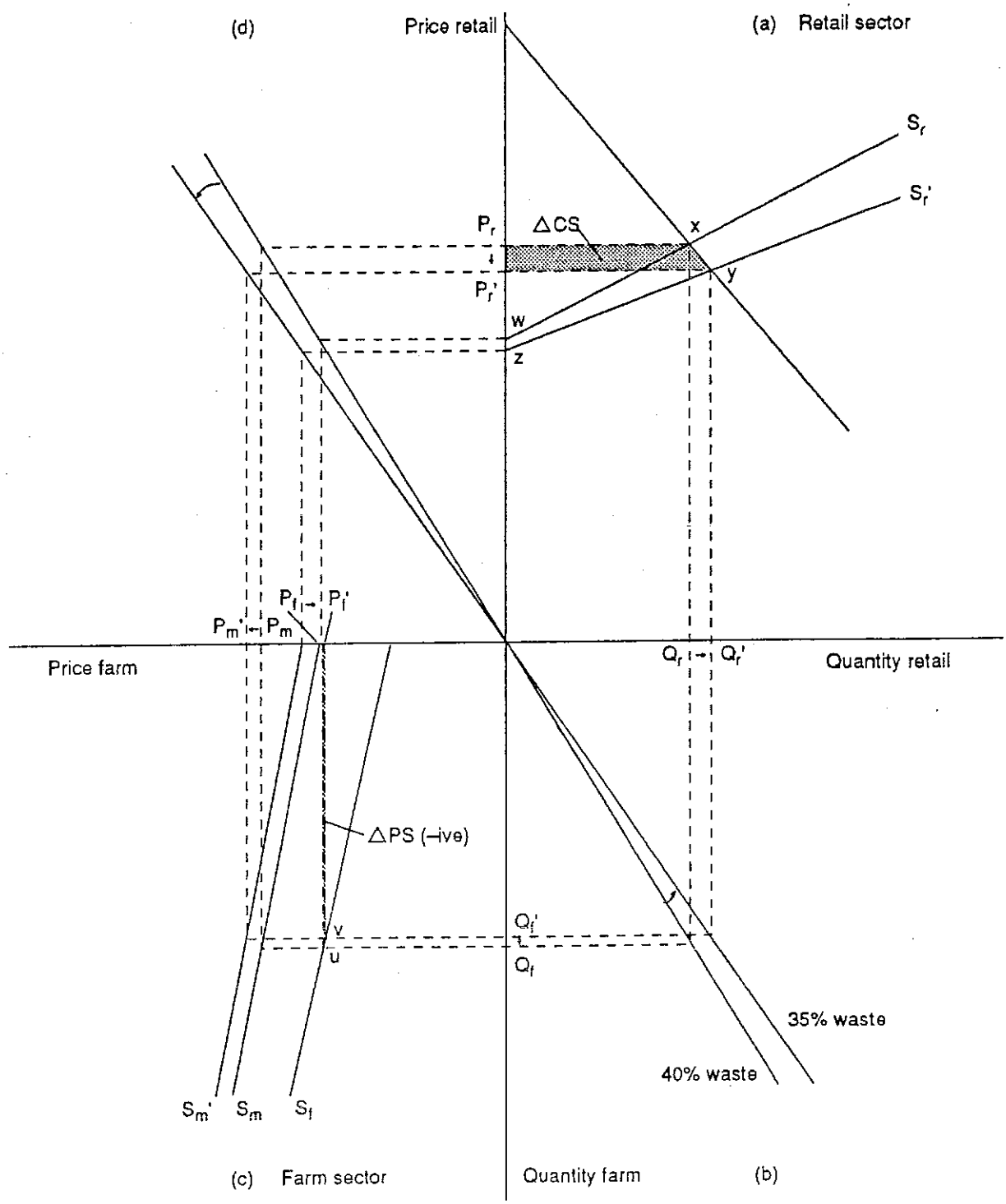
This project aims to develop edible coatings that will extend the postharvest life and maintain the quality of fresh fruits handled under ambient or low temperature conditions in Thailand and Australia. The coatings - which serve to modify atmospheres within the produce - are simple to apply, non-toxic, accessible and affordable to the user. Produce dipped in the water-soluble coatings are coated with a natural microfilm, which is odourless, tasteless and invisible. The coatings can be applied at any stage, can be washed off with water later and are compatible with the commonly used fungicides. The project will involve further research and development on properties of the films, including mechanical (eg thickness and strength) and barrier attributes (eg permeability to water vapour, oxygen and carbon dioxide). The coatings will be tested under a range of climates and handling conditions to optimise the effectiveness and commercial suitability of different coatings on different produce. The project will also investigate disease control in tropical fruit which is a major constraint in the commercial application of coating and film technologies, particularly in the tropics.

