Chapter 16
Pesticides and Integrated Pest Management Practice, Practicality and Policy in Australia

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Abstract Policy settings influence how farmers manage pests. To successfully grow and market a crop an individual farmer has to engage in pest management. Their management strategy is subject to the relevant domestic policies. These policies are in turn shaped by international agreements concerning maximum residue levels for pesticides and the sanitary and phytosanitary (SPS) agreements on trade. Policies are designed to solicit a response by using incentives and penalties to achieve a set of social objectives. These policies create signals to which the wider domestic settings and international economies respond. Consequently the ultimate

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outcome from these signals may be counter to the initial design (or intention) of the policy. This chapter outlines some of the economic underpinnings required for good pest management policy and it explores why farmers respond to the same pest problem differently. The discussion will examine the national drivers behind pest management in Australia and discuss the implications for both on-farm pest management and the wider community. To enable this discussion the economics of integrated pest management is presented to articulate individual responses to a policy setting. Finally we examine the policies required to create successful area-wide management systems in rural Australia.

Keywords Economics · Policy · Resource · Allocation · Decision making

16.1 Introduction

The central narrative of this chapter is built around a simple question, but one which is deceptively difficult to answer:

Why do we manage pests?

This question can be broken down to a number of subsidiary issues. What drives the decision to undertake pest management? Is the individual's decision based on a passive action (for example, only undertaking routine pest management actions or purchasing pre-treated seed), an active response to a situation (for example, monitoring and responding to density thresholds), or was the individual compelled to act by the direction of another individual (for example, legal enforcement to comply with an eradication campaign)? How does an individual justify the decision to allocate financial, capital and labor resources to their chosen response, which may include no action? At a given point in time are the constraints on the available management choices due to policy, subjective preferences, the individual's ability to manage pests or the resource endowments available? What role does policy play in framing the pest management context for an individual and society at large?

Ultimately the complexity of the initial question is daunting and well beyond the scope of a single chapter. This chapter summarizes the economic arguments that drive the national approach to pest management in Australia and the resulting policy implications for the farming community and Australian society as a whole. To maintain focus, practical case studies help frame the economic debate.

The definitions and practice of Integrated Pest Management (IPM) are context specific. The 'I' in IPM has been challenged and it has been suggested that in practice 'I' could be defined as 'integrated', 'improved' or even 'incidental' (Zalucki et al. 2009). If 'I' truly represents integrated then the problem becomes how an individual would best manage a pest with all available resources. 'Best' to an economist would be an optimal combination of management tools derived from all possible management options with the objective function to maximize economic rents through time, subject to resource limitations. 'Best' could equally apply in a scientific framework as the eradication (or sustainable abatement) of a pest population, or 'best' as in least pesticide use, or 'best' as the adoption of 'natural enemies' (predators, parasitoids, etc.). If 'I' implies 'improved' then what is improved, the financial bottom line, efficiency of pesticide use or biodiversity within a paddock or landscape? If 'I' really means incidental, does this mean that we have arrived at a research treadmill where we jump from one problem to the next to achieve short-term gains but create no long-term solution? For IPM to be a plausible alternative to a pure pesticide management strategy, the benefits from its adoption must be justified either from an individual or national perspective. If it is the individual farmer who benefits, then no compensation is required. If the transformation to adopt IPM is for the national good, but the shift comes at direct private costs for individual farmers or managers, then what policy signals are required to stimulate wide-scale adoption of IPM? Policy engages in trade-offs between groups aiming to maximize social objectives. It must determine which instruments (regulations, prices and/or compensation) are required to facilitate this adoption of new policy.

We deliberately take a wide view of pesticides, integrated pest management and policy to illustrate the complexity and diversity of issues that policy must consider within an integrated world. First, we contextualize how Australia's domestic policy has been shaped by international regulatory frameworks, the biophysical characteristics of Australia's agricultural development, past policy decisions and national social objectives.

16.2 Policy and Pest Management in Australia: A Top Down View

Domestic pest management policy is a multifaceted legislative framework that has scale, scope, spatial and temporal dimensions. Policy scale ranges from compliance with international agreements through to local government and industry requirements. Policy scope includes issues as diverse as chemical regulation procedures, minimizing environmental harm and protecting human health and providing the legal and financial settings for compliance in pest management procedures. The spatial dimension defines at which scale and scope settings apply. The temporal dimension adds both obsolescence to existing policy settings and evolving requirements in response to emerging issues at a scale, scope and spatial level. Policy has created an intertwined quagmire of compulsory regulations and suggested management practices that have evolved through time, creating opportunities and constraints for producers. This policy labyrinth can create conflicting signals for farm managers.

Australian agriculture is export-focused. Consequently Australia has developed a rigorous policy stance on quarantine and food safety to preserve its comparative export advantage, maintain its biodiversity and protect human health. This stance has three key aspects. First, the policy stance defines the level of risk from the unintended consequences of international trade (to humans, economic activity and impacts on the environment) that Australia is willing to accept. Second, Australian policy focuses on maximizing trade opportunities by ensuing that agricultural products meet international standards for market access. Third, it subsidises the costs of managing existing and new pest issues.

Policy impacts do not stop at the intended target. Their signals influence Australian society and international markets. These signals can unintentionally create perverse outcomes for both those directly targeted but also in the wider community. Within this policy framework individuals operate within a range of personal, industry and institutional goals. The adherence to these goals occurs at a cost, both financially and operationally. An individual's compliance to all policies can be circumspect since, despite a range of incentives and penalties designed to solicit a given response, the outcome can be counterintuitive. This section focuses on the past policy settings and the resource endowments that have shaped production systems in Australia. We discuss two policy areas: the national approach to chemical registration, which increases costs and limits management choice; and public expenditure, which subsidizes management expenditure.

16.2.1 International Policies and National Objectives

Donald (1982) argues that a combination of just plain "dumb luck", strict quarantine regulation and geographical isolation are responsible for Australia being free of many of the trade restrictive sanitary and phytosanitary (SPS) issues facing producers in the rest of the world (Nairn et al. 1996). This quarantine policy has contributed to Australia becoming the fourth largest net food exporter in the world (Keogh 2011). Australia specializes in producing bulk commodities including wheat (McNeill and Penfold 2009), barley (Murray and Brennan 2010), canola (Gu et al. 2007), sugar (Allsopp 2010), cotton (Agbenyegah 2012), pasture-based beef (Petherick 2005) and sheep-based products (Kahn and Woodgate 2012). A combination of a highly variable climate (Khan 2008), biophysical resource constraints (Davidson 1965) and limited assistance to agricultural producers (Anderson et al. 2007) have driven this specialization towards low input, low output production systems.

A reliable market is essential to retain the economic viability of low-input bulk commodity production. Due to the limited Australian domestic market, the agricultural industry is heavily reliant on international market access. Between 2003–2004 and 2010–2011, over 70% of the gross value of Australia's agricultural production was derived from international market sales (ABARES 2011).This dependence on exporting ensures that the wider agriculture sector delivers outputs that meet international market requirements. Here we simplify market requirements as 'nil' for both pests and chemical residues. 'Nil' pest compliance occurs when no live pest is found at the import terminal. The compliance to 'nil' chemical residues is achieved when detectable residue is less than or equal to the predetermined maximum residue levels (MRL) described by the market. Failure to comply can result in direct financial penalty, the partial loss of market access where only areas that are declared to be designated free of the problem can export, the temporary closure of the market until the issues are resolved and ultimately total closure of the market. At each stage in the process, the net costs for exporters and Australia as a whole increase.

The CODEX Alimentarius Commission (Codex), which is recognized under the World Trade Organization's SPS Agreement, develops internationally recognized food safety standards, including MRL levels. However, an individual country can apply alternative standards to the Codex based upon scientific evidence relevant to their specific risk profile. As both science and the 'willingness to accept risk' evolve through time, MRLs remain fluid, as they are defined by both real and perceived risk. This fluidity creates both opportunities and threats for producers in individual countries (Adamson 2010) and can be met with an appropriate response in changes to inputs for producers determining management options.

This combination of export market preservation and a low input agricultural production system drives Australia's national policy in pest management. This includes constraining the inputs pest managers use, shaping research and development priorities and providing wider social benefits.

16.2.2 Competing National Goals

Australian policies related to agriculture, trade, veterinary products, chemical registration and the environment are designed to maximize social welfare, but they constrain how farmers use pesticides. While strict quarantine policies aim to provide an environment free from exotic pests, they create higher prices for domestic consumers. Sound policy must determine the trade-offs from alternative actions and decide if compensation is required for those adversely affected by a policy. Policy needs to determine what is best for the nation now and into the future. However, policy is based on subjective social preferences and incomplete information. As social preferences change and future uncertainty abounds, policy must adapt.

