Contributed paper presented at the 41st Annual Conference of the Australian Agricultural and Resource Economics Society, Broadbeach, January 20-25, 1997

An Integrated Economic Approach to Evaluating the Farm and Industry Benefits of Weed Control in Agricultural Production Systems

D.T. Vere[1], R.E. Jones[1] and G.R. Griffith[2]

[1] NSW Agriculture and Cooperative Research Centre for Weed Management Systems, Agricultural Research and Veterinary Centre, Forest Road, Orange, NSW 2800, Australia.
[2] NSW Agriculture, Regional Veterinary Laboratory, University of New England, Armidale, NSW 2351, Australia.

Abstract

The annual economic loss of agricultural production caused by weeds in Australia has been estimated to exceed $3.3 billion. This loss now approximates the average annual net value of Australian farm production. In an attempt to address this problem, the Cooperative Research Centre for Weed Management Systems (CRCWMS) was established in 1995 under the federal government's cooperative research centre program. To achieve its goal of reducing the annual costs of weeds to Australia by at least 10percent by the year 2000, the CRCWMS must demonstrate that its research will benefit both the farming sector and the overall community. This paper describes the development of an integrated economic system for evaluating these benefits and its application in evaluating the benefits of controlling a major weed of Australian grazing systems in the Murrumbidgee Irrigation Area.

1. Introduction

Weeds are a major economic problem in Australian agriculture because most farm products are produced under extensive systems at yields which are low relative to those in other countries. Weed losses result from yield and quality reductions, the costs of control inputs and in extreme weed-effected situations the costs of adjustment to new production systems. Spreading weeds also impose external costs where their effects are not internalised within the farm. The total cost of weeds to Australian agriculture is estimated to be $3.3 billion per annum in terms of lost productivity and control costs (Anon. 1995). The most recent disaggregated cost estimate comes from Combellack (1987) who suggested that weeds annually cost $2.1 billion based on 1981-82 statistics and this was likely to increase to $2.8 billion by 1987. This estimate comprised the direct costs of weed control (cultivation, herbicides and application), and the indirect costs of yield loss and product contamination. Losses in crops and pastures were 61% and 24% of this cost estimate respectively.

Estimates of weed costs provide an economic basis for rationalising the weed control programs of producers and governments, and for directing weeds research programs (Vere and Auld 1982). Despite the economic importance of weeds in Australian agriculture, there have been few attempts to rigorously estimate their costs. The available estimates tend to be presented in aggregate and apart from Combellack (1987), rarely reveal how they were derived or even what they include. Over 30 years ago, it was suggested that weeds tend to be taken for granted, and are so common and widespread that their economic costs in terms of productivity losses and control inputs are not generally appreciated (United States Department of Agriculture 1965). This remains the case despite advances in the methods for mapping weed populations and in assembling other weed data.

To be able to realistically assess the extent to which it has achieved its goal of having reduced the costs of weeds in Australia by at least 10% per annum by 2000, the Cooperative Research Centre for Weed Management Systems (CRCWMS) must demonstrate that its research into improved weed management will benefit both the farming sector and the community. First, new weed control technologies have to be assessed as being both technically and economically feasible to encourage producer adoption. This requires the use of farm-level models to establish the output and revenue changes resulting from the better weed control, given farm constraints and producer objectives. The results of applying these models provide producers with comparative assessments of the economic benefits of achieving improved weed management which come through the opportunities to lower production costs. Second, the widespread adoption of improved weed control might also be expected to have important industry effects where this results in an increased level of production at lower unit cost. This is because the competitive nature of most of Australia's agricultural industries suggests that an increase in supply is likely to result in average farm and retail prices which are lower than those existing prior to the adoption of improved weed management. Both these considerations indicate that the adoption of improved weed control is likely to have economic implications beyond the production level, and that a modelling system which incorporates both the farm and market components of the industry is required to accurately assess the potential benefits.

The modelling system for evaluating the impacts of weeds and of improved weed management described in this paper is intended to address two important economic issues to the CRCWMS; (i), the need to evaluate the relative impacts of the target weeds at both the farm and industry levels, and (ii), the need to determine the full range of potential farm and industry benefits from the development and adoption of improved weed control practices. Achieving these purposes will facilitate the promotion of improved weed control to producers, and also assist management in assessing the extent to which the program's goals have been achieved.

2. An Economic Modelling System for Evaluating Weed Problems

The application of economic models to weed management problems has not been extensive in Australia. Most of the past economic research in the weeds area has been in relation to the effects of weeds in production systems. In this context, optimisation methods and dynamic programming (DP) and linear programming (LP) in particular, have been used to evaluate control strategies for several weed species (Pannell 1988). Fisher and Lee (1981) used DP to solve the rotation problem faced by grain growers in north-west New South Wales in areas where wild oats and crown rot have a significant effect on wheat yields. Kennedy (1987) also adopted a DP approach to calculate the optimal herbicide rates for controlling hardyheads in Victoria. Pandey (1989) developed a stochastic dynamic programming (SDP) model to assess control measures for wild oats, while Pandey and Medd (1990) used deterministic DP, linked to a bio-economic simulation model, to assess the economic feasibility of seed kill for controlling wild oats in wheat. Further research by Pandey and Medd (1991) again utilised the SDP-bio-economic simulation model framework to analyse a continuous wheat cropping system infested with wild oats. The Pandey (1989) and Pandey and Medd (1991) studies are two of the very few which have considered the effects of risk in Australian weed problems. Gorddard (1991) used DP to identify optimal resistance management strategies using the example of ryegrass herbicide resistance in Western Australian wheat production systems.

