Valuing Honeybee Pollination

A report for the Rural Industries Research & Development Corporation

by Jenny Gordon and Lee Davis
Centre for International Economics (CIE)

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Researcher Contact Details
Jenny Gordon and Lee Davis
Centre for International Economics
GPO Box 2203
CANBERRA ACT 2601

Phone: (02) 6238 3365
Fax: (02) 6247 7484
Email: jgordon@thecie.com.au, ldavis@thecie.com.au

n submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details
Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone: 02 6272 4539
Fax: 02 6272 5877
Email: rirdc@rirdc.gov.au
Website: http://www.rirdc.gov.au

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Foreword

The honeybee industry produces a diverse range of valuable commodities including honey, beeswax, propolis and royal jelly, with a contribution to GDP estimated to be around $60 million. This contribution is small, however, compared to the importance to Australian agriculture of the ‘free’ pollination services provided by the industry. Around 65 per cent of Australian crops are estimated to be dependent to some extent on honeybees for pollination.

This report was commissioned to update estimates made by Gill in 1989, which put the value of the honeybee pollination services to Australian agriculture as between $0.6 and $1.2 billion. This value is estimated as the cost to Australia of a sudden and complete loss of honeybee pollination services. Expanding the number of crops included in the impact estimates to 35 and allowing for adjustments in exports and imports the loss to Australian producers and consumers of the affected crops is estimated to be $1.7 billion in 1999-2000. The decline in the value of agricultural production would be $1.6 billion putting 9 500 jobs at risk. And the flow-on impacts of this magnitude of shock to the Australian economy are also potentially high with an additional $2 billion loss in surplus and 11 000 jobs.

The study points to the need to better understand the potential for the development of commercial pollination services, which is an alternative approach for ‘valuing’ honeybee pollination. Constraints on honeybee producers to expand the industry and provide such services will limit their capacity to respond to demand and result in higher costs imposed on agriculture should an exotic disease incursion arise.

This project was funded from industry revenue which is matched by funds provided by the Federal Government and is an addition to RIRDC’s diverse range of over 900 research publications, forms part of our Honeybee, which aims to improve the productivity and profitability of the Australian beekeeping industry.

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Simon Hearn
Managing Director
Rural Industries Research and Development Corporation

Contents

Executive Summary

HONEYBEE POLLINATION SERVICES are largely provided free to Australian agriculture. Honeybee pollination is essential for some crops, while for others it raises yield and quality. In 1989 Gill estimated that total honeybee pollination services — from farmed and feral honeybees — was worth between $0.6 and $1.2 billion. Replicating Gill's work for a 35 largely honeybee pollination dependent crops, and allowing for the adjustments in imports and exports the value of honeybee pollination services was estimated to be $1.7 billion for 1999-2000 production. In addition to the 35 crops for which data was available, a wide range of pastures, including lucerne and clover, are pollinated by honeybees hence this estimate understates the potential value of the pollination services.

The estimate of $1.7 billion may look high compared to the value of horticulture, which in 1999-2000 was $3.8 billion, but this is the cost if farmers were unable to adjust as would be the case of a sudden disease outbreak. With such an outbreak, not only would growers of honeybee dependent crops and pastures suffer, but so too would Australian consumers with the sudden and sometimes complete decline in the availability of many fresh fruits and nuts and some major vegetables such as carrots and onions, not to mention honey. The capacity to import many of the products that would be affected is limited due to quarantine restrictions and prices for what remained would be driven up to the detriment of the consumer.

The direct costs of a loss in pollination services fall roughly equally on Australian consumers and the producers of the honeybee dependent crops. A little over half, or $877 million, is a loss to producers and $839 is the loss to consumers due to higher prices and not being able to obtain certain products. The decline in the value of agricultural output of some $1.6 billion and around 9 500 jobs are directly affected.

In addition to the direct effect on the industries relying on the agricultural inputs, flow-on effects could result in an *additional* $2 billion loss in industry output and 11 000 jobs following the loss of all honeybee pollination services. These latter losses do not persist over time as unutilised resources will move to other industries in the longer term. They do however have significant implications for regions with high shares of honeybee dependant crops in the few years following a honeybee decline.

The results are highly sensitive to the assumptions about the dependence on honeybees for pollination. But even if the dependence on the honeybee as pollinators is half that reported in the pollination trials then the loss is estimated as $0.6 billion.

Given that over 65 per cent of horticultural and agricultural crops introduced to Australia since European settlement require honeybees for pollination the impact of a sudden loss of all honeybee populations, commercial and feral, would require considerable adjustment in agriculture. The speed of adjustment to a world without honeybee pollinators, and hence the longer term costs of a major uncontrolled disease outbreak, depends on several factors. One factor is the extent to which other pollinators can replace the honeybee and this varies greatly between crops, with some such as almonds unable to be pollinated by other insects. A second factor is the profitability of the current crops relative to the next best, but not honeybee pollination dependent, crops. A third factor is the impact on market prices of a large scale switch in domestic production, which will depend critically on the scope to export production. While for consumers, the loss will decline if current restrictions on imports, that would no longer be justified for disease control reasons, are lifted.

This paper also estimates the longer term costs to farmers under three scenarios for the loss in income before farmers switch to an alternative. These scenarios assume production can be exported at world prices, and that consumers are able to access imports.

- If farmers absorb a 25 per cent loss in income before they switch to alternative crops, the estimated loss declines to $1.2 billion.
- If a 10 per cent decline in income results in farmers switching, then the estimated loss declines to $1 billion.
- Over time if all producers other than those experiencing a decline in income of less than 5 per cent switch to non-honeybee pollinated crops, then the lost producer surplus declines to $100 million.

In practice, even a problem such as *V.destructor* will not wipe out all honeybees immediately across Australia, so farmers have some time to adjust. So too do honeybee producers, and it is likely that a market for pollination services would develop rapidly in the heavily honeybee dependent industries, lowering the impact of exotic incursions largely to losses incurred from foregone production while honeybee producers expanded supply to meet the demand for pollination services. The final outcome would depend on the costs to the honeybee producers of expanding production. These costs include the additional costs of disease control, the access to areas to rebuild the health of the hives, and the market for honey.

This study did not aim to estimate the potential size of the market for commercial pollination services, nor the price these services would attract. It can be argued that the value of this market is a more accurate way to estimate the value of honeybee pollination services than the approach followed in this paper and by other studies that have attempted to estimate the value of honeybee pollination. The large estimates of value come from the fact that the loss of a critical ingredient – the honeybee pollination service – renders all the other inputs valueless in the case of the 100 per cent honeybee dependent crops, and by a proportional amount for the less dependent crops. While these costs would adjust downwards over time, such a loss would see a major restructuring of agriculture in Australia, making the humble honeybee one of the unsung heroes of Australian agriculture.

1. Introduction

HONEYBEES ARE RESPONSIBLE for the production of a diverse range of valuable commodities. The typically cited ‘outputs’ of honeybees includes products such as honey, beeswax, propolis and royal jelly. On this basis the contribution of the honeybee industry to Australia’s economic welfare is estimated to be around $50 million.

However, the contribution of the honeybee industry extends beyond the value of honey and other apiary products. In undertaking their daily routine of foraging for nectar and pollen, honeybees come into contact with numerous flowering plants, and in so doing effect fertilisation of those plants through the transfer of pollen. While numerous vectors — such as other insects, birds, animals and wind — can carry out pollination, honeybees are the most significant pollinators of some crops due to the efficiency of their foraging activities (Gibbs and Muirhead 1998). Indeed, 65 per cent of horticultural and agricultural crops introduced in Australia since European settlement require honeybees for pollination (Jones 1995, cited in Gibbs and Muirhead 1998). Given the importance of primary industries to the Australian economy, the value of pollination services carried out by honeybees is likely to substantially exceed the value of honey and other apiary products.

The value of honeybee pollination services

A credible estimate of the value of honeybee pollination services is important information for the honeybee industry. Such an estimate will help to raise the profile of the industry and establish the total contribution of the industry to Australia’s economic welfare. As noted above, the contribution of the honeybee industry extends beyond the value of honey and other apiary products and includes substantial services to agriculture in the form of pollination services. Honeybee pollination is essential for some crops, enhances fruit set in others and can play a major role in improving fruit quality.

Valuation of honeybee pollination services will allow identification of what is potentially being put at risk should Australia’s honeybee populations be threatened. For example, the exotic mites *V.destructor*, currently present in New Zealand, pose a significant threat to the Australian beekeeping industry. Knowing the value of honeybee pollination services will allow, via use of a cost–benefit framework, insight into the cost–effective level of resources to be devoted to preventing the spread of exotic mites to Australia. Such information is central to informed policy making.

The principle piece of Australian research in this area is Gill’s (1989) paper *‘The social value of commercially managed honeybee pollination services in Australia’*. Gill valued honeybee pollination services at between $600 million and $1.2 billion (based on 1989 data). In a later study, utilising some of Gill’s data, Gibbs and Muirhead (1998) valued honeybee pollination services at $1.2 billion (1994-95 data) although they estimated only the value of production lost. This focus on value of production lost is similar to the approach taken for the New Zealand estimate that put the value of honeybee pollination to primary production at $3.1 billion (1992) discussed in Gibbs and Muirhead (1998). The estimate of US$14.6 billion (2000) for the contribution of honeybee pollination in the United States also takes this ‘value of production’ approach (Morse and Calderone 2000).

This report

This study replicates the methodology of Gill (1989) which estimated the losses arising from a sudden loss of honeybee pollination services — ‘the morning after shock’. Gill’s approach allows for both producers and consumers to respond to the price changes that result from the shock. The impact on both producers of honeybee dependent crops and consumers of these products is estimated. This study extends Gill’s approach by allowing for adjustments in exports and imports within current quarantine constraints. It also extends the number of crops covered to 35 due to greater data availability. However, the scope of this study is limited to where data is available, so it does not include the impact of the loss of pollination services on pasture growth and the flow-on impacts for the dairy and grazing industry.

While the ‘morning after’ approach is a fairly standard approach to valuing the contribution of important inputs, it attributes the contribution of all the inputs to the missing critical input. This is only valid to the extent that all these costs are committed (sunk), and this cost is only the immediate impact. The longer term costs depend on the honeybee pollination dependent producers capacity to switch out of these crops to alternative non-honeybee dependent products. One way to look at this is the loss of income they will bear before they will reallocate resources (labour, land, and other inputs) to non-dependent crops.

This report describes how the estimates are made and presents the results by crop type. It also discusses the major factors that would impact on the long-term loss if honeybee pollination services were to decline. This long-term loss is more relevant for honeybee producers in understanding their long-term capacity to charge for pollination services, which is an increasing trend in other countries. It also highlights the structural change that will arise if honeybee producers reduce production in response to rising costs associated with environmental and other regulations.

The methodology used to value honeybee pollination services is detailed in chapter 2. The value of honeybee pollination services is quantified through the use of partial equilibrium economic models. Results of the economic modelling work are reported in chapter 3, where we also investigate the flow-on effects of decreased economic activity in the rural sector. Factors influencing the long-term value of honeybee pollination services are discussed in chapter 4.