3.2 Project Evaluation Methodology

Davis (1993) proposed a possible wastage reduction model for evaluating postharvest research. The model was presented in diagrammatic form with the potential changes in welfare for different groups clearly identified. To effectively apply this model it is important to also derive the formulae for estimation of these welfare changes. The model and derived formulae are briefly summarised in this section.

Figure 1 is the diagrammatic representation of the model as developed in Davis (1993). It is a two sector or region model with the postharvest sector services supply assumed to be

Figure 1. Postharvest wastage model with research



perfectly elastic. Research is assumed to result in new technologies which reduce the wastage between the farm and retail levels, that is, change the farm to retail quantity conversion rate. The new technologies are also assumed to change the cost of the postharvest activity. In the illustrated example these costs are increased. As was discussed in detail by Davis (1993) the welfare changes to this type of technical change are given by the shaded areas in Figure 1 (a) and (c). Consumers are seen to gain by the area $P_r xyP'_r$ and producers are seen to lose by the area $P_f uvP'_f$. As was also discussed by Davis (1993) producers will not necessarily lose. This will depend on the relative changes due to the research and the levels of the various supply and demand parameters.

Formulae can be derived to estimate these areas. The following model can be used to represent Figure 1.

Before Research

Farm level supply (Figure 1[c]):

$$Q_{fh} = a_h + b_h P_{fh} \qquad (1)$$

where:

Q_{fh}	is the quantity of a commodity produced at the farm level in country h
P_{fh}	is the farmgate price of the commodity in country h
a_h and b_h	are the intercept and slope of the supply curve in country h.

Farm to retail production linkage (Figure 1[b]):

$$Q_{rsh} = \delta_h Q_{fh} \qquad (2)$$

where:

Q_{rsh}	is the quantity supplied at the retail level
δ_h	is farm to retail level conversion factor and is the rate at which the farm level quantity is converted to the retail quantity in country h. The wastage rate of the commodity from the farm level to retail is then $(1-\delta_h)$ where $0<\delta_h<1$. For example, if 30% of the farm product is lost between the farm gate and consumer purchases the wastage rate is 0.3 and therefore $\delta_h = 0.7$.

Farm to retail price linkage (Figure 1[d]):

$$P_{fh} = \delta P_{rh} - M_h \qquad (3)$$

where:

P_{rh}	is the retail level price
M_h	is the postharvest cost per unit of farm level output produced.

Retail sector supply (Figure 1[a]):

$$Q_{rsh} = \delta_h\left(a_h + b_h\left[\delta_h P_{rh} - M_h\right]\right) \tag{4}$$

Retail demand (Figure 1[a]):

$$Q_{rdh} = c_h - d_h P_{rh} \tag{5}$$

where:

c_h and d_h are the intercept and slope of the demand curve in country h.

Retail market equilibrium (Figure 1[a]):

Solving equations (4) and (5) gives:

$$P_{rh} = \frac{\left(c_h + b_h\delta_h M_h - \delta_h a_h\right)}{\left(b_h\delta_h^2 + d_h\right)} \tag{6}$$

and substituting (6) in (5) gives:

$$Q_{rh} = c_h - d_h\frac{\left(c_h + b_h\delta_h M_h - \delta_h a_h\right)}{\left(b_h\delta_h^2 + d_h\right)} \tag{7}$$

These can be substituted in equation (3) and the inverse of equation (2) to give the associated farm level equilibrium.

After Research

In this simplified model it is assumed that research changes both the wastage rate and the postharvest costs. For example in the case of tropical fruit projects, fruit loss reductions are achieved by additional postharvest treatments of various kinds. In most cases these require additional inputs and, therefore, associated costs. In terms of the above model these changes can be represented in the following manner.

Reduction in the postharvest wastage rate:

A reduction in the wastage rate between the farm and retail levels is equivalent to an increase in the farm to retail conversion rate, that is, δ_h. This impact of research can be represented as:

$$\delta'_h = \left(\delta_h + \Delta\delta_h\right) \tag{8}$$

where:

$\Delta\delta_h$ is the change in the farm to retail conversion rate due to the research in country h.

Change in the postharvest input costs

The associated change in the postharvest input costs can be represented as:

$$M'_h = (M_h + \Delta M_h) \tag{9}$$

where:

ΔM_h is the change in the unit cost of postharvest activity associated with the new technology in country h.