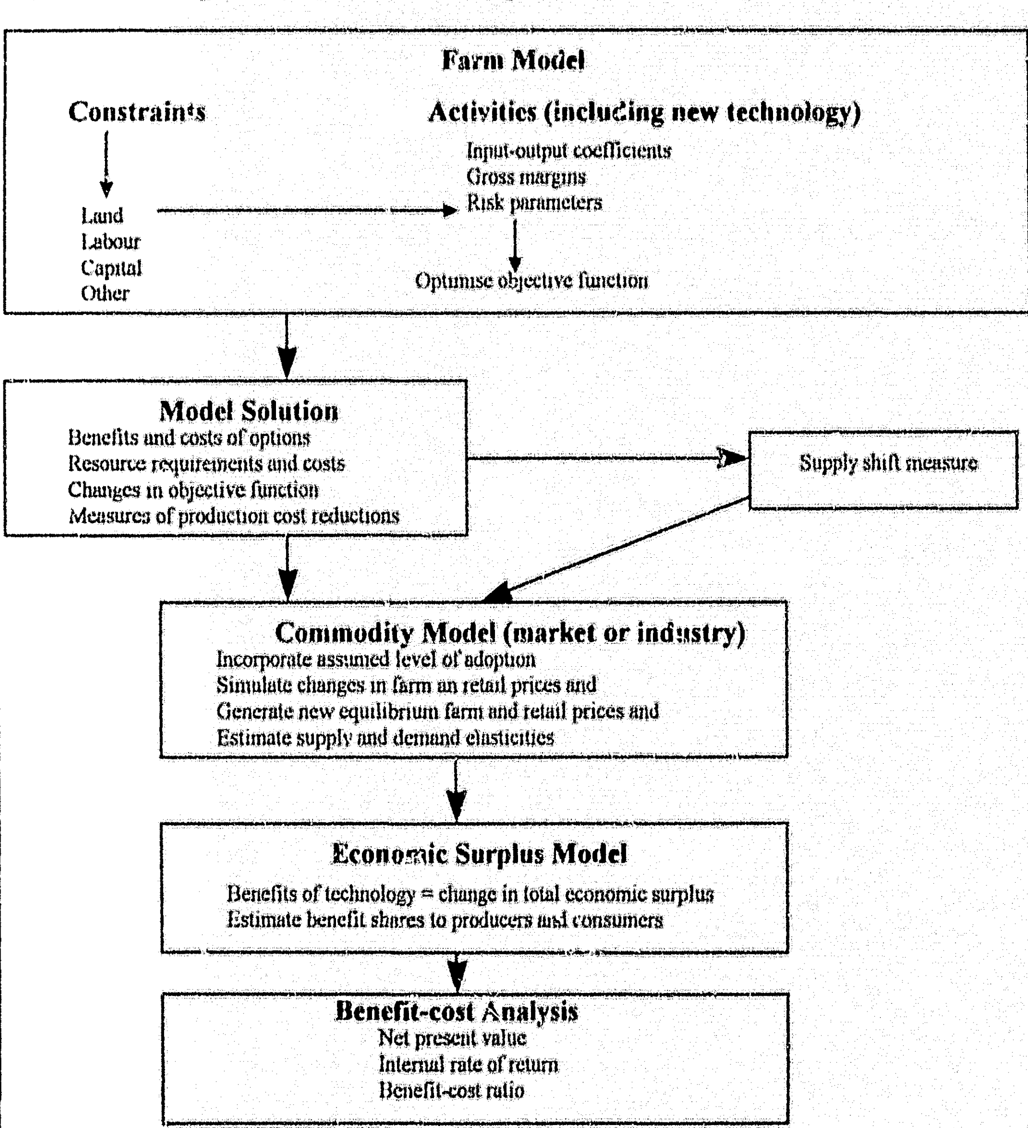
Of the LP applications, Pannell and Panetta (1986) used a whole-farm mixed integer programming (MIP) model to estimate the cost of skeleton weed in the Western Australian wheatbelt, while Schmidt, Pannell and Stewart (1994) used LP to assess the economic implications of adopting alternative management practices for the control of herbicide resistance in ryegrass. Other economic weed analyses have utilised simulation in assessing the skeleton weed eradication program in Western Australia (Pannell 1984), and response functions and differential calculus to determine optimal herbicide rates (Pannell 1990).

Analyses which have considered the impacts of weeds beyond the farm have mainly involved the application of benefit-cost and economic surplus analysis to assess the costs of weeds at the farm and community (e.g., Vere, Sinden and Campbell 1980; Edwards and Freebairn 1982; Industries Assistance Commission 1985; Vere, Auld and Campbell 1993).

The main components of the integrated economic modelling system for evaluating weed impacts and improved weed control in farm production systems is illustrated in Figure 1. This indicates that the modelling sequence is to establish the initial production effects in terms of the costs of production losses and the benefits of control, to evaluate the market impacts under a given level of control technology adoption, and thence to calculate the changes in economic surplus and the social benefit-cost criteria.

In evaluating either the impact of a weed or the benefits of its control, this modelling system enables the with and without weed production differences to be established and these to then be translated into an industry supply change under a given level of weed infestation or weed control adoption. The two questions this system assists in answering are (i), what are the economic effects of weeds in production systems and how might these change with better weed control? and (ii), how might the commodity market change and what are the industry-wide economic effects? The answers to these questions determine whether the development of improved weed control is likely to be profitable from both the producer's and industry's perspectives.