There are three appendices. Appendix A details the equations underlying the economic model(s) and the formulae used to calculate changes in consumer and producer surplus. The data behind the various economic models is presented in appendix B. Results of the modelling work are presented in full in appendix C.

2. Methodology

EVALUATING THE ECONOMIC BENEFITS of honeybee pollination services is a complex task. Difficulties arise as we are attempting to place a value on an input to production — honeybee pollination services — that is typically ‘free’ for producers of agricultural and horticultural products. This free input, along with other free inputs and purchased inputs, combine to deliver a product that is valued by the market. Removal of any one of these inputs will impact, often significantly on supply. Thus the cost of the loss of an input is not the same as the contribution of the input to product value. This work focuses on the cost of a sudden loss of honeybee pollination services, rather than the ‘value’ of honeybee services. In the absence of honeybee pollination services, some products will not be produced at all, while others will suffer a reduction in supply. Essentially, we are trying to estimate the economic value associated with the loss of supply of a range of agricultural products.

The approach builds on previous work

The value of production approach first estimates the value of output in relevant agricultural sectors. The change in supply of products reliant on honeybee pollination services (as identified by Gill for the Gibbs and Muirhead study) is then applied to the relevant value of production, with the aggregate value of lost production being equivalent to the value of honeybee pollination services. This approach excludes any responses by consumers and producers to changed market conditions, in particular the potential for prices to rise in response to the decline in supply, partially offsetting producer losses.

Gill’s analysis is more sophisticated than these ‘value of production’ approaches as it calculates the ‘surpluses’ accruing to consumers and producers from participation in agricultural markets that rely on honeybee pollination as an input to production. Consumer surplus is formally defined as the net benefit to consumers from being able to buy products more cheaply than they were willing to pay. Producer surplus is defined as the net benefit a producer of agricultural products appropriates by obtaining a price higher than the costs of production. For a range of crops dependent on honeybee pollination services, Gill quantified the change in supply of those products that would occur if honeybees were removed. He then calculated consumer and producer surplus under the new ‘without honeybees’ scenario, and compared this to the surpluses generated under the ‘with honeybees’ scenario. Gill assumed the resulting change in consumer and producer surpluses from removal of honeybees as being equivalent to the economic value of pollination services. The difficulty with this approach is that we know little about demand and supply of substantially lower volumes and linearisation can lead to substantial measurement errors. As noted above, the other issue is that farmers will substitute towards other crops. At a minimum, even in a ‘morning after’ scenario further expenditures on spraying, harvest and distribution would be avoided — yet these costs are assumed expended in the approach taken.

Key differences in approach

Gill (1989) assumed the complete removal of all honeybee pollination services, with the resulting change in consumer and producer surpluses being equivalent to the economic value of those pollination services. Gill’s methodology is advanced by taking into account:

- the potential for consumers to substitute between domestically produced agricultural commodities and imports should loss of pollination services see an increase in price of domestic production;
- the decrease in international competitiveness of Australia’s agricultural exports should they become relatively more expensive than products sourced from other countries;
- revised estimates of key supply and demand elasticity parameters and updated price and quantity data;

- estimating the dispersion (standard deviation) around key economic variables following removal of honeybee pollination services; and
- decreased economic activity in the agricultural sector that will have flow-on, or multiplier, effects.

Some effects, such as allowing for import substitution, act to lower the economic value placed on honeybee pollination services, while others such as including the multiplier effects act to make it larger.

An alternative approach

The standard approach taken here assumes that the loss of honeybee pollination services would be complete, yet this is highly unlikely. The more interesting question is what market for commercial pollination would develop in the absence of 'free' pollination services. In many ways this is a more accurate approach to estimating the economic contribution of pollination services. This report does not go down this path due to the lack of information on the factors influencing the supply of commercial pollination, particularly with considerably higher volumes of production and the potential disease control costs. Estimates of supply are further complicated by the mutual benefits of locating hives near to pollinating plants as the honeybee producer gets 'paid' in honey. With much higher numbers of hives areas to restore hive health and the impact that higher production of honey has on its price also need to be incorporated.

The derived demand for pollination services also presents challenges as it depends on average profit margins, investment costs, and the markets for alternative crops. The potential size of this market and the price for pollination services would vary across regions reflecting the importance of honeybee pollination to different agricultural regions in Australia.

The ideal model

To provide a *credible and rigorous* estimate of the value of honeybee pollination services, a well specified economywide economic model would be required. Economywide models are readily available, however, it would need to be augmented to take into account the nature of honeybee pollination services. Ideally, the model would identify two honeybee populations — feral and managed hives — and account for the portion of crops pollinated by each population. Two populations would need to be identified due to the (potentially) differing impact of disease entry. The model would also need to be highly disaggregated and separately identify *each* of the commercial crops grown in Australia that are both dependent (to some extent) and non-dependent on honeybee pollination services.

On the supply side, the model would need to allow producers to change to other crops (or other economic activities altogether) should their access to pollination services decline, or the cost of those services increase. The 'willingness' of producers to substitute to other crops will be dependent on the availability and cost of production inputs needed for alternative crops, and current returns compared with those available under reduced pollination services or alternative crops. On the demand side, consumers would be allowed to consume imported products should domestic products become more expensive (assuming that AQIS allows imports of agricultural products). Hence, the model would need to consider import markets. As Australian producers export a large share of production, export markets should also be included.

It is obvious that a credible and rigorous estimate of the value of honeybee pollination services is an exceptionally data and resource intensive exercise, assuming such data is even available. The honeybee industry will need to decide whether the cost of building such a model represents value for money. In the interim, a simplified model is proposed. The proposed model offers the advantage of being less resource and data intensive while still providing insight into the value of honeybee pollination.

An approach to estimating the value of honeybee pollination services

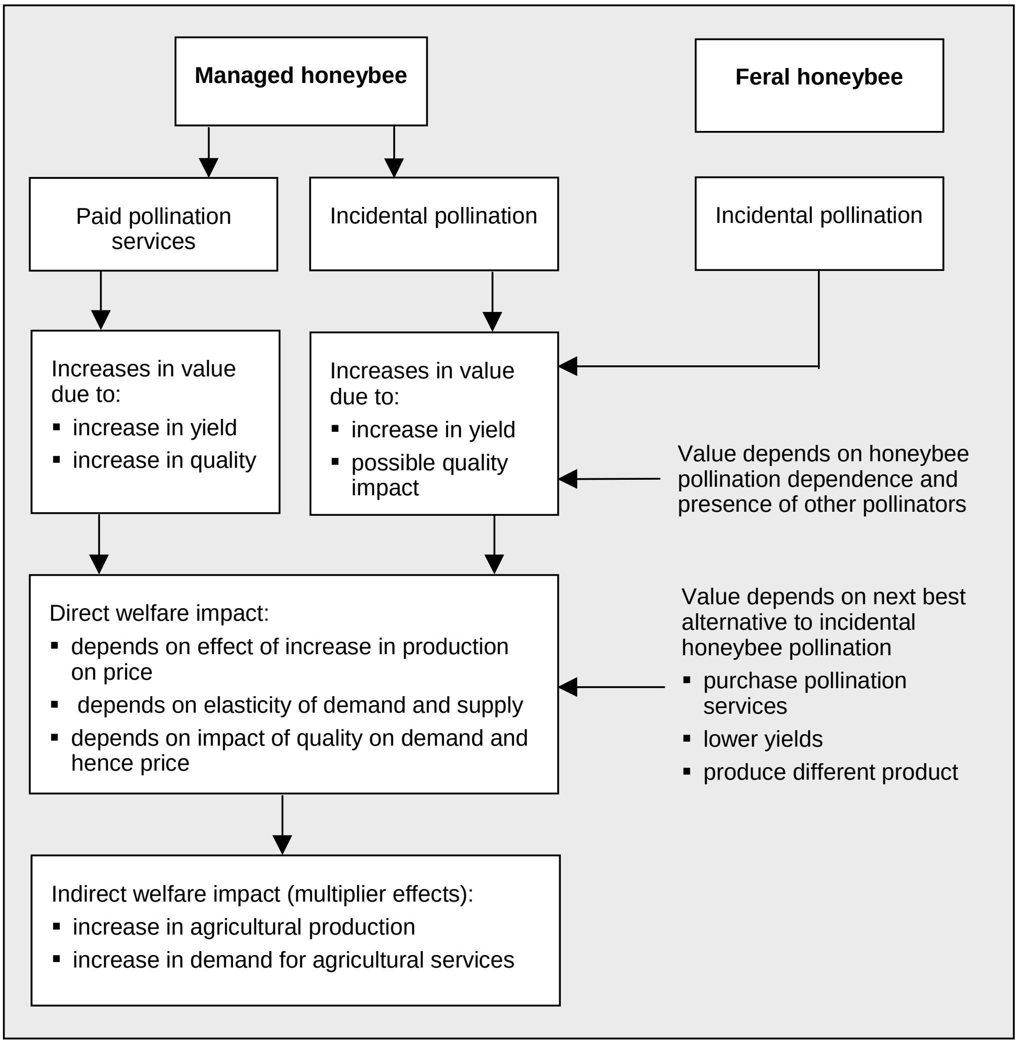
Both commercially managed and feral honeybee populations provide pollination services. In the case of commercial hives, pollination services can either be a purchased service or incidental to bee foraging activities. Pollination by feral honeybees is incidental. Removal of honeybees — both commercially managed and feral — from the Australian landscape will see a marked decline in the supply of pollination services. As supply of pollination services is reduced, we can, *a priori*, anticipate a reduction in supply and hence possible increase in price of horticultural and other agricultural products. Other things being equal, the magnitude of the price increase/ supply decrease will be proportional to the dependence of that particular crop on honeybee pollination services.

Chart 2.1 identifies the sources of economic benefit arising from honeybee pollination services. Both direct and indirect benefits from managed and feral honeybee pollination services need to be included in the analysis so as to provide a comprehensive estimate of the value of pollination services. Ideally, the impact of honeybees on crop *quantity* and *quality* would be included in the analysis. However, information limitations have prevented consideration of the role of honeybee pollination in improving crop quality. As such, the analysis is restricted to consideration of the role of honeybees in improving crop yields only and hence will understate the true value.

To calculate changes to consumer and producer surplus, we need to know how prices and quantities change in the inter-related domestic, import and export markets following a decline in production resulting from the loss of honeybee pollination services. Such changes can be determined using partial equilibrium models. The cost of the loss of honeybee pollination services is calculated as the sum of changed consumer and producer surplus in each of the three (domestic, import and export) product markets. We consider these three markets as:

- reduction of honeybee pollination services is associated with a decline in product availability and rising prices in the domestic market for domestically produced product (domestic market);
- faced with higher prices, domestic consumers substitute from domestically sourced produce to the now relatively cheaper imports (import market); and
- Australian agricultural exports will now be relatively more expensive than products sourced elsewhere, leading to a decline in their export demand (export market).