Equations (8) and (9) can be substituted into equations (1) to (5) to give an 'after research' model of the farm to retail sectors. It can then be shown that the following are the 'after research' equilibrium retail prices and quantities:

$$P'_{rh} = \frac{(c_h + b_h \delta'_h M'_h - \delta'_h a_h)}{(b_h \delta'^2_h + d_h)} \tag{10}$$

and substituting (10) in the 'after research' version of (5) gives:

$$Q'_{rh} = c_h - d_h \frac{(c_h + b_h \delta'_h M'_h - \delta'_h a_h)}{(b_h \delta'^2_h + d_h)} \tag{11}$$

These can then be substituted into the 'after research' versions of equations (2) and (3) to give the revised farm level equilibrium prices and quantities, P'_{fh} and Q'_{fh}.

The change in welfare from the research can be estimated using these equilibrium values and the following:

The change in the consumers' surplus :

$$\Delta CS_h = (P_{rh} - P'_{rh})Q_{rh} + 0.5([P_{rh} - P'_{rh}][Q'_{rdh} - Q_{rdh}]) \tag{12}$$

The change in producer surplus:

$$\Delta PS_h = (P'_{fh} - P_{fh})Q_{fh} + 0.5([P'_{fh} - P_{fh}][Q'_{fh} - Q_{fh}]) \tag{13}$$

In a linear model such as this, if estimates of the supply and demand elasticities are available, the following relationships are useful when estimating these welfare changes:

$$b_h = \frac{\varepsilon_{sh} Q_{fh}}{P_{fh}} \tag{14}$$

and therefore:

$$a_h = (1 - \varepsilon_{sh}) Q_{fh} \qquad (15)$$

where:

ε_{sh} is the farm level supply elasticity in country h.

Similarly for the retail demand it can be shown that:

$$d_h = \frac{-\varepsilon_{dh} Q_{rh}}{P_{rh}} \qquad (16)$$

and therefore:

$$c_h = (1 - \varepsilon_{dh}) Q_{rh} \qquad (17)$$

where:

ε_{dh} is the retail level demand elasticity

3.3 Project Evaluation Results

The previous section illustrated a simple two sector wastage reduction postharvest evaluation model. The welfare measures developed in equations (12) and (13) provide estimates of the annual changes once the research has been fully adopted. Research lags, adoption lags and levels, chances of success and other dimensions of the research process can be included as, for example, has been shown in Davis et al. (1987). With these factors the present value of the research gains can be estimated and compared with the present value of research costs.

Evaluation of the six ACIAR funded collaborative postharvest tropical fruit projects involved an extensive effort to collect a range of the parameters included in the model described in section 3.2 plus research and adoption lags and patterns. Lubulwa and Davis (1993) provide details of all this information and the sources and procedures for their collection and/or estimation. A brief summary of the important features is:

(i) Pre-research industry structure

Detailed information was collected on farm level quantities produced and the farmgate and retail level prices of tropical fruits in the five countries covered. Also important were estimates of supply and demand elasticities. These were collected from a range of previous studies. However, there have been very few of these for tropical fruit, so interpolation and extrapolation were also used.

(ii) Before research practices

A detailed assessment was made of the 'before research' postharvest practices for each commodity and each country. Discussions with scientists and other experts were important. This information was crucial for assessing the potential nature of the technologies and whether they have been adopted. Table 4 provides a brief summary of the final assessment of some of these points.

(iii) Adoption patterns

Adoption of the technologies was found to be especially dependent on the share of the product which in fact was sent to the retail market. Local on-farm or nearby town sales are not likely to be influenced by many of the technologies. Estimates of the shares of production entering each market were developed.

(iv) Reductions in total wastage of fruit

Estimation of the changes in the wastage or conversion rates was a crucial aspect of the assessment. Some of the projects considered the same fruit in the same countries. This required careful consideration of the sequential complementarity and/or replacement of one technology with another.

(v) Changes in postharvest costs as a result of changes

Detailed discussions were held with the researchers and others involved in the postharvest sector to determine the additional and in some cases reduced level of input use due to the new technologies. Cost analyses were used to determine the before and after research levels of these costs.

(vi) Other assumptions

The discount rate used was 8 per cent. This rate is used to discount both the costs incurred and benefits received over a 30 year time horizon. The research costs which were incurred before 1991 were adjusted to 1991 by using inflation deflators between 1983 and 1991, all other values were in 1991 Australian dollars.