Being 'pest free' and having the ability to determine individual MRL levels allows the Australian Pesticides and Veterinary Medicines Authority (APVMA) to specify what pesticides (insecticides, herbicides and disease management compounds) and production additives (hormone growth regulators) are registered and the conditions for their use within specified production systems are specified (Adamson 2010). These specifications are altered through time as new information emerges and results in change, not only in which types of pesticides remain registered for use, but also how they are used by different industries.

For a new pesticide to be registered in Australia, it must pass three tests. First, the compound and its handling must be deemed safe for the commodity it is applied to, the individual applying it, consumers of the final product and the environment in which it is applied. Second, the stated benefits of the compound must be substantiated. Third, it must be ensured that its use "would not unduly prejudice trade or commerce between Australia and places outside Australia" (Commonwealth of Australia 2011, p. 20). The registration testing operates on a cost recovery basis and is applicable to each application, variation of compound or use, and for each major food group that the pesticide is applicable to. For a pesticide to remain registered, both an annual fee and a levy on the value of sales must be paid. This pricing structure forces costs to be passed onto consumers in one of two ways. First, due to the high cost of registration and a small market, not all pest management products are registered in Australia. Second, the cost of purchasing some pesticides deters their widespread use.

This combination of high cost and limited options drove Walker and Stirling's (2008) work to explore nonchemical approaches for nematode management in viticulture. In this situation only a limited number of pesticides were registered. The first, a nematicide (fenamiphos) was facing deregistration in response to new scientific information in the United States concerning human health. A second group, fumigants based on 1,3-dichloropropene, were in practice only used as an option of a last resort due to high costs. In this case, Australia's registration policy forced producers to adopt industry specific research that had developed low pesticide integrated pest management strategies.

Is low pesticide use for nematodes then, an example of traditional IPM practice, which is driven by intelligent policy design, or an accidental outcome that is an artifact of inflexible policy? There are wider social benefits and costs applicable to the registration process that need investigation.

Climatic conditions complement the low input farming systems and the stance on chemical registration by the Australian Government. As cattle production in Australia is primarily low-input pasture-based and, due to a moderate climate, animals are not over-wintered. In production systems that have to over-winter stock at high densities, preventative disease management treatments (antimicrobials) are used to maintain health and livestock receive production supplements to ensure live weight gain. This has allowed APVMA to separate antimicrobial agents between humans and livestock in Australia and not register a number of production supplements used overseas. Although in practice not always perfectly applied, only those antimicrobial agents considered as low importance for humans are registered for livestock (Jordan 2007). This separation of antimicrobial registration has two impacts. First, it slows the rate of antimicrobial resistance caused by cross species use (JETACAR 1999) reducing human medical costs. Second, based on cross-country studies, there is clear evidence of lower antimicrobial resistance in piggeries in Australia, implying costs savings from the reapplication of treatments (Adamson 2010).

However, the lack of registered antimicrobial compounds in Australia encourages loophole exploitation through'off-label' use in intensive industries, especially in in aquaculture. (Akinbowale et al. 2006). 'Off-label' usage ranges from deliberate breaches of regulations where legal penalties can be applied, especially if detection threatens trade, to legally prescribed use on the basis of animal health and welfare issues (Bond 2005). Akinbowale et al. (2006) reported that the resistance to antimicrobials detected in Australian aquaculture posed a human health risk. This policy outcome occurs when ethical and welfare issues coincide with a lack of management alternatives, creating a disincentive for policy enforcement. Such intractable situations then require increased research to develop alternative practices. The

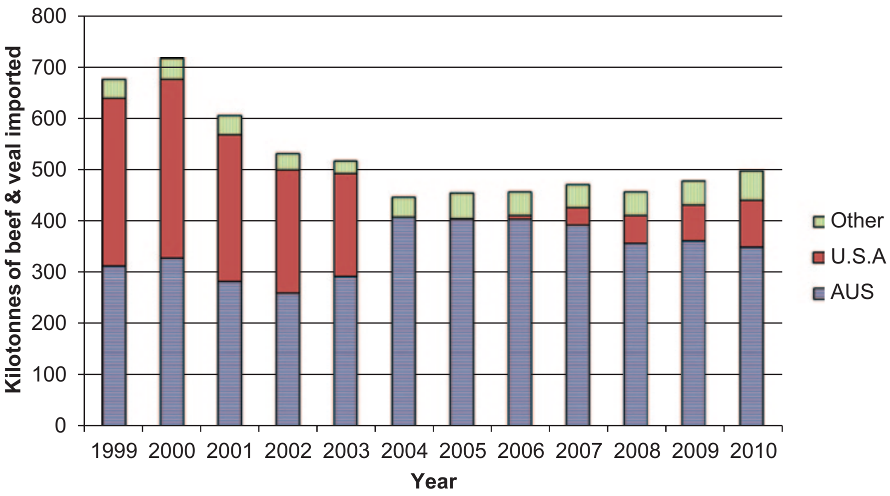

Fig. 16.1 Japanese beef and veal imports (kilotonnes) from all sources from 1999 to 2010. Bovine Spongiform Encephalopathy (BSE) was detected in the U.S.A. in late 2003 and it allowed Australia to dominate the market. Data from ABARE (2007) and ABARES (2011)

questions then become who should pay for this policy remedy, and whether there is an economically viable solution.

Australia's deliberate registration approach to additives (chemicals and feed stuffs) and strict quarantine barriers help exporters gain and retain market access by exploiting differences in international food standards and taking opportunities when they present themselves (Buzby and Mitchell 2006). For example, the outbreak of Bovine Spongiform Encephalopathy (BSE) in the United States of America (U.S.A) in December of 2003 effectively gifted the entire Japanese beef market to Australia (Adamson 2010). Since the outbreak, Australia has dominated the high value Japanese import market for beef and veal (ABARE 2007; ABARES 2011), see Fig. 16.1. These preventative measures in effect provide a positive feedback loop for a policy continuing without the need for rigorous analysis.

Although strict quarantine barriers provide market access for producers, it comes at a direct cost to Australian consumers. The embargo of banana imports is a prime example (James and Anderson 1998). This quarantine policy was exposed by the recent cyclones, which decimated the Australian banana industry and crippled local supply. The inability to import bananas to meet demand then created a price spike causing inflation to rise (Australian Bureau of Statistics 2011).

Policy is about trade-offs. For example, social pressures may lead to a desire to reduce the negative externalities associated with pesticides in order to improve human and environmental health. Policy then must trade these improvements off against any reduction in economic returns from constraining pesticide use. Policy analysis needs to consider who benefits, who is made worse off and determine if compensation is required or justified. To achieve the stated goals of the policy, the best mechanisms to facilitate the transition to the policy need to be determined. This will include choosing which incentives, regulations, or combination thereof to send the appropriate signals to create the transition to the policy objective. If policy priorities are poorly stated, economic growth will be slowed because the restrictive nature of policy can create situations where the outcomes were not intended in the original design. Policy is derived from social preferences that can be subject to changes in social ideals leading to a reallocation of policy priorities (Rostow 1959). Policy is also about stimulation and compensation and in the current case it involves definition of the role of government in managing pests.

16.2.3 National Expenditure on Pest Management

Determining the total public expenditure on managing pests in Australia is difficult for a number of reasons. First, there is inconsistent reporting and the ability to identify direct public expenditure on pests varies greatly between all levels of government and public research providers. Inconsistencies include whether or not funding by external research organizations is included in costs, whether expenditure on different objectives within research programs can be differentiated and different methods for estimating costs of policy development, staffing, overheads and infrastructure. Second, the federal government provides a combination of tax incentives for private companies to sponsor research; subsidizes funds raised by rural development corporations (RDCs) to undertake research; and provides a proverbial raft in the form of alternative funding mechanisms available for community-based programs and university research opportunities. The following data (Table 16.1) has a number of limitations and double counting problems[1].

Public expenditure on pest management was at least AUD$ 1 billion in 2007–2008 (Table 16.1). The Australian Federal government directly allocated AUD$ 735 million to fund federal government departments to work or commission activities associated with pest management. The data for Commonwealth Scientific and Industrial Research Organization (CSIRO) is incomplete and may be misleading. A further AUD$ 208 million was spent by state governments and RDCs spent at least AUD$ 25 million. The total figure is an underestimate since not all departments could be contacted or considered. Also, local government expenditure and university funding are not included.