Chart 2.1 **Economic benefits attributable to honeybee pollination services**



In using (computable) partial equilibrium models, we are only concerned with the changes in the agricultural markets of interest to us. That is, we deliberately ignore the possible implications of changes in these markets on the rest of the economy. As such, there is potential that important 'second round' effects will have been omitted from the analysis. On the one hand consumers will switch their consumption to other fruits and foods that are not dependent on honeybee pollination. To the extent that these are domestically produced the loss due to the decline in pollination will be overstated. Given limited substitution across different food types and the potential to shift to imports in most products, this impact is likely to be small. On the other hand, the decline in the income of affected producers will have flow-on effects to the regions. Recognising this limitation of partial equilibrium analysis, we include a multiplier analysis as a means of incorporating the wider economic effects resulting from a decline in honeybee pollination services.

A further limitation associated with partial equilibrium models is that they are better suited to marginal (or small) changes. Partial equilibrium models are not well suited to large changes in for example, crop production as the (point) elasticity estimates are valid only for small changes in price and quantity.

The model and its underlying equations are detailed in appendix A.

The steps below detail the approach used to quantify the economic cost of the loss of honeybee pollination services.

Step 1: Identify relevant markets

Gill (1989) identified some 75 Australian horticultural and agricultural products that were dependent, either fully or partially, on honeybee pollination. However, before the partial equilibrium models can be constructed, further market and economic data is required. For each identified product estimates of the following parameters are required:

- product quantity and price in each of the three markets;
- price elasticity of domestic and export demand for product;
- price elasticity of supply for product;
- degree of substitutability between domestically sourced products and competing imports (Armington elasticity); and
- dependence of product on honeybee pollination services.

Gill (1989) restricted his analysis to 27 crops pollinated by honeybees due to data limitations. Despite the Australian Bureau of Statistics making data on a larger range of crops more readily available, we have only been able to extend the analysis to 35 crops due to the increased data requirements. To the extent that some 40 crops, identified by Gill as dependent to some extent on honeybee pollination, have been excluded from the analysis due to the absence of necessary market and economic information, the valuation of honeybee pollination services calculated will be a lower bound.

Table 2.1 shows those crops for which the full data requirements were available. Partial equilibrium models were built for each of these crop types. Price, quantity and elasticity values used in the partial equilibrium models are reported in appendix B. Table 2.1 also shows the dependence of crops on honeybee pollination services. The dependence on honeybee pollination services is equivalent to the change in supply for the various crops following the *total* removal of honeybee pollination services.

Table 2.1 **Crops included in the analysis**

Crop type	**Dependence on honeybees**[a]	**Crop type**	**Dependence on honeybees**[a]
	Per cent		Per cent
Almond	100	Lemon & Lime	20
Apple	90	Lettuce	10
Apricot	70	Lupin	10
Asparagus	90	Macadamia	90
Avocado	100	Mandarin	30
Bean	10	Mango	90
Blueberry	100	Nectarine	60
Broccoli	100	Onion	100
Brussels sprout	30	Orange	30
Cabbage	30	Papaya	20
Carrot	100	Peach	60
Cauliflower	100	Peanut	10
Celery	100	Pear	50
Cherries	90	Plum and prune	70
Cotton lint	20	Pumpkin	90
Cucumber	90	Strawberry	40
Grapefruit	80	Watermelon	70
Kiwi	90		

a Dependence on honeybees reports the relationship between crop production and honeybee pollination services. Removal of *all* honeybees would see pollination and hence product supply decline by the reported figure.

Source: Table 2.1 of Gill (1989).

The (potential) ‘crowding out’ of other pollinators by honeybees limits the valuation of honeybee pollination services to a present day ‘snapshot’. If, for example, honeybee pollination services were reduced by the entry of exotic mites, then we could reasonably expect that over time other pollinators would uptake *some* of the void left by honeybees. Hence the extent of the decline in pollination services listed in table 2.1 will in part be tempered by any increase in pollination services from other pollinators, such as native bees, other insects, birds, animals and so on. It is anticipated, however, that the extent of any such crowding out is likely to be small. The process of evolution sees insects and animals native to Australia being unlikely to replace — for many years — the activities of *introduced* honeybees in pollinating *introduced* crops. As a result, the main adjustment to a massive decline in honeybee populations and hence pollination services would be farmers switching to non-honeybee pollination dependant crops.

To model the dynamic (time dependent) countervailing forces requires detailed biological and epidemiological information as well as a knowledge of the next best non-honeybee pollinated alternatives available to farmers. Obtaining such information is beyond the scope of this study, so the analysis is restricted to simulating a fixed decrease in crop production following a decline in honeybee pollination. The elasticities used in the modelling reflect consumer and production responses to price changes over the short to medium term. Factors influencing the long-term impact on the true economic value of honeybee pollination services are discussed in chapter 4.

Step 2: Modelling the effects of a decline in honeybee pollination services

The partial equilibrium model is ‘shocked’ by a change in crop production, reflecting a decline in honeybee pollination services. When estimating the value of honeybee pollination services, Gill assumed the complete removal of all honeybees. For example, Gill calculated the loss of consumer and producer surplus associated with a 100 per cent reduction in almond production, 90 per cent reduction in apple production and so on (see table 2.1). The same approach is used here.

However, partial equilibrium models (of the type used here — see appendix A) are typically not well suited to such large shocks. Problems arise as point estimates of elasticities are used, and in reality, these are not accurate over large changes. For example, at current prices, the elasticity of demand for apples is inelastic (that is, not particularly sensitive to price changes). However, at substantially higher prices, the elasticity of demand would be very elastic. When interpreting the results it needs to be noted that partial equilibrium models cannot incorporate such large changes in elasticities, and hence may produce unrealistic results for large shocks. Furthermore, the non-linear nature of demand and supply can pose problems when supply is decreased by a large amount.

The partial equilibrium models are used with updated parameters and relevant supply shock to derive the new equilibrium price and quantity for each of the relevant product markets. The new equilibrium provides us with the ‘no pollination services’ market outcome.

Faced with price increases for horticultural and agricultural products dependent on honeybee pollination services, consumers will decrease their demand for those products. The extent to which demand falls depends on the elasticity of demand. Including competing imports in the analysis imposes a further price discipline on producers. Consumers may not change their overall demand for the product, but may substitute away from the now more expensive domestic product to the now relatively cheaper import. The ability to substitute to cheaper imports lessens the loss of consumer surplus. The extent to which domestically sourced products and imports are substitutable is given by the Armington elasticity of substitution.

Price increases are transmitted to the export market, which sees Australian exports now being relatively more expensive than products sourced elsewhere. As around two thirds of Australia’s total agricultural production is sold on the highly price competitive export markets, the potential economic losses for producers from cost increases are significant.

Step 3: Calculate economic losses in each market

Economic loss stemming from a decline in honeybee pollination has been estimated by calculating the change in consumer and producer surplus in each of the relevant markets following a decline in honeybee pollination services (Step 2). The formulae used to derive the change in consumer and producer surpluses can be found in appendix A. The change in surplus is assumed to be equivalent to the economic loss should honeybee pollination services be removed.

Step 4: Multiplier effects

Horticultural and agricultural activities generate significant economic benefits for Australia.

First, there are the direct benefits — direct employment in production — which generates wages, revenue and value added in the horticultural and agricultural industries. Next, there are the indirect or flow-on effects. These measure the stimulus to value added and employment in other industries in the region through the linkages between horticultural and agricultural industries and other industries. These links are of two types.

- First, the industries purchase goods and services — fertilisers, fuels, accounting services and so on — as inputs to production (production links).
- Second, some part of the wages and profits earned by farmers and the wages of those employed on farms is spent on local goods and services (consumption links).

This expenditure provides a stimulus to economic activity and employment in supplying industries. In turn, some of the wages and profits earned in these industries are spent locally, which provides a further (smaller) stimulus to the regional economy. As a result of these links and interdependencies between horticulture/agriculture and other industries in the region, an adverse shock in one market can have considerable flow-on or multiplier effects throughout the wider regional community. Partial equilibrium models ignore these flow-on effects.

The flow-on effects have been calculated from estimates of agricultural multipliers. These multipliers are in turn derived from Input–Output tables compiled by the Australian Bureau of Statistics. Input–Output multipliers are summary measures used for estimating the total economywide impact of changes in demand for the output of any one sector. Table 2.2 shows the total multiplier effect for the relevant agricultural activities. The multipliers used to analyse the economywide effects arising from loss of honeybee pollination services are detailed in appendix B.

The multiplier represents the proportional change in output, value added, household income and employment following a change in industry output. For example, if the value of agricultural output declined by $1 million following a decline in honeybee pollination services, then we could expect economywide output to contract by $2.3 million, value added to fall by $1.3 million, household income to fall by $0.7 million and 13 full time jobs to be lost. These losses reflect the direct impact of the supply shock on the particular agricultural industry itself, indirect losses experienced by those industries linked to the directly affected industry, and losses arising through decreases in household income and subsequent expenditure.

Table 2.2 **Economywide multipliers for Other Agriculture**[a]

Multiplier	Unit	Multiplier
For a $1 million change in industry output:		
▪ Output	$ million	2.296
▪ Value added	$ million	1.226
▪ Income	$ million	0.720
▪ Employment	Full time equivalent jobs	13

a The ABS identified industry of 'Other Agriculture' comprises the Plant Nursery, Cut Flower and Flower Seed Growing, Vegetable Growing, Fruit Growing, Other Livestock Farming and Other Crop Growing industries.

Source: ABS unpublished data.

The multipliers reported in table 2.2 should however be interpreted with caution. They represent the economywide changes that could be expected in the *short run* following a change in the value of industry output. Multipliers assume that the economy does not adjust overtime, and hence they do not represent a long run change to economywide output, employment and so on. For example, we anticipate (*a priori*) that a decline in honeybee pollination will be associated with a substantial decline in the value of agricultural and horticultural output. For every $1 million decline in output, 13 people will lose their (full time equivalent) job. Overtime we would anticipate that these labour resources would be used elsewhere in the economy. This has been the pattern of Australia's microeconomic reforms over the last two decades. Hence over the long run, the decline in output, unemployment and so on resulting from a reduction in honeybees will not be as great as that predicted by the multiplier analysis.

The multiplier analysis provides insight into the (short run) economic effects of losing honeybee pollination services. However, these economywide effects will not be equivalent to the economic value of the pollination services.

3. The value of honeybee pollination services

THE LOSS OF ECONOMIC SURPLUS from a 100 per cent decline in honeybee pollination services is significant, estimated at $1.7 billion (based on 1999–2000 data). The loss of pollination services is associated with a decline in value of agricultural output of $1.6 billion, and the loss of some 9500 full time equivalent (FTE) jobs. As would be expected, the flow-on effects are also significant — the value of regional output is estimated to fall by an *additional* $2 billion, culminating in the loss of a *further* 11 000 FTE jobs.

Selected results of the modelling are presented here, with full modelling and multiplier analysis reported in appendix C.

Economic value of honeybee pollination

The change in consumer and producer surplus following a decline in honeybee pollination services is the direct economic cost of the loss of honeybee pollination services. Table 3.1 reports the change in consumer and producer surplus. Also reported is the change in value of output of the various crops.