Figure 1: An integrated economic model of production technology evaluation



3. Modelling System Components

3.1 Production systems models

Production systems models can be grouped as being either deterministic or stochastic. The deterministic group of models are those developed under conditions of assumed certainty. The advantage of these models is that they can be developed and solved with greater ease and this enables the analysis of complex production systems. Stochastic models allow for the explicit incorporation of uncertainty in the model and this allows the problem to be more realistically represented in many situations. However, stochastic models entail greater complexity in their development and are often more difficult to solve.

The choice of the appropriate model depends on the characteristics of the problem under investigation, i.e., whether it is deterministic or stochastic, static or dynamic, whether optimisation, budgeting or simulation is required, and whether the level of analysis is partial or whole-farm. A problem is considered to be stochastic if important variables (such as rainfall and commodity prices) are uncertain and can be formulated as a probability distribution. Where uncertainty is expected to affect the performance of alternative strategies, a stochastic methodology should be used. Deterministic approaches are appropriate where these variables can be adequately described by their expected values or the uncertainty is unlikely to affect the ranking or performance of the strategies.

A static methodology only considers a problem over a discrete time period such as a season or year. Dynamic methodologies consider intertemporal effects and solves the problem over a predetermined time. If the problem requires the optimisation of various options, the objective of the model is to maximise or minimise an objective function of a number of possible variables, subject to a range of physical and institutional constraints. Alternatively, simulation modelling seeks to conduct sampling experiments on a mathematical model of the system. Reasons for adopting simulation over optimisation models are mainly to account for risk or where there are complex objective functions (such as utility functions).

Optimisation models remain a powerful and efficient means (even when risk is involved) for determining an optimal plan or strategy from a large range of alternatives. Modelling choice is also based on whether the problem is to be evaluated at a partial or at a whole-farm level. In agricultural research, optimisation models are often specified as whole-farm while particular budgeting techniques such as gross margins and partial budgets can only be conducted at a partial level. A whole-farm approach should be adopted where there are important interactions between farm resources and on-farm activities.

A considerable amount of biological and physical information on the production systems involved are required to develop production system models. This information mainly requires the specification of resource endowments, input-output coefficients, costs and returns, and crop and farming systems. Some of these data are in the form of point estimates while other data, for random variables, are required in the form of probability distributions. The main types of data in the resource endowments category are the basic physical constraints of the research problem, e.g., the size of the representative farm or paddock, depending on the scale of the analysis, soil types, irrigation technologies, availability of labour and capital, and institutional restrictions such as production quotas.

Input-output coefficients are the major data requirements and generally are the most demanding in terms of biology and physical attributes. Particular data needs for weed research will include yields of pasture activities (daily dry matter production) and grain crops (tonnes per ha) without weeds and the yield loss relationships for different crop-weed densities. Estimates of the relationship between seed banks and weed densities are also required for different weed species, a range of crops, different geographical locations and soil types. Other important information required by these models is the effectiveness upon yield loss of alternative control agents, whether they are chemical, mechanical or biological. Examples of other input-output coefficient data include fecundity equations for determining weed reproduction, feed energy requirements of livestock (e.g. metabolisable energy per cow, ewe or DSE), response functions to different inputs (e.g. fertilisers), evapotranspiration demands, labour requirements per unit (hours per ha), fodder feed energy equivalents (e.g. metabolisable energy per ha, bale or tonne), and seasonal or monthly pasture transfer efficacy.

Cost and return data are associated with each of the decision variables, or enterprises, of the model. Most of these data are specified in the form of gross margins and variable costs on a hectare, tonne, ewe, cow and bale basis. Where there are investment activities (e.g. land purchase, irrigation technology, headers, spray equipment and hay and silage making equipment) these data must be specified at either their capital value in the year of acquisition in a dynamic or multiperiod framework or amortised, using the term (years) and interest rate that is applicable, in a static framework. For some problems that require a risk analysis, a time series of cost and return data may need to be developed.

The crop and farming systems data required generally indicate whether the problem requires an analysis of rotations, where there are multiple choices among crops, pastures and livestock. This will sometimes be governed by the scale of the study as determined by the resource availability, i.e., a representative farm compared to a single paddock or ha analysis. The crop and farming systems data should comprehensively cover the detailed interactions that occur between crops, pasture and livestock enterprises.