These funds help manage pests that occur on both private and public lands. They help to varying degrees of success by reducing the costs, both direct and indirect, borne by farmers. They also prevent pest spread to and from public and private land. For example, investment includes research into classical biological control agents with the aim of reducing the density and spread of established exotic pests. McFadyen's (2007) review of economic analyses of Australia's weed biological control program suggests that the annual benefit to Australia was greater than

[1] These data were derived by contacting finance officers in state departments and from publically available budgetary expenditure reports.

Table 16.1 Estimated national expenditure on pest management in Australia (2007–2008) by federal government agencies, state based agencies, research corporations (RDCs) and universities (– indicates unknown)

	Expenditure By Organization	Amount (million AUD$)	Data source and notes
Federal Departments	Department of Agriculture, Forestry and Fisheries	$ 699.6	Commonwealth of Australia (2008)
	CSIRO	$ 19.1	CSIRO (2008) includes all in-kind expenditure to rural CRCs only.
	Department of the Environment and Water Resources	$ 16.5	DEWH (2008)
	Others	–	
	Total federal	*$ 735.2*	
State Governments	New south wales	$ 14.9	Personal communication, Brad McCartney 2009
	Northern territory	$ 5.6	Personal communication, John Thomson 2009
	Queensland	$ 90.3	Queensland Government (2009)
	South Australia	$ 5.2	PIRSA (2008)
	Tasmania	$ 13.9	DPIW (2009)
	Victoria	$ 101.8	Department of Primary Industries (2008)
	Total states	*$ 208.6*	
RDCs	Cotton	$ 3.3	CRDC (2008)
	Grain	$ 18.8	GRDC (2008)
	Sugar	$ 0.5	SRDC (2008)
	Beef	$ 2.8	MLA (2008)
	Others	–	
	Total RDCs	*$ 25.4*	
Universities	–		
Total Expenditure		$ 1,041.2	

AUD$ 95 million per year for an AUD$ 4.3 million annual investment. Biological control programs often provide the classical 'free rider' outcome for producers where an individual directly benefits from a program despite not directly contributing to the costs of the program. These types of expenditures help Australian farmers to maintain low input production systems.

Despite the policy focus on strict quarantine and managing pests, the true economic benefits or costs from this expenditure are unknown, making it difficult to justify policy decisions. A major limitation is the complexity involved in estimating the true costs of all pests and identifying the major current and future problems.

Broad analyses of rapidly obsolescing estimates of annual costs (generally described as management costs plus residual production losses) of either pest groupings or specific species examples do exist (see below). Pest groups or key species analyses are designed to provide policy makers with an estimate of the magnitude of the problem to highlight where to allocate funding. For example, weeds top the national expenditure bill at AUD$ 4 billion per annum (Sinden et al. 2004), vertebrate pests cost AUD$ 720 million per annum (McLeod 2004), *Helicoverpa* species were estimated to cost between AUD$ 159 to $ 328 million per annum (Adamson et al. 1997) and diseases in barley are estimated at AUD$ 252 million per annum (Murray and Brennan 2010).

Specific analyses of individual species or management programs are designed to justify expenditure or obtain funding. For example, the 2010 control of locusts by the Australian Plague Locust Commission (APLC) is estimated to have prevented over AUD$ 913 million in losses. The benefits from controlling Siam weed are estimated to be approximately AUD$ 14 million by 2044 (Adamson et al. 2000). Programs designed to meet the 'nil' pest requirement in Australian grain exports are estimated to be worth at least AUD$ 70 million per annum (Adamson 2002). However, these values are generally only useful as discussion points for two reasons. First, the critical understanding of what the monetary value means, the underlying assumptions upon which the estimate is built, why the study was undertaken and who commissioned it is often either lacking or not clear. Second, the numbers used take little account of what other research into rival species or groupings have found or claimed as their benefit and double counting of management costs and yield losses is rampant. Many of the examples listed above use the default setting of a residual 10 % yield loss, with no justification.

Once this data gets into the public arena, it is readily accepted in an information poor environment and rarely challenged, thereby reducing the quality of the policy debate. Zalucki et al. (2012) provide a rare example of what is needed by directly challenging the often quoted US$ 1 billion worldwide cost of diamondback moth, *Plutella xylostella* (L.) and providing a detailed analysis of the process and assumptions used to calculate a revised estimate of the costs of this pest. Javier (1992) raised the initial value as a suggestion, not an analysis, in a short forward for a conference. Despite it being only a suggestion the value remained constant over time and reached axiomatic status. This acceptance creates problems, as the value is over 20 years old. Either those quoting have not adjusted the value for inflation or they are assuming that 20 years of research and implementation has achieved nothing. By shedding light on the original number and offering an evaluation of the global impacts the Zalucki et al. (2012) study suggests that the current cost is four to five times greater than Javier (1992) suggested. This lack of economic justification about the relative importance of existing, emerging, exotic and yet to be discovered pests compounds the misallocation of research funding towards pet projects.

The allocation of funding to individual pest management programs can create transitory patterns of adoption of the different aspects of IPM in two ways. First, suppose that funding is allocated in the short term as a piecemeal process with no solid foundations of what to fund and why. The result is then a range of temporary reductions in pesticide use for individual farmers, but not necessarily an overall reduction in pesticide use nationwide in the longer term. Zalucki et al. (2009) found that over a 30-year period in Australia the national cost of insecticides per hectare increased dramatically in real terms, in part due to the transition away from low-input wheat to higher input oilseed and cotton production systems.

Second, it fails to ask the simple question: is the objective of IPM to reduce pesticides or to provide managers/producers with the tools to create greater return on their assets? These can be mutually exclusive goals. To understand this, we need to understand the economics behind allocating resources from a farmer's perspective.

There is a wider problem associated with many pest programs and policies. By treating each pest or industry group as separate, they ignore the fundamental problem a decision maker faces, how they allocate scarce resources to maximize economic return through time (Villano et al. 2010). A farmer does not deal with only one pest but a range of pest management issues over their entire farm. Therefore we need to understand not only the farmers' expenditure on pest management but the rationale for managing pests as a whole.

16.3 Pest Management: A Bottom Up Approach

Integrated pest management is a subset of the overall allocation problem that farmers face in their day-to-day activities. In a steady state, under active management, the combination of individual pest species 'success' (their composition within the base load) then defines a baseline pest level (or pest load) in temporal and spatial terms. This premise then allows for the estimation of the economic return of alternative management options for all enterprise choices. This information then helps determine how farmers allocate their resources between alternative production choices.

16.3.1 Allocating Resources On-farm

Farmers have to allocate limited resources between all activities on a farm. Pest management like all management options requires the use of capital equipment, labor and financial resources. A producer has to decide the quantity of all resources they can allocate to all competing activities. The relative importance of a single activity can be determined by its share of the total resources available for use on a farm.

The breakdown of total average financial expenditure on Australian farms over a 15 year time period is presented in Fig. 16.2. The use of the averages smooths annual discrepancies and impacts of drought. In droughts the declining income is matched by a contraction in expenditure allocation. By assuming that everything termed 'chemicals' is the cost of purchasing chemicals for active pest management, it is estimated that on average about 5.7 % of total farm financial costs in Australia

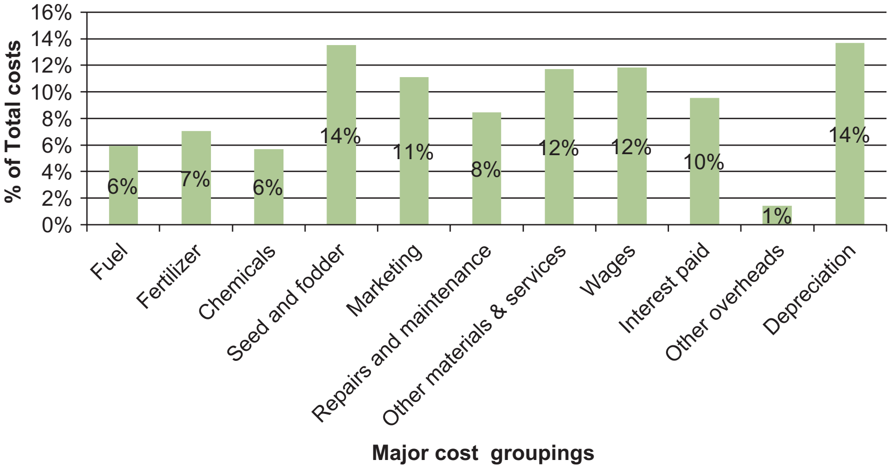

Fig. 16.2 Average percentage breakdown of the major on-farm costs Australia wide from 1995–1996 to 2010–2011 based on ABARES (2011). It has been assumed that all costs associated to the cost group chemicals applies to pest management costs. Therefore approximately 6 % of total farm costs are allocated to purchasing chemicals to control pests

are allocated to chemical cost for pest management. This is about the same as that allocated to fuel costs.