Several factors govern the magnitude of surplus loss, namely:

- crop value prior to the decline in honeybee pollination;
- loss of production following the decline in honeybee pollination;
- the amount of production exported; and
- the quantity of domestic demand met by imports.

The role of the first two factors in determining the surplus loss is self-explanatory. The greater the amount of domestic production exported to international markets, the greater the loss of producer surplus as export demand is significantly more price sensitive than domestic demand. Hence a price increase is associated with a greater reduction in demand in the export market than in the domestic market. For example, with a 100 per cent decline in honeybee pollination services, the price of domestically produced oranges is estimated to increase by 11.51 per cent (see table C.1 in appendix C). This is associated with a fall in domestic demand of 20.37 per cent, but a fall in export demand of 59.06 per cent. Consequently, those industries exporting a greater share of their production stand to lose more than industries with a greater domestic focus.

Table 3.1 **Economic cost of the loss of honeybee pollination services**

Crop	**Lost producer surplus**	**Lost consumer surplus**	**Total lost surplus**	**Change in industry output**
	$m	$m	$m	$m
Almond	-21	-8	-29	-46
Apple	-174	-125	-298	-261
Apricot	-11	-5	-17	-17
Asparagus	-26	-1	-27	-46
Avocado	-30	-11	-40	-52
Bean	-1	-2	-3	-2
Blueberry	-12	-21	-33	-20
Broccoli	-35	-89	-124	-61
Brussels sprout	-1	-1	-2	-1
Cabbage	-2	-3	-5	-4
Carrot	-95	-82	-177	-167
Cauliflower	-32	-78	-110	-56
Celery	-15	-12	-26	-26
Cherries	-18	-19	-37	-27
Cotton lint	-120	0	-120	-240
Cucumber	-10	-5	-15	-17
Grapefruit	-2	-4	-6	-4
Kiwi fruit	-3	0	-3	-6
Lemon & Lime	-2	-1	-3	-3
Lettuce	-3	-4	-7	-5
Lupin	-6	-12	-18	-12
Macadamia	-26	-6	-32	-60
Mandarin	-8	-8	-15	-17
Mango	-28	-22	-50	-55
Nectarine	-13	-14	-27	-26
Onion	-67	-174	-242	-117
Orange	-29	-23	-52	-65
Papaya	0	-1	-1	-1
Peach	-19	-19	-38	-28
Peanut	-1	-1	-2	-2
Pear	-25	-27	-51	-37
Plum and prune	-15	-5	-20	-26
Pumpkin	-17	-29	-46	-29
Strawberry	-14	-12	-26	-25
Watermelon	-9	-15	-24	-15
Total	**-887**	**-839**	**-1 726**	**-1 578**

Source: CIE calculations.

The ability of consumers to substitute to (now relatively cheaper) imported product acts to offset some of the consumer surplus lost in the domestic market. Despite this, lost consumer surplus is still significant, accounting for around 49 per cent of total lost surplus.

Whether producer surplus declines by $887 million as the fall in pollination services approaches 100 per cent is uncertain — we would expect that at some stage producers would move into alternative economic activities rather than persist with honeybee dependent crops, hence diminishing net losses. However, information is not readily available to allow an assessment of the point at which producers of various crops dependent on honeybee pollination services will ‘switch’ to alternative crops/economic activities should the availability of pollination services decline.

Table 3.2 shows the loss of producer surplus under different assumptions about the decline in income (surplus) absorbed before producers would move into alternative economic activities. From table 3.2 it can be seen that the lower band of lost producer surplus is $100 million, while the upper band is $887 million.

Table 3.2 **Alternative activities and loss of producer income**

Loss in income absorbed before changing activities	Lost producer income
Per cent	$m
5	100
10	191
15	282
20	356
25	405
30	452
35	494
40	535
100	887

Source: CIE calculations.

As information about production alternatives becomes available, it will be possible to definitively identify the net economic value of honeybee pollination services.

The decline in value of output ($1.6 billion) has important implications for those other industries with production and/or consumption linkages to the agricultural and horticultural industries that stand to be affected by a decline in honeybee pollination. As is shown further below, these ‘flow-on’ (or multiplier) effects are frequently greater than the direct effects.

Sensitivity analysis

Due to uncertainty surrounding key parameters used in the modelling — most notably elasticities of domestic demand and supply — a sensitivity analysis was undertaken.

Table 3.3 shows the loss of consumer (CS), producer (PS) and total (TS) economic surplus under different assumptions about domestic demand and supply elasticities. Two elasticity variations are modelled — ‘Standard’ and ‘High’. Standard elasticities refer to those that were used when generating the results that are reported in table 3.1 (standard elasticities can be found in table B.2). High elasticities have been arbitrarily chosen to reflect a situation in which consumers and producers are very responsive to price changes. The High elasticity of demand is assumed to be -5.00, while the High elasticity of supply is assumed to be 2.00. Other model parameters and input data are unchanged. The Standard–Standard scenario is the same as that reported in table 3.1.

From table 3.3 it can be seen that the more elastic demand and supply are (that is, the High simulations), the lower is the loss of economic surplus. Under the High–High scenario, the loss of economic surplus is around half of that ($914 million) lost under the Standard–Standard scenario ($1 726 million). In calculating the economic value of honeybee pollination services, a short to medium term outlook was adopted, and elasticities chosen to reflect this. That is, demand and supply elasticities were relatively inelastic, meaning that over the short term consumers and producers are relatively unresponsive to price changes. However, over the longer term demand and supply elasticities are typically quite high. Hence valuing honeybee pollination services over the long-term is likely to see those services being assigned a value closer to $914 million than to $1 726 million.

Table 3.3 **Sensitivity analysis — alternative demand and supply elasticities**

			Elasticity of demand		
			Standard		**High**
			$ million		$ million
		CS:	-839	CS:	-361
		PS:	-887	PS:	-933
	Standard	TS:	**-1 726**	TS:	**-1 294**
Elasticity of supply		CS:	-839	CS:	-361
		PS:	-526	PS:	-553
	High	TS:	**-1 365**	TS:	**-914**

Source: CIE calculations.

To reflect uncertainty surrounding the dependence of various crop yields on honeybee pollination services, a simulation was modelled whereby the loss of yield for each of the crops was 50 per cent of that reported in table 2.2. For example, in table 2.2 apple production is reported as being 90 per cent dependent on honeybee pollination services, hence removal of all honeybees would be associated with a fall in domestic apple production of 90 per cent. In this exercise, it has been assumed that removal of honeybees would be associated with a 45 per cent in apple production (50 per cent of 90). Under this scenario, the loss of surplus is significantly reduced — from $1 726 million to $619 million (comprising lost consumer surplus of $253 million and lost producer surplus of $367 million).

Comparison with Gill's estimate

The economic cost of the loss of honeybee pollination services has also been calculated according to the methodology used by Gill so as to provide a point of comparison. Gill's results and the results presented in table 3.1 are not strictly comparable due to differing methodologies.

Applying Gill's approach — linear demand and supply curves, consideration of domestic market effects only and total loss of all honeybee pollination services — to the data reported in table B.2 of appendix B puts the value of honeybee pollination services at $2.1 billion. Gill calculated a value of between $600 million and $1.2 billion (value varies depending on elasticities chosen). We would expect the value calculated here to be (significantly) greater due to increased crop coverage (Gill included 27 crops, we have included 35), and price and production increases since 1989.

The estimate of $2.1 billion has been calculated for comparative purposes only — it should not be interpreted or reported as being a rigorous assessment of the value of honeybee pollination services or even of the cost of a loss of these services. Using Gill's methodology will greatly overstate the net contribution of honeybee pollination services to Australia's economic well being. If all honeybee pollination services are removed then resources employed in producing crops dependent on honeybee pollination will not lie idle (as assumed in Gill's methodology) — they will be employed elsewhere in the economy. Furthermore, if consumers cannot purchase a particular agricultural product they will simply purchase other goods (potentially imported agricultural products) and hence regain some lost surplus. Hence the *net* loss of economic surplus will be substantially lower.

Multiplier analysis

From the results presented in table 3.4, it is apparent that the agricultural and horticultural industries have extensive production and consumption linkages to other industries. However, when interpreting the estimated regional effects, the results presented in table 3.4 should be viewed as an upper bound. Should some apiarists leave the industry or scale down their operations, farmers may expand into other enterprises. This will deliver some regional benefits, and will act to limit the losses associated with a downturn in honeybee pollination services. Hence the *net impact* on the regional economy will be lower than that reported here. Whether alternative activities can fully offset the losses arising from a reduction in honeybee production will depend on the nature of those activities, their relative profitability, labour intensity, value adding and links to other industries within the region.

With the exception of household income, the flow-on effects from a decline in honeybee pollination services are greater in the interdependent industries than in those directly effected. The decrease in production sees the value of output of those agricultural industries reliant (to some extent) on honeybee pollination services falling by $1.6 billion. The decrease in output means that those agricultural industries will use less production inputs, and farm income will be reduced which in turn sees less spending by farmers on local goods and services. These factors combine, and those industries dependent on the directly effected agricultural industries experience a $2 billion decline in sales. In aggregate, removal of honeybee pollination is associated with a $3.6 billion fall in value of production. As a result of this fall in production, 9471 FTE jobs are lost in the industries directly effected, and 11 049 FTE jobs are lost in those industries which have production and consumption linkages to the directly effected industries.

Valued added — defined as wages, salaries and supplements plus gross operating surplus — can be considered as a proxy for gross domestic product (GDP). It should only be considered a proxy as GDP is given by value added plus taxes. Under the simulation modelled, GDP is estimated to fall by $1.9 billion.

Table 3.4 **Flow-on effects of a decline in honeybee pollination**[a]

Indicator	**100% decline in pollination**
Industry output ($m)	
Direct	-1 578
Flow-on	-2 046
Total	-3 624
Household income ($m)	
Direct	-672
Flow-on	-464
Total	-1 137
Value added ($m)	
Direct	-923
Flow-on	-1 012
Total	-1 935
Employment (FTE jobs)	
Direct	-9 471
Flow-on	-11 049
Total	-20 520

a Direct and flow-on numbers may not add to totals due to rounding.

Source: CIE calculations.

4. The long-term value of paid pollination services

AN IMPORTANT CONSIDERATION for the honeybee industry concerns the willingness of the agricultural sector to pay for honeybee pollination services. Whilst on the increase, paying for honeybee pollination services is not common place in Australia.

Willingness to paying for honeybee pollination services

The long-term value of paid pollination services, and the willingness of farmers to pay for those services, is dependent on many factors, particularly:

- the dependence of various agricultural crops on honeybee pollination services for yield quality and quantity;
- awareness by farmers of the role of honeybees in improving yield quality and quantity;
- the responsiveness of consumers to price increases and their ability to source products from alternative sources (that is, imports); and
- the ability of farmers to substitute from crops dependent (to some extent) on honeybee pollination services to non-honeybee dependent crops.

Consideration of these factors will provide insight into how apiarists can raise returns by selling pollination services.

Dependence on honeybee pollination

The dependence of crops on honeybee pollination services for fruit set varies between 10 and 100 per cent (see table 2.2). Variation in the dependence on honeybees has implications for the ability of apiarists to extract payment for pollination services.

