The Applicability of the Economic Surplus Model to the Valuation of Honeybee Pollination Services in Australia

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1 Introduction

The agronomic and economic value of honey-bee effected pollination has been an internationally contentious issue since at least the turn of the century. As early as 1913, horticultural scientists were urging cherry growers in Oregon State of the USA to employ bees for pollination:

> "*...There is little question ...that many cherry orchards would be rendered much more productive if their owners would give proper recognition to the known facts regarding the importance of bees in the orchard.*" (Oregon Agricultural College Experiment Station, 1913).

The recognition of the value of honey bees as pollinating agents has not always been unanimous. The US State of Utah passed legislation in 1929 to effectively prohibit the movement of honey bees into that State. This legislation was designed to protect alfalfa from the presumed ravages of honey bees which "*...made alfalfa wilt and fail to set seed.*" (Whitcombe, 1955). Californian alfalfa growers were more progressive in their thinking. Early trials at about the same time in the latter State indicated increases in alfalfa yields of up to 500 per cent as a result of managed honey bee pollination (Whitcombe, ibid.). By 1950, Californian alfalfa growers were generally prepared to pay a pollination contract fee of $5.00 per hive to beekeepers Some beekeepers were successful in negotiating share contracts with growers whereby a proportion of the extra yield attributable to beneficial effects of honey bees was paid to the beekeeper (Whitcombe, ibid).

Today, most beekeepers in the Pacific North West region of the USA generate at least 40 per cent of their annual income from pollination contract fees (Burgett, D.M. and Mayer, D.F., personal communications). The US pollination services market is most active in California where around 70 per cent of all US managed pollination contracts are negotiated (Robinson, et al., 1989). This market is largely dominated by almond pollination. The latter market's requirements for bees is so large that the demand for hives cannot be satisfied by Californian beekeepers alone. Beekeepers from Washington State and even from Florida participate in this market (Robinson, F, personal communication) At least two pollination brokerage operations exist largely to place hives with almond growers in California.

The pollination services market is not as active anywhere in Australia as it is in California and the Pacific North West or in New Zealand (where an active market exists to pollinate kiwi fruit among other crops). Nevertheless, the issue of the value of pollination services to the agricultural economy is topical in this country. The Australian Honey Research Council has nominated this issue as one of its priority research areas. In its recent report on the biological control of Paterson's Curse, the Industries Assistance Commission noted submitted evidence suggesting that the eradication of that important honeybee nectar source would subsequently reduce the amount of managed and unmanaged pollination provided by bees as bee populations decline in response (IAC, 1985 p. E.12). The IAC noted substantial difficulties in estimating the value of the pollination benefit to agricultural industries. The estimates provided as evidence (to be discussed in Section 3), were as rudimentary (and of as doubtful value) as the plethora of other attempts to value the pollination benefit in this and other countries since the turn of the century.

The technical literature pertaining to the agronomic benefits of managed honey bee pollination is large. Six international pollination symposiums have been organised since 1960 to serve as forums for the discussion of the technical implications of the managed honey bee pollination of crops. A recent review of the technical literature by this author revealed over 300 articles pertaining to the results of field pollination trials since 1970. Australian researchers are also active in this field (notable publication/dissemination venues include the proceedings of a Pollination Symposium hosted by the New South Wales Department of Agriculture at Dubbo, 1981, the domestic beekeeping press, and industry conferences such as the recent International Bee Congress and Second Australian Conference on Tree and Nut Crops). A detailed publication by the United States Department of Agriculture (McGregor, 1976) provides a summary of the advantages of managed pollination for commonly cultivated crops. This publication is probably the most widely referenced source of pollination recommendations in the world at present.

While the technical literature pertaining to the pollination of cultivated (and to some extent, non-cultivated) plants is relatively well founded, that pertaining to the economic value of the pollination benefit is not. This is not to imply that the literature pertaining to the latter is not voluminous. Much has been written on this subject since as long as the agronomic benefits conferred by bees have been recognised. Attempts to value the pollination activity have ranged from "guestimates" of no empirical substance, to informed estimates (largely by apiculturists) to a few concerted efforts by economists (which have not necessarily been any more credible than those generated by apiculturists). US researchers have estimated the value of the pollination benefit to US agriculture to be anything from US$4.5 billion to US$40 billion. Evidence to the 1984 IAC Inquiry into the control of Echium species suggested that the value of insect pollination to Australian crops was $158.6 million (IAC, 1985).

The aim of this paper is the derivation of a 'social' (or surplus based) valuation of honeybee pollination services in Australia. The ensuing valuation will be the product of a systematic exploration of the conceptual underpinnings of the economic surplus model. Perhaps of more relevance than the actual valuation, is the list of supporting assumptions regarding the behaviour of relevant economic agents and processes. A heavily qualified valuation will be shown to be the only feasible result from any such investigation.

Most honeybee pollination services are provided at no cost to beneficiaries. Such services may be provided by 'feral' (unmanaged) honeybees or inadvertently by beekeepers as part of the process of honey production. No attempt will be made to distinguish between managed or unmanaged pollination services. This distinction is, however, of central relevance to the policy arena which provides the context for the current valuation. Economists have long advocated government intervention to redress presumed inefficiencies implied by the existence of unremunerated pollination services. A relatively recent analysis (Cheung, 1973) has suggested that unpaid pollination is not necessarily consistent with economic inefficiency. This body of literature will be reviewed in the last section of this chapter. In the absence of any real externalities, private and social benefits and costs will correspond and the valuation generated within this chapter will reflect the 'true' social contribution of honeybee pollination.

A priori, it will not be possible to value every facet of the pollination benefit. Many aspects of incidental (or unmanaged) pollination services have not been technically established. It is not possible to value effects which have not been technically established (the benefits and costs associated with the incidental pollination of plants in National parks and even in private gardens are examples of effects which are unlikely to be amenable to economic assessment).

2 The Nature of Pollination Benefits

Honey bees effect the cross pollination of receptive plants as they forage for nectar and pollen. The nature and significance of this effect varies between plant species. Some plants are solely dependent on insect pollination for pollen transfer. Other plants may be responsive to wind, bird or other non-insect agent pollination. The commercial pollination services market has evolved to service those crops which are clearly advantaged by honey bee pollination. A list of commercially cultivated plants which are benefited by insect (honey bees, wild bees and others) pollination is presented in Table 1. Some attempt has been made in that Table to summarise the degree of dependence of each crop on insect effected pollination. Degree of dependence is measured on a scale of one to three; a value of one denoting that insects are essential for effecting pollination, a value of two indicates a beneficial effect is provided by insects and a value of three indicates a possibly beneficial effect.

The major conceptual hurdle encountered in any valuation of the pollination benefit is the valuation of unmanaged or incidental pollination. Such pollination services, if provided unwittingly by beekeepers, are unremunerated. Such services may be provided to crops adjoining a contract crop or by bees which are employed specifically for the extraction of nectar for honey or they may be provided by feral or wild bees. Evidence abounds to suggest that many growers depend on incidental or "free" pollination services for their crops. Avocado and macadamia growers on the North Coast of New South Wales are understood to rely largely on such services (Stace, personal communication). Crop yields may well be at uneconomically low levels in the absence of such services.

Feral and managed honey bees are equally capable of pollinating plants. Where feral bee populations are high, incidental pollination may completely satisfy a specific crop's pollination requirements. The pollination requirements of other crops (such as almonds), are unlikely to be satisfied by anything other than professionally managed pollination. Where pollination benefited crops are grown in large scale monocultural conditions, such as almonds in California and the Riverina and pome fruits in the US Pacific North West, commercially managed colonies of bees are usually required. Viable commercial pollination markets also exist where feral bee populations are low or non-existent as a consequence of widespread pesticide usage and/or bee disease/parasite infestations. The active pollination markets in Washington and Oregon in the US may at least partially be attributed to the prevalence of Varroa mites in those States (Burgett, personal communication). Varroa is known to virtually eliminate feral bee populations.

Any social valuation of the pollination benefit must, therefore, include the contributions of managed contractual pollination and incidental pollination provided by managed hives and by feral bees. In addition, bees contribute to social welfare through the pollination of crops which are themselves intermediaries in the production processes of other agricultural commodities. Honey bees contribute to the propagation of livestock pastures through the pollination of clovers and other pasture species. Such pollination services are almost universally incidental and unremunerated. Bees also pollinate plants which are not marketed such as garden vegetables and ornamental flowers. Though these services do not contribute directly to the cash flows of the respective resource owners, the welfare of such individuals is enhanced by the pollinating activities of bees.

It should now be apparent that a complete social accounting of the benefits provided by honey bees is infeasible due to problems associated with the identification, measurement and valuation of some of the associated effects. The above discussion, however, should provide a useful context for the following assessment of the various attempts which have been made in this area.