Total resources allocated to managing pests are greater than direct chemical expenditure. Australian Bureau of Statistics (2008) data suggests that chemical costs contribute to about 60 % of total active pest management expenditure with the remainder spent on labor and application costs, see Table 16.2. Assuming that this estimate holds constant, it implies that active pest management costs are not 5.7 % of total farm costs, but at least 9.5 % of total financial costs. Total resources to pest management need to include passive pest management costs, which includes genetic material bred to be resistant to a pest (for example, tick resistant cattle or root stock resistant to nematodes), chemical seed treatments and licence fees paid to access genetically modified organisms (e.g., cotton, see below), but such costs are often unknown.

The data presented is based on an average for all Australian producers. What this data does not illustrate are the changes in expenditure by commodity groups across Australia through time. Some of this analysis is provided in Zalucki et al. (2009) where it was illustrated that the real total unit cost of insecticide treatments, ignoring application and labor costs, had increased over time. Part of the increasing cost could be explained by the transformation of grain producers away from wheat, where insecticides are rarely used, to other commodities where the economic returns justify increased management expenditure. The increased insecticide costs could also indicate a substitution away from labor requirements found under IPM systems. Once again the lack of data impedes the analysis. Logically the time period, the climatic conditions and how the agricultural sector changes to seek higher returns all contribute to how inputs are allocated on-farm.

Table 16.2 Itemized expenditure on pest control in Australia in 2006–2007. (Australian Bureau of Statistics 2008)

	Pesticides (Million AUD$)	Contractors (Million AUD$)	Labor costs (Million AUD$)	Other (Million AUD$)	Total expend-iture (Million AUD$)	Pesticides % of total costs
Weeds	982	159	211	222	1,574	62%
All other Pests	430	77	153	109	768	56%
Total	1,412	236	364	331	2,342	60%

There is no national time series data set for pest management approaches, including IPM adoption, to help augment this discussion. Consequently we are reliant on case studies and economic theory to explain why individuals adopt different approaches to pest management in Australia.

16.3.2 Justifying Pest Management Resource Allocation

Starting with a steady state, where we hold the pest base load and all prices and costs of producing goods constant, we can assume that the objective of a farmer is to make money (or profit). Profit can simply be defined as:

$$\text{Profit} = (\text{Price} \times \text{Quantity}) - \text{Costs}$$

Where the profit made on the farm at a given time is subject to the income made (price) from all that is produced (quantity) less the total farm costs. From this premise we then relax the steady state assumption about pests and density through time and we can examine the economic foundations of IPM, economic thresholds and the pay-off matrix.

The transition of pest management from the concept of economic injury (Stern et al. 1959) to economic thresholds (Headley 1972) allows for the theoretical understanding of why rational farmers would not spend money on managing pests based upon their density in crops. Economic injury or the damage threshold (DT) is the density where a pest starts causing economic harm, the economic threshold (ET) occurs when the costs of controlling the pest are equal to the harm caused by that pest (that is the benefit of the control), see Fig. 16.3. Consequently a background pest level at which it is not economic to implement management activities will always exist. These foundations help in understanding of the nature (both economic and ecological) of the pest problem and the options available for its management in space and time.

Carlson's (1970) examination of pest management using a pay-off matrix to specify alternative sets of rational decision-making responses to given pest densities is central to explaining why producers' behavior changes. For example, the pay-off matrix helps explain why producers switch management practices at different pest densities (at X in Fig. 16.3, the returns from calendar spraying and IPM are equal)

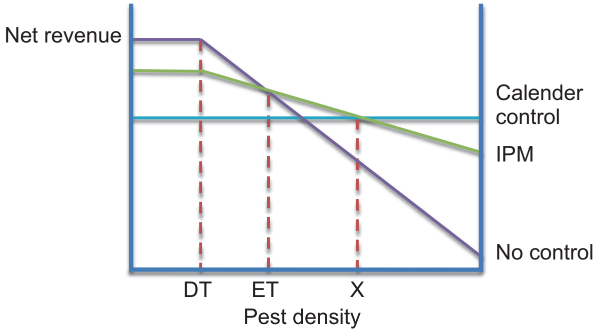

Fig. 16.3 The economics of integrated pest management (Norton 1985). Here net revenue of production is a function of the density of a given pest and the management decision. DT (damage threshold) is the pest density level where it causes 'injury' to production. ET (economic threshold) is the density at which the costs of control equal the benefits of control. Here the costs of adopting IPM is economically justified when compared to calendar spraying until density X is reached. After X, IPM provides less revenue than calendar spraying

and justify why producers switch between commodities based upon changing background pest load. In economic terms, IPM can be described as decision makers making informed decisions about how to allocate resources to management of all pests throughout a farm, based on the impact on profit from their response. It is this understanding about the nature of the resources allocated to manage pests and the benefits from that action that, in given situations, can justify either greater expenditure on pest management through increased pesticide use (Maupin and Norton 2010) or the movement of producers between bio-control programs and calendar spraying programs when resources are constrained or returns are better in alternative systems (Wilson and Tisdell 2001).

Economic return (profit) is not constant as there are continuous endogenous (on farm events, such as changing crops or pest management responses) and exogenous (off-farm factors such as prices, interest rates, climatic variability) variables that change through time. Climatic variability can be a major determinant of pest management strategy as during times of drought, farmers stop spending money. This inconsistent profit in time and space not only directly impacts an individual's allocation of resources to pest management now but also their future responses. Fluctuating farm debt levels can then constrain an individual's ability to actively respond to a pest incursion. Australia's emergence from the millennium drought has coincided with high commodity prices. For the first time in 30 years the broadacre industries throughout Australia are expected, on average, to make an annual operating profit (ABARES 2012). Blank et al. (2004) study of farm wealth in the United States helps explain why farms continue to operate despite negative or low returns. By having the ability to diversify into off-farm capital acquisitions and income streams, farm operating costs can be augmented in bad years. Continuation of activity then allows the farm returns to be invested into capital assets both on- and off-farm to minimize tax liabilities. However, this asset-rich and cash-flow-poor status can result in an individual opting in and out of IPM programs depending on liquidity issues. This situation can be exacerbated if the individual has mounting debt allowing both the distribution and densities of pests to increase. This is a common theme underlying the spread of woody weeds in Australia's dry land pasture systems (Zull et al. 2009).

The decision of whether or not to use certain pesticides can also be determined by an individual's beliefs and preferences. For example, an individual may believe that they have a social obligation to head towards biodynamic or organic farming. They may also see it as a choice to obtain a marketing advantage (Chang et al. 2003) and possibly a higher return (McBride et al. 2012). These subjective decisions are, in essence, a subset of IPM as they limit the available management choices. The diversity in individual preferences and attitudes to pest management can be reflected in alternative economic objectives. This may include profit maximization, bounded rationality to satisfy a given set of goals (Simon 1955), and maximizing utility through time.

In addition, an individual's decision to manage a given pest is dependent on the rigorous stance of a policy that may be based on transitory social beliefs (that is mandatory involvement in an eradication campaign, to a self-defeating loophole system), their ability to act within legal frameworks applicable to application of controls and the species being controlled, environmental legislation, social expectations (NSW Department of Primary Industries 2012), and their ability to allocate resources. Their final management choice ultimately determines which market they then interact with. These choices are underpinned within an uncertainty framework and the consequences of their actions have implications for area-wide management programs (see Sect. 16.4).

16.3.3 Risk, Uncertainty and Pests: Is it Adoption, Adaptation or Luck?

Pannell's (1991) review of risk, uncertainty and pesticide use highlights the complex nature of IPM through time. Policy makers and pest managers operate with incomplete current information and have to deal with unknown future issues. This complexity has to deal with the existing stochastic nature of biological functions and the non-linear response from management choices. The paradox that over time IPM programs can both reduce and increase the long term risks (social, environmental and economics) associated with managing different pests within a landscape. While the future is unknown, it will contain unwelcome surprises. The frequency of unwelcome surprises increases if management and policy decisions are predicated on using the mean or average to explain the future. The focus on averages to justify decisions results in the failure to anticipate the next pest problem. Consequently policy and pest managers end up jumping from one pest crisis to another, causing a backsliding in the level of IPM adoption (Zalucki et al. 2009).