Results from the base case analysis

The base case (or most likely parameter value) assessments are summarised in Table 5. The projects are arranged in descending order of the net present values. The net present value (column 7 of the table) is the difference between the monetary value of benefits and the research costs of a project, over a 30 year period, discounted at a rate of 8 per cent per annum. The internal rate of return (column 8 of Table 5) is the rate which would be required to equate the discounted benefits flowing from the project to the discounted research costs. These results depend on a number of factors including:

Table 4. Six ACIAR projects and associated tropical fruit postharvest technologies

Project Number	PN8319	PN8355	PN8356	PN8844	PN9313	PN9105
Solution devised	Vacuum infiltration of calcium	Postharvest technology for bananas	Chemical controls to fruit disease	Cool storage, CA[a], and chemical controls	Non-chemical controls of fruit disease	Edible coatings for shelf life extension
When did the project finish	1987	1987	1987	1991	1996[b]	1994[b]
Has the research solution been translated into a technology in South East Asia	Not yet	Yes	Yes	Yes	Not yet	Not yet
Basis for the assessment	Dr C Yuen, Department of Food Science and Technology, University of New South Wales Personal communication	Thompson (1990, P14)	Thompson (1990, P12) ASEAN (1989)	Thompson (1990, P15) ASEAN (1989)	Not applicable	Not applicable
Comments	Still requires to develop a machine embodying the technology	Used mainly for banana exports	Used to control disease in mango and banana	Used extensively in transportation of fruit over long distances	Research in progress	Research in progress

a. CA stands for controlled atmosphere

b. Planned completion date

Table 5. Results from a preliminary evaluation of six tropical fruit postharvest research projects : the base case ($A'000s, Present Value, 1991)

Project Number	Project Title	Consumer Benefits	Producer Benefits	Total Benefits	Total Research Costs	Net Present Value	Internal Rate of Return
PN9313	Non-chemical controls of fruit disease	74,945	5,182	80,127	1,235	78,892	38
PN8355	Postharvest technology for bananas	49,367	2,060	51,427	801	50,627	48
PN9105	Edible coatings for fruit shelf life extension	35,820	7,425	43,246	1,235	42,010	34
PN8356	Chemical controls of fruit disease	33,079	4,500	37,579	1,001	36,578	41
PN8844	Cool storage, controlled atmospheres and chemical controls	17,729	2,243	19,970	1,235	18,735	27
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	3,120	71	3,191	458	2,733	21

- the farm level quantities of fruit produced - the larger the volume of fruit produced the larger the potential benefits;

- the proportion of the fruit produced which is likely to be affected by the new technology and the pattern of adoption of the technology;

- the impact of research on wastage rates - the larger the reduction in wastage rates as a result of research, the larger the potential gain;

- the change in postharvest costs - the higher the increase in postharvest costs relative to the before research level of postharvest costs, the lower the potential gains.

Although generally all the projects increased both producer and consumer welfare, consumers gain more than the producers. The main source of the gains to consumers is the decrease in the prices of fruit as the retail supply of fruit is increased. The share of the gains to producers is influenced by the elasticity of demand for fruit. In the base case it is assumed that demand is elastic (own price elasticity of demand of -1.5). However, if demand is inelastic producers may lose as a result of technologies developed under the projects covered in this preliminary evaluation.

Sensitivity Analysis

A sensitivity analysis was undertaken to assess how the preliminary base case results in Table 5 would change if several of the important parameters took on different values. The following summarises some of the results:

- Wastage rate reductions. In order to assess the sensitivity of the results in Table 5 to the estimated change in wastage rates, the analysis was repeated using the assumption that research leads to twice the reduction in wastage rates used in the base case. Generally doubling the wastage rate reduction led to a doubling of total discounted benefits but only increased the internal rate of return by about 7 per centage points.

- The elasticity of demand. When the demand elasticity was reduced from -1.5 to -0.6, the net present values tended to decrease marginally and the internal rates of return were slightly lower than in the base case. More significantly, the model indicates that producers of fruit under conditions of inelastic demand (-0.6) may incur net welfare losses as a result of the research.

- The change in post harvest costs. The analysis was repeated with the assumption that research leads to a doubling of the base case change in postharvest costs. Generally, doubling of the research-induced change in postharvest costs leads to a small decrease in consumer benefits, a comparatively larger reduction in producer benefits and a reduction in the internal rate of return.

The distribution of benefits between each type of fruit and the collaborating countries

Table 6 shows the distribution of benefits between the different types of fruit for each project. This rank ordering according to potential benefits of research is similar to the ranking ordering

Table 6. The distribution of gross benefits according to type of fruit covered by ACIAR research projects ($A'000s, 1991)

Project Number	Project Title	Mango	Avocado	Longan	Lychee	Rambutan	Mangosteen	Durian	Banana	Total
PN9313	Non-chemical controls of fruit disease	46,068	15,638	3,317	618	8,098	6,388	0	0	80,127
PN8355	Postharvest technology for bananas	0	0	0	0	0	0	0	51,427	51,427
PN9105	Edible coatings for fruit shelf life extension	39,074	3,555	0	616	0	0	0	0	43,246
PN8356	Chemical controls of fruit disease	29,531	0	1,753	183	2,087	4,025	0	0	37,579
PN8844	Cool storage, controlled atmospheres and chemical controls	2,569	0	10,926	2,293	2,860	122	1,200	0	19,970
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	0	3,191	0	0	0	0	0	0	3,191

of production levels of the different fruits. For example, the top two fruits in terms of potential benefits are also the top two in terms of production levels in the 5 countries in the study. The fruit with the least potential to generate research benefits is also the one produced in the smallest quantities in the 5 countries.

