An Economic Framework for Evaluating the Size of Benefits from Weeds Research

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Abstract

A conceptual framework is developed for evaluating the relative size of benefits from research at manipulating various demographic parameters such as fecundity and seed mortality of weeds. Demographic studies indicate that long term control of weeds might be better achieved by these means in conjuction with herbicide treatment. An optimal control theory approach is used to predict the optimal steady-state population of weeds resulting from research-induced changes in demographic parameters. The benefits from research are evaluated by estimating the magnitudes of the ensuing supply shifts.

1. Introduction

Demographic studies in weed science indicate that long term control of weeds might be better achieved by reducing weed fecundity and by increasing weed seed mortality (Medd and Ridings 1990) as opposed to the more common approach of killing weed plants by herbicide treatments. However, no practical means are currently available for attacking weeds during phases other than the plant. From an economic-point-of-view, it would be useful to attempt to quantify the size of gains that could be expected if technologies could be developed to alter the demographic parameters in the desired directions. Such information would be useful in deciding whether or not research into these alternative modes of weed control are to be supported. The objective in this paper is to present a framework to estimate such benefits.

In this paper, weed management is cast in a more general framework of management of renewable biological resources. However, unlike fisheries which produce economically valuable outputs, weeds are negative resources in the sense that they reduce outputs. The well-known economic externality issues involved in the management of such resources are not addressed here by assuming weeds to be privately-owned resources.

In the next section, an economic framework for evaluating research benefits in the context of a renewable biological resource is developed. An illustrative application of the model for the management of grass weeds in Australian wheat production is presented in the subsequent sections.

2. An Economic Framework

Adoption of knowledge resulting from applied research in agriculture leads to an outward shift in the commodity supply function. The gross benefits of research are usually evaluated as the sum of the changes in producers' and consumers' surpluses. Numerous studies have been undertaken at the commodity level using this framework (Lindner and Jarrett 1978, Norton and Davis 1981). In an ex-ante analysis the parameters required for estimating the size of gross agricultural research benefits (GARB) are the demand and supply elasticities at the pre-innovation market equilibrium, the intercepts of the old and new supply functions with the price axis, and the magnitude of cost reduction at different levels of output. As the magnitude of cost reduction for infra-marginal units of output is difficult to estimate in studies based on observed output and prices, the usual procedure has been to estimate the magnitude of cost reduction at the pre-innovation market equilibrium point and infer such estimates for other output levels by assuming a specific form of the post-innovation supply function. If the post-innovation supply function is assumed to be linear, the intercept at the price axis and the magnitude of cost reduction at the initial equilibrium point define the whole supply function.

Lindner and Jarrett (1978) have shown that the size of GARB depends on the nature of the supply shift. They speculate that the nature of the supply shift could be ascertained by examining the effects of innovation on the infra-marginal units of output. If the relevant range of the supply function could be synthesised by modelling as opposed to the alternative of assuming it to be of a particular form, the nature and the extent of the supply shift could be derived from the underlying normative model. Thus the model could be freed of some of the arbitrariness involved in determining the nature and the magnitude of the supply shift.

Under perfect competition, a long run supply curve is, by definition, the locus of the minimum points in the average cost curves. Thus at each point along the long run supply curve, the average cost and the average revenue (or price) are equal. At the long run equilibrium, the profits, prices, and the number of firms remain constant from one time period to the next. If output is a function of the stock of renewable biological resources as well as of other inputs, the stock of biological resource must also be at a steady-state equilibrium at each point along the long run supply curve. Thus points along the long run supply curve satisfy the following conditions:

(a) the stock of renewable biological resources is in a steady-state equilibrium,
(b) the steady-state equilibrium is the one that maximises profits, and
(c) the price of output is equal to the average cost.

It may be conven[illegible] to divide the task of synthesising a long run supply curve into two steps. The first ste[illegible] to estimate the economically optimal steady-state stock of biological resources given the prices and costs. The second step is to ensure that the price of output at the optimal steady-state is equal to the average cost.