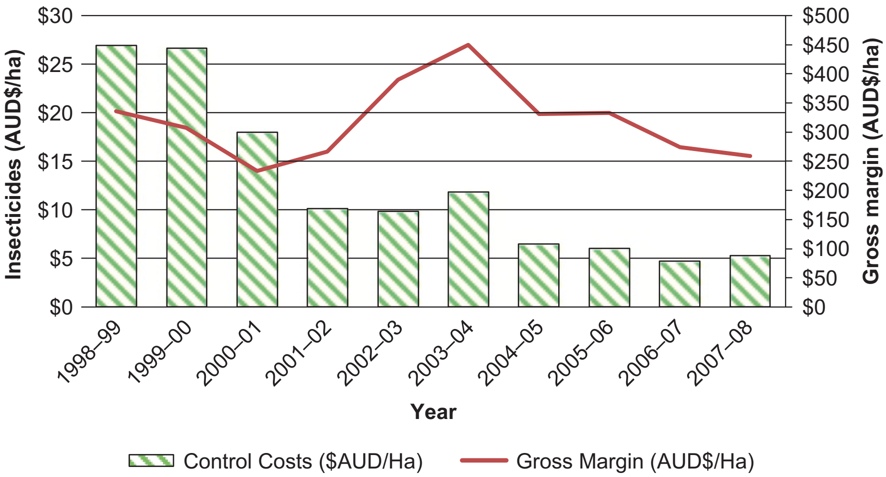

Fig. 16.4 Real costs of managing insects (AUD$/ha) in canola and the real gross margin return (AUD$/ha) in the Southern Zone of New South Wales from 1998–1999 to 2007–2008, all values in 2007–2008 AUD dollar terms. The data suggests that farmers have reduced the real insecticide costs of controlling insects in canola from over AUD$ 25/ha in 1998–1999 to about AUD$ 5/ha in 2007–2008

A bio-security breach leading to a pest or disease outbreak is a situation where the pest base load is altered in such a way that either management costs increase or there is a negative influence on yields or price, thereby changing the comparative advantage of production systems beyond the known distribution. The ability to adapt to pests is determined by the individual's ability to recognize the pest state; the constraints on the management options and the success of the response are all underpinned by uncertainty. The pests' state of nature is the fundamental understanding of economic thresholds in IPM. Further complexity and error in successful management occurs when producers invest in a 'new' activity, because they have to re-learn about managing the dynamic pest base load in regards to the new activity (Shea et al. 2002).

We can illustrate this by examining the case of pest management costs for canola in New South Wales. Brennan et al. (2005) outline the introduction of canola as a viable economic alternative to wheat within the winter cropping rotation system over the period of 1984 to 2004. By examining a set of gross margin budgets from 1989–1999 to 2007–2008, we see that the cost (insecticides and application costs) of managing pests per hectare decreases through time, see Fig. 16.4. We cannot definitively prove that a direct relationship between time and efficiency of control exists, as the data was not collected for this purpose. We know that costs have reduced, but we have no documented reasons why. Have farmers learnt from past mistakes and adapted their managing strategies? Has there been a fundamental change in the pest base load? Are producers benefiting from a collective wider regional control strategy? Is this a prime example of a successful IPM program (Gu et al. 2007)? Is it a direct response to falling commodity prices? Or is some other factor at play?

A producer's attitude to pest management may not be constant through time due to risk preferences, understanding of the problem, learning how to manage, financial constraints on resources, the policy settings constraining or influencing choices, and off-farm shocks like the Global Financial Crisis. However, IPM does change the nature of the management approach, as once an individual becomes aware of the issues and the options available, it can lead to non-linear changes to management strategies. Nevertheless, even a diligent farmer may find that the successes of their management activities are in fact largely due to activities of their neighbors creating an opportunity for a spatial free rider.

16.4 Pests, Policy and How's My Neighbor?

Within a landscape the actions of farmers in response to policy signals, their choice in management participation and their management action impacts directly on the composition and the density of the pest load. Rebaudo et al. (2011) point out that the diversity of managers within a landscape influences the success of regional control, as each group responds to different pest signals with varying degrees of success. Ceddia et al. (2008) illustrate this by examining how alternative levels of hobby farmers and professional farmers within a landscape influence the rate of pest spread. Collective management opportunities exist not only when production systems are similar but when the pests are the same. For example, citrus producers in the Central Burnett region of Queensland developed an area-wide management strategy for fruit fly in response to possible MRL levels for dimethoate and the ability to diversify into previously closed domestic markets (Lloyd et al. 2007).

Public area wide management strategies subsidize individuals' management costs. They may use alternative management options to allow producers to operate as normally as possible. For example, plague locusts are considered a public problem in Australia (Millist and Abdalla 2011) and their management falls under the purview of the Australian Plague Locust Commission (APLC). The ability to migrate throughout Australia over areas of environmental significance and well-defined organic beef enterprises in the Channel country (Wynen 2006) drove the adoption of *Metarhizium,* a bio-insecticide (Story et al. 2005). The cost of preserving market integrity is then paid for out of the public purse.

The success of an action is not predetermined solely by the wider public and private management strategies employed, but also by the path by which the pest arrived. For example, a lettuce IPM program in New South Wales (NSW) resulted in a net financial gain and a reduction in 'active ingredients' (g/ha) used to manage *Helicoverpa* spp.from 1998 to 2006 (Orr et al. 2008). Although the authors claim the net benefits would be greater if the spill over effects to other industries and human health were considered, they fail to consider the spill over benefits from other research. This was around the same time as when genetically modified cotton was being adopted in Australia. This acted as a population sink for *Helicoverpa* spp. (Knox et al. 2006) while the climate was not conducive for *Helicoverpa* spp. population development (Zalucki et al. 2009). A question then needs to be asked in the context of the review: did the lettuce IPM program really deliver benefit? Or was its success a product of timing or the limited scope of the review?

Schellhorn et al. (2008) suggest that the spatial scale of the ecological and economic problem need to be intertwined in order to develop successful management programs. The heterogeneity of the spatial landscape, how it has been modified, the temporal cropping patterns, localized and regionalized climatic events, available refuges and the management actions taken by individuals and groups not only provides pre-selection bias for the pests but the beneficials as well. A polyphagous migratory species can experience rapid population expansion under a changing landscape where the change in farming systems creates a favorable redistribution of its traditional overwintering locations. This is the case for *Helicoverpa* spp. and cotton in northern Australia. By providing policy incentives (price bounty systems and subsidized irrigation) to develop the cotton industry in the Ord, the landscape transformation provided a favorable habitat for *Helicoverpa* spp. (Davidson 1965). The rapid increase in *Helicoverpa* spp. density combined with tactically naïve management strategies resulted in unprecedented levels of insecticide resistance to develop. Ultimately, the combination of increasing costs and falling yields saw the cotton experiment in the Ord finish after ten years (Longworth and Rudd 1975).

The *Helicoverpa* spp. and cotton story does not end there. The cotton industry in Queensland and New South Wales was able to continue despite the removal of the price bounty. This continued industry development provided a positive correlation for *Helicoverpa* spp. development and a continual cycle of insecticide resistance creating a corresponding 'new' crisis for IPM research on a regular basis (Zalucki et al. 2009). These crises continued to occur despite the cotton industry's wide adoption of resistance management programs at a regional scale and other IPM strategies for over 30 years with temporary success permeated with the next spray and pray failure. The continual search for a 'magical bullet' culminated in the development of genetically modified (GM) cotton.

The search for the magic bullet in cotton is still debated. Although GM cotton undoubtedly acted as a population sink, the recent drought reduced the area of cotton planted and had a negative impact on *Helicoverpa* spp. populations, thereby clouding the true success of GM cotton to manage the pest complex (Zalucki et al. 2009). The long run success of GM cotton is still being debated as the recent resistance tests suggests that *Helicoverpa* spp. express natural resistance to the novel Vip3A Bt toxin which forms part of the next commercial release of GM cotton in 2016 (Mahon et al. 2012). Even if GM cotton eventually proves to be a technical success in suppressing *Helicoverpa* spp. in both the short and long term with a revolving rerelease of GM cotton varieties, it has perverse impact on IPM. In effect it turns the economic notion of IPM back into a calendar spray, see Fig. 16.5.