Finally, Table 7 shows that all countries collaborating in the research projects are likely to gain. The relative sizes of the benefits accruing to each country are dependent on the relative shares of production of the mix of fruit covered under the given project. The results for the distribution of benefits between different countries reflect the countries which collaborated in the different projects. In the recent past, projects in the tropical fruits postharvest area have focused on Thailand. This explains the larger share of benefits accruing to Thailand. Similarly, Indonesia has collaborated in one tropical fruit postharvest project to date. Thus the zero entries for Indonesia indicate that Indonesia has not been a collaborated partner in 5 of the 6 projects assessed.

At this stage the potential spillovers to countries other than those collaborating in the project have been ignored. This is due largely to the preliminary nature of the results; it has not been possible yet to collect fully reliable, verified estimates for the collaborating countries especially regarding adoption levels. It would be too hypothetical to estimate spillovers to non-collaborating countries at this stage. It is important to note though that given the relatively homogeneous nature of postharvest activity between many countries these spillover benefits are likely to occur.

4. SUGGESTIONS FOR FURTHER METHODOLOGY DEVELOPMENT

4.1 Some Implications from the Evaluation Experience

A crucial part of the evaluation process for the six projects was detailed interaction with the technical scientists involved in each project. It was also important to develop a detailed understanding of the postharvest sectors of the range of countries involved in the projects and the recent and future trends in these. Several issues have arisen through this process which suggests that further refinements to the evaluation methodology may be appropriate. The following summarises some of these:

(i) Although currently there is only limited trade in tropical fruit for the countries collaborating in the projects, suggestions are that this situation will change. Many of the technologies which have been, and are expected to be developed, facilitate longer distance transport of these relatively fragile fruit. Many of the technologies especially extend the shelf life of the fruit which facilitates trade.

(ii) Many of the earlier and even current methods of postharvest treatment of fruit involves the use of chemicals which are increasingly generating health concerns. There is a trend to place restrictions on the trade in products treated with these chemicals.

(iii) Postharvest activities are often very similar in nature between a range of geographical locations. Technologies developed for one country or region are likely to be very applicable to other regions or countries. That is, the potential spillover effects of postharvest research are likely to be high.

Table 7. The distribution of benefits between countries collaborating in ACIAR projects ($A'000s, 1991)

Project Number	Project Title	Indonesia	Malaysia	Philippines	Thailand	Australia	Total
PN9313	Non-chemical controls of fruit disease	0	0	0	54,378	25,749	80,127
PN8355	Postharvest technology for bananas	0	4,075	40,679	0	6,673	51,427
PN9105	Edible coatings for fruit shelf life extension	0	0	0	39,320	3,926	43,246
PN8356	Chemical controls of fruit disease	0	2,676	15,899	15,443	3,561	37,579
PN8844	Cool storage, controlled atmospheres and chemical controls	0	0	0	13,893	6,077	19,970
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	3,191	0	0	0	0	3,191

In all of these situations the need to include the possibility of trade between regions and/or countries is an important addition to the wastage reduction model. The rest of this section provides a first step in this process.

4.2 Some Illustrations of an Open Economy Postharvest Wastage Reduction Model for Different Technical Change Situations

The issues listed above can lead to a wide range of possible trading environments and therefore differences in the market conditions 'before' and 'after' the research has an impact. In this section two of the many possibilities are illustrated.

Figure 2 illustrates the situation of a simple open economy model. Sections (a), (b), (c) and (d) are the same as in Figure 1 and represent the farm and retail sectors in the country of research focus. In this illustration trade with the rest of the world is represented by a simple 'rest of the world' excess demand, which is given as E_d and refers to some central trading location. Transport costs from the country to this central location are assumed to be 'z'. The fob excess demand is therefore given by $E_d - z$. The total 'retail' demand in the country in this open economy situation is then represented as the kinked line D_rD_t. The 'before research' equilibrium is determined as the point 'a' in Figure 2(a). If research has the same impact as discussed in Figure 1, that is, reduces the farm-to-retail wastage rate from 40% to 35% and increases the postharvest costs by $S'_m - S_m$, then the 'after research' equilibrium is determined as the point 'b' in Figure 2(a). The three shaded areas in Figure 2 represent the welfare changes due to this research. Now some of the gains flow to the rest of the world. The area $P_wefP'_w$ is the net result of changes in producer and consumer surpluses in all other countries effected by this trade. Notice under the conditions illustrated now both producers and consumers gain in the country undertaking the research. As was discussed earlier this result will not necessarily hold, although it will be more common in a traded environment than closed economy, provided there are not research spillover effects to other countries.