Table 1

Crops Known to be Benefited by Insect Pollination with an Indication of their Degree of Dependence Upon Pollinating Agents

Crop	Scientific Name	Degree of Dependence on Pollinating Insects	% 'Supply Shock' from Removal of Bees[a]
A. Non-Tropical Crops[b]			
Alfalfa (seed)**	*Medicago sativa*	1[c]	100
Almond**	*Prunus amygdalus*	1	100
Apple**	*Malus sylvestris*	1[d]	90
Apricot**	*Prunus armenica*	1	70
Artichoke	*Cynara scolymus*	2[e]	30*
Asparagus	*Asparagus officinalis*	1	90*
Avocado**	*Persea americana*	1[f]	100
Bean**	*Phaseolus vulgaris*	3	10*
Beet, sugar	*Beta vulgaris*	3	10*
Blackberry	*Rubis* spp.	2	30*
Blueberry	*Vaccinium* spp.	1[g]	100
Carrot (seed)	*Daucus carota*	2	100
Celery	*Apium graveolens*	3	100
Cherry**			
sweet	*Prunus avium*	1	90
tart	*Prunus cerasus*	1	90
Citrus	*Citrus* spp.		
Grapefruit		3	80
Lemon**		2	20
Lime**		2	30
Orange**		2[h]	30
Mandarin**		2	30*
Cole crops (seed)	*Brassica oleracea*		
Broccoli		2	100
Brussels sprout**		2	30*
Cabbage**		2	30*
Cauliflower**		2	100
Kale		2	30*
Mustard		2	30*
Radish		2	30*
Cotton**	*Gossypium* spp.	2[i]	20
Cucumber	*Cucumis sativus*	1[j]	90
Eggplant	*Solanum melongena*	2	30*
Flax (linseed)	*Linum usitatissimum*	3[k]	10*
Goosberry	*Ribes grossularia/* *R. hirtellum*	3	10*
Lettuce**	*Lactuca sativa*	3[l]	10*
Lupines**	*Lupinus angustifolius*	3	10*
Mustard	*Brassica* spp.	3	10*

contd.

Table 1 (Continued)

Crop	**Scientific Name**	**Degree of Dependence on Pollinating Insects**	**% 'Supply Shock' from Removal of Bees[a]**
Onion**	*Allium cepa*	1[m]	100
Passionfruit	*Passiflora* spp.	2	*10**
Peach and Nectarine**	*Prunus persica*	2	60
Peanut**	*Arachis hypogaea*	3[n]	10
Pear**	*Pyrus* spp.	2	50
Plum and Prune**	*Prunus* spp.	1	70
Pumkin and Squash**	*Cucurbita* spp.	1	*90**
Pyrethrum	*Chrysanthemum*	3	*10**
Quince	*Cydonia oblonga*	3	*10**
Radish	*Raphanus sativus*	2	*30**
Rape	*Brassica* spp.	3	*10**
Raspberry	*Rubus* spp.	2	*10**
Red clover (seed)	*Trifolium pratense*	1[o]	*90**
Safflower	*Carthamus tinctorius*	2	*30**
Strawberry**	*Fragaria X ananassa*	2	40
Sunflower**	*Helianthus annuus* L	2[p]	100
Turnip	*Brassica rapa* L	2	*30**
Vetch (seed)	*Vicia* spp.	2	*30**
Watermelon	*Citrullus lanatus*	2	70
White clover (seed)	*Trifolium repens*	1	*90**
B. Tropical Crops[r]			
Cherimoya	*Annona cherimola*	3	*10**
Coffee	*Coffea arabica*	2	*30**
Coffee	*Coffea canephora*	2	*30**
Coffee	*Coffea liberica*	2	*30**
Eucalyptus (seed)	*Eucalyptus* spp.	1	*90**
Feijoa	*Feijoa sellowiana*	1	*90**
Guava	*Psidium guajava* L.	2	*30**
Jackfruit	*Artocarpus heterophyllus*	3	*10**
Kenaf	*Hibiscus cannabinus*	3	*10**
Kiwi fruit	*Actinidia chinensis*	1[s]	*90**
Litchi	*Litchi chinensis* sonn.	1	*90**
Longan	*Euphoria longana*	1	*90**
Macadamia	*Macadamia integrifolia*	1	90
Macadamia**	*Macadamia tetraphylla*	1	*90**
Mango**	*Mangifera indica* L.	1	*90**
Papaya	*Carica papaya* L	2	*20**
Pomegranate	*Punica granatum* L.	3	*10**
Tamarind	*Tamarindus indica* L.	2	*30**
Tea	*Camellia sinensis*	1	*90**

* Italicised and asterisked per cent 'supply shock' values indicate interpolation from degree of dependence estimates. All other values in this per cent 'supply shock' category were as estimated by Robinson et al. (1989).

** Double asterisked crops are those for which price and quantity data is available.

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[a] The per cent supply shock from the 'removal' of honeybees is, in effect, the percentage reduction in yield which could be expected if the crop in question were totally isolated from insect pollination. All estimates of the per cent supply shock were derived from Robinson et al. (1989).

[b] The principal source of information for non-tropical crops was McGregor (1976). Other references are as indicated.

[c] The effectiveness with which the honey bee pollinates alfalfa is variable with geographical region. Honey bees are the main pollinating agents in the US state of California, whereas the alfalfa leaf-cutter bee (*Megachile pacifica)* is the main pollinating agent in the US Pacific North West. The latter species has been imported to Australia on a trial basis to determine its effectiveness in pollinating Australian lucerne crops.

[d] McGreggor, (1976) and for the Australian situation: Langridge and Jenkins, (1970).

[e] Foury and Delage, (1983). French evidence suggests that artichoke seed production is benefited by honey bees and by bumble bees.

[f] McGregor, (1974).

[g] Evidence relating to the usefulness of bees to blueberry production is varied. Whatley, and Lackett (1978), indicated that the pollination advantage of commercially managed honeybees was doubtful for *Vaccinium ashei* (rabbiteye blueberries). Rajotte and Roberts (1978) indicated that the sugar content of *Vaccinium corymbosum* was an important determinant of the attractiveness of that variety to honeybees and consequently, to the likely importance of honeybees to blueberry pollination. McGregor (1976) reviews extensive literature to indicate that honeybee pollination is essential to commercial blueberry production.

[h] A general statement about the importance of honeybee pollination for oranges is difficult because of the variation in pollination response exhibited by the various cultivars. Robinson (personal communication) indicated that some of the newer hybrid varieties in Florida (USA) require pollination to effect commercial yields and honeybees are an appropriate pollinator.

[i] The use of honeybees for systematic or saturation pollination of cotton fields is widely practiced in the USSR. US growers use bees less due to a reliance on pesticides and other agronomic practices. Pesticides appear to be the major limitation on the application of bees for pollination. Waller (1982), has indicated that honeybees are central to the economic production of hybrid cotton seed. As hybrid cotton varieties replace the open-

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pollinated varieties in common cultivation, at least in the US, the use of honeybees as pollinators is likely to increase (presuming the pesticide problem can be contained).

[j] McGregor (1976) and Woyke and Bronikowska (1983). The latter reference pertains to Polish conditions and Polish cultivars.

[k] McGregor (1976) suggests that honeybees are of significance in the pollination of hybrid flax or linseed.

[l] McGregor (1976) indicated that honeybees may be of some value to the production of lettuce seed for hybrid varieties.

[a] The per cent supply shock from the 'removal' of honeybees is, in effect, the percentage reduction in yield which could be expected if the crop in question were totally isolated from insect pollination. All estimates of the per cent supply shock were derived from Robinson et al. (1989).

[m] Honey bees are effective pollinators of open-pollinated onions (McGregor, 1976). The advantage of honey bees for hybrid onion seed production where male sterile plants are used is less clear cut (Waters, 1978).

[n] Rashad, Ewies and Rabie (1978) indicated that various species of bees including those belonging to the families Halictidae, Megachilidae and Apidae were successful in pollinating peanut in Egypt.

[o] In Australia, honey bees would be the main commercially managed pollinators. Bumble bees are, however, very effective pollinators, so much so, that they were transported from England and established in New Zealand for the express purpose of pollinating red clover.

[p] Jones (address to 1988 Second International Bee Congress), indicated that all sunflower cultivars currently available in Australia are responsive to pollination by honey bees. An overall yield advantage of 15.71% was quoted. Leclercq and Madeuf (1983), indicated that insect pollination has a positive effect on sunflower yield, and seed oil content. This effect was especially significant for highly self-fertile cultivars.

[r] The principal reference for crops in this section is McGregor (1974). Other references are as indicated.

[s] Macfarlane and Ferguson (1983), describe the importance of honey bees to commercial kiwifruit production. Bumble bees are particularly important to the commercial pollination of this fruit in New Zealand.

3 A Review of Previous Attempts to Value Pollination Effects

Valuing the pollination product of honeybees has been a farourite pastime of apicultural scientists and other interested parties in various countries since the early part of this century. The methodological approaches adopted for these valuations have been as varied as the estimates. An understanding of the motivations for such valuations can place the choice of valuation methodology in context. Both methodological approach and motivation will be simultaneously considered in the following review.