By setting the licensing fee to plant GM cotton identical to the cost of the 11 insecticides used to control *Helicoverpa* spp. in conventional cotton, GM cotton resembles the calendar spray (Fig. 16.5). In this case it only remains profitable to grow GM cotton if the density of *Helicoverpa* spp. remains high. As GM cotton operated as a population sink, there were reported cases where conventional cotton

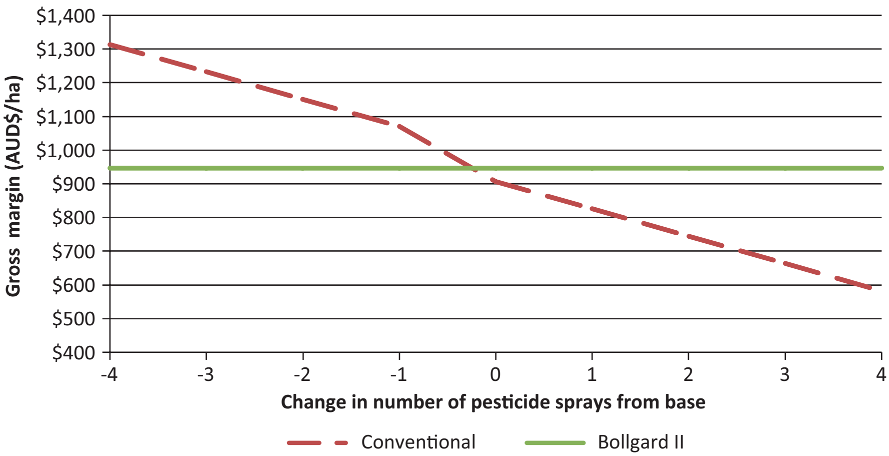

Fig. 16.5 The Genetically modified (GM) technology trap. Based on expected gross margin data from Bollgard II has a higher return than conventional cotton. However, if the expected density of pests is less than forecasted, then conventional cotton producers can reduce the number of sprays applied and increase their return per hectare above Bollgard II returns. This occurs as Bollgard II costs are primarily due to the licence fee which is fixed. Please see the discussion in Fig. 16.3 where 0 sprays equates to X and Bollgard II is calendar spraying and conventional cotton equates to IPM. (Cotton production costs based on the NSW Department of Primary Industries Enterprise Budget Series for Bollgard II cotton and conventional cotton, Northern Zone for 2005/2006)

was not being sprayed in 2006 (Personal communication, David Murray 2007). In effect encouraging the use of conventional cotton for individuals and not the industry as a sensible IPM farmer would free ride on the wide scale industry adoption.

Back and Beasley (2007) found that farmers have adopted GM despite the reduction in revenue because it is considered easier to grow, not because of the environmental and social benefits from using fewer pesticides. Thus GM technology is a passive pest management response and not really an active IPM tool. As the cotton industry is now firmly committed to GM crops the question from an IPM perspective remains are we doing our 'best' or have we accepted 'incidental' yet again?

16.5 Concluding Comments

This chapter aims to provide an understanding of how policy decisions can influence the adoption and use of IPM. The choice of how to manage pests is dependent upon: the regulatory environment in which they operate, the market the producer is aiming for, the inputs and management options available, the cost of the choice and the benefits of the decision. A combination of these factors then influences a producer's final decision regarding the adoption of a pest management strategy. Producers also take other factors into account, including subjective preferences and beliefs, to determine if they want to maximize profit, satisfy their desires or attempt to maximize their utility. This helps explain why some producers adopt a subset of IPM practices at the expense of profit.

Producers' attitudes to resource allocation can be dependent upon time and the net returns of actions. Australia specializes in producing bulk commodities with low inputs. The development of variable output and marginal prices leads to a system of low management inputs. For example, wheat crops are generally only sprayed once for insects. Beef is primarily produced on open rangelands systems without the need to overwinter stock thus limiting the need for preventative disease management. The combination of low inputs, marginal returns and time poor individuals often leads to the use of chemicals where possible. If the use of IPM requires increased time and inputs, then there has to be a net positive return to the producer. This then raises several questions: are we using IPM as it is the only option left? Or does it provide a clear market advantage? Or is it just "dumb luck" in the production system choice?

Every policy has positive and negative implications for alternative sections of the community. There are always winners and losers but the objective of 'good' policy is to attempt to improve. Policies at an international, domestic and industry levels are not constant but are continuously evolving, changing the incentives and disincentives for a given outcome. Sometimes the end point of a policy is not what was expected. This can provide positive and negative outcomes for farmers, the environment, the community and the economy as a whole. The current lack of information on what are the current economic problems, the emerging problems and a framework for forecasting the next adverse pest requires a mythical 'silver bullet'. This prevents the requisite detailed discussion to drive policy decisions to the next level.

The inability to analyze the policy at the next level may be a blessing in disguise. This chapter has barely scratched the surface of the policy winners and losers, as well as the difficulties in attempting to quantify the economic benefits and costs throughout society, the environment and the economy. Since the domestic pest management policies work with international SPS policies, perhaps this lack of clarity in the debate is a deliberate strategy for Australia. If only one country brings clarity to the discussion in the international arena, it may create a self-defeating outcome (Adamson and Cook 2007).

Perhaps the only certainty we have in evaluating Australia's policies on pest management is that despite the quarantine barriers sooner or later the plain 'dumb luck' described by Donald (1982) will run out as geographical barriers are overcome with both the increased speed and volume of trade. A single 'BSE' style event in Australia will have ramifications that are not yet in the public consciousness.

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References

ABARE. (2007). *Australian commodity statistics 2007*. Canberra: Australian Bureau of Agriculture and Resource Economics. http://data.daff.gov.au/data/warehouse/pe_abarebrs99001410/acs07.pdf. Accessed 16 April 2014

ABARES. (2011). *Agricultural commodity statistics 2011, December*. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences. http://adl.brs.gov.au/data/warehouse/agcstd9abcc002/agcstd9abcc0022011/ACS_2011_1.0.3.pdf. Accessed 7 Nov 2012.

ABARES. (2012). *Australian farm survey results 2009–10 to 2011–12*. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences. http://adl.brs.gov.au/data/warehouse/afsr_p9aabf002/afsr_p9aabf0022012042700/FarmSurveyResults2012.pdf. Accessed 7 Nov 2012.

Australian Bureau of Statistics. (2008). *Natural resource management on Australian farms: 2006–07, 4620.0, by ABS*. Canberra: Australain Bureau of Statistics. http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4620.02006-07. Accessed 7 Nov 2012.

Australian Bureau of Statistics. (2011). *Consumer price index: December Quarter 2011*. Canberra: Australian Bureau of Statistics. http://www.ausstats.abs.gov.au/ausstats/meisubs.nsf/0/1D1EAFC5A0E1C2B5CA25798F000D359F/$File/64010_dec%202011.pdf. Accessed 7 Nov 2012.

Adamson, D. (2002). *The benefit of the CSIRO Stored Grain Research Laboratory to the Australian grain industry*, Technical Paper no. 39 May 2002, CSIRO, Canberra.

Adamson, D. (2010). Quarantine and food safety issues in a TPPA. In J. Kelsey (Ed.), *No ordinary deal: Unmasking free trade and the trans-pacific partnership deal*. Wellington: Bridget Williams Books Ltd.

Adamson, D., Bilston, L., & Lynch, K. (2000). *The potential economic benefits of the Siam weed (Chromolaena ordata) eradication campaign*. Brisbane: RDE Conncectons, NRSM, The University of Queensland.

Adamson, D., & Cook, D. (2007). Re-examining economic options for import risk assessments. Paper presented to *AARES Conference*, Queenstown, New Zealand, 13–16 February 2007. http://ageconsearch.umn.edu/bitstream/10365/1/cp07ad02.pdf. Accessed 7 Nov 2012.

Adamson, D., Thomas, G., & Davis, E. (1997). *An economic estimate of helicoverpa's effect on Australian agricultural production: Report 1 in the Helicoverpa Series*. Brisbane: CRC for Tropical Pest Management.

Agbenyegah, B. K. (2012). Cotton. In ABARES. (Ed.), *Agricultural commodities september quarter*. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences. http://adl.brs.gov.au/data/warehouse/agcomd9abcc004/agcomd9abcc004201209/AgCommodities2012.Vol2.No3_Ver1.1.0.pdf. Accessed 7 Nov 2012.