3.2 Industry models

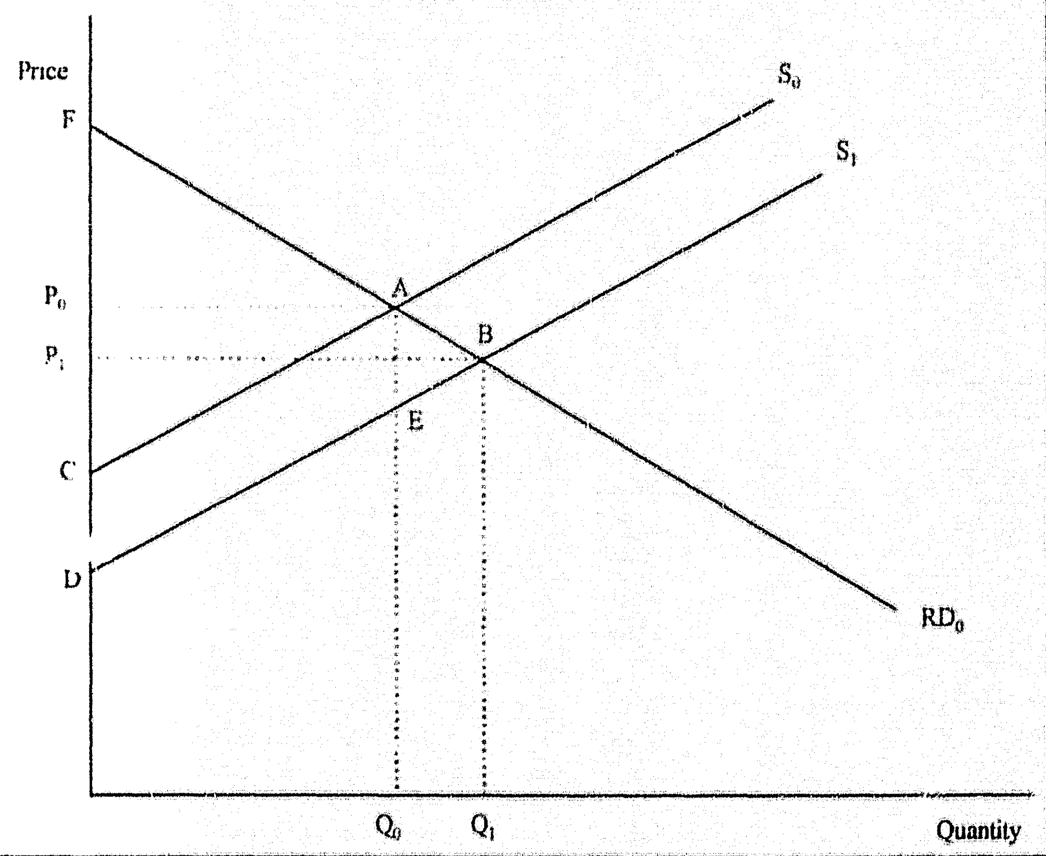
Industry level evaluations of weed impacts are also necessary because production systems models typically assume that output prices are not affected by the changes in resource allocation or product mix. This may be realistic when one farm is considered since changes in its output will rarely affect market price. However, when improved weed control technology is expected to be widely adopted in an industry, the aggregate of all farm level changes may result in a change in commodity prices. The economic surplus model provides a means of calculating the size of these changes where the supply of a commodity is either constrained by weeds, or increased by the adoption of improved weed control. There are two general situations in which the economic surplus model is useful in the weed impact context.

3.2.1 Schematic economic surplus model

The schematic economic surplus model is illustrated in Figure 2 in which weed control shifts the commodity supply curve (S_0) outward (to S_1) while the demand curve (RD_0) remains stationary. Pre-weed control production is at Q_0 which attracts a market price of P_0. Producers have an economic surplus equivalent to P_0AC while consumers' surplus is the area P_0AF. The main economic effect of weed control is to reduce per unit production costs and shift the product's supply curve outwards to S_1. The area of economic surplus is now *FBD* comprising consumers' and producers' surpluses of P_1BF and P_1BD, respectively.

These areas of total economic surplus change represent the impact of weed control on both consumers and producers. The net change in economic surplus is equivalent to the benefits of control and this is given by the area *CABD*, the difference between the areas *FAC* and *FBD*. The incremental benefit area (*CABD*) incorporates the production cost reductions for the initial output Q_0 (the area *CAED*), and the value to consumers of the extra production at S_1, net of production costs (the area *ABE*). Where the supply curve shift is parallel so that the vertical distance between the two supply curves is constant, and following Alston (1991), the changes in the economic surplus areas from weed control can be estimated as;

Figure 2: The effect of a supply shift from improved weed control



Change in consumers' surplus;

$$\Delta CS = P_0 Q_0 Z(1 + 0.5Z\eta) \qquad (1)$$

Change in producers' surplus;

$$\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5Z\eta) \qquad (2)$$

Change in total surplus;

$$\Delta TS = P_0 Q_0 K(1 + 0.5Z\eta) = \Delta CS + \Delta PS \quad (3)$$

where, P_0 and Q_0 are the initial equilibrium market-clearing price and quantity for the commodity, Z is the percentage reduction in price arising from the supply shift defined as $Z = K\varepsilon/(\varepsilon+\eta)$, K is the initial vertical supply shift expressed as the percentage reduction in production costs from the adoption of the new technology, and ε and η the price elasticities of supply and demand.

3.2.2 Industry (econometric) model-economic surplus model

This approach requires the use of a quantitative industry model to predict new equilibrium prices and quantities following weed control. Such a model permits the impacts of weeds and their control to be simulated on the main variables (supply, demand and prices), and for these impacts to be translated into measures of economic surplus change. One type of industry model which has been used in technology impact evaluations is the structural econometric model (Figure 3). This model is specified as a system of equations which represent the industry's production, consumption, and price determination processes. The model solves simultaneously to generate the equilibrium values for the set of endogenous variables. The results enable the direct calculation of the new equilibrium prices and quantities and the elasticity values which are obtained from the estimated relationships. The structural industry model is particularly useful in evaluating weed impacts because it explains how past economic decisions were made so that these decisions might be predicted into the future. The main advantage of econometric simulation in this situation is that the dynamic effects of weeds and the responses to weed control can be traced out over time as the model solves period by period.