3.1 Valuations Based on an Infinite Elasticity of Demand Assumption

Typically, analysts have attributed either all or a portion of the output of bee dependent crops to honeybees and multiplied this portion by the current market price of those commodities. If the services of honeybees were removed, the economy would be worse off by the exact amount of the value of lost production. Levin (1983) generated a value of $18.9 billion for the US pollination market by application of such a methodology. Wooten (1987) attempted to conceptualise such a methodological approach as part of his Phd thesis. Figure 1 reflects Wooten's conceptualisation.

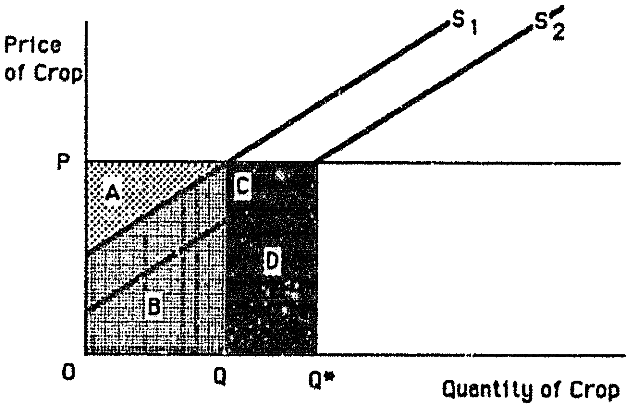


Figure 1 Loss in Producer Surplus Following Removal of the Honeybee Pollination Benefit Assuming an Infinite Demand Elasticity.

The supply schedule applicable to the with-pollination services case is S_2. The appropriate equilibrium quantity is Q*. If growers are deprived of all pollination services, the supply of affected crops would shift to S_1 as output will be lower at all price levels. Though the technical literature would support the latter contention that the production of at least the range of crops represented in Table 1 would decline in the absence of honeybees, Levin's (1983) valuation of that loss is open to question. The appropriate areas in Figure 1 corresponding with Levin's (1983) valuation are C and D.

The inclusion of area D in the calculation of the value of the pollination service is fallacious unless supply is assumed to be perfectly inelastic or close to that extreme. Area C is the decline in producer surplus and is the true loss to society as defined by the standard surplus model. Area D is not a social consequence of the hypothesised removal of honeybees. The monetary value of D is the savings in production costs associated with the lower output level Q. Levin's (1983) valuation is, however, not confined to areas C and D as implied by Wooten (1987). Levin's (1983) valuation included the entire revenue associated with output Q*. The conceptualisation illustrated by Figure1 is for a crop which exhibits a yield advantage from the activities of bees. Areas A and B are associated with the without-pollination output Q. The value of both the without-pollination producer surplus, area A and the cost of production B, is also attributed by Levin to the activities of honeybees. If a crop is entirely dependent on honeybees, the relevant conceptualisation would exclude S_1. S_2 would be the only relevant supply function as, without bees, there would be no production. In the latter case, the relevant valuation attributed to the honeybee pollination service by Levin and associated researchers would again be represented by the area to the left of the supply schedule and below the price line.

The assumption of an infinite price elasticity of demand for all affected crops is limiting. Consumers are unlikely to be willing to pay the same for an agricultural product when supply is abundant as when scarcity prevails.

The third major fallacy of Levin's (1983) approach is the inclusion in area C in Figure 1 of the value of services provided by feral bee populations and probably of other pollinating agents. To the extent that the latter is true, the monetary value of area C will, therefore, overstate the contribution of the commercial beekeeping sector.

US beekeepers do have an incentive to inflate the value of their pollination product to the maximum to lend weight to their arguments for continuing government support for the honey loan scheme. Perhaps this incentive inspired Martin (1975) to claim that the direct and indirect economic contributions of pollination may approach US$40 billion. Martin's accounting included the full market value of beef and dairy products which are derived from honey bee pollinated legumes. O'Grady (1987) revalued Levin's estimate down to $US4.6 billion by attempting to value the actual yield advantage conferred by bees on selected crops and simultaneously attempting to exclude the contribution of alternative pollinators. This approach still implicitly assumes an infinite demand elasticity, and over-values the pollination service by 'only' area D in Figure 1.

Robinson, Nowogrodzki and Morse (1989), based their recent analysis of the value of honey bee pollination in the US on the approach adopted by O'Grady (1987). US pollination services (presumably attributable to all species of bees and also including the inputs of 'feral' bees) were valued at $9.7billion.

Robinson et al.'s approach involved the identification of a set of commercially important crops which are benefited by bees A 'dependence factor' was subsequently derived which indicates the dependence of any crop on insect affected pollination (from 0 for no dependence to 1 for complete dependence). A second factor was derived to estimate the relative importance of bees as opposed to other pollinating insects to the pollination of each of these dependent crops. The value of honeybee pollination to each pollination dependent crop was consequently calculated as the product of the estimated money value of each dependent crop, the dependence factor and the 'honeybee contribution factor'. The aggregate US value of honeybee pollination figure was derived by summing the pollination values for each of the specified crops.

Though Robinson et al.'s approach appears to be well supported by agronomic data, the calculated value of pollination services is represented by areas C and D in Figure 1. Area D is as fallaciously included here as it was in Levin's (1983) valuation. The magnitude of the shift in the supply function indicated in Figure 4.1 resulting from the removal of honeybees would be described by the product of Robinson et al.'s two 'factors'. Included in that valuation, therefore, is the cost of producing the extra production attributable to bees Robinson et al.'s valuation is not, therefore, an appropriate measure of the 'true social value' of honeybee pollination. Once again, the assumption is that the extra production attributable to bees is offered at the same price as the lower output which may be producible in the absence of bees. In other words, the price elasticity of demand is implicitly assumed to be infinite.

In all the valuations cited above, the surplus derived by consumers from the extra production attributable to honeybee pollination has been ignored (or effectively assumed away by the assumption of an infinite price elasticity of demand). The true social value of the pollination services conferred by honeybees is measured by the sum of appropriate producer and consumer surpluses.

The Australian Industries Commission (then Industries Assistance Commission) considered the economic contribution of honeybee effected pollination in its inquiry into the biological control of Paterson's curse (1985). The Commission felt compelled to undertake such a valuation to quantify the social effects claimed to emanate from a reduced beekeeping industry following the eradication of the important bee forage plant in question. As Paterson's curse is a major forage source for bees, a reduction in that resource could cause a decline in the pollination potential of the beekeeping industry as a consequence of reduced bee numbers. Beekeeper evidence to the Commission claimed an inevitable decline in the size of the beekeeping industry as a consequence of the biological control programme under reference. A smaller industry may provide fewer pollination services (both commercial and incidental). If the pollination services currently provided by the industry could be valued, and if a sound estimate of the magnitude of the decline in the industry following the eradication of Paterson's Curse could be formulated, the social consequences attributable to this aspect of the control programme could, in theory, be estimable and weighed up against the claimed benefits of control.

Following some discussion of the data limitations and identification problems which would frustrate a "first best" valuation of pollination for the specific context of the inquiry, the IAC attempted a more restricted assessment based on a number of naive assumptions. The primary assumption was that growers of crops which are benefited by incidental pollination would notice a reduction in crop yield following the assumed post-eradication decline in bee numbers and would respond by employing contracted pollination to "top up" yields. Growers would be willing to pay an upper limit equivalent to the net value of their diminished output to beekeepers for replacement managed pollination. The value of the relevant pollination was, therefore, measured as the cost of hiring replacement commercial pollination services. The resulting estimate was $545,000, seven years after a successful Echium eradication programme. If this annual loss is considered to be an annuity, the present value of this loss becomes $10,900,000 for a social time preference rate of 5 per cent.

The IAC's calculation procedure involved the assumption of a perfectly elastic demand relationship for pollination effected crops, effectively assuming that consumers receive no surplus from the crops over the relevant range. This assumption is is based on the notion that crops affected by reduced Echium related pollination '...tend to be sold on world markets over which Australia holds little if any pricing influence' review, and that the specific impact of a reduction in Echium on pollination would be of relatively minor significance to aggregate crop supplies (Parnam, personal communication).

The IAC claimed empirical simplicity for its approach (Parham, personal communication). The attendant data requirements are, however, no less limiting than for any other empirically based approach. The central data requirement is for the quantification of the likely yield effects of reduced pollination. It would be extremely difficult to separate the concurrent yield effects of environmental variability, management and even highly variable feral bee populations from that attributable to a theorised reduction in the post-eradication honeybee population. The implicit behavioural assumption that growers would respond to an observed decline in post control crop yields by contracting for paid pollination is also naive. This assumption, in turn, implies that growers are perfectly informed about the physical yield, pollination relationship; the results of the attitudinal survey undertaken by this author would indicate the prevalence of a less than perfectly informed market in this regard. These limitations were recognised by the Commission in its report.