Akinbowale, O. L., Peng, H., & Barton, M. D. (2006). Antimicrobial resistance in bacteria isolated from aquaculture sources in Australia. *Journal of Applied Microbiology, 100*(5), 1103–1113. doi:10.1111/j.1365–2672.2006.02812.x.

Allsopp, P. G. (2010). Integrated management of sugarcane whitegrubs in Australia: An evolving success. *Annual Review of Entomology, 55,* 329–349. doi:10.1146/annurev-ento-112408-085406.

Anderson, K. Y. M., Lloyd, P., & Maclaren, D. (2007). Distortions to agricultural incentives in Australia since World War II. *Economic Record, 83*(263), 461–482. doi:10.1111/j.1475-4932.2007.00434.x.

Back, W., & Beasley, S. (2007). Case study analysis of the benefits of genetically modified cotton. In S. O'Reilly, M. Keane, & P. Enright (Eds.), *16th International Farm Management Association Congress*. Cork: University College Cork.

Blank, S. C., Erickson, K. W., Moss, C. B., & Nehring, R. (2004). Agricultural profits and farm household wealth. *American Journal of Agricultural Economics, 86*(5), 1299–1307. doi:10.1111/j.0002-9092.2004.00681.x.

Bond, M. P. (Ed.). (2005). *Guidelines for prescribing, authorising and dispensing veterinary medicines*. Kingston: Australian Veterinary Association, ACT. http://www.ava.com.au/sites/default/files/documents/Other/Guidelines_for_prescribing_authorising_and_dispensing_veterinary_medicines.pdf. Accessed 7 Nov 2012.

Brennan, J. P., Sykes, J. D., & Scott, F. J. (2005). *Trends in pulse and oilseed crops in winter cereal rotations in NSW: Economic research report No. 26*. Wagga: NSW Department of Primary Industries. http://www.dpi.nsw.gov.au/research/economics-research/reports/err2. Accessed 7 Nov 2012.

Buzby, J. C., & Mitchell, L. (2006). Private, national, and international food-safety standards. *Journal of Food Distribution Research, 37*(1). http://ageconsearch.umn.edu/handle/8563. Accessed 7 Nov 2012.

Carlson, G. A. (1970). A decision theoretic approach to crop disease prediction and control. *American Journal of Agricultural Economics, 52*(2), 216–223.

Ceddia, M. G., Heikkilä, J., & Peltola, J. (2008). Biosecurity in agriculture: an economic analysis of coexistence of professional and hobby production. *Australian Journal of Agricultural and Resource Economics, 52*(4), 453–470. doi:10.1111/j.1467-8489.2008.00438.x.

Chang, H.-S. C., Griffith, G. R., & Zepeda, L. (2003). *An overview of the organic food products market in Australia*. University of New England, School of Economics, Working Paper 2003–10, Armidale. http://www.une.edu.au/business-school/working-papers/ag-res-econ/are-wp03-10.pdf. Accessed 7 Nov 2012.

Commonwealth of Australia. (2008). *Portfolio budget statements 2007–08: Agriculture, fisheries and forestry portfolio*. Canberra: Commonwealth of Australia. http://www.daff.gov.au/about/budget/07-08/pbs. Accessed 7 Nov 2012.

Commonwealth of Australia. (2011). *Agricultural and veterinary chemicals code act 1994: Act No. 47 of 1994 as amended*. Canberra: Office of Legislative Drafting and Publishing, Attorney-General's Department. http://www.comlaw.gov.au/Details/C2012C00004. Accessed 7 Nov 2012.

CRDC (2008). *Cotton research and development corporation: Annual report 2007–08*. Narrabri: Cotton Research and Development Corporation. http://cottonaustralia.com.au/uploads/publications/2007-08_Cotton_Australia_Annual_Report.pdf. Accessed 7 Nov 2012.

CSIRO. (2008). *CSIRO annual report 2007–08*. Canberra: Commonwealth Scientific and Industrial Research Organisation. http://www.csiro.au/files/files/pmvp.pdf. Accessed 7 Nov 2012.

Davidson, B. R. (1965). *The Northern Myth* (1st edn.). Adelaide: Melbourne University Press.

Department of Primary Industries. (2008). *Department of primary industries financial statements & appendices 2007–08*. Melbourne: Department of Primary Industries. http://www.dpi.vic.gov.au/__data/assets/pdf_file/0016/565/web_version_DPI_FinsApps_2007-08.pdf. Accessed 7 Nov 2012.

DEWH.(2008). *Envioronment budget overview 2007–08*. Canberra: Department of the Environment and Water Resources. http://www.environment.gov.au/about/publications/budget/2007/index.html. Accessed 7 Nov 2012.

Donald, C. M. (1982). Innovation in Australian agriculture. In D. B. Williams (Ed.), *Agriculture in the Australian economy* (2nd edn.). Parramatta: Sydney University Press.

DPIW. (2009). *DPIW annual report 2007–08*. Tasmania: Department of Primary Industries, Parks, Water and Environment. http://www.dpiw.tas.gov.au/inter.nsf/Attachments/SSKA-7KD5C8/$FILE/DPIW_AR0708_Main.pdf. Accessed 7 Nov 2012.

GRDC. (2008). *GRDC annual report 2007–08*. Canberra: Grains Research and Development Corporation. http://www.grdc.com.au/~/media/FE763DF0AB5343AFA738BE1699ECCB90.pdf. Accessed 7 Nov 2012.

Gu, H., Fitt, G. P., & Baker, G. H. (2007). Invertebrate pests of canola and their management in Australia: A review. *Australian Journal of Entomology, 46*(3), 231–243. doi:10.1111/j.1440-6055.2007.00594.x.

Headley, J. C. (1972). Defining the economic threshold. In National Research Council (Ed.), *Pest control strategies for the future*. Washington, DC: National Academy of Sciences.

James, S., & Anderson, K. (1998). On the need for more economic assessment of quarantine/SPS policies. *Australian Journal of Agricultural and Resource Economics, 42*(4), 425–444.

Javier, E. Q. (1992). Foreword. In N. S. Talekar (Ed.), *Management of diamondback moth and other crucifer pests: Proceedings of the Second International Workshop*. AVRDC- The World Vegetable Center, 10–14 December 1990. Shanhua, Tainan.

JETACAR. (1999). *The use of antibiotics in food-producing animals:antibiotic-resistant bacteria in animals and humans*. Canberra: Commonwealth Department of Health and Aged Care, Commonwealth Department of Agriculture, Fisheries and Forestry- Australia. http://www.health.gov.au/internet/main/publishing.nsf/Content/2A8435C711929352CA256F,180057901E/$File/jetacar.pdf. Accessed 8 Nov 2012.

Jordan, D. (2007). Antimicrobial resistance in animals and impacts on food safety and public health. *Microbiology Australia, 28*(4), 163–164.

Kahn, L. P., & Woodgate, R. G. (2012). Integrated parasite management: Products for adoption by the Australian sheep industry. *Veterinary Parasitology, 186*(1–2), 58–64. doi:10.1016/j.vetpar.2011.11.046.

Keogh, M. (2011). Food security, food reality and Australian agricultural opportunity. *Farm Policy Journal, 8*(4), 1–6.

Khan, S. (2008). Managing climate risks in Australia: Options for water policy and irrigation management. *Australian Journal of Experimental Agriculture, 48,* 265–273.

Knox, O. G. G., Constable, G. A., Pyke, B., & Gupta, V. V. S. R. (2006). Environmental impact of conventional and Bt insecticidal cotton expressing one and two Cry genes in Australia. *Australian Journal of Agricultural Research, 57*(5), 501–509. doi:http://dx.doi.org/10.1071/AR05366.

Lloyd, A., Chambers, S., & Franco-Dixon, M. A. P. (2007). *Area wide management of fruit fly, Central Burnett. Final report AH03002*. Sydney: Horticulture Australia Limited.

Longworth, J. W., & Rudd, D. (1975). Plant pesticide eonomics with special reference to cotton insecticides. *Australian Journal of Agricultural Economics, 19,* 210–226.

Mahon, R. J., Downes, S. J., & James, B. (2012). Vip3A resistance alleles exist at high levels in Australian targets before release of cotton expressing this toxin. *PLoS ONE, 7*(6), e39192. doi:10.1371/journal.pone.0039192.

Maupin, J., & Norton, G. W. (2010). Pesticide use and IPM adoption: Does IPM reduce pesticide use in the United States? Paper presented at the *Agricultural and Applied Economics Association, 2010 Annual Meeting*, Denver, Colorado, July 25–27, 2010. http://purl.umn.edu/61306. Accessed 9 Nov 2012.