The problem in the first step is represented in the following mathematical formulation

$$\text{Maximise PV} = \int_{t=0}^{\infty} \text{Exp}(-\alpha t)[P_y \, B(S_t\,, X_t\,/\,Z_t) \; - P_x \, X_t] \,, \qquad (1)$$

subject to

$$dS/dt \;=\; G(S_t\,, X_t), \text{ and} \qquad (2)$$

$$G(S_t\,, X_t) \;=\; 0, \qquad (3)$$

where, PV is the present value, P_x and P_y are the vectors of input and output prices, respectively and α is the discount rate. Gross revenue B is a function of the stock of biological resources (S), the quantities of inputs X which influence S, and other inputs Z assumed to be employed at a constant level. The function G represents the dynamics of the stock of biological resources.

Privately-owned renewable biological resources are managed so as to maximise the discounted sum of all future gains. This is represented in equation (1). The maximisation in (1) is constrained by equation (2) which defines the feasible changes in the stock of biological resources which are subject to their own natural growth. At a steady-state, the stock of biological resources remains constant. This is shown in equation (3). Thus by jointly solving equations (1) through (3), the economically optimal steady-state can be obtained. The supply of output corresponding to each optimal steady-state can be obtained by solving the optimisation problem for a range of output prices. The model can be solved by applying the tools of the optimal control theory.

To derive a valid long run supply function, the second step is to ensure that the output price is equal to the average cost. In an ex-ante evaluation, it may be reasonable to assume that the pre-innovation average cost is equal to the price corresponding to each optimal quantities of output. Under perfect competition, entry or exit of firms will ensure that equilibrium price is always equal to average cost. Thus if pre-innovation markets are assumed to be in a long run equilibrium, solution of the optimisation problem produces a long run supply curve. The solution also gives the optimal cost of input X. This is denoted by C_0.

In this framework, the effect of an useful innovation is to lower the average cost of inputs X at a given output level. For example, research leading to a reduction in fecundity of weeds may result in savings in the cost of herbicides at constant output level. If it is assumed that the innovation alters functions B and/or G, the steady-state optimal output after the innovation is adopted can be obtained by solving the model described above for new functions B and/or G. The optimal cost of input X corresponding to the pre-innovation output level (Q) can also be derived. Let us denote this by C_1. Since average revenue (or price) must equal the average cost for a long run equilibrium, the post-innovation average revenue at Q must be equal to $P - (C_0 - C_1)/Q$. In Figure 1, the savings in cost at Q is MN and NQ is both the average cost and average revenue corresponding to Q. Thus N is a point in the post-innovation long run supply function. Other points in the supply function can similarly be derived. In this procedure, the nature of the supply shift becomes endogenous and is dictated by the nature of the optimisation problem.

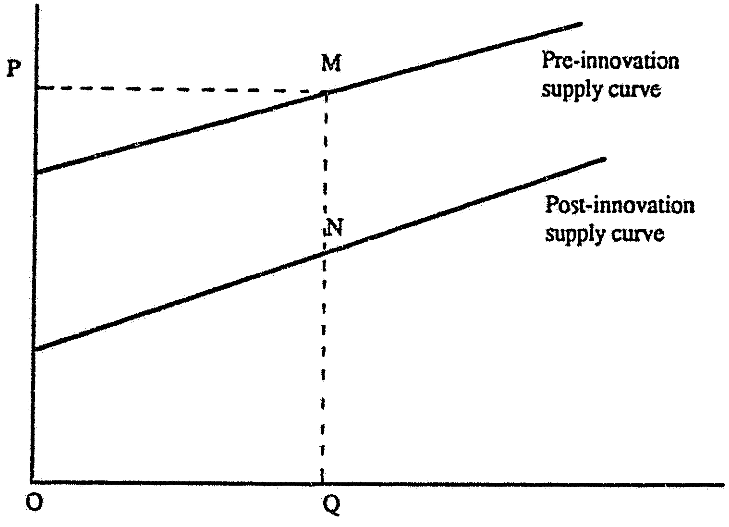

Figure 1: Derivation of the Post-innovation Supply Curve

3. Weed management model

The weed management model consists of submodels for weed demography, crop yield response to weed density and weed kill response to herbicide dose.