For instance, growers of crops only marginally dependent on honeybee pollination services — such as lettuce and peanut — are unlikely to consider it ‘worthwhile’ paying for such pollination services (as the additional gains from honeybee pollination services are small) unless the costs in fees and organisational effort are very low. In contrast, growers of crops highly dependent on honeybee pollination services — such as almond and apple — will be more inclined to pay for pollination services due to the dependence of crop yield on honeybee pollination. Faced with the prospect of inadequate or no honeybee pollination, these farmers will be more likely to pay for the presence of honeybees due to the lack of alternative pollinators. Accordingly, apiarists should market pollination services to growers of crops *highly dependent* on honeybee pollination.

This observation is however contingent on the absence of feral honeybees. Putting aside the issue of optimal stocking densities, farmers will likely be indifferent as to whether their crops are pollinated by managed or feral honeybees. The presence of feral honeybees will diminish the ability of apiarists to charge for pollination services.

Market development

Related to the area of marketing is the issue of market development. The market for honeybee pollination could be enlarged through educating those that stand to benefit from honeybee pollination — the farmers — as to the role of honeybees in improving yield quantity and quality. If left uninformed, farmers will not be aware of what ‘could be’ if optimal honeybee stocking densities are employed (rather than leaving pollination up to feral bees).

Response of consumers

Paying for pollination services is likely to increase the per unit cost of production. The extent to which farmers will be willing to pay depends on the extent to which they can pass on the increased production costs to consumers. The greater the elasticity of demand, the less producers are able to pass on cost increases (see table B.2 in appendix B for the elasticity of demand for various crops). Apiarists will therefore be better able to sell pollination services to farmers of crops where demand is less responsive to price changes.

Move to growing alternative crops

If farmers can easily substitute between growing crops dependent on honeybee pollination services to growing non-honeybee dependent crops, then the ability of apiarists to charge for pollination services is diminished. Quite simply, if paying for pollination services is associated with a decline in profits, then those farmers able to change to other (non-honeybee dependent) crops will likely do so.

Change may take some time as perennial crops have a high share of fixed costs in total costs. This makes it more difficult for these farmers to substitute to other crops. However, if the industry is already 'squeezed' and only covering variable costs then change could be rapid. Thus to assess the likely impact of having to pay for pollination services we need to know the current cost structure and performance of current crops as well as the availability (and profit margins) of alternatives for farmers currently growing crops dependent on honeybee pollination.

The possibility for substitution into other activities will affect the demand for pollination services and hence the price agricultural producers are willing to pay for pollination services.

Effect on market outcomes of paying for pollination services

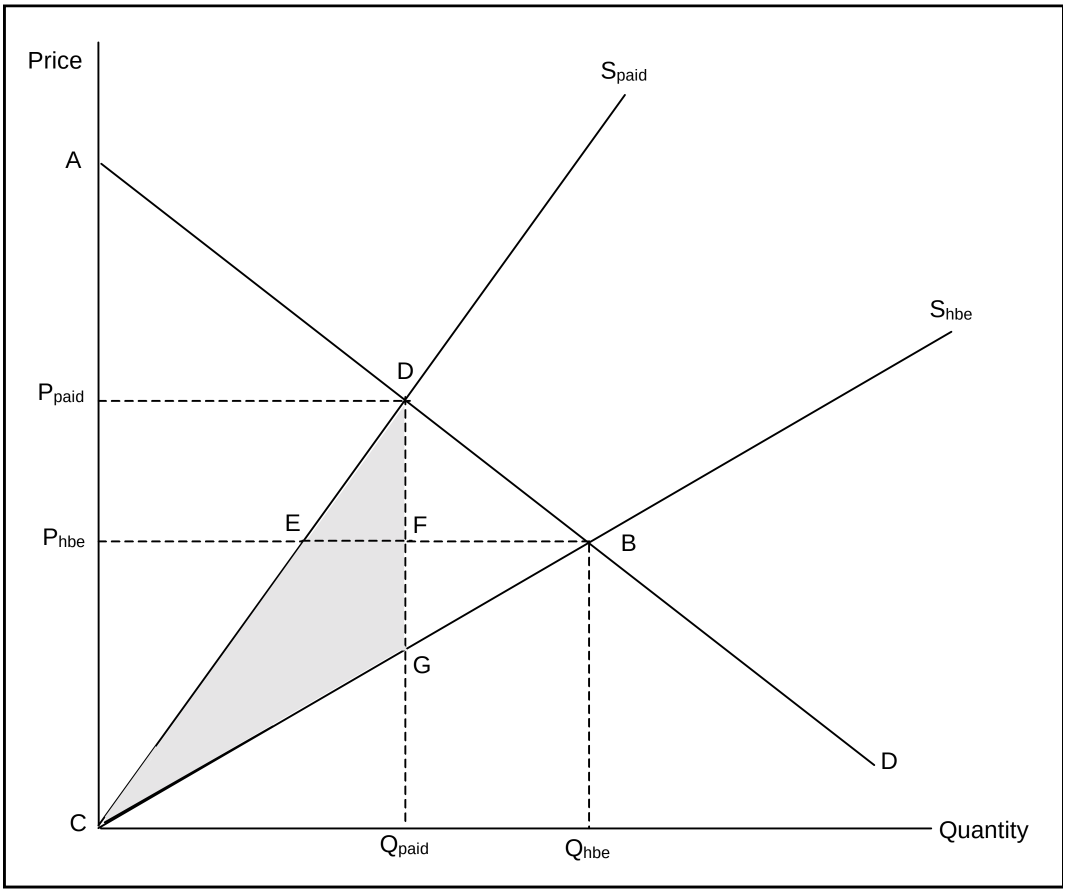
Chart 4.1 provides a stylised representation of the effects charging for honeybee pollination services has on market outcomes (price, quantity and welfare).

Suppose chart 4.1 represents the market for an agricultural product whose production is totally reliant on honeybee pollination services. In the presence of (free) honeybee pollination, the intersection of supply (S_{hbe}) and demand (D) determines the market outcomes — hence quantity Q_{hbe} is produced and sold at price P_{hbe}. If all honeybees are lost, and hence no pollination takes place, then no quantity of product will be produced. The economic value of honeybee pollination services — given by the aggregate loss in consumer and producer surplus in the absence of honeybee pollination — will be equivalent to area ABC. (Although, as noted in the earlier chapters, the net loss of economic value will be smaller than area ABC due to producers moving into other economic activities and consumers consuming other products including imports.)

Faced with the total loss of production, assume farmers choose to pay for honeybee pollination services. Paying for pollination services will increase the cost of production, represented in chart 4.1 by a pivoting of the supply curve (from S_{hbe} to S_{paid}). The increase in production costs sees the new market price being P_{paid} with quantity Q_{paid} of the crop being produced (given by the intersection of the D and S_{paid} curves). At this price and quantity, the economic surplus generated by the production and sale of the crop is given by area ADC.

Under the paid pollination scenario, economic welfare (in this market) is lower by area DBC. Consumer surplus is reduced by area $P_{paid}DBP_{hbe}$, and the change in producer surplus is given by (-)EBC + $P_{paid}DEP_{hbe}$. But compared to the alternative — no pollination and hence no crop production — paying for pollination services increases the economic surplus generated in this market by area ADC.

Chart 4.1 **Paying for pollination — effect on market outcomes**



In paying for pollination services, farmers transfer some of their producer surplus to apiarists. Hence some of the net loss of economic value in this market is actually captured by apiarists. Paying for pollination services sees apiarist collecting payments given by the shaded area DGC. Of this amount, surplus given by area FGCE is appropriated from crop producers while surplus given by area DFE is taken from consumers.

The most accurate estimate of the value of pollination services that can be compared to GDP based measures of production value is given by the area DGC. Estimating this area is data intensive and requires extensive understanding of how farmers would react to loss of free pollination services. As noted, this will differ across crops.

The approach utilised in this report estimates of the cost of the loss of pollination services to have an upper bound of $887 million for producers and $839 million for consumers. From chart 4.1 it can be seen that the surplus able to be captured by apiarists is lower than that attributed to honeybee pollination (area DGC is smaller than area ABC). Hence the cost of the loss of honeybee pollination services calculated here is not an indication of the gains that can be appropriated by apiarists — the true market value of honeybee pollination services.

A. Valuing honeybee pollination services

A PARTIAL EQUILIBRIUM FRAMEWORK was used to value the pollination services undertaken by honeybee. Models were built for each of those agricultural crops for which sufficient data was available and that stand to be affected by removal of honeybees. This saw 35 partial equilibrium models being used (one for each of the crops reported in table 2.2).

The model

To calculate changes to consumer and producer surplus, we need to know how prices and quantities change in the inter-related domestic, import and export markets following removal of honeybee pollination services. The equations — denoted in percentage change form — underlying the model are shown below.

Total Australian supply: $\Delta q_s = \Sigma_s \Delta p_d + \upsilon_s$

Total Australian demand: $\Delta q_t = \Sigma_d \Delta p_{avg} + \upsilon_d$

Average consumer price: $\Delta p_{avg} = S_{dom} \Delta p_d + S_{imp} \Delta p_m$

Demand for domestic good: $\Delta q_d = \Delta q_t - \delta(\Delta p_d - \Delta p_{avg})$

Demand for imported good: $\Delta q_m = \Delta q_t - \delta(\Delta p_m - \Delta p_{avg})$

Demand for exported good: $\Delta q_x = \Sigma_x \Delta p_d + \upsilon_x$

Market clearing condition: $Q_s \Delta q_s - Q_t \Delta q_t - Q_x \Delta q_x = 0$

The change in average price is calculated as the share weighted average of the change in price of domestically ($S_{dom} \Delta p_d$) sourced and imported ($S_{imp} \Delta p_m$) product. As the change in import price is exogenously set to zero, the change in average price is simply the change in domestic price weighted by the share of domestic production in total consumption.

For simplification, we assume that product sold to the domestic market is perfectly homogeneous to that exported, and as such are priced the same (hence $P_d = P_x$).

Exogenous data observations required before the model can be solved are shown in table A.1, and reported in full in appendix B. We assume that the various markets are initially in equilibrium (at the observed price and quantity values). Removal of honeybee pollination services is associated with a supply shock, which enters the model via parameter q_s.

The supply shocks range between –10 and –100 per cent (see table B.1 in appendix B). With the larger shocks, the model outlined above is subject to linearisation errors, making the results non-sensible. The linearisation problem has been overcome through using the GEMPACK software suite to establish a multi-step solution methodology. This approach offers the additional advantage in that it permits demand and supply to be non-linear.

The model is solved for Δp_d such that the market clearing condition holds. The model calculates the percentage change in equilibrium prices and quantities following removal of honeybee pollination services. These results are then used to calculate the economic value of honeybee pollination services.