The Victorian Department of Agriculture compiled an alternative valuation of the pollination benefit in its submission to the same IAC inquiry. The methodological approach adopted in the latter valuation was similar to that employed by Robinson et al. (1989). Unlike the approach of Robinson et al.,however, the Victorian valuation neglected to isolate the contribution of honeybees to pollination from that of other pollinating agents. The ensuing valuation was $158.6 million. The author of the Victorian submission recognised that his valuation was restricted to a limited set of crops potentially benefited by honeybee pollination. It was also recognised that any product quality differentiation between pollinated and un-pollinated or inadequately pollinated crops was ignored. Though some production may be possible from certain crops in the absence of adequate pollination, that production may by unsalable due to inferior quality. Once again, the implicit assumption of an infinite price elasticity of demand would effectively preclude the consideration of such an effect.

The Victorian Department of Agriculture's (1985) valuation methodology is subject to the same general criticisms outlined previously for that of Robinson et al. (1989). The former did, however, discuss the potential social significance of incidental or unremunerated pollination in its submission. Commercially controlled honeybees and feral honeybees are both capable of pollinating crops incidentally. When such services are provided inadvertently by commercial beekeepers, the recipient crop producer will receive some form of monetary gain at zero cost. Due to the nature of beekeeping, feral honeybee populations originate from man-managed apiaries. Feral bees also provide pollination services at zero cost to the owners of the recipient crops. Incidental pollination may, therefore, be either directly or indirectly attributable to the activities of beekeepers, who in either case, receive no remuneration for services rendered. The value of such services should, in a first best sense, be included in any social accounting of the contribution of the pollination activity of bees.

3.2 Valuations Based on Parameterised Elasticity Assumptions

Wooten (1987), attempted to value pollination services in the US by measuring the appropriate surpluses for a range of demand and supply elasticity assumptions. His approach is otherwise essentially similar to the 'residual imputation method' employed by, for example, Robinson et al. (1989).

As for Robinson et al. (1989), Wooten (1987) developed a list of crops which require pollination for commercial yields and the per cent decline in the yields of those crops following the removal of all bee affected pollination. Wooten's list of crops benefited by pollination did not encompass the complete set presented in Table 1; nor was it as comprehensive as that employed by Robinson et al. (1989). Wooten argued that the effective range for the elasticity of supply would be between 1 and 5. The lower limit precludes supply functions with negative price axis intercepts and consequently, loss-incurring production at low output levels. The upper limit on the elasticity of supply was assumed to define the maximum responsiveness likely to be encountered in any agricultural production system. The pollination service was valued at the two extreme values for price elasticity of demand: zero and infinity.

The gross value of US pollination services (for 1982 prices and recorded contract numbers) was determined by Wooten (1987) to be between US$182 million and US$2.43 billion. The lower estimate was applicable to the dual assumptions of an infinite price elasticity of demand and a supply elasticity of 5.0. The upper estimate was applicable to a supply elasticity of 1.0 and a price elasticity of demand of 1.0. As supply elasticity increases, pollination service users assume proportionately more of the total welfare loss in relation to consumers following the hypothesised removal of pollinating bees.

Wooten (1987) also attempted to value the contribution of unmanaged or feral bees to US agriculture. The estimated range in pollination values described above was determined only for that volume of product for which pollination services were secured as a paid input Many crops for which no active pollination services market can be observed are still benefited by the activities of bees. In addition, many growers in markets characterised by active commercial pollination markets rely on incidental or 'free' pollination services. Using field trial data to value the theoretical yield advantage conferred by bees on these crops, an estimate of the gross value of non-commercially provided pollination services could be added to the previously enumerated estimate for commercially conferred pollination services. The resulting aggregate valuation would, in effect, measure the value added to all agriculture by the pollinating activities of bees. This is presumably what Wooten attempted in his second and larger valuation of the pollination benefit. For the same elasticity assumptions, the revised maximum value of pollination services exceeded US$3 billion.

Though Wooten (1987) has explicitly considered consumer welfare, (unlike the valuations of those authors discussed previously), the resulting estimated range in the value of US pollination services is probably too wide to be useful in a policy context. Ideally, the appropriate surpluses should be estimated for each of the considered pollination responsive crops for individually appropriate elasticities. The result of such an analysis would be a single value for the pollination services conferred by bees.

The set of crops for which the pollination input was valued was only a sub-set of all crops which are benefited by bees. A realistically comprehensive sub-set of crops is presented in Table 1. This list is considerably more comprehensive than that considered by

Wooten. The complete set of pollination benefited crops is being continually redefined by technical research.

Wooten (1987) recognised that his valuation did not incorporate any allowance for non-marketed pollination effects. For example, the social contribution of bees in reducing soil erosion by the pollination and consequent propagation of plant species significant in reducing erosion was ignored. The contribution of bees to the propagation of non-agricultural vegetation is also likely to be significant (though may be negative for some species thought to be adversely selected by bees).

4 General Methodological Considerations

In the preceeding review, a number of specific methodological limitations were identified for each individual attempt to value honeybee pollination. Appropriate to all the reviewed approaches, however, are a number of concerns of a more fundamental nature which need to be assessed prior to the undertaking of a new valuation for the Australian situation. The very notions of producer and consumer surplus and their capacity to reflect real social outcomes have been the subject of some debate in the economics literature since at least the middle of this century. Implicit to all of the valuations previously reviewed has been the assumption of linear demand and supply schedules and parallel shifts. These assumptions are not necessarily appropriate to the estimation problem at hand and are certainly not necessary for the estimation of surplus changes. The body of literature which has focused on these and other concerns will be reviewed in this Section with a view ultimately to the formulation and application of a feasible and conceptually defensible valuation methodology. The argument to be presented in this Section will involve an initial exploration of the relevance and meaning of the concept of economic surplus to be followed by a detailed review of measurement considerations.

4.1 Measurement of Consumer Welfare Changes

In a completely informed market a consumer's demand curve is taken to be indicative of the utility derived from all units of consumption. Willingness to pay and utility or satisfaction are usually considered to be positively correlated. The difference between the market price actually paid for a unit of a good and the maximum amount an individual would be willing to pay for that same unit (assuming the latter is greater than the former) may be regarded as a true economic 'surplus' to that individual. Whilst this surplus value is not a direct measure of utility, it is of application in analyses which aim to assess the welfare consequences of specified changes in market circumstances. The magnitude of any measured change in consumer surplus will reflect the associated change in satisfaction.

For the excess of willingness to pay over market price measure described above to be a true measure of a consumer's economic surplus, Marshall (1930) specified that the marginal utility of money (MUM) should be constant over all units. Bishop (1943) noted that this condition is required if money is to be a useful cardinal index of utility. In reality, it would be expected that money is in limited supply to most consumers and that additional expenditure on one item would be at the expense of consumption of other items. The marginal utility of money in this case would not be constant. If diminishing marginal utility is assumed for all goods, the marginal utility of money for other goods in the consumption set would rise. The only way out of this quandary is to assume that a consumer's expenditure on a specific good is small in comparison with total expenditure, so effectively minimising this substitution effect on the other goods comprising a consumer's consumption set.

Where several prices change simultaneously or where income changes together with price, consumer surplus may provide an ambiguous measure of consumer welfare change. Consumer surplus will vary according to the assumed sequence or *path* of price or price and income changes. In Figure 1, all prices for other goods comprising the relevant consumption set are assumed to remain constant. Such an assumption may not conform with observed practice and would assume away may adjustment effects relevant to consumer welfare. If, for example, honeybees are removed from an apple crop in market A (as a consequence, for example, of an unusual and unseasonal pesticide application), the ensuing shortage of that commodity will result in an increase in local price and encourage increased consumption of apples from geographically separated market B. Prices for the market B crop would also be expected to rise in response to the supply shortfall in Market A. An adjustment such as that depicted by S_1 in Figure 2 is possible. Alternatively, reduced pollination might originate in Market B with the price effect filtering through to Market A. The relevant adjustment path for the latter scenario is depicted by S_2 in Figure 2.