In simulating the industry impacts of weeds using a structural econometric model, parameter values are altered to reflect the new technology, the model re-solved, and the results compared with the base model solution. Here, the model defines the initial industry equilibrium quantity (Q_0) and price (P_0), which together define point A (Figure 2), the changed quantities and prices Q_1 and P_1, which together with the elasticities of supply (ε) and demand (η) for the commodity, and K, the vertical shift in the supply function, define point B. These calculations enable the changes in economic surplus to be determined. The economic surplus formulae in this situation differ from those in the first because they are based on the simulated price and quantity changes rather than on assumed parameter and initial equilibrium values, and are given as;

Change in consumers' surplus;

$$\Delta CS = -P_{0R} Q_{0R} EP_R (1 + 0.5EQ_R) \quad (4)$$

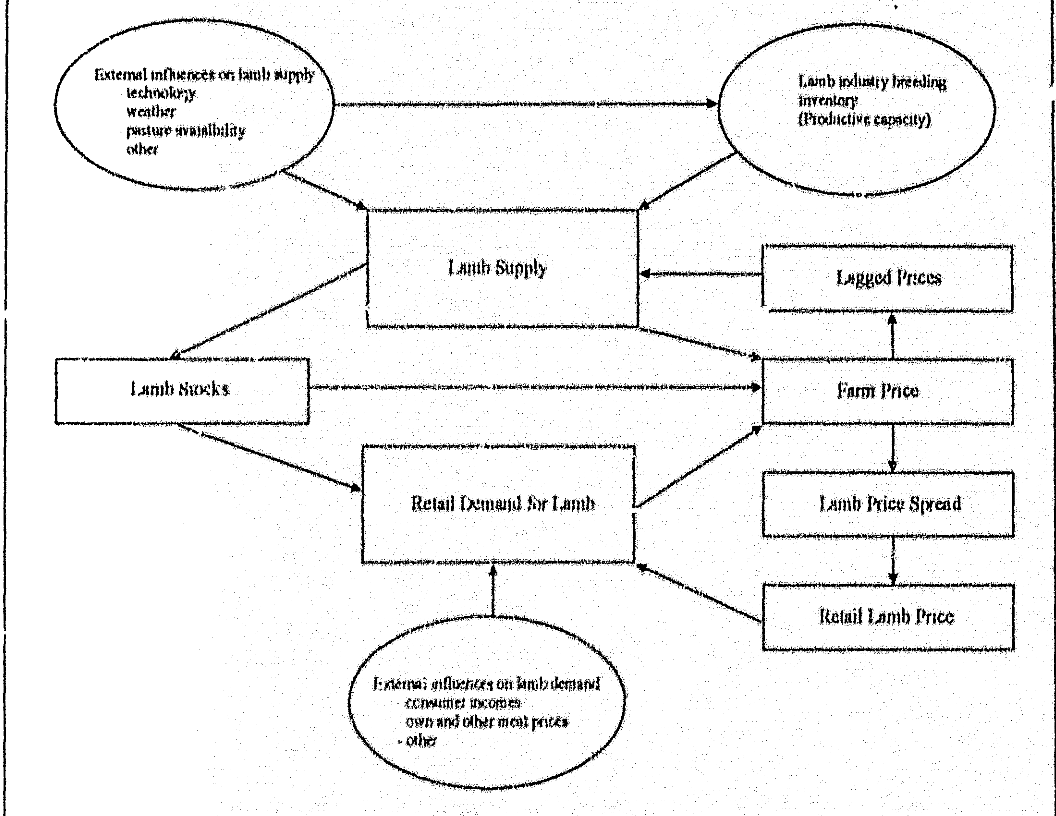
Change in producers' surplus;

$$\Delta PS = P_{0F} Q_{0F} (EP_F - K)(1 + 0.5EQ_F) \quad (5)$$

Change in total surplus;

$$\Delta TS = \Delta CS + \Delta PS \quad (6)$$

Figure 3: Australian lamb industry model components and linkages (Vere et al., 1994)



where, the subscripts $_R$ and $_F$ relate to the retail and farm levels of the industry respectively, and the parameters EP_R, EP_F, EQ_R and EQ_F are the relative changes in retail and farm prices and quantities which are derived from the model simulation solutions.

The main difference between the schematic and the econometric economic surplus methods in evaluating weed impacts is that in the first, an initial market equilibrium is given and the given supply shift and industry parameters determine the new equilibrium prices and quantities. Economic surplus is measured as a shift away from the initial point. In the second, the econometric model predicts the new prices and quantities and economic surplus change is measured as a shift towards the new equilibrium. The first method is easier to implement, but the second is more reliable. Using either method in a weed impact evaluation context, three issues have to be addressed; (i) the extent of the supply shift caused by the weed, (ii) the effects of different levels of adoption of a control technology on an industry, and (iii) the time path of adoption of the control technology within the industry.

The extent of the supply shift is a major factor in determining weed impacts. In the weed control situation, the supply shift parameter (K) in the producer surplus equations is measured in terms of the production cost reductions which result from weed control. K can be derived as a proportional supply shift directly from the farm model solutions where it is defined as being the percentage reduction in the marginal unit cost of production for the weed-affected and weed-free systems, expressed as a proportion of the commodity's farm price. Alternatively, *K* can be derived from production or cost function analysis where it is considered that the components of technical change are important. This method allows the incorporation of the effects of both neutral technical change, where the technology results in a shift in output from the same mix of inputs and their proportions, and biased technical change which occurs where production shifts are due to a change in the input mix which biases the use of one factor of production. The second method might sometimes be preferred because it conforms more closely to production economics theory. If *K* is to be determined from a production function, it is necessary to convert the biological effects of weed control on yield into an equivalent shift in the initial supply curve S_0 in Figure 2. This is given as the difference in the marginal costs of production between the weed-affected and weed-free systems.