Table A.1 **Data observations required to solve model**

Parameter	Parameter
Quantity of imports (Q_m)	Elasticity of domestic supply (Σ_s)
Quantity of exports (Q_x)	Elasticity of domestic demand (Σ_d)
Quantity of domestic sales (Q_d)	Elasticity of export demand (Σ_x)
Price of imports (P_m)	Armington elasticity of substitution (δ)
Price of domestic sales (P_d)	Supply shock (q_s)

Valuing honeybee pollination services

We assume that the economic value of honeybee pollination services is equivalent to the change in value of consumer and producer surplus following the supply shock. Consumer and producer surplus are not included in GDP so the economic value measures should not be compared with GDP measures. Output estimates are also generated and it is inappropriate to compare these to GDP.

In the domestic market, the loss of honeybee pollination services is associated with a decline in product availability and rising prices. This sees consumer surplus (CS) contract. The effect on producer surplus (PS) is also negative. However, the loss in producer surplus associated with a fall in quantity provided is partially offset by the rise in equilibrium price. Faced with higher prices, consumers substitute from domestically sourced produce to the now relatively cheaper imports, which acts to reduce the loss in consumer surplus. Finally, producers experience a loss of surplus in the export market as Australian agricultural exports are now relatively more expensive than products sourced elsewhere.

The equations underlying the calculation of changes in consumer and producer surpluses are shown below. We have assumed that the non-linear supply curve takes the form of $P(q) = \alpha Q^{\beta}$. The change in producer surplus is given by the difference between the producer surplus available under the pre honeybee removal and post honeybee removal scenario.

As we have assumed that product sold to the domestic market is perfectly homogeneous to that exported, we can calculate the total change in producer surplus as the sum of the changed producer surplus in the domestic and export markets.

As an Armington elasticity has been included in the model, we have implicitly assumed that domestically produced products and imported products are not perfect substitutes. Strictly speaking, this means that the change in total consumer surplus is not equivalent to the sum of changed consumer surplus in the domestic and import markets. Hence only the change in total consumer surplus is reported.

Producer surplus:

$$\Delta PS_d = PS_d^{new} - PS_d^{eq}$$
$$= \left(TR_d^{new} - \int \alpha_d^{new} Q^{\beta}.dq\right) - \left(TR_d^{eq} - \int \alpha_d^{eq} Q^{\beta}.dq\right)$$
$$= \left(P_d^{eq}(1+\Delta p_d)\cdot Q_d^{eq}(1+\Delta q_d) - \left[\frac{\mathrm{P}_d^{eq}(1+\Delta p_d)}{\left(Q_d^{eq}(1+\Delta q_d)\right)^{\beta}}.\frac{1}{\beta+1}.Q^{\beta+1} \right]_0^{Q_d^{new}} \right)$$
$$- \left(P_d^{eq}.Q_d^{eq} - \left[\frac{P_d^{eq}}{\left(Q_d^{eq}\right)^{\beta}}.\frac{1}{\beta+1}.Q^{\beta+1} \right]_0^{Q_d^{eq}} \right)$$

$$\Delta PS_x = PS_x^{new} - PS_x^{eq}$$
$$= \left(TR_x^{new} - \int \alpha_x^{new} Q^{\beta}.dq\right) - \left(TR_d^{eq} - \int \alpha_x^{eq} Q^{\beta}.dq\right)$$
$$= \left(P_x^{eq}(1+\Delta p_d)\cdot Q_x^{eq}(1+\Delta q_x) - \left[\frac{\mathrm{P}_d^{eq}(1+\Delta p_d)}{\left(Q_x^{eq}(1+\Delta q_x)\right)^{\beta}}.\frac{1}{\beta+1}.Q^{\beta+1} \right]_0^{Q_x^{new}} \right)$$
$$- \left(P_d^{eq}.Q_x^{eq} - \left[\frac{P_d^{eq}}{\left(Q_x^{eq}\right)^{\beta}}.\frac{1}{\beta+1}.Q^{\beta+1} \right]_0^{Q_x^{eq}} \right)$$

$$\Delta PS_t = \Delta PS_d + \Delta PS_x$$

Consumer surplus:

$$\Delta CS_t = 0.5\left(P_{avg}^{eq} - P_{avg}^{new}\right)x\left(Q_t^{eq} + Q_t^{new}\right)$$
$$= 0.5\left(-\Delta p_{avg} P_{avg}^{eq}\right)\left(2Q_t^{eq} + \Delta q_t Q_t^{eq}\right)$$
$$= 0.5\left(-\Delta p_{avg} P_{avg}^{eq}\right)\left[2\left(Q_d^{eq} + Q_m^{eq}\right) + \Delta q_t \left(Q_d^{eq} + Q_m^{eq}\right)\right]$$

B. Data observations used in analysis

VALUATION OF honeybee pollination services is a data intensive exercise. Table B.1 shows the simulation modelled, with the data observations underlying the modelling being presented in table B.2. Table B.3 shows the multipliers used to assess the wider economic effects flowing from loss of honeybee pollination services.

The simulation modelled

The simulation modelled saw a 100 per cent decline in honeybee pollination. We use a decline in pollination rather than a decline in honeybee population because it is not clear that there is a one to one relationship between honeybee numbers and pollination. A linear mapping is likely but it needs to be established what share of the honeybee population does what share of pollination.

The change in crop supply (see table B.1) is taken directly from Gill (1989). The modelling sees the parameter q_s being assigned the values reported in table B.2.

Price and quantity data

The data observations reported in table B.2 were obtained from various sources, including Australian Bureau of Statistics and Horticulture Australia publications, unpublished ABS data and CIE estimates. The latest available data was used. However, due to price and quantity data being needed for three markets (domestic, export and import), the need for comparability between data meant that the latest readily available data typically related to year 1999 or 1999-00.

In some instances it was necessary to manipulate the data so as to arrive at the required information. In addition to direct data observations, the following steps were undertaken:

- domestic consumption was calculated as being the quantity of domestic production remaining after accounting for exports;
- the import price of a commodity was calculated using the total value of imports and the quantity imported;
- where import values were not reported, the price of those imports was assumed to be the same as the relevant domestic price;
- the domestic price and the price of exports have been assumed to be equal; and
- where ABS data does not allow identification of import quantities for single crops, reported quantities were disaggregated into required single crop quantities using domestic production weights. Import prices were assumed to be the same across crops within the ABS classification.

Table B.1 **Change in crop supply**

Crop type	Change in crop supply	Crop type	Change in crop supply
	Per cent		Per cent
Almond	100	Lemon & Lime	20
Apple	90	Lettuce	10
Apricot	70	Lupin	10
Asparagus	90	Macadamia	90
Avocado	100	Mandarin	30
Bean	10	Mango	90
Blueberry	100	Nectarine	60
Broccoli	100	Onion	100
Brussels sprout	30	Orange	30
Cabbage	30	Papaya	20
Carrot	100	Peach	60
Cauliflower	100	Peanut	10
Celery	100	Pear	50
Cherries	90	Plum and prune	70
Cotton lint	20	Pumpkin	90
Cucumber	90	Strawberry	40
Grapefruit	80	Watermelon	70
Kiwi	90		

Source: Table 2.1 of Gill (1989).

The partial equilibrium model used to estimate the value of honeybee pollination services allows consumers to switch to imported products should the price of domestically produced product rise following loss of honeybee pollination services. To calculate any change in the quantity of imports, the model requires a non-zero (that is, positive) base to work off. For example, Australia currently bans the imports of apples and hence the quantity of apple imports is zero. As the model calculates the *percentage change* in economic variables, there will be no increase in quantity of imports consumed due to the underlying data having a zero base.

This problem arises for the apple, brussels sprout, celery, macadamia nut, onion and watermelon crops — there are currently no imports for each of these crops. The ‘zero base’ problem has been overcome through assuming that imports of each of these crops account for 1 per cent of total domestic consumption, and the price of imports is identical to that of domestic production. It is important to note that making these adjustments to the underlying data requires the assumption that Australia loosens any quarantine restrictions preventing the entry of agricultural products, thereby allowing Australian consumers to switch to imports. (The issue of import substitution is discussed further below.)

The ABS reports that Australia produced 634 000 tonnes of cotton lint in 1999-2000, of which all is ‘consumed’ domestically. However, the vast majority of cotton — in the order of 99 per cent — is exported. As cotton lint is the precursor to cotton, it has been assumed that 99 per cent of Australia’s cotton lint production is exported, with the remaining 1 per cent being consumed domestically.

Demand and supply elasticities

Where possible, demand, supply and Armington elasticities were obtained from published research. For example, the price elasticity of domestic demand for apples was obtained from the Industries Assistance Commission 1985 report *Apples and pears*, and Armington and export demand elasticities were obtained from the Murphy Model 600 Plus (Murphy 2000). However, for the majority of crops listed in table B.2 elasticity estimates for Australian demand and supply are not available. Deriving elasticities requires comprehensive and reliable price and quantity time series data, which is unlikely to be available for the majority of crops listed in table B.2.

The absence of published elasticity estimates and/or necessary underlying data has meant that elasticities have had to be 'approximated' for various crops. To the extent possible, elasticities reported in published research have been used as benchmarks. Factors influencing the various elasticities are discussed below.

Elasticity of domestic demand

The price elasticity of demand is defined as the percentage change in the quantity of demand resulting from a one per cent change in price of that good. The greater the response to a price change, the more *elastic* is demand. The (price) elasticity of demand is determined by a range of factors — the availability of substitutes, the period of adjustment to price changes, and the share of consumer budget allocated to the product. Goods that are more essential to everyday living, and that have fewer substitutes, typically have lower elasticities (staple foods are a good example). However, there are undoubtedly many vegetables and fruits that can offer consumers the same benefits (health and taste) as those vegetables and fruits reliant to some extent on honeybee pollination services. Goods with many substitutes, or that are not essential, have higher elasticities.

Elasticity of domestic supply

The price elasticity of supply measures the change in quantity supplied by producers following a change in product price. The (price) elasticity of supply is dependent on a range of factors — the extent of spare capacity and surplus stocks, ease of substitution between production factors, ease of firm entry/exit and the time period being considered. When supply is inelastic there are factors limiting the supply response in a given period, when supply is elastic firms can respond quickly to a change in price.

Agricultural production is dependent on land, which is a fixed factor. Faced with a price increase, producers will want to expand production. However, increasing production is dependent on the availability of additional land (in addition to other production factors such as capital and labour), which is not readily available in the short term (the time period we are considering). As land cannot be substituted with other production factors, the price elasticity of supply is assumed to be relatively inelastic for all crops.

Elasticity of import substitution

An Armington framework allows a country's imports to be treated as imperfect substitutes for domestically produced goods. Armington elasticities are defined as the proportionate change in the ratio of imports to domestically produced goods, relative to the proportionate change in the ratio of domestic to import prices. A high Armington elasticity implies a high degree of substitutability between the domestic and foreign goods.