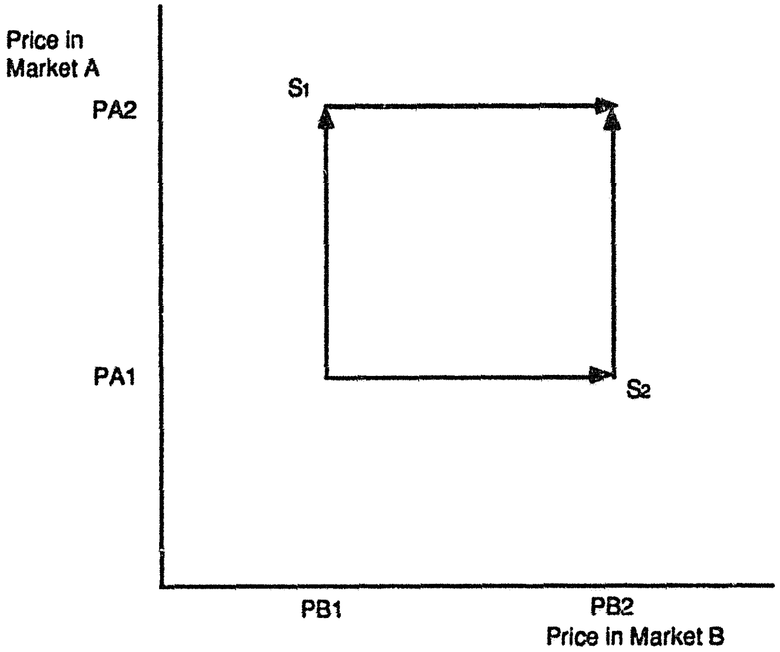
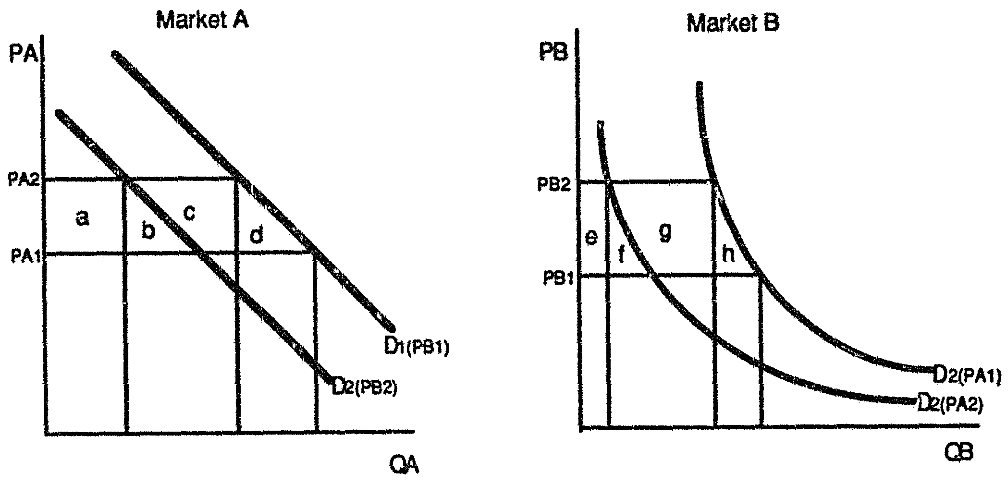


Figure 2. Alternative Price Adjustment Paths

The consumer surplus changes associated with the two adjustment scenarios depicted in Figure 2 are indicated in Figure 3. Following path S_1, a rise in the price in Market A from PA1 to PA2 will reduce consumer surplus by areas a+b+c+d in Figure 3(a). As part of the adjustment process, the demand for the commodity in Market B (where pesticides were not a problem and production was 'normal') will shift to D2(PA2) in response to the higher price applying across both markets. The relevant consumer surplus loss in Market B will be represented by areas e+f. The total consumer surplus loss associated with path S_1 will, therefore, be a+b+c+d+e+f. For path S_2, price changes first in Market B so the loss in Consumer surplus is areas e+f+g+h. The demand curve in Market A will shift from D1(PB1) to D1(PB2) so the consumer surplus loss in that market will be areas a+b. The total consumer surplus loss for path S_2 will, therefore, be e+f+g+h+a+b which will not (except under special circumstances) be of the same money equivalent value as the change appropriate to path S_1.



(a) (b)

Figure .3 Path Dependency and Consumer Surplus Changes

This *path dependency problem* can only be avoided if the income elasticities for all goods for which prices change are the same. Such an assumption would indicate a consumer preference structure which is unlikely in practice. Price changes, in reality, lead to both income effects and substitution effects between commodities comprising the relevant consumption set.

Hicks (1943), proposed four alternative willingness to pay measures which avoid the restrictive behavioural assumptions discussed above. Compensating and equivalent variation may be directly applied to the measurement of a consumer's ordinal preferences. Both describe income adjustments for an assumed constant level of utility or welfare. Compensating variation refers to the amount of income which must be taken away from a consumer after a price and or income change to maintain that individual's original welfare position. Equivalent variation refers to the amount of income which must be given to a consumer in lieu of price and income changes such that that individual can attain that level of welfare which would prevail in the absence of compensation. Hick's other two measures are compensating and equivalent surplus, both of which presume that consumers do not have freedom of choice to adjust to a changing economic environment. As consumers generally do have the ability to adjust to changing circumstances, compensating and equivalent variations are the more useful measures.

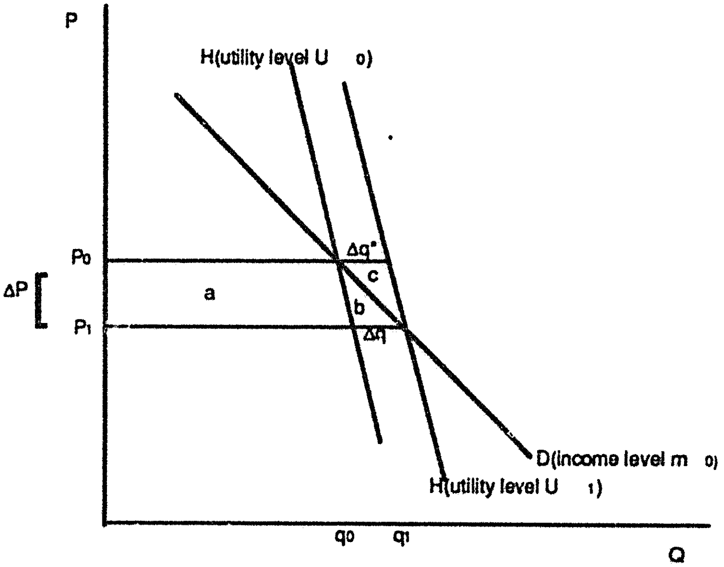
To relate compensating and equivalent variations to observed prices and quantities, a compensated demand curve is employed. The compensated demand curve relates quantities demanded over the relevant price set for a set level of utility or welfare. Such a construct is established by allowing income to vary. The standard Marshallian demand curve, in comparison, is constructed by holding income at a constant level and allowing utility to vary.

For price falls, compensating variation defines the lower limit of welfare change. Equivalent variation defines the upper limit. These results apply only to normal goods.

Choice between compensating and equivalent variation depends on the perspective of the policy maker and the circumstances of the market in question. One approach to the quantification of welfare effects is to present both values and leave any choice between these values to the decision maker. However, such an approach may be less than helpful. A project justified using one measure may be rejected if the other is applied. In addition, compensating and equivalent variations would be difficult to establish empirically as individual welfare contours cannot be directly observed.

Both compensating and equivalent variation measures are the same only when income effects are assumed to be zero. For such a condition, the compensated and Marshallian demand curves would be equivalent. Such a result is unlikely in reality. If, however, the income effects are 'small', the three measures of welfare change may be close. Income effects are only likely to be 'small' if the proportion of a consumer's total expenditure on a good is itself small in comparison with total consumption expenditure. The definition of 'small' here requires some elaboration.

The extent to which the true consumer surplus measure can overstate compensating variation and understate equivalent variation is illustrated in Figure 4. Compensated demand curves are superimposed on a standard demand relationship. For a price fall from P0 to P1, quantity demanded will increase from q0 to q1. The change in consumer surplus is depicted by areas a+b. The compensated demand curve associated with this price fall where utility remains at its initial level is H1. Compensating variation is, therefore, depicted by area a only. The compensated demand curve corresponding with an increase in utility post price change is H2. The related equivalent variation is area a+b+c. Equivalent variation is greater than consumer surplus by the area c. Compensating variation is less than consumer surplus by the area b. The smaller are areas a and b, the closer will be the three measures of consumer welfare change. Both can be estimated with some information regarding the magnitude of the price change (which will establish the height of the relevant triangles, Δp) and some knowledge of the income elasticity of demand (which will establish the base length of each triangle, Δq, as the horizontal separation between the two compensated functions is essentially an income effect).



Source: Just et al (1982)

Figure 4. Measurement of Consumer Welfare Effects With Compensated and Marshallian Demand Curves.

Willig (1976), devised an empirical test to determine the likely disparity between compensated and equivalent variation and consumer surplus for market changes where price, quantity and income elasticity information is known. This test essentially involves the measurement of the triangular areas b and c in Figure 4. In his analysis, Willig noted that where the product of income elasticity (η) and the ratio of surplus change to total income (s) divided by 2 ($\eta|s|/2 = \mu$) is less than 0.05 in absolute value, the disparity between compensating or equivalent variation and consumer surplus will be less than five per cent. The latter condition is likely to hold for commodities to which consumers allocate only a small part of their total expenditure outlays. The ratio μ, is, in effect, an error term which defines the relationship between the size of areas a (the compensating variation), area a plus b (consumer surplus) and a plus b plus c (equivalent variation) in Figure 4. Compensating variation, (C) would be approximated by $C \approx \Delta S - \mu|\Delta S|$ where ΔS is change in consumer surplus and equivalent variation (E) by $E \approx \Delta S + \mu |\Delta S|$. If $|\mu| > 0.05$, consumer surplus will be 'in error' by more than 5 per cent. In summary, as expenditure on an individual item increases in relation to outlays on other commodities, the greater will be the income effect associated with any change in the price of that item which implies an increase in $|\mu|$ and consequently, a decrease in the accuracy with which the consumers surplus measure reflects the true change in that individual's welfare.