Estimating the adoption rates of a new weed control technology defines the part of the industry most likely to be affected by its introduction. In *ex ante* situations, adoption rates are often given in terms of either the number of producers expected to adopt improved weed control or the number of production units likely to be affected. These can be established by elicitation methods (asking researchers and industry experts to nominate likely adoption scenarios), and are most conveniently expressed as changes in the level of production, i.e., controlling a certain weed is likely to increase average production by some proportion. This can then be converted into an adjustment factor to the equilibrium production level for use in the econometric simulations. Adoption rates measured in these terms are usually sensitised according to various criteria. In *ex post* analyses, adoption rates can be more directly measured through surveys and other methods.

The need to incorporate the industry's time path of adjustment recognises the time required for improved weed control to be absorbed into an industry. This consideration affects the time flow of benefits from weed control, which then affects the benefit-cost comparisons over time. This means that technologies which are rapidly adopted are likely to have greater long term payoffs that those with longer adoption profiles. The effects of different adjustment periods can be examined by simulating the weed impacts over different samples within the econometric model's estimation sample period. For example, the effects of quick adoption might be simulated over one year and over several years where adoption is based on longer lags. This is likely to produce different sets of equilibrium prices and quantities, different levels of change in economic surplus and hence, different benefit-cost criteria when the benefit flows are discounted over time.

4. Benefit-Cost Analysis

In this integrated modelling system, the benefit-cost analysis (BCA) is the endpoint of the evaluation for a particular weed. This will usually be a social BCA in which the benefit estimates are derived from the economic surplus model component and the costs are those of the research program for the weed in question. BCA is necessary because weed control options will likely involve different flows of costs and returns over time and this requires the use of discounting procedures. Some difficulties may arise in the social BCA context where it is necessary to measure all monetary benefits and costs and those for which market prices do not exist or are difficult to establish under normal pricing methods. Valuing environmental benefits and costs from weeds on public lands is an example in which non-market pricing methods have to be adopted.

5. Evaluating Weed Impacts: An Example Application

This section presents an example to demonstrate the application of this economic modelling system in evaluating weed problems. The example describes the application of this system in evaluating the farm and industry impacts of a weed problem and traces the cost from the farm level to the broader industry using a combination of LP, econometric modelling and economic surplus analysis. This weed scenario is hypothetical and considers the effects of Paterson's Curse in an irrigated sub-clover pasture in the Murrumbidgee Irrigation Area[1]. Here, the main assumption is the impact of Paterson's Curse in these pastures results in a 20 percent reduction in dry matter production.

5.1 Production system analysis

A LP model was constructed to represent a 250 hectare farm which is fully irrigable and 70 percent landformed. The irrigation allocation is 1,400 megalitres annually and there is a water delivery constraint of 550 megalitres per month to the farm. There is one owner-operator who contributes 56 hours of labour per week to the farm operation which is converted into a seasonal equivalent. The main activity is second-cross lamb production which utilises lucerne and sub-clover pastures. Lucerne is only grown on the landformed areas while sub-clover is produced on both layout types. Sub-clover can also be grown as a dryland enterprise if irrigation water is limiting. Both lucerne and sub-clover are directly consumed by livestock.

The objective function values are given in Table 1. Only second-cross lamb production and sub-clover have positive values, while the remaining activities have negative values as they are production inputs. The objective function of the model is to maximise whole-farm gross margin. Dry matter production is 10.42 and 9.02 tonnes per hectare for landformed and non-landformed sub-clover respectively. The annual lucerne dry matter production is 14.75 tonnes per hectare. These yield figures are converted to an energy equivalent in livestock months (LSMs) to be consistent with the feed energy demands of livestock. Details of the seasonal demands and supply of feed energy, along with seasonal labour demands, are given in Table 2. Lucerne requires 10 megalitres per hectare of irrigation water, sub-clover on landformed layouts 5.6 and sub-clover on non-landformed layouts 4.9 megalitres per hectare. The monthly irrigation requirements specified for these activities in the model are given in Table 3.

The LP results in Table 4 indicate the differences in the with and without weed situations. Here, the impact of Paterson's Curse, represented through a 20 percent decline in sub-clover pasture dry matter production, reduces farm gross margin by $7,303, or 12 percent. Breeding ewe numbers decline by 144 (8.6 percent) because of the lower feed availability, while sub-clover hay sales decline by 473 bales (8.7 percent). There is a small increase in the area of landformed sub-clover at the expense of lucerne pasture, because winter feed availability becomes a limiting resource as ewe feed requirements are highest in this period. As lucerne provides only minimal feed in winter, it is partly offset by the higher winter

[1] Paterson's Curse is one of the four main "target" weeds in the CRCWMS research program. To date, the actual parameters required for this type of analysis have yet to be established under research. This *ex ante* example is intended to demonstrate the potential benefits of using this modelling system to evaluate weed control where it involves direct interactions between farm resources over time and market effects from supply increases.

producing sub-clover despite this activity having suffered a yield decline due to Paterson's Curse. Overall, the effects of Paterson's Curse is to reduce whole farm profit by approximately $29 per hectare. At present gross margin estimates, this loss is equivalent to about 1.5 breeding ewes per hectare.