The Armington elasticities reported in table B.2 take the value of either 3 or 10. Domestic production is assumed to be highly substitutable for imports (that is, high Armington elasticity) if imports currently command greater than 10 per cent of market share. If import penetration is below this threshold, it may be because of Australia's stringent quarantine requirements, which effectively prevent greater market penetration. Those domestically produced agricultural products with such protection have been identified. The question then is 'if honeybees disappear from the Australian landscape and (some) domestic agricultural sectors are decimated, will the quarantine restrictions remain in place?' If there is no domestic industry to protect from introduced diseases and pests, then there is little justification for maintaining the quarantine restrictions. It has been assumed that if the contraction in domestic supply is to be greater than 50 per cent, then quarantine restrictions (if in place) will be lifted and imports will be allowed to enter Australia unimpeded. Products for which this situation is applicable have been assigned at Armington elasticity of 10. The remaining products have been assigned an Armington elasticity of 3, reflecting moderate substitutability with domestically produced product.

Elasticity of export demand

The (price) elasticity of export demand relates to how foreign demand for Australian produced product changes following a change in the price of that product. In practice, export demand is typically more elastic than domestic demand as other countries can source product from numerous countries (of which Australia is but one). If, for example, the price of Australian oranges increases, then foreign consumers of oranges can substitute from Australian to the now relatively cheaper US or Brazilian produced oranges. This typically sees the export demand elasticity being around ten times the domestic demand elasticity.

Table B.2 **Data observations used in partial equilibrium modelling**

Crop	**Domestic market**		**Import market**		**Export market**		**Elasticity of domestic demand**	**Elasticity of domestic supply**	**Elasticity of import substitution**	**Elasticity of export demand**
	Quantity	**Price**	**Quantity**	**Price**	**Quantity**	**Price**				
	Tonnes	$/tonne	Tonnes	$/tonne	Tonnes	$/tonne				
Almond	6 449	5 170	1 019	4 298	2 522	5 170	-2.00	1.25	10.00	-8.00
Apple	297 636	960	3 006	960	33 711	960	-2.00	0.50	10.00	-8.00
Apricot	21 309	1 300	1 297	3 133	174	1 300	-2.00	0.50	10.00	-8.00
Asparagus	985	5 958	295	6 434	7 893	5 958	-2.00	0.75	10.00	-8.00
Avocado	24 182	2 130	3 027	3 974	129	2 130	-2.50	0.75	10.00	-8.00
Bean	29 478	1 410	2 092	740	902	1 410	-2.00	0.75	3.00	-8.00
Blueberry	1 279	13 270	9	9 706	247	13 270	-2.50	0.75	3.00	-8.00
Broccoli	30 960	1 560	1	2 401	8 429	1 560	-2.00	0.75	3.00	-8.00
Brussels sprout	6005	1 430	61	1 430	98	1 430	-2.00	0.75	3.00	-8.00
Cabbage	51 336	407	2	500	1 835	407	-2.00	0.75	3.00	-8.00
Carrot	200 408	651	409	922	56 200	651	-2.00	0.75	10.00	-8.00
Cauliflower	56 669	757	3	2 401	16 763	757	-2.00	0.75	3.00	-8.00
Celery	40 680	600	411	600	2 117	600	-2.00	0.75	10.00	-8.00
Cherries	5 465	5 820	242	7 495	555	5 820	-2.50	0.50	3.00	-8.00
Cotton lint	6 340	2 130	205	409	627 660	2 130	-2.00	1.00	3.00	-8.00
Cucumber	17 492	1 100	2 197	655	428	1 100	-2.00	0.75	10.00	-8.00
Grapefruit	12 685	540	907	814	145	540	-2.00	1.25	3.00	-8.00
Kiwi fruit	1 192	2 030	12 206	1 864	2 005	2 030	-2.50	1.00	10.00	-8.00
Lemon & Lime	24 904	770	4 031	813	4 390	770	-2.00	1.25	10.00	-8.00
Lettuce	127 970	672	1	2 857	3 170	672	-2.00	0.75	3.00	-8.00
Lupin	1 696 000	143	257	7 544	0	143	-2.00	1.25	3.00	-8.00
Macadamia	7 603	2 340	77	2 340	22 320	2 340	-2.50	1.25	3.00	-8.00
Mandarin	62 528	1 050	1 472	813	15 730	1 050	-2.00	1.25	3.00	-8.00
Mango	23 146	2 520	210	3 362	3 226	2 520	-2.50	1.00	10.00	-8.00

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Table B.2 **Data observations used in partial equilibrium modelling (continued)**

Crop	Domestic market		Import market		Export market		Elasticity of domestic demand	Elasticity of domestic supply	Elasticity of import substitution	Elasticity of export demand
	Quantity	Price	Quantity	Price	Quantity	Price				
	Tonnes	$/tonne	Tonnes	$/tonne	Tonnes	$/tonne				
Nectarine	22 256	2 150	86	2 790	5 167	2 150	-2.00	1.00	10.00	-8.00
Onion	195 852	529	1 978	529	26 159	529	-2.00	0.75	3.00	-8.00
Orange	334 897	660	10 000	1 751	110 943	660	-2.00	1.25	3.00	-8.00
Papaya	7 057	860	17	2 630	1	860	-2.50	1.00	3.00	-8.00
Peach	65 242	990	231	3 003	794	990	-2.00	0.50	10.00	-8.00
Peanut	43 124	660	5 446	1 197	3 876	660	-2.00	1.25	10.00	-8.00
Pear	140 705	720	1 352	1 466	16 009	720	-2.00	0.50	3.00	-8.00
Plum and prune	16 336	1 870	1 363	3 403	6 329	1 870	-2.00	0.75	10.00	-8.00
Pumpkin	80 412	450	631	2 300	7 177	450	-2.00	0.75	3.00	-8.00
Strawberry	12 466	6 070	138	3 251	1 735	6 070	-2.50	0.75	3.00	-8.00
Watermelon	63 731	493	644	493	1 971	493	-2.00	0.75	3.00	-8.00

Source: Market information obtained from ABS (2001a), ABS (2001b), Horticulture Australia (2001), ABS unpublished data and CIE estimates; elasticities obtained from Murphy (2000), various research publications (not listed) and CIE estimates.

Multipliers

Multipliers were obtained from the Australian Bureau of Statistics. The multipliers were derived from the 1996-97 Input-Output tables compiled by the ABS. As such, the multipliers reported in table B.3 relate to the year 1996-97 (the latest year for which multipliers are available).

Input-Output multipliers are a summary measure used for estimating the total economywide impact of changes in the demand for the output of any one sector. Multipliers describe average effects, and hence do not take into account economies of scale, unused or excess capacity or technological change (ABS 1990).

Despite relating to the Australian economy as it existed in 1996-97, multipliers are relatively stable over time and hence the economywide effects estimated should be representative of the effects that could be expected today if honeybees were removed from the Australian landscape. However, an exception to the above rule would be those sectors producing products that are susceptible to wide fluctuations in world prices and those agricultural sectors most affected by adverse climatic conditions. In the absence of more recent multiplier estimates, we have assumed that the 1996-97 multipliers are relevant to today.

Table B.3 **Other agriculture multipliers**[a]

Multiplier	Unit	Initial effects	Production induced effects	Consumption induced effects	Simple multipliers	Total multipliers
Output	$	1.000	0.673	0.623	1.673	2.296
Value added[b]	$	0.585	0.307	0.334	0.892	1.226
Income	$	0.426	0.135	0.159	0.561	0.720
Employment	FTE jobs	6	4	3	10	13

a The ABS identified industry of ‘Other Agriculture‘ comprises the Plant Nursery, Cut Flower and Flower Seed Growing, Vegetable Growing, Fruit Growing, Other Livestock Farming and Other Crop Growing industries. **b** Value added (at factor cost) is defined as being wages, salaries and supplements plus gross operating surplus.

Source: ABS unpublished data.

C. Partial equilibrium modelling results

SOLVING THE PARTIAL EQUILIBRIUM MODEL detailed in appendix A yields the percentage change in a range of economic variables. Specifically, the model determines how prices and quantities in each of the inter-related domestic, export and import markets change following removal of honeybee pollination services and the associated supply shock. The outputs of the partial equilibrium model(s) are then used to calculate the change in consumer and producer surplus.

Table C.1 shows the full results of the economic modelling. The standard deviation for the various economic variables is reported in table C.2. Table C.3 shows the flow-on (multiplier) effects of a decline in the honeybee pollination services.

Confidence intervals around the estimated economic variables can be established using Chebyshev's Inequality, which says that, whatever the distribution of the variable in question, the probability that the value of the variable does not lie within K standard deviations of the mean is *no more than* $1/K^2$. For example, by Chebyshev's Inequality, the probability that the value of a variable does not lie within 2 standard deviations of the mean is 25 per cent ($0.25 = 1/2^2$). Or, in other words, we can be 75 per cent sure that the value does lie within ± 2 standard deviations from the mean. The confidence interval for various standard deviations from the mean is shown below.

Chebyshev's Inequality

Number of standard deviations from mean	Confidence interval
2	75.00 per cent
3	88.89 per cent
4	93.75 per cent
4.47	95.00 per cent
5	96.00 per cent
10	99.00 per cent

As a practical example, consider the change in domestic demand for strawberries following a 100 per cent decrease in honeybee pollination. From table C.1 we can see that mean change in domestic demand for strawberries is estimated to be -35.03 per cent. The standard deviation for this variable is 0.34 (table C.2). Using Chebyshev's Inequality we can be 75 per cent confident that the change in domestic demand lies between -35.71 (given by -35.03 – 2*0.34) and -34.35 (given by -35.03 + 2*0.34). We can be 99 per cent sure that the change in domestic demand for strawberries lies between -38.43 and -31.63.

The approach outlined in the above example can be used to establish confidence intervals around the estimated changes in the economic variables reported in table C.1.

Table C.1 **Modelling results — 100 per cent decrease in honeybee pollination**

Crop	**Change in economic variables**						**Domestic market producer surplus**	**Export market producer surplus**	**Total producer surplus**	**Total consumer surplus**	**Total surplus**	**Change in value of industry output**
	Domestic demand	**Domestic price**	**Quantity exports**	**Quantity imports**	**Average price**	**Total demand**						
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	$m	$m	$m	$m	$m	$m
Almond	-100.00	69.15	-99.78	546.97	27.52	-39.01	-15	-6	-21	-8	-29	-46
Apple	-88.91	80.53	-99.62	3668.08	63.46	-63.87	-152	-21	-174	-125	-298	-261
Apricot	-69.85	28.89	-88.42	285.25	18.95	-29.61	-11	0	-11	-5	-17	-17
Asparagus	-83.53	31.18	-90.81	185.84	14.40	-23.79	-3	-24	-26	-1	-27	-46
Avocado	-100.00	63.07	-99.58	286.29	20.38	-37.54	-29	0	-30	-11	-40	-52
Bean	-9.32	4.93	-32.21	4.80	4.74	-8.82	-1	0	-1	-2	-3	-2
Blueberry	-100.00	257.49	-100.00	101.55	247.18	-99.59	-10	-2	-12	-21	-33	-20
Broccoli	-100.00	368.18	-100.00	398.97	367.96	-99.99	-28	-8	-35	-89	-124	-61
Brussels sprout	-29.25	18.64	-75.74	18.74	18.40	-28.81	-1	0	-1	-1	-2	-1
Cabbage	-28.40	18.07	-74.72	18.39	18.06	-28.40	-2	0	-2	-3	-5	-4
Carrot	-100.00	141.78	-100.00	14333.53	101.79	-77.43	-75	-21	-95	-82	-177	-167
Cauliflower	-100.00	364.02	-100.00	393.55	363.28	-99.97	-25	-7	-32	-78	-110	-56
Celery	-100.00	116.92	-99.99	5147.66	71.66	-67.48	-14	-1	-15	-12	-26	-26
Cherries	-88.99	116.89	-99.99	44.21	98.17	-84.38	-16	-2	-18	-19	-37	-27
Cotton	-5.46	2.83	-20.15	2.82	2.82	-5.41	0	-120	-120	0	-120	-240
Cucumber	-89.81	53.74	-97.88	744.61	32.24	-43.44	-9	0	-10	-5	-15	-17
Grapefruit	-79.77	98.51	-99.89	77.29	75.39	-69.07	-2	0	-2	-4	-6	-4
Kiwi	-92.94	27.81	-88.25	7.88	1.02	-2.50	-1	-2	-3	0	-3	-6
Lemon & Lime	-17.21	5.63	-35.84	43.02	4.61	-8.62	-1	0	-2	-1	-3	-3
Lettuce	-9.43	5.09	-33.05	5.16	5.09	-9.43	-2	0	-3	-4	-7	-5
Lupin	-10.00	5.40	-34.64	5.43	5.36	-9.88	-6	0	-6	-12	-18	-12