The percentage of household income that would be spent at any price on any of the pollination effected crops listed in Table 1 is likely to always be small enough to ensure the integrity of the condition $|\mu| < 0.05$. This would be the case even if income elasticity is 2 or 3. It is, therefore, considered reasonable to assume that any errors in measuring the consumer welfare consequences of a hypothetical changed pollination environment by the standard surplus approach are likely to be small. Such a conclusion is consistent with Willig's contention that for most practical applications $|\mu|$ is likely to be small enough for consumers surplus to provide an adequate measure of consumer welfare change. At the level of the individual consumer, "...cost benefit welfare analysis can be performed rigorously and unapologetically by means of consumers surplus" (Willig, 1976, p. 596).

4.2 Measurement of Producer Welfare Changes

The measurement of producer welfare is subject to a degree of qualification similar to that outlined previously for the consumer counterpart. The extent of any ambiguity attached to the results of such an evaluation will be reduced by a clear statement of the relevant assumptions.

Producer surplus is the analogue of consumer surplus for the sellers' side of a market. As for consumer's surplus, producer's surplus provides an indirect measure of utility or welfare. The production side of a market is, however, more difficult to define. Producer surplus may be described for suppliers of productive inputs or for suppliers of final products. A producers surplus, for example, may be defined (data availability withstanding) for beekeepers as suppliers of pollination services. Another may be defined for the producers of final agricultural commodities who utilise honeybee pollination as a productive input. The interpretation and underlying assumptions pertaining to these two surpluses may be dissimilar.

For the factor supply case (the example of a beekeeper as a provider of pollination services will serve as a useful illustration), supply is not just governed by the market price for the productive input on offer. A beekeeper's decision to supply pollination services may also be influenced by that operator's general economic circumstances. Such an economic agent must be considered concurrently as a supplier of a productive resource and as a consumer other agents' goods and services. Just et al. (1980) distinguish between exogenous and endogenous income. Endogenous income is that proportion of the example beekeeper's income over which some control is possible (specifically, the income derived from the provision of pollination services is endogenously determined; the beekeeper can manipulate this income stream by varying the level of involvement in that market). Exogenous income cannot be readily manipulated in the short term; examples may include investment income, social security payments and so on. The beekeeper's pollination services supply curve would be determined by exogenous income and by the prices of consumption commodities and other resources under the beekeeper's control. Throughout this process, the economic agent of concern is assumed to be a utility maximiser.

The interdependency of exogenous and endogenously determined forces in the factor supply decision implies a path dependency problem similar to that described for the consumption case. The magnitude of any producers surplus change associated with some variation in the circumstances of the pollination market will be contingent on the sequence of events. An initial change in exogenous income which subsequently inspires a change in the level of participation in the pollination services market may generate a producers surplus change which is different from that which may prevail if the above path of events were reversed. An illustrative scenario here might involve an all-round improvement in apiary income through an initial increase in honey price (exogenously determined) and a subsequent increase in pollination fees (endogenously determined through an improvement in the quality of services on offer). The relevant surplus change might be quite different if the above sequence of events is reversed. Under both scenarios, the beekeeper maintains some diversified interest in both honey and pollination markets. The possible surplus implications of both scenarios are illustrated in Figure 5.

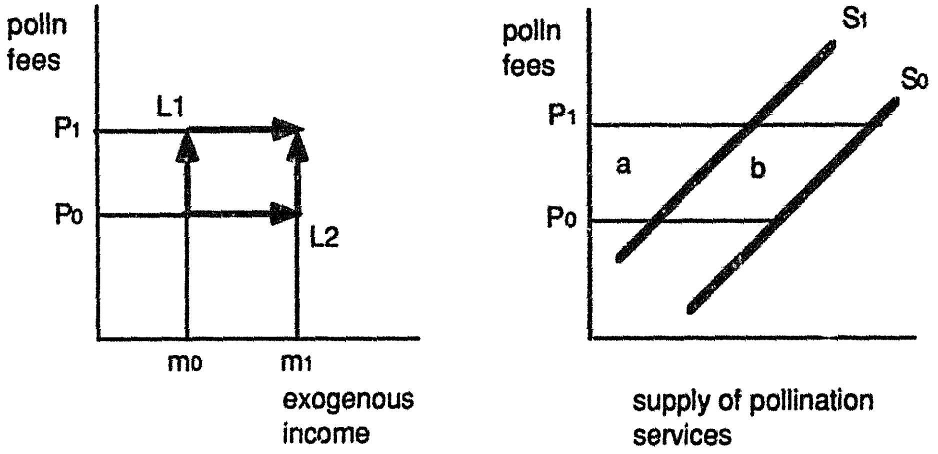


Figure 5. Path Dependency of Producers Surplus

The first path is represented by L_1 in Figure 5. Pollination fees increase first promoting an increase in producers surplus of areas a + b. The relevant change in supply of pollination services is represented by a movement along the existing pollination supply schedule S_0. The adjustment in exogenous income will accrue subsequently. The alternative path L_2 involves an initial increase in exogenous income. The main component of such an increase would be an increase in the exogenously determined honey price. As a response, the beekeeper increases honey production; the opportunity cost of involvement in pollination increases and this effect is represented by a leftward shift in the supply of such services toward S_1 (the complete movement from So to S1 is explained by the combined effects of increased opportunity cost and a conscious improvement in the quality and hence price of such services as are provided). The subsequent rise in pollination service fees would generate a producers surplus change of only area a.

The supply side path dependency problem will persist whenever factor supply decisions are at least in part determined by conditions exogenous to the immediate factor market of concern but which are within the larger set of conditions which determine the overall welfare picture of the individual. Few (if any) operators would determine their level of involvement in a market in isolation from such exogenous considerations.

Analogously to the consumption case, a non-ambiguous measure of producers surplus is likely to be elusive under real-world conditions. Also analogously to the consumption case, an unambiguous measure can, at least in theory, be derived by application of a *compensated supply function*. Such a relationship is established by holding an individual's utility at a constant level and adjusting the level of exogenous income. The ordinary supply function (and hence, standard producers surplus) is effectively derived by assuming constant exogenous income (that is, all other prices are assumed to be fixed) and variable utility.

As for the consumption case, the compensated supply function can not easily be directly estimated. The approximation relationships established by Willig (1976) may be extended to the production case. Essentially, the smaller are exogenous income effects, the less ambiguous will be producers surplus as a measure of a factor supplier's welfare. Such income effects are never likely to be zero.

Just et. al. (1982) considered the extent of likely estimation errors from employing producers surplus as an approximation of the 'true' change in producer welfare. They demonstrated that if a change in producer surplus is less than ten per cent of initial exogenous income, no more than a five per cent error will be incurred in using producers surplus as an approximation of willingness to pay. If the likely surplus change exceeds this bound, compensating and equivalent variations can be estimated (by application of a set of algebraic relationships not described here) to reduce likely estimation errors to more acceptable levels. As for the consumer surplus case, however, a surplus range bounded by compensating and equivalent variations may be construed as unacceptably large by policy makers.

Another practical limitation of the producers surplus concept is the necessary assumption that the prices all variable factors of production must be fixed, or, in other words, that the supply of all variable factors must be perfectly elastic to the industry in question. This requirement is demonstrated in Figure 6 where the initial market situation is depicted by the short run supply function ΣMC_1, price P_1, quantity Q_1 and an initial producers surplus of ABP_1. A product price rise to P_2 will encourage an increase in production to Q_3 and an associated producers surplus represented by AEP_2 If, as a consequence of increased production, the price of the essential production factor rises, the short run supply curve may shift to ΣMC_2. Output in this case would rise to only Q_2 and the surplus accruing to the owner of the firm would be CDP_2. The actual industry supply function is S' and the area above it and below the price line has no welfare meaning.

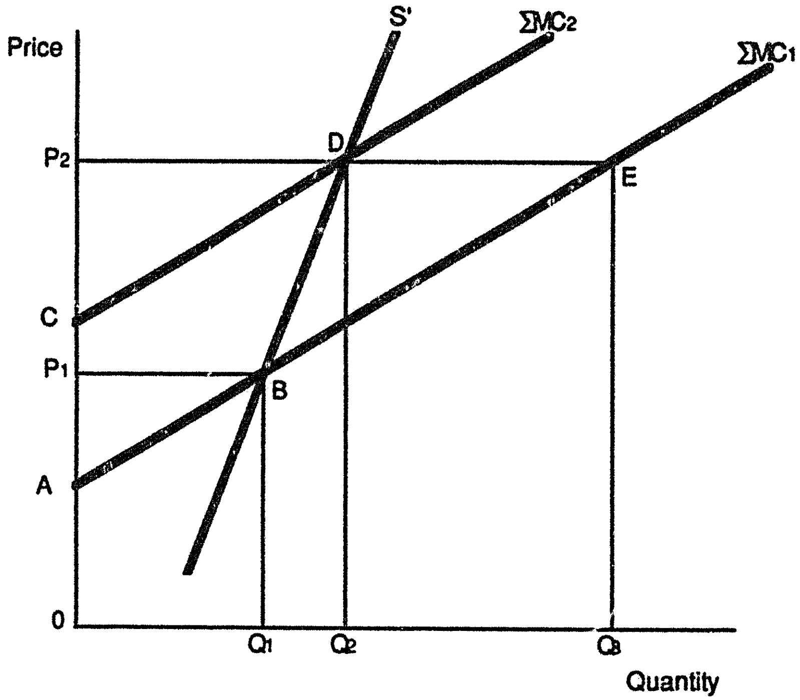


Figure 6. Producers Surplus Changes for Non-Fixed Variable Factor Prices.