Figure 3 illustrates a mixed situation. Before research transport costs from the country to the 'world market' are assumed to have been high enough that trade was not profitable. The country, therefore, operated as a closed economy with the same 'before research' equilibrium as in Figure 1. The postharvest research is assumed to have the same effect on domestic postharvest activity. However, in addition it is assumed to reduce the transport costs to the world market. This might be through an increase in shelf life which facilitates the use of, for example, a less expensive form of transport. Under these conditions the 'after research' excess demand becomes $E_d - z'$ and therefore the aggregate domestic demand shifts from the kinked line D_rD_t to the kinked line $D_rD'_t$. The equilibrium 'after research' is then given by the point 'x'. The three shaded areas indicate the welfare changes due to the research. Under the illustrated conditions we now find the situation where domestic consumers lose, by the area $P'_r wvP_r$, as a result of the research, that is, due to the domestic retail price increase from world market access.

A range of alternative situations can be illustrated. If the research has applicability to other countries then the 'rest of the world' excess demand will also shift, either to the left or right depending on the types of conditions in the rest of the world. These possibilities can result in

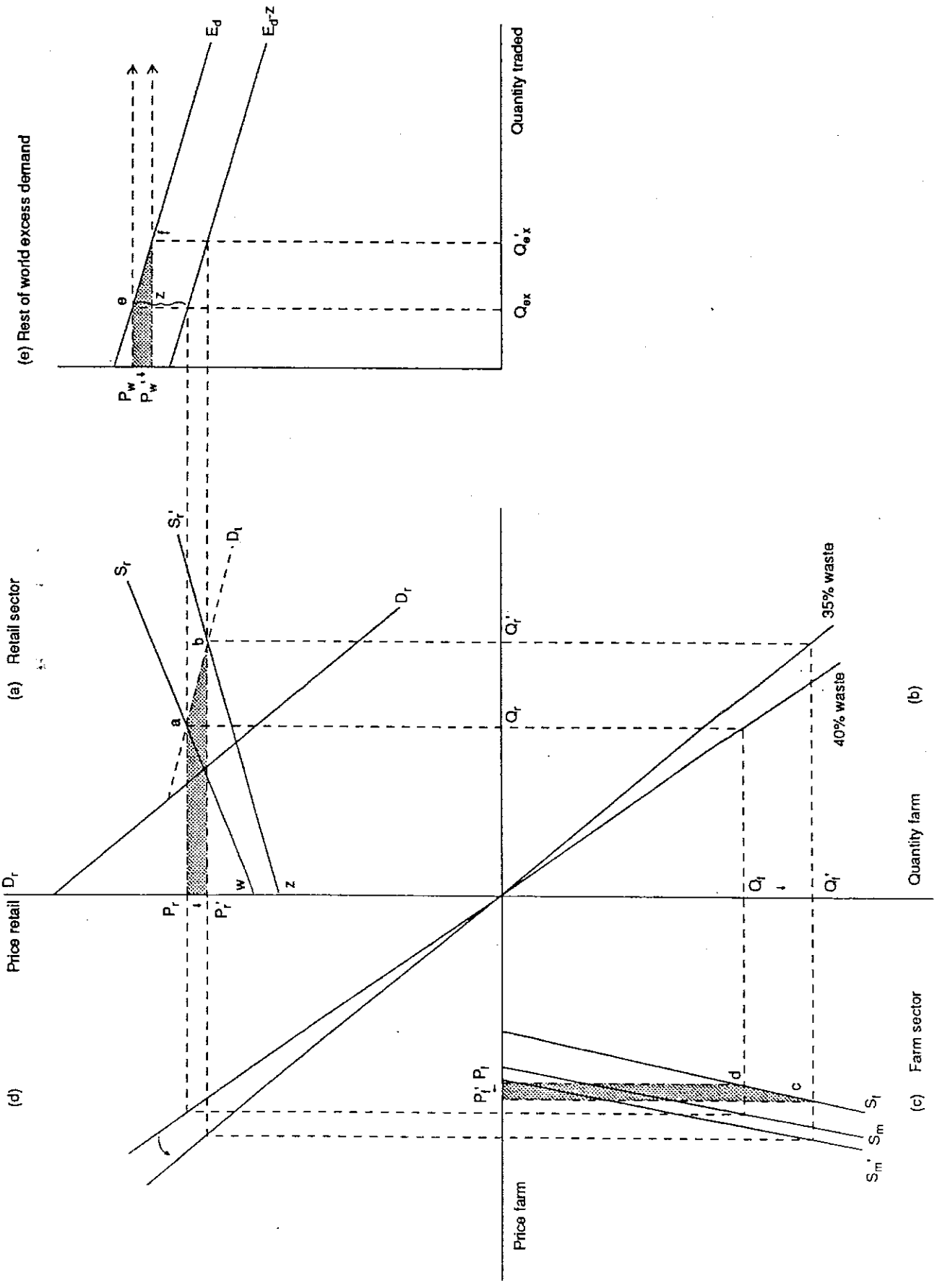


Figure 2. An open economy wastage reduction model

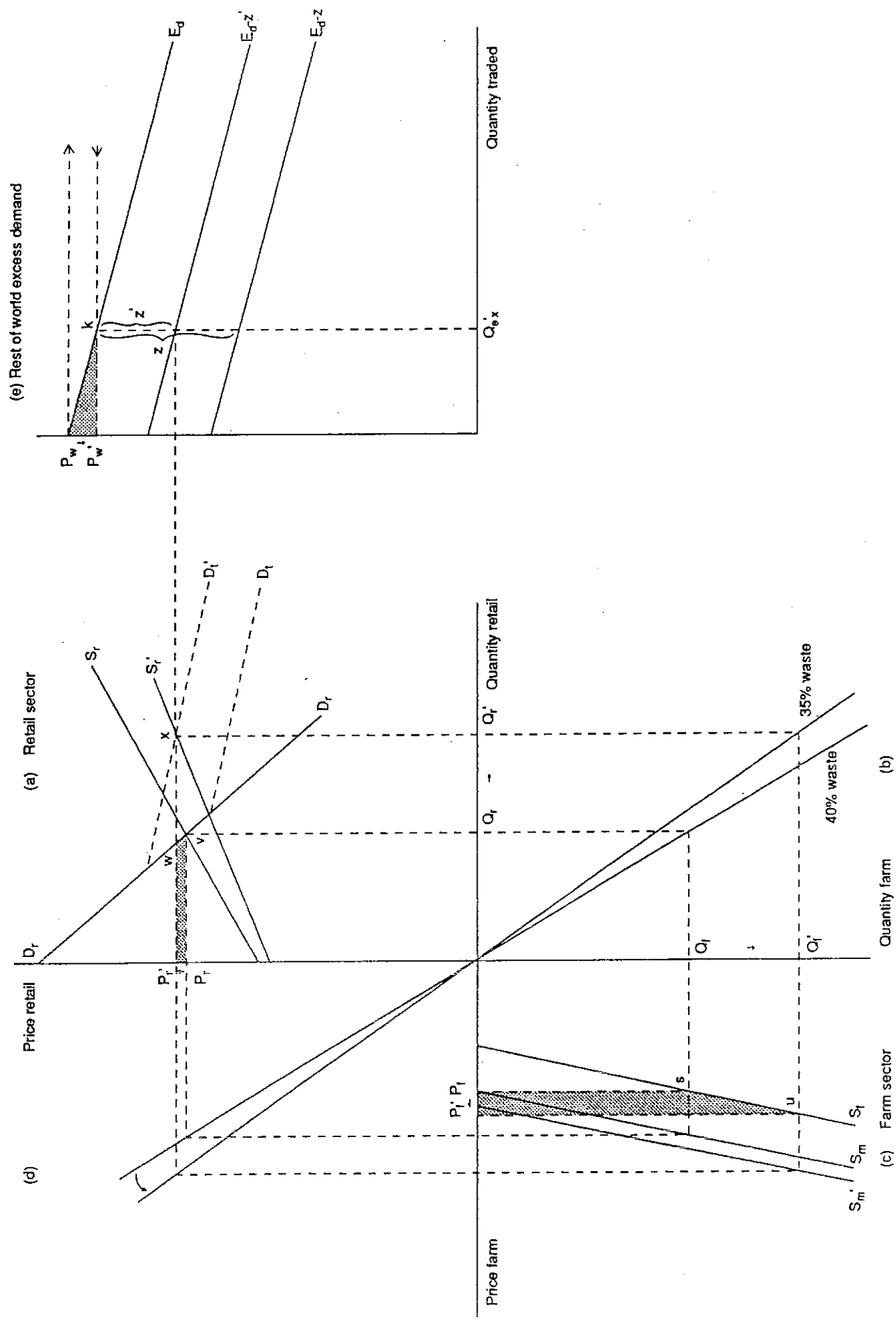


Figure 3. Model where research facilitates access to world trade

a range of welfare change combinations for the various groups involved in production and consumption activities.

4.3 A Generalised Wastage Reduction Model for Estimation of Annual Research Gains

The closed economy model illustrated in equations (1) to (11) can be expanded to give a multi- country (or region) model with the following additional equations.