McBride, W. D., Greene, C. R., Ali, M. B., & Foreman, L. F. (2012). The structure and profitability of organic field crop production: The case of wheat. Paper presented at the *Agricultural and Applied Economics Association, 2012 Annual Meeting*, August 12–14, 2012, Seattle, Washington. http://purl.umn.edu/123835. Accessed 9 Nov 2012.

McFadyen, R. (2007). Return on investment: Determining the economic impact of biological control programmes. Paper presented at the *Proceedings of the XII International Symposia on Biological Control of Weeds*, La Grande Motte, France. http://bookshop.cabi.org/Uploads/Books/PDF/9781845935061/9781845935061.pdf. Accessed 9 Nov 2012.

McLeod, R. (2004). *Counting the cost: Impact of invasive animals in Australia 2004*. Canberra: Cooperative Research Centre for Pest Animal Control. http://www.feral.org.au/counting-the-cost-impact-of-invasive-animals-in-australia-2004/. Accessed 9 Nov 2012.

McNeill, A. M., & Penfold, C. M. (2009). Agronomic management options for phosphorus in Australian dryland organic and low-input cropping systems. *Crop and Pasture Science, 60*(2), 163–182. doi:http://dx.doi.org/10.1071/CP07381.

Millist, N., & Abdalla, A. (2011). *Benefit–cost analysis of Australian plague locust control operations for 2010–11*. Canberra: ABARES report prepared for the Australian Plague Locust Commission. http://www.daff.gov.au/animal-plant-health/locusts/publications/abares-study11. Accessed 9 Nov 2012.

MLA. (2008). *Partners from paddock to plate: MLA Annual Report 2007–08*. Sydney: Meat & Livestock Australia. http://www.mla.com.au/CustomControls/PaymentGateway/ViewFile.aspx?x49CiqfXDxxsdJttKdU2cndZWsj49JufzmvZOG+snvgaFbYCbsBiOcIzQK0ex9D33EYMKKAfsht7d1Tnt3BqiA=. Accessed 9 Nov 2012.

Murray, G., & Brennan, J. (2010). Estimating disease losses to the Australian wheat industry. *Australasian Plant Pathology, 38*(6), 558–570. doi:10.1071/ap09053.

Nairn, M. E., Allen, P. G., Inglis, A. R., & Tannder, C. (1996). *Australian Quarantine: A shared responsibility*. Canberra: Department of Primary Industries and Energy, Commonwealth of Australia.

Norton, G. A. (1985). Economics of pest control. In P. T. Haskell (Ed.), *Pesticide application: Principles and practice*. Suffolk, U.K: Clarendon Press.

NSW Department of Primary Industries. (2012). *Vetebrate pest control manual*. Orange: Department of Department of Trade and Investment, Regional Infrastructure and Services. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/439201/Vertebrate-pest-control-manual.pdf. Accessed 9 Nov 2012.

Orr, L. M., McDougall, S., Napier, T., & Mullen, J. D. (2008). Returns to investment in IPM research in lettuce by NSW DPI. Paper presented at the *Australian Agricultural and Resource Economics Society Conference* (52nd), Canberra, Australia, February 5–8, 2008. http://purl.umn.edu/94283. Accessed 9 Nov 2012.

Pannell, D. J. (1991). Pests and pesticides, risk and risk aversion. *Agricultural Economics, 5*(4), 361–383. doi:10.1016/0169-5150(91)90028-j.

Petherick, J. C. (2005). Animal welfare issues associated with extensive livestock production: The northern Australian beef cattle industry. *Applied Animal Behaviour Science, 92*(3), 211–234. doi:10.1016/j.applanim.2005.05.009.

PIRSA. (2008). *PIRSA 2007–08 Annual Report*. Adelaide: Government of South Australia. http://www.pir.sa.gov.au/_data/assets/pdf_file/0011/88427/Annual_Report_07-08.pdf. Accessed 9 Nov 2012.

Queensland Government. (2009). *State Budget 2008–09: Department of Primary Industries and Fisheries: Agency Budget Highlights*. Brisbane: Queensland Government. http://www.daff.qld.gov.au/documents/Corporate/DPIF-BudgetHighlights2008-09.pdf. Accessed 9 Nov 2012.

Rebaudo, F., Crespo-Pérez, V., Silvain, J.-F., & Dangles, O. (2011). Agent-based modeling of human-induced spread of invasive species in agricultural landscapes: Insights from the Potato Moth in Ecuador. *Journal of Artificial Societies and Social Simulation, 14*(3). http://jasss.soc.surrey.ac.uk/14/3/7.html. Accessed 9 Nov 2012.

Rostow, W. W. (1959). The stages of economic growth. *The Economic History Review, 12*(1), 1–16.

Schellhorn, N. A., Macfadyen, S., Bianchi, F. J. J. A., Williams, D. G. P., & Zalucki, M. P. (2008). Managing ecosystem services in broadacre landscapes: What are the appropriate spatial scales? *Australian Journal of Experimental Agriculture, 48*(12), 1549–1559. doi:http://dx.doi.org/10.1071/EA08112.

Shea, K., Possingham, H. P., Murdoch, W. W., & Roush, R. (2002). Active adaptive managment in insect pest and weed control: Intervention with a plan for learning. *Ecological Applications, 12*(3), 927–936. doi:10.1890/1051-0761(2002)012[0927:AAMIIP]2.0.CO;2.

Simon, H. A. (1955). A behavioral model of rational choice. *The Quarterly Journal of Economics, 69*(1), 99–118. doi:10.2307/1884852.

Sinden, J., Jones, R., Hester, S., Odom, D., James, R., & Cacho, O. (2004). The economic impact of weeds in Australia. *CRC for Australian Weed Management technical series; no. 8*, CRC for Australian Weed Management, Glen Osmond, S.A.

SRDC. (2008). *Sugar Research and Development Corporation Annual Report 2007–08*. Brisbane: Sugar Research and Development Corporation. http://www.srdc.gov.au/icms_docs/131296_SRDC_Annual_Report_2007_-_2008.pdf. Accessed 9 Nov 2012.

Stern, V. M., Smith, R. F., Van Den Bosch, R., & Hagen, K. S. (1959). The integrated control concept. *Hilgardia, 29*(2), 81–101.

Story, P. G., Walker, P. W., McRae, H., & Hamilton, J. G. (2005). A case study of the Australian plague locust commission and environmental due diligence: Why mere legislative compliance is no longer sufficient for environmentally responsible locust control in Australia. *Integrated Environmental Assessment and Management, 1*(3), 245–251. doi:10.1897/2004-028.1.

Villano, R., Fleming, E., & Fleming, P. (2010). Evidence of farm-level synergies in mixed-farming systems in the Australian Wheat-Sheep Zone. *Agricultural Systems, 103*(3), 146–152. doi:10.1016/j.agsy.2009.11.005.

Walker, G. E., & Stirling, G. R. (2008). Plant-parasitic nematodes in Australian viticulture: Key pests, current management practices and opportunities for future improvements. *Australasian Plant Pathology, 37*(3), 268–278. doi:10.1071/ap08018.

Wilson, C., & Tisdell, C. (2001). Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics, 39*(3), 449–462. doi:10.1016/s0921-8009(01)00238-5.

Wynen, E. (2006). Organic beef production and marketing in Australia. *Journal of Organic Systems, 1*(1). http://www.organic-systems.org/journal/Vol_1 %281 %29/index.html. Accessed 9 Nov 2012.

Zalucki, M. P., Adamson, D., & Furlong, M. J. (2009). The future of IPM: Whither or wither? *Australian Journal of Entomology, 48*(2), 85–96. doi:10.1111/j.1440-6055.2009.00690.x.

Zalucki, M. P., Shabbir, A., Silva, R., Adamson, D., Shu-Sheng, L., & Furlong, M. J. (2012). Estimating the economic cost of one of the world's major insect pests, Plutella xylostella (Lepidoptera: Plutellidae): Just how long is a piece of string? *Journal of Economic Entomology, 105*(4), 1115–1129. doi:10.1603/ec12107.

Zull, A. F., Cacho, O. J., & Lawes, R. A. (2009). Optimising woody-weed control. Paper presented at the *Australian Agricultural and Resource Economics Society Conference* (53rd), Cairns, Australia, February 11–13, 2009. http://purl.umn.edu/47620. Accessed 9 Nov 2012.