In the short-run, the area above a competitive firm's short-run supply curve and below the price line provides a measure of the excess of gross receipts over prime costs (Currie et.al., 1981) because the short run supply curve coincides with the firm's short-run marginal cost curve. Such a surplus is in the nature of a 'quasi-rent' and is attributable to the short run fixity of some factors of production.

In the long-run, all excess profits are competed away for competitive firms. By the preceeding definition of producers surplus, it would seem that the area above the long-run supply function has no welfare meaning. In their survey of consumer and producer welfare measures, Currie et al. (1981) defined the appropriate set of circumstances which must prevail for the attribution of welfare significance to long-run supply relationships. The area above a competitive firm's supply curve exhibits true welfare significance (that is, this area represents rents to the producer) only if, as well as being an average cost curve *including* rents, the same long-run function represents the firm's marginal cost curve *excluding* rents.

The case of agricultural production with a fixed supply of land and all other factors being available at constant prices is one which is consistent with the latter requirements. The appropriate long-run supply function would exhibit a positive slope as a function of diminishing returns to the land resource only. The supply function would be equivalent to the long-run average cost curve including rent to land and a long-run marginal cost curve excluding rents. The area above this supply function would provide an unambiguous measure of the Ricardian rent to land.

Another case which is consistent with an unambiguous long-run producers surplus is where one necessary factor of production has some inelasticity of supply. As demand for this factor increases, price will increase via the competitive bidding process. If all other factors are perfectly elastic in supply, it should be possible to estimate an unambiguous measure of producers surplus. In this case, the area above the long-run supply function would represent the rents received by the owners of the factor in short supply.

Where an industry employs more than one factor exhibiting some inelasticity in supply, the area above the long-run supply curve will not represent the [illegible] net gain of all those factors.

Producers surplus is, perhaps, easier to interpret for non-competitive organisations. Monopolised and other imperfectly competitive firms may derive surpluses in both the short and long-run. Excess profits are not necessarily driven to zero under such structures so surpluses may represent some return to a firm's degree of market power.

4.3 Asymmetrical Shifts and Non-Linear Supply and Demand Relationships

The shape of the respective demand and supply relationships will have a bearing on the magnitude of the respective surplus areas. The functional form of these relationships depends, amongst other things, on the nature of the respective market participants' preferences and the nature of the relevant production processes. Miller et al. (1988, p.887), observed that "*...assumptions about the form of the supply curve and the type of supply curve shift ...largely predetermined, independently of empirical observations, whether the change in producers' surplus would be positive or negative*". In essence, they recommended that the functional form of the relevant functions must be chosen with care.

Technical advance is traditionally represented by a shift in the relevant product supply relationship. The magnitude of any benefit to society from such an advance and the return to the research processes which generated the technical advance is usually measured by the related change in producers' and consumers' surpluses. Such a construct is of convenient application to the measurement of honeybee pollination benefits. In the absence of data pertaining to the pollination activity per se, (largely as a consequence of the predominantly unpriced nature of this productive activity), the relevant social benefits may be indirectly estimated by the changes in surpluses accruing to users of the pollination input and consumers of pollination benefited crops. The direct benefits to beekeepers (as suppliers of this productive factor) are ignored in such an evaluation. As outlined in Section 4.3, the pollination benefit may be measured as the change in surpluses following an hypothesised total elimination of bees from all crops which benefit from bee visitation.

All investigations outlined in Section 4.3, considered surplus changes for parallel shifts in supply only. Supply may conceivably shift in a divergent, parallel or convergent manner. Divergent shifts (where the pre and post innovation supply functions separate more the greater the distance from the origin) may be pivotal or proportional. A divergent shift implies that absolute reductions in average cost are greater for marginal than for inframarginal firms (marginal firms occupy a position further out from the origin in product space than inframarginal firms). A convergent shift is one where the absolute cost reduction at inframarginal levels of output is greater than at marginal levels of output. Lindner et al. (1978), investigated the significance of each of these possibilities in relation to the size of research gains. The likely nature of any supply shift may, in the absence of empirical substantiation, be established by qualitative observation of the relevant processes.

A pivotal shift generates the smallest surplus change. As the pivotal shift becomes more convergent and less divergent, the relevant surplus change becomes larger. Convergent shifts are associated with larger surplus changes than parallel shifts. In the absence of quantitative measurement, the likely type of supply shift may be established by qualitative assessment. The validity of the usual assumption of parallel shifts for the valuation of the pollination benefit will be assessed in the Section 5.

5 Parameters of a Workable Valuation of the Pollination Benefit

In order to value the social return from honeybee pollination in Australia, choices have to be made regarding the various valuation parameters outlined in Section 4. The central assumptions pertinent to a feasible valuation are outlined in the following sections.

5.1 Market Level

As data regarding the price and quantity of pollination services performed in this country are almost completely lacking, it will not be possible to directly measure the surpluses accruing to beekeepers as the suppliers of pollination services. This deficiency is in no small part attributable to the high proportion of total pollination services provided by un-managed honeybees and the various kinds of (non-monetary) remuneration traditionally accepted by beekeepers for the provision of such services. The social contribution of pollination must, instead, be evaluated at the final product level of the market. To facilitate such a valuation, the standard hypothesised scenario of valuing the decline in surpluses accompanying a complete eradication of honeybee pollination will be adopted here. Such an approach, though straight forward, is also limited by data availability problems, mainly to do with the nature of post zero pollination output response. These matters will be discussed in further detail in Section 6.

5.2 Short Verses Long-Run Analysis

The assumed valuation scenario involving the complete removal of all honeybee pollination is, in effect, a reverse or negative process innovation. Output response to process innovation is a long-run phenomenon so the appropriate length of run for the current valuation must also be the long-run.

5.3 Assumptions Regarding the Valuation of Consumer Welfare

As discussed at some length in Section 4.1, consumers surplus can only provide an a reasonable approximation to either compensating or equivalent variation if the relevant income effect is "small" enough. The percentage of household income that would be spent at any price on any of the pollination effected crops listed in Table 1 is likely to always be small enough to ensure the integrity of the approximation. This would be the case even if income elasticity is 2 or 3. It is, therefore, considered reasonable to assume that any errors in measuring the consumer welfare consequences of a hypothetical changed pollination environment by the standard surplus approach are likely to be small. Accordingly, consumer welfare will be measured via the standard consumer surplus approach.

Another major data limitation problem is the almost complete lack of price and quantity time series information for the set of pollination relevant crops represented in Table 1. It will, therefore, not be possible to assign appropriate demand elasticities for those commodities and consequently, to define the appropriate slope for the relevant demand curves. Rather than assign arbitrary unitary elasticities to each crop in question, it is considered more meaningful to qualitatively define an appropriate range of elasticities and present parameterised surplus values.

For no other reason than computational simplicity, all demand relationships are assumed to be linear (at least over the relevant output ranges contemplated). The limitations of this approach were discussed briefly in Section 4 and will be assessed at greater length in the final section of this paper.

5.4 Assumptions Regarding the Valuation of Producer Welfare

As discussed in Section 4.2, producers surplus can only provide a meaningful measure of producer welfare if the relevant long-run supply relationship is an average cost curve including rents and a marginal cost relationship excluding rents. This will only be the case when not more than one factor of production exhibits any inelasticity in supply. The supply prices of production factors to producers of most, if not all, the relevant set of crops would, more than likely, be highly 'inflexible'. The production of any one grower would constitute a small proportion of total industry output, thus reducing the ability of any one grower to significantly influence factor supply prices. Such a scenario approximates the theoretical requirements for the derivation of meaningful producers surplus measures. Consequently, if the supply of honeybee pollination were somehow removed, the resulting change in producers surplus may reasonably be regarded to approximate the change in rent accruing to that factor only.

It is also important to predict the type of supply shift that may result from the removal of honeybees. As discussed in Section 4.3, convergent shifts generate the largest surplus changes and pivotal the smallest. In the absence of empirical measurement (impossible for the envisaged scenario), the likely type of shift may be established by observation of the markets under consideration. A divergent shift would be appropriate if larger (marginal) producers were more affected by the removal of honeybees than smaller (inframarginal) producers. The reverse would be true for a convergent shift. If all producers would be equally affected, a parallel shift would be likely. Due to the nature of the production processes involved, any reduction in the level of pollination would impact on all growers equally in a technical sense. If, for example, apple pollination can somehow be prevented, crop output will be zero for small and large producers alike. Output is likely to decline in equal proportion for all producers of each crop included in the valuation. A parallel shift is, therefore, the most likely in each case.