Table 1: Objective function values of model activities	
Second-cross lambs ($/ewe)	50.00
Sub-clover hay ($/bale)	2.50
Lucerne ($/ha)	40.00
Landformed sub-clover ($/ha)	30.00
Non-landformed sub-clover ($/ha)	25.00
Dryland sub-clover ($/ha)	10.00
Irrigation water ($/megalitre)	12.73
Hay making ($/bale)	1.35
Permanent labour ($/man year)	30,000

Table 2: Seasonal feed energy and labour coefficients

	Spring	Summer	Autumn	Winter
Feed supply (LSM/ha):				
Lucerne	66.90	91.55	51.47	35.60
Landformed sub-clover	49.98	0.00	32.59	56.23
Non-landformed sub-clover	43.16	0.00	28.14	48.90
Dryland sub-clover	14.38	0.00	8.99	25.48
Feed demand (LSM/ewe):	5.69	4.29	6.67	8.49
Labour requirements:				
Lucerne (hrs/ha)	1.60	4.80	1.91	0.65
Landformed sub-clover (hrs/ha)	1.00	1.19	1.16	0.10
Non-landformed sub-clover (hrs/ha)	0.50	0.76	1.87	0.13
Dryland sub-clover (hrs/ha)	0.10	0.15	0.37	0.03
Second-cross lambs (hrs/ewe)	0.15	0.05	0.07	0.06

Table 3: Monthly irrigation requirements (Ml/ha)

Month	Lucerne	Landformed sub-clover	Non-landformed sub-clover
September	1.12	1.00	
October	0.80		
November	1.12		
December	1.12		
January	1.12		
February	1.16	2.30	
March	0.80	1.40	2.30
April	0.80	0.90	0.70

Table 4: Effect of Paterson's Curse in sub-clover on farm plan		
	Without weed	With weed
Farm gross margin ($)	62,175	54,872
Number of ewes	1,669	1,525
Sell sub-clover hay (bales)	5,431	4,958
Lucerne (ha)	78.2	71.5
landformed sub-clover (ha)	96.8	103.5
Non-landformed sub clover (ha)	75.0	75.0
Sub-clover LSM's:		
- spring	4,266	3,897
- summer	0	0
- autumn	6,581	6,012
- winter	11,386	10,405
Lucerne LSM's:		
- spring	5,233	4,782
- summer	7,161	6,544
- autumn	4,026	3,679
- winter	2,785	2,545
Hay making (bales)	6,122	5,592
Feed hay in autumn (bales)	692	634
Allocation (ML's)	1,396	1,379
Operators labour (hrs):		
- spring	505	480
- summer	624	593
- autumn	524	508
- winter	180	167

5.2 Industry analysis

The significance of this loss to the prime lamb industry was evaluated using a structural econometric model of the Australian industry (Vere, Griffith and Bootle, 1994), where the benefits of Paterson's Curse control was considered to be equivalent to the prevention of the economic loss it causes. This was expressed through the increased number of breeding ewes that could be carried in the region on the additional feed (and the subsequent effects of this on the lamb industry), and was estimated to be equivalent to a 1 percent increase in the Australian short wool breeding ewe inventory. The supply shift parameter following weed control (K in equation 2) was derived from the LP solution and was estimated to be a 19 cent per kilo liveweight reduction in the cost of lamb production. The lamb prices and quantity changes (Table 5) came from the results of an econometric simulation of what where the before and after weed control situations where the latter was represented by the breeding ewe inventory increase (a 2 percent inventory increase was also evaluated for comparison).

5.3 Economic surplus analysis

Incorporating these parameters in the economic surplus equations gave the benefit levels for Paterson's Curse control (Table 6). The results indicate that the control of this weed in one New South Wales lamb producing region has the potential to generate significant annual benefits to Australian lamb producers and consumers. Producers gain because the revenue gains from the increased lamb production outweigh the losses from the slightly reduced farm lamb price. Lamb consumers gain from the combined effects of higher quantities of lamb on the market and the corresponding lower retail prices. Producers gain the greatest benefit share because lamb has a low price elasticity of supply and an elastic retail demand relative to other meats in the Australian domestic meat market. Overall, the lamb industry has the potential to gain about $8.5 million per annum where improved weed control in a small part of the industry enables higher lamb production in the lamb industry. This is despite the falls in both farm and retail prices as a consequence of the production increases[2].

It should be noted that these benefits are net of the input costs of lamb production and weed control which are incorporated in the industry supply curve, but they do not include the costs of the development of any new Paterson's Curse control technology that may be developed. Also, the partial nature of the analysis means that there will elements of both over and understatement of the benefits. The benefits will be partly overstated because they do not consider the adjustments in closely related product markets, such as the effects on the demand for other meats from increased lamb supplies and lower retail lamb prices. Also, the benefits may be understated since other industries (e.g., wool and fodder) are also likely to benefit from improved weed control. A BCA has not been attempted because the costs of research into this weed have yet to be determined.