A simple weed demography model is used here. The natural dynamics of seed bank is represented by the Schaeffer model which has been extensively used in the fishery literature (Hartwick and Olewiler 1986). The model is written as

$$dS/dt = \gamma S (1 - S/K), \tag{4}$$

where, γ is the intrinsic growth rate and K is the carrying capacity of the environment. The parameter γ represents the growth rate when the seed bank approaches zero. It is a function of recruitment (g), seed mortality (m) and fecundity (f) and is approximated as

$$\gamma = \ln (1 - g - m + f g). \tag{5}$$

The yield response to weed density is represented by a linear function of weed density (W) at harvest.

$$Y = Y^* (1 - \delta W) \tag{6}$$

where, Y^* = weed-free yield, and
δ = marginal yield reduction due to weed.

The yield response in equation (6) is assumed to be weakly separable in herbicide and non-herbicide inputs. W is a function of herbicide whereas Y^* is a function of all other inputs. A change in output price alters output through changes in weed-free yield and herbicide dose. The response of Y^* to output price is represented by

$$Y^* = C P_y^e, \tag{7}$$

where, C and e are parameters.

The weed density at maturity is a function of pre-treatment weed density and the herbicide dose. The pre-treatment weed density is assumed to be a constant proportion of the seed bank. The kill function (k), defined as the proportion of weeds killed, is assumed to be exponential

$$k = 1 - \mathrm{Exp}\,(-\theta\ X), \qquad (8)$$

where, X is the herbicide dose and θ is a parameter. The herbicide considered is diclofop-methyl which is widely used to control grass weeds in wheat.

4. Estimation of GARB

Given the likely complexities of the functions B and G, the optimisation problem will have to be solved generally by numerical methods. Since the exercise here is purely illustrative, a closed form solution was derived by assuming that the farmers implement weed control decisions so as to maximise current profits (as opposed to profits over several periods). This is equivalent to assuming the discount rate to be infinity. Both the pre- and post-innovation supply functions were obtained by following the procedure described in section (2).

The synthesised supply functions were mildly non-linear. To simplify estimation of GARB, the supply functions were linearised by reference to two points : the intercepts at the price axis and the market equilibrium points.

At the point where supply function cuts the price axis, farmers are able to meet all costs of production. The pre-innovation intercept is thus derived as the sum of the optimal herbicide cost and the minimum cost of cropping an unit area of land. For Australian wheat production, the minimum cost was assumed to be $59/ha. The output corresponding to the price intercept is not zero but is a positive quantity that equates the total cost and the total revenue. The post-innovation intercept is derived from the pre-innovation intercept by re-solving the optimisation problem for the output corresponding to the pre-innovation intercept.

Given the export-orientation of Australian wheat market, the elasticity of demand was assumed to infinite at price level $120/t. Demand function of any elasticity can easily be incorporated if considered appropriate.

5. Results and Discussions

GARB corresponding to research on 'idealised' weed types were estimated. The weed types correspond to different combinations of the three demographic parameters viz. seed mortality, recruitment and fecundity. For each parameter, two values, one high and another low, were considered. Thus weed type 'A' in Table 1 consists of weeds with low seed mortality, low recruitment and low fecundity. Results for six different permutations are presented in Table 1. The parameters that are assumed to be manipulated by research are seed mortality, fecundity, weed competitiveness and the herbicide productivity. GARB per unit area corresponding to one-at-a-time change by 50 per cent of the initial values of each of these parameters are presented.

Table 1 indicates that reducing the herbicide dose by 50 per cent to achieve the same proportion of weed kill produces the highest gain whereas a reduction of weed competitiveness by 50 per cent produces the lowest gain. As mentioned in section (2), the magnitude of the supply shift measured here is equal to the cost savings in herbicide. Hence, it is not surprising to find largest gain being produced by an increase in herbicide productivity.

Of the demographic parameters considered, a reduction in fecundity by 50 per cent appears to be more beneficial than an increase in seed mortality by an equal per cent. Benefits from the reduction in fecundity is high when the initial fecundity is low (weed types A and E). Thus, it appears that the reduction in fecundity is subject to increasing returns. This means that if the cost of reducing fecundity is independent of the initial fecundity, research in fecundity reduction will be more attractive for weeds with low fecundity. However, the marginal cost of reducing fecundity is likely to increase as the weeds become less fecund. A complete picture could be obtained by considering the benefits and costs together.