Before Research

If the country is a net exporter the retail-to-world price linkage is:

$$P_{rh} = P_w - z_h \tag{18}$$

where:

P_w is the 'world market' price
z_h is the transport cost from country 'h' to the world market before research.

The excess supply from this exporting country 'h' is given as:

$$Q_{esh} = Q_{rsh} - Q_{rdh} \tag{19}$$

If the country is a net importer the retail-to-world price linkage is:

$$P_{rj} = P_w + z_j \tag{20}$$

where:

P_w is the 'world market' price
z_j is the transport cost to country 'j' from the world market before research.

The excess supply from this importing country 'j' is given as:

$$Q_{esj} = Q_{rdj} - Q_{rsj} \tag{21}$$

The world market equilibrium 'before research' is given by solving the following:

$$\sum_{h=1}^{n} Q_{esh} = \sum_{j=n+1}^{N} Q_{edj} \tag{22}$$

where there are h=1..n exporting countries and j=N-n importing countries.

It can be shown that the equilibrium world price is given as:

$$P_w = -\frac{\sum_{i=1}^{N}(\delta_i a_i - c_i)}{\sum_{i=1}^{N}(\delta_i^2 b_i + d_i)} + \frac{\sum_{h=1}^{n}(\delta_h^2 b_h + d_h) z_h - \sum_{j=n+1}^{N}(\delta_j^2 b_j + d_j) z_j}{\sum_{i=1}^{N}(\delta_i^2 b_i + d_i)} + \frac{\sum_{i=1}^{N}\delta_i b_i M_i}{\sum_{i=1}^{N}(\delta_i^2 b_i + d_i)} \qquad (23)$$

The domestic equilibrium values of P_{rh}, Q_{sh}, Q_{dh} and P_{fh} can be found by substituting this world price into the appropriate equation.

After Research

The technologies resulting from this type of research can be represented in the following manner.

Reduction in the postharvest wastage rate:

$$\delta'_h = (\delta_h + \Delta\delta_{hh}) \qquad (24)$$

where:

$\Delta\delta_{hh}$ is the change in the farm to retail conversion rate in country 'h' due to the research undertaken in country 'h'. Note $\Delta\delta_{ih}$ is the spillover effect of this research to country 'i'

Change in the postharvest input costs

The associated change in the postharvest input costs can be represented as:

$$M'_h = (M_h + \Delta M_{hh}) \qquad (25)$$

where:

ΔM_{hh} is the change in the unit cost of postharvest activity in country 'h' associated with the new technology developed in country 'h'. Note ΔM_{ih} is the spillover effect of this research to country 'i'

Change in the world market transport costs

$$z'_h = (z_h + \Delta z_{hh}) \qquad (26)$$

where:

Δz_{hh} is the change in the world market transport cost from (to) country 'h' associated with the new technology developed in country 'h'. Note Δz_{ih} is the spillover effect of this research to country 'i'

The 'after research' world equilibrium price is found by substituting these changes in the appropriate equations and solving for the equivalent of equation (22). This can be shown to give:

$$P'_w = -\frac{\sum_{i=1}^{N}(\delta'_i a_i - c_i)}{\sum_{i=1}^{N}(\delta'^2_i b_i + d_i)} + \frac{\sum_{h=1}^{n}(\delta'^2_h b_h + d_h)z'_h - \sum_{j=n+1}^{N}(\delta'^2_j b_j + d_j)z'_j}{\sum_{i=1}^{N}(\delta'^2_i b_i + d_i)} + \frac{\sum_{i=1}^{N}\delta'_i b_i M'_i}{\sum_{i=1}^{N}(\delta'^2_i b_i + d_i)} \qquad (27)$$

Again these can be substituted into the appropriate equations to find the 'after research' domestic equilibrium values of P'_{rh}, Q'_{sh}, Q'_{dh} and P'_{fh}.

It can be seen by substituting zero values for the international transport costs and removing the summations for all except country 'h', equation (27) reduces to the closed economy case given in equation (6). It is therefore a special case of this general form.

5. CONCLUDING REMARKS

This paper has considered the issue of a sub-set of postharvest research which has been called 'wastage reduction' research. It briefly reviewed past applications of research evaluation methods specifically focused on postharvest research activity. It found that there have only been a few such studies and many of these have not evaluated actual research projects. Two attempts to categorise postharvest research programs suggested that wastage reduction research is an important sub-area. A recently suggested method for evaluation of wastage reduction research was applied to six collaborative postharvest tropical fruit research projects which have been funded by ACIAR. Results of these evaluations suggest that the expected returns to these projects have been high, IRRs ranging from 21 to 48 per cent. The distribution of these welfare gains was estimated and discussed.

Interaction with scientists during these evaluations suggested the potential need to expand the methodology to include various traded good environments. These were discussed in the paper and a generalised wastage reduction estimation model was developed.

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