(Continued on next page)

Table C.1 **Modelling results — 100 per cent decrease in honeybee pollination** **(continued)**

Crop	**Change in economic variables**						**Domestic market producer surplus**	**Export market producer surplus**	**Total producer surplus**	**Total consume r surplus**	**Total surplus**	**Change in value of industry output**
	Domestic demand	**Domestic price**	**Quantity exports**	**Quantity imports**	**Average price**	**Total demand**						
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	$m	$m	$m	$m	$m	$m
Macadamia	-66.02	49.82	-98.17	23.10	48.93	-65.30	-4	-23	-26	-6	-32	-60
Mandarin	-21.72	12.82	-62.90	12.70	12.55	-21.14	-3	-4	-8	-8	-15	-17
Mango	-88.70	70.81	-99.34	2265.70	57.14	-69.12	-24	-4	-28	-22	-50	-55
Nectarine	-52.08	38.56	-94.09	1023.23	37.45	-47.78	-8	-5	-13	-14	-27	-26
Onion	-100.00	369.95	-100.00	351.50	328.52	-98.51	-59	-8	-67	-174	-242	-117
Orange	-20.37	11.51	-59.06	10.63	10.53	-18.21	-11	-18	-29	-23	-52	-65
Papaya	-20.00	9.31	-51.56	4.69	9.23	-19.82	0	0	0	-1	-1	-1
Peach	-59.57	42.52	-95.40	1159.05	39.55	-49.38	-18	0	-19	-19	-38	-28
Peanut	-9.18	2.68	-19.16	18.27	2.13	-4.12	-1	0	-1	-1	-2	-2
Pear	-45.25	33.94	-91.78	33.64	32.94	-43.95	-18	-7	-25	-27	-51	-37
Plum and prune	-64.12	25.33	-85.19	245.16	17.23	-27.48	-10	-6	-15	-5	-20	-26
Pumpkin	-89.11	156.18	-100.00	138.21	132.94	-84.16	-15	-2	-17	-29	-46	-29
Strawberry	-35.03	18.60	-75.74	9.20	18.46	-34.79	-10	-4	-14	-12	-26	-25
Watermelon	-69.09	74.76	-99.42	75.47	73.03	-68.05	-8	-1	-9	-15	-24	-15

Source: CIE calculations

Table C.2 **Modelling results — standard deviation of economic variables**

Crop	Domestic demand	Domestic price	Quantity exports	Quantity imports	Average price	Total demand
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Almond	0.03	0.66	0.03	26.25	0.07	2.43
Apple	0.02	2.34	0.05	420.69	1.04	2.60
Apricot	0.00	0.57	0.46	16.09	0.24	1.74
Asparagus	0.34	0.06	0.05	6.39	0.02	1.67
Avocado	0.03	0.66	0.02	14.86	0.05	2.36
Bean	0.06	0.36	1.88	1.13	0.34	0.09
Blueberry	0.02	32.95	0.00	58.49	30.24	0.10
Broccoli	0.00	53.26	0.03	164.91	53.19	0.02
Brussels sprout	0.05	1.58	2.79	4.82	1.55	0.09
Cabbage	0.10	1.51	2.79	4.71	1.51	0.10
Carrot	0.03	3.71	0.00	1 831.67	0.96	2.67
Cauliflower	0.02	52.35	0.00	161.95	52.13	0.00
Celery	0.02	2.45	0.00	487.64	0.52	2.86
Cherries	0.00	11.21	0.03	22.94	8.18	0.65
Cotton	0.43	0.00	0.00	0.47	0.00	0.43
Cucumber	0.00	0.93	0.12	46.06	0.25	2.44
Grapefruit	0.00	7.76	0.05	20.86	4.90	1.19
Kiwi	0.01	0.01	0.01	0.22	0.00	0.20
Lemon & Lime	0.14	0.16	0.80	2.38	0.13	0.46
Lettuce	0.05	0.40	2.06	1.25	0.40	0.05
Lupin	0.00	0.45	2.27	1.34	0.44	0.01
Macadamia	1.41	2.45	0.48	10.98	2.39	1.48
Mandarin	0.50	0.72	2.01	2.87	0.70	0.54
Mango	0.01	2.54	0.09	312.92	1.24	2.43
Nectarine	0.24	2.56	1.03	188.70	2.37	0.93
Onion	0.00	46.96	0.00	133.53	36.15	0.34
Orange	0.53	0.52	1.61	2.27	0.47	0.65
Papaya	0.01	0.78	2.89	2.26	0.78	0.01
Peach	0.01	2.33	0.70	183.79	1.91	1.42
Peanut	0.05	0.08	0.51	0.97	0.06	0.21
Pear	0.18	2.82	1.60	8.87	2.71	0.31
Plum and prune	0.18	0.44	0.46	1 3.15	0.21	1.65
Pumpkin	0.00	15.45	0.00	43.04	11.33	0.74
Strawberry	0.34	1.39	2.46	4.41	1.37	0.36
Watermelon	0.02	7.55	0.26	22.68	7.26	0.14

Source: CIE calculations.

Table C.3 **Flow-on effects — 100 per cent decrease in honeybee pollination**

Crop	Output			Household income			Value added			Employment		
	Direct	**Flow-on**	**Total**	**Direct**	**Flow-on**	**Total**	**Direct**	**Flow-on**	**Total**	**Direct**	**Flow-on**	**Total**
	$m	$m	$m	$m	$m	$m	$m	$m	$m	FTE jobs	FTE jobs	FTE jobs
Almond	-46	-60	-106	-20	-14	-33	-27	-30	-57	-278	-325	-603
Apple	-261	-338	-598	-111	-77	-188	-152	-167	-320	-1 564	-1 825	-3 389
Apricot	-17	-22	-39	-7	-5	-12	-10	-11	-21	-103	-120	-223
Asparagus	-46	-60	-106	-20	-14	-33	-27	-29	-56	-276	-322	-597
Avocado	-52	-67	-119	-22	-15	-37	-30	-33	-63	-311	-362	-673
Bean	-2	-3	-5	-1	-1	-2	-1	-2	-3	-14	-17	-31
Blueberry	-20	-26	-46	-9	-6	-15	-12	-13	-25	-122	-142	-263
Broccoli	-61	-80	-141	-26	-18	-44	-36	-39	-75	-369	-430	-799
Brussels sprout	-1	-2	-3	-1	0	-1	-1	-1	-2	-9	-10	-19
Cabbage	-4	-5	-9	-2	-1	-3	-2	-2	-5	-23	-26	-49
Carrot	-167	-216	-384	-71	-49	-120	-98	-107	-205	-1 002	-1 169	-2 172
Cauliflower	-56	-72	-128	-24	-16	-40	-33	-36	-68	-334	-389	-723
Celery	-26	-33	-59	-11	-8	-18	-15	-16	-31	-154	-180	-334
Cherries	-27	-36	-63	-12	-8	-20	-16	-18	-34	-165	-192	-357
Cotton lint	-240	-310	-550	-102	-70	-172	-140	-154	-294	-1 437	-1 677	-3 114
Cucumber	-17	-22	-38	-7	-5	-12	-10	-11	-20	-100	-117	-217
Grapefruit	-4	-5	-10	-2	-1	-3	-2	-3	-5	-25	-29	-54
Kiwi fruit	-6	-7	-13	-2	-2	-4	-3	-4	-7	-34	-40	-74
Lemon & Lime	-3	-5	-8	-1	-1	-3	-2	-2	-4	-21	-24	-45
Lettuce	-5	-6	-11	-2	-1	-3	-3	-3	-6	-29	-33	-62
Lupin	-12	-16	-29	-5	-4	-9	-7	-8	-15	-75	-87	-162
Macadamia	-60	-77	-137	-25	-18	-43	-35	-38	-73	-357	-417	-774
Mandarin	-17	-22	-40	-7	-5	-12	-10	-11	-21	-104	-121	-225
Mango	-55	-71	-127	-23	-16	-40	-32	-35	-68	-331	-386	-716
Nectarine	-26	-34	-60	-11	-8	-19	-15	-17	-32	-158	-184	-342

(Continued on next page)

Table C.3 **Flow-on effects — 100 per cent decrease in honeybee pollination (continued)**

Crop	Output			Household income			Value added			Employment		
	Direct	**Flow-on**	**Total**	**Direct**	**Flow-on**	**Total**	**Direct**	**Flow-on**	**Total**	**Direct**	**Flow-on**	**Total**
	$m	$m	$m	$m	$m	$m	$m	$m	$m	FTE jobs	FTE jobs	FTE jobs
Onion	-117	-152	-270	-50	-35	-85	-69	-75	-144	-705	-822	-1 527
Orange	-65	-84	-148	-28	-19	-46	-38	-41	-79	-387	-452	-839
Papaya	-1	-1	-2	0	0	-1	0	0	-1	-5	-5	-10
Peach	-28	-36	-65	-12	-8	-20	-16	-18	-34	-169	-197	-365
Peanut	-2	-3	-5	-1	-1	-2	-1	-2	-3	-14	-16	-31
Pear	-37	-48	-86	-16	-11	-27	-22	-24	-46	-224	-261	-484
Plum and prune	-26	-34	-61	-11	-8	-19	-15	-17	-32	-159	-185	-344
Pumpkin	-29	-38	-67	-12	-9	-21	-17	-19	-36	-176	-205	-381
Strawberry	-25	-32	-57	-11	-7	-18	-15	-16	-30	-149	-174	-323
Watermelon	-15	-20	-35	-7	-5	-11	-9	-10	-19	-92	-108	-200
Total	**-1 578**	**-2 046**	**-3 624**	**-672**	**-464**	**-1 137**	**-923**	**-1 012**	**-1 935**	**-9 471**	**-11 049**	**-20 520**

Source: CIE calculations

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