The research leading to an increase in seed mortality seems to generate more benefits when the initial mortality is high and the initial recruitment is low (weed types E and F). When recruitment is low, the only means of depleting the size of the seed bank is through increased seed mortality. However, when recruitment is high (as with weed types C and D), GARB from an increase in mortality is low, as would be expected.

Table 1

Estimates of GARB Per Unit Area

Weed type	Demographic* characteristics	Research Activity: 50% increase in seed mortality	50% reduction in fecundity	50% reduction in weed competitiveness	50% increase in herbicide efficiency
		($/ha)	($/ha)	($/ha)	($/ha)
A	$m_1g_1f_1$	0.49 (0.23)**	1.05 (0.48)	0.31 (0.14)	4.60 (2.11)
B	$m_1g_1f_1$	0.30 (0.22)	0.52 (0.38)	0.53 (0.40)	4.85 (3.61)
C	$m_1g_2f_1$	0.17 (0.07)	0.67 (0.29)	0.04 (0.02)	4.70 (2.04)
D	$m_1g_2f_2$	0.16 (0.10)	0.32 (0.20)	0.06 (0.04)	5.46 (3.34)
E	$m_2g_1f_1$	0.85 (0.24)	1.59 (0.46)	0.12 (0.03)	4.14 (1.19)
F	$m_2g_1f_2$	0.72 (0.32)	0.51 (0.23)	0.30 (0.14)	4.67 (2.11)

* m, g and f denote seed mortality, recruitment and fecundity, respectively. The initial values assumed are $m_1 = 0.1$, $g_1 = 0.1$, $f_1 = 20$, $m_2 = 0.5$, $g_2 = 0.5$ and $f_2 = 200$.

** Figures in parentheses are the elasticities of changes in GARB with respect to changes in the respective parameters.

The benefits from reduction in weed competitiveness are highest for weed type B which has low mortality, low recruitment and high fecundity. For all other weed types, research into reduction of weed competitiveness seems low yielding.

The results presented in Table 1 indicate that research into improving the herbicide productivity is by far the most profitable. However, the marginal cost of doing so might be very high given the current high productivity of herbicides and substantial research already undertaken by private companies to improve herbicide efficiency. The benefit cost ratio may actually favour research into manipulation of fecundity and seed mortality because these avenues are relatively unexplored. For the sake of illustration, if GARB is linearly related to herbicide efficiency, and if achievement of a 10 per cent increase in herbicide efficiency costs as much as a 50 per cent decrease in fecundity, then research into reduction of fecundity becomes relatively more attractive for weed types A and E.

Although the results of the type presented in Table 1 tell only the benefit side of the story, they, nevertheless, are useful information for research resource allocation. The analysis can be made complete if a research production function relating the cost of research to the magnitude of changes in parameters could be derived. Given the uncertainties involved in research, such an exercise is unlikely to yield precise results. Thus, decision making would of necessity have to be based on judgement backed up by whatever incomplete and imprecise information that can be generated.

6. Summary and conclusions

In this paper, a generalised framework for evaluating gains from research aimed at altering the parameters of a production system based on renewable biological resources was developed The research benefits were evaluated in terms of consumers' and producers' surpluses. Both the pre-and post-innovation long run supply functions were derived by solving a set of dynamic optimisation problems. In this approach, the nature and the magnitude of estimated supply shift are endogenous and depend on the parameters of the production system. The model thus avoids the arbitrariness that exist in determining the nature of supply shift in the currently available models of estimating research benefits.

The model was illustrated by application to weed control research. Although benefits from improving herbicide effectiveness were found to be substantial, conditions under which reductions in fecundity and weed seed mortality might be profitable were identified.

The results indicate that research into fecundity reduction is likely to be more profitable for weeds which have low recruitment and low initial fecundity. On the other hand, efforts to increase seed mortality are likely to be worthwhile when recruitment is low and initial mortality is high. Such information can be expected to facilitate improved allocation of resources in weeds research.

7. References

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