As for the consumer side of the market, data limitations would prevent the precise measurement of the shape of most of the relevant supply relationships. For computational ease, linear relationships will be assumed.

6. An Estimate of the Social Value of Pollination Services in Australia

The range of estimated social valuations of the Australian pollination services market are presented in Table 2 and graphically illustrated in Figure 6. A total of 25 alternative valuations have been estimated for the relevant ranges of assumed supply and demand elasticities. The maximum valuation is around $4.4 billion for the extremes of a demand elasticity of 0.1 and a supply elasticity of 1. The minimum valuation is around $213.7 million for demand and supply elasticities of 3 and 5 respectively. This rather unwieldy range can be constrained, to some extent, by subjective countenance of the nature of supply and demand response for the set of relevant crops.

Table 2
Social Value of Pollination Services for a Range of Elasticity Assumptions
($millions)

		Supply Elasticity				
		1	2	3	4	5
	0.1	4,435.54	4,233.93	4,166.72	4,133.12	4,112.96
Demand	0.5	1,209.69	1,008.08	940.87	907.27	887.11
	1	806.46	604.85	537.64	504.04	483.88
Elasticity	2	60[illegible].85	403.23	336.03	302.42	282.26
	3	536.30	334.68	267.48	233.87	213.71

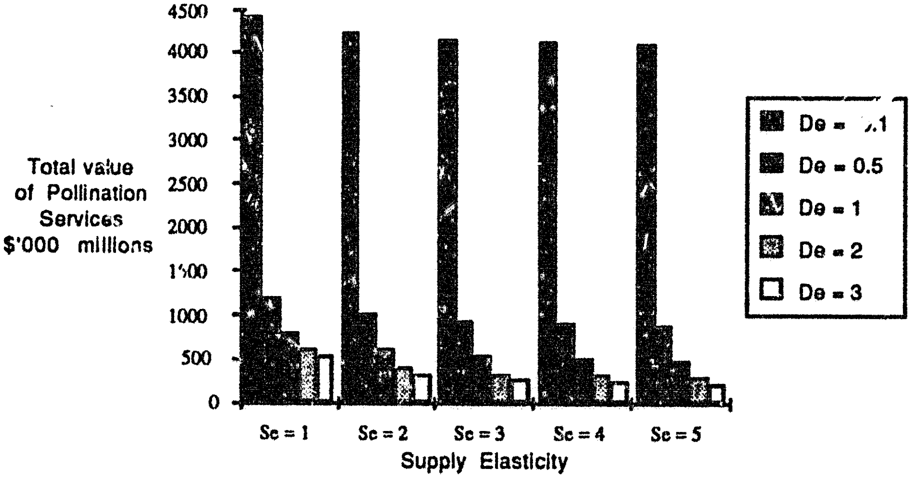


Figure 6 The Social Value of the Australian Pollination Services Market for a Range of Possible Elasticity Assumptions.

The assignation of a single value of pollination estimate for the Australian market would imply that either all included crops shared the same demand and supply elasticity values or single specific elasticity values have been assigned to each crop included in the aggregation. The nature of supply and demand response will, however, vary widely for the range of crops included in this valuation. Some rough rules of thumb may help define a 'most likely' range of elasticity values and subsequently, a 'most likely' range of aggregated value of pollination estimates. Demand will be more elastic :

- i) as the proportion of the domestic crop that is exported increases and the smaller is the proportion of the Australian crop to the world supply;
- ii) the more it is perceived to be a luxury item in the average household's consumption portfolio; and
- iii) the greater are the number of substitutes for an individual commodity.

A grower's intra-seasonal supply price response is likely to be limited for most of the crops included in this valuation. Growers can do little to adjust output once a crop is sown. The 'most likely' range of supply elasticities for the purposes of this valuation are within the lower end of the assumed range of 1 ≤ Se ≤ 5, say, 1 ≤ Se ≤ 2.

To establish an appropriate 'most likely' range of demand elasticities, it is not necessary to examine the subjective demand price response attributes of all of the included crops. It will suffice to examine such attributes for only a selected high valued sub-set of crops. For unitary supply and demand elasticities, four of the 25 crops considered contributed 57 per cent of the aggregate total social value of pollination. The qualitatively assessed 'most likely' range of demand elasticities for this group of five crops comprising apples, cotton, oranges and pears may be employed as an approximation to the 'most likely' elasticity range for the complete set of included crops.

None of the major four commodities are considered to be luxury items and they have few substitutes. Without further information, demand for apples, oranges and pears is expected to be relatively inelastic. US evidence suggests a price elasticity of demand for apples of -0.72[1]. Though a large proportion of the Australian cotton crop is exported (more cotton was exported than produced in 1986/87 with the deficit being derived from stocks), Australian output was only one per cent of the volume of world cotton consumption in 1986/87. Australia is, therefore, unlikely to be in a position to influence world cotton prices. Given the existence of some substitutes and the assigned moderate to low luxury status of this commodity, the Australian price elasticity of demand for cotton is likely to be unitary to moderately elastic. This contention is supported by a US empirical long-run estimate of -1.84[2]

It may seem reasonable to constrain the range in demand elasticities for the group of four crops considered above and, consequently for the complete set of crops included in the current social valuation to the moderately inelastic to moderately elastic segment of the range considered. It is, therefore, likely that the 'overall' elasticity of demand will be between -0.5 and 2. If a unitary supply elasticity is assumed, the range in the social value of pollination will be between $1.2 billion and $604.8 million.

If an overall unitary elasticity of demand is assumed, the range in the social value of pollination for various supply elasticity assumptions is illustrated in Figure 7.

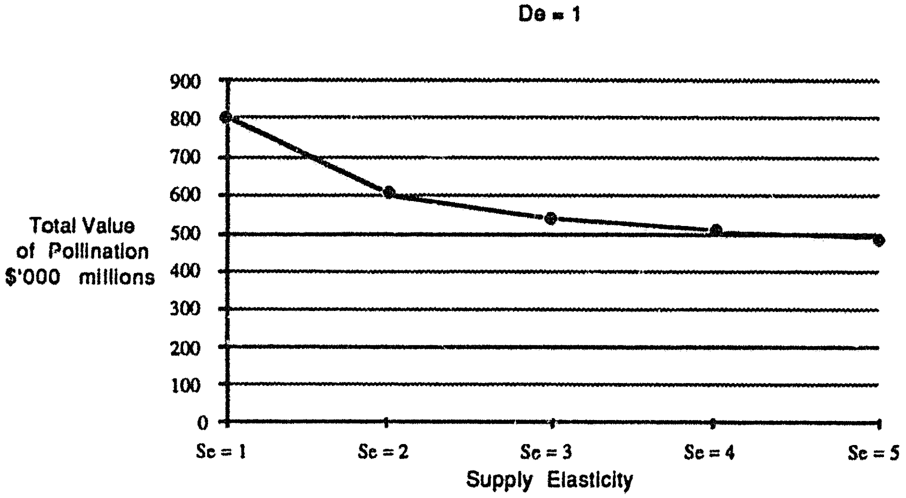


Figure 7 The Social Value of the Australian Pollination Services Market for a Unitary Demand Elasticity and a Range of Possible Supply Elasticity Assumptions.

The current valuation does not incorporate many socially significant unpriced benefits of pollination. The contribution of bees to the propagation of clover based pastures and home gardens have, for example, been excluded. Only 25 of the 77 crops listed in Table 1 as being benefited by bees have been valued (though not all of these crops are grown in Australia on a commercial basis). The contribution of bees to the Eucalyptus seed industry could also not be valued. For any set of assumed elasticities, the 'true' social value of honeybee pollination will be higher than those values estimated in this study.

7. Policy Implications and Discussion

Most of the attempts to value honeybee pollination in the past have been based on theoretically unsupportable premises. The assignation of a pollination value equivalent to the full market value of pollination benefited crops is fallacious, yet such results have been widely promoted in many countries. A recent (Robinson et al., 1989) US valuation sponsored jointly by the Economic research Service of the USDA and the US National Honey Board and criticised at length in this paper, evidences many unsupportable premises. The author's aims were to discuss the methodological limitations of preceding analyses and to identify and illustrate by application an economically defensible valuation methodology within the context of the Australian market.

The results are not definitive. Too many data limitations and identification problems preclude the derivation of a single value for honeybee pollination in Australia. The results do, however, help establish an order of importance for the Australian pollination market. The extreme minimum value of pollination estimated in this study is almost twice that submitted to the 1985 IAC inquiry into the control of Paterson's Curse by the Victorian Department of Agriculture; the first serious attempt at such a valuation undertaken in Australia. This analysis has hopefully indicated, through its social welfare context, the nature and significance of the linkages between the beekeeping and other agricultural industries. An understanding of such linkages is an important input into efficient resource allocation decision making in the public arena.

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