Table 5: Parameter estimates for economic surplus model

Parameter	Base values	Short wool breeding ewe inventory increase 1 %	2 %
Farm lamb price (P_{0F})	20.77	20.33	19.85
Lamb production (Q_{0F})	259.41	262.59	265.12
Retail lamb price (P_{0R})	88.13	87.57	87.10
Retail lamb demand (Q_{0R})	227.84	230.79	232.83
Supply shift (K)		-0.14762[b]	-0.14762

[a] given as average 1990 values; prices are in real terms (deflated by the CPI)
[b] K = 19/128.71 where the denominator is the nominal 1990 average farm lamb price

Table 6: Results of economic surplus analysis - annual benefits from Paterson's Curse control in the MIA ($millions)

	Short wool breeding ewe inventory increase 1 %	2 %
Change in consumers' surplus	1.091	2.172
Change in producers' surplus	7.348	6.620
Change in total surplus	8.44?	8.791

[2] Because this example considers a technology which affects only part of the lamb industry in a specific region, the more complete evaluation of the benefits from weed control should also consider how the regional lamb supply shift relates to the lamb industry, as this might influence the overall level of industry benefits. Edwards and Freebairn (1982) have described the economic rationale for this level of benefit disaggregation and the methods required to estimate them.

6. Summary

The objective of this paper has been to describe the use of an integrated economic modelling system for evaluating the impacts of weeds and the benefits of weed control in Australian agricultural industries. This objective recognises that improved technology adoption is an important source of productivity gains in farm production and that improved weed control is a prominent example of a technology which could produce such gains.

Producers benefit from the adoption and maintenance of improved weed control through opportunities to lower their production costs. However, widespread weed control can be expected to have market impacts where it results in increased output. Because weed control is likely to have economic implications beyond the farm, an economic modelling approach which considers both the farm and market components of the affected industry is required to assess the potential benefits.

Farm models establish the output and revenue changes resulting from weed control under farm constraints and producer objectives. The approach adopted for any particular evaluation will depend on the characteristics of the farm and the technology being modelled. The results of applying these models provide producers with assessments of the benefits of adopting the weed management options. By highlighting the productivity and profitability changes, producers gain an appreciation of those weed control options best suited to their situations and improving resource use is encouraged as a result. Industry supply responses are estimated by aggregating the farm responses under an assumed level of technology adoption across the industry. With estimates of the supply and demand curves, the type of supply shift, and the relationship between producer and consumer prices, measures of total benefits and costs from improved weed control are derived. Both sets of results are useful in identifying the options in weed research programs to allow the efficient allocation of the research budget.

References

Alston, J.M. (1991). "Research benefits in a multimarket setting: a review", Review of Marketing and Agricultural Economics 59(3), 23-52.

Anon, (1995), Introduction, in Weed Watch Newsletter, Cooperative Research Centre for Weed Management Systems, No. 1, CSIRO Entomology, Canberra.

Combellack, J.H. (1987), "Weeds in cropping - their cost to the Australian economy", Plant Protection Quarterly 2(1), 2.

Edwards, G.W. and J.W. Freebairn (1982), "The social benefits from an increase in productivity in a part of an industry," Review of Marketing and Agricultural Economics 50(2), 193-209.

Fisher, B.S. and R.R. Lee (1981), "A dynamic programming approach to the economic control of weed and disease infestations," Review of Marketing and Agricultural Economics 49(3), 175-187.

Industries Assistance Commission (1985), *Biological Control of Echium Species (including Paterson's Curse/Salvation Jane)*, AGPS, Canberra.

Kennedy, J.O.S. (1987), "The economics of weed control," Plant Protection Quarterly 2(3), 118-123.

Pandey, S. (1989), Economics of wild oats control: an application of a stochastic dynamic programming model, Paper presented to the 33rd Annual Conference of the Australian Agricultural Economics Society, Lincoln College, New Zealand.

Pandey, S. and R.W. Medd (1990), "Integration of seed and plant kill tactics for control of wild oats: an economic evaluation," Agricultural Systems 34, 65-76.

Pandey, S. and R.W. Medd (1991), "A stochastic dynamic programming framework for weed control decision making: an application to *Avena fatua* L.," Agricultural Economics 6, 115-128.

Pannell D.J. (1984), "Using simulation for economic assessment of the skeleton weed eradication programme in Western Australia," Australian Weeds 3(4), 146-149.

Pannell, D.J. (1988), "Weed management: a review of applied economics research in Australia," Review of Marketing and Agricultural Economics 56(3), 255-269.

Pannell, D.J. (1990), "An economic response model of herbicide application for weed control", Australian Journal of Agricultural Economics 34(3), 223-241.

Pannell, D. and D. Panetta (1986), "Estimating the on-farm cost of skeleton weed (*Chondrilla juncea*) in Western Australia using a wholefarm programming model," Agricultural Ecosystems and Environment 17(3/4), 213-217.

Schmidt, C., Pannell, D. and V. Stewart (1994), Economics of herbicide resistance in weeds, Paper presented to the 38th Annual Conference of the Australian Agricultural Economics Society, Wellington, New Zealand.

United States Department of Agriculture (1965), *Losses in Agriculture*, Agricultural Handbook No. 291, USDA, Washington, DC., pp. 120.

Vere, D.T. and B.A. Auld (1982), "The cost of weeds", Protection Ecology 4, 29-42.

Vere, D.T., Griffith, G.R. and B.W. Bootle (1993), "Alternative breeding inventory specifications in a livestock market model," Australian Journal of Agricultural Economics 37(3), 181-204.

Vere, D.T., Auld, B.A. and M.H. Campbell (1993), "Economic assessments of serrated tussock (Nassella trichotoma) as a pasture weed", Weed Technology 7, 776-782.

Vere, D.T., Sinden, J.A. and M.H. Campbell (1980), "Social benefits of serrated tussock control in New South Wales", Review of Marketing and Agricultural Economics 48(3), 123-138.