ECONOMIC THRESHOLDS IN PEST MANAGEMENT UNDER RISK

by
Yusman Syaukat, PhD
Department of Resource and Environmental Economics
Faculty of Economics and Management
Bogor Agricultural University, Bogor - Indonesia
ysyaukat@ipb.ac.id

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ysyaukat2@yahoo.com

ABSTRACT

Pesticide use in agricultural production is a controversial issue. The issues include: measurement of pesticide productivity, contribution to the crop yield, rate of application, and its economic contribution to the decision makers. The other important issue is related to the consideration of risk and uncertainty in modelling of the economics of pesticide control. The purpose of the paper is to explore the relationship between the damage and control functions, and to extend the model of economic thresholds to include risk and uncertainty.

Measurement of pesticide productivity is frequently biased. This is due to the functional form chosen for the control and damage functions in empirical work on pest control. Most studies on the economics of pesticide control have neglected the existence of risk and uncertainty. In fact, risk and uncertainty are important factors in decision making in pest management. Ignoring risk and uncertainty may lead to wrong recommendations. In general, existence of risk and uncertainty does not necessarily lead to increase pesticide use by individual farmer. There are some sources of uncertainty that affect decision making for pest management.

Results of incorporating a stochastic initial pest population variable into an exponential control function and a linear damage function show that the farmer will apply pesticide until its price is just equal to the reduction in profit variability plus the expected loss reduction. The threshold pest population increases with the cost of pesticide and decreases with increases in output price, marginal damage coefficient, variance of pest population, and risk aversion parameter.

Keywords: pesticide economics, risk, damage and control functions, pest threshold

1. BACKGROUND

Damage control agents, such as pesticides and herbicides, are important factors in agricultural production. Unlike standard factors of production (land, labour or fertilizer), these inputs do not directly increase output. Instead, their contribution lies in their ability to increase the share of potential output by reducing damage from both natural and human causes (Lichtenberg and Zilberman, 1986).

Pesticides are arguably the class of damage control agents most in the public eye at present (Babcock *et al*, 1992). Objections to the use of synthetic chemicals in food and fibre production have grown over the years, forcing government regulators to make increasingly hard choices concerning their availability to producers. Accurate information about the productivity effects of pesticides is increasingly important.

Economic efficiency is another important issue related to pest management economics. Inadequacy and inaccuracy of information on the impact of pesticide on crop productivity have resulted in an economic inefficiency[1]. Farmers, animated by risk aversion, tend to over-apply pesticides (Chambers and Lichtenberg, 1994). Since they do not have adequate information, they apply pesticide on the basis of precaution. In other situations, the neglect of economically optimal pesticide rates in the agricultural economics and pest science literatures, has caused many farmers to use pesticide rates other than those recommended on chemical labels (Pannell, 1990)[2]. Pannell reports that in the Western Australian wheat belt, farmers routinely cut rates. Halving of recommended dosages is not uncommon. They are determining the optimal dosages on a trial-and-error basis. This result has been particularly surprising since there is evidence that pesticide is overused in agriculture.

A number of studies have been conducted the economics of pesticide use in agriculture. They include theoretical and normative empirical models of pest management at the farm and at regional level. Studies have incorporated the available entomological knowledge in their specification and have derived optimal management patterns and policy recommendations (Lichtenberg and Zilberman, 1986). Most studies have used econometric models with various functional forms of pest and disease management (Lichtenberg and Zilberman 1986, Blackwell and Pagoulatos 1992, Carrasco-Tauber and Moffitt 1992, Fox and Weersink 1995). However, those studies still neglect the existence of risks, both risks on crop production activities and

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[1] The information is not only from technical relationship between pesticide use and crop productivity, but also from economic point of view.

[2] Although it is clear that the pesticide rates recommended on the product labels are not economically efficient in many circumstances.

farmers' risk preferences. Incorporation of risks in the model of pest management strategy will make it more realistic. Risk has been perceived as an area of considerable important in the literature on the economics of pest control in agriculture (Pannell, 1990).

The purpose of this paper is to explore the relationship between the damage and control functions, and to extend a model of economic thresholds to incorporate risk and uncertainty. They include both farmers' risk preference and uncertainty on agricultural production. Incorporation of risk and uncertainty in the model could improve the capability of the model in predicting the intensity of crop damage and crop yield, therefore it could help farmers in allocating their scarce resources efficiently. This model is a modification and extension of the previous studies. In this study, some deterministic assumptions of the damage control models, particularly assumption that the farmers have perfect knowledge, will be relaxed. This will allow the model to provide more realistic solutions that are beneficial to the farmers.

2. LITERATURE REVIEW

The purpose of this literature review is to discuss some important issues on the economics of pesticide management. The issues involve the estimation of pesticide productivity and the functional forms chosen for the control and damage functions, the consideration of risk and uncertainty in the model of pest management economic, and the farmers' risk preferences.

Mumford and Norton (1984) described three different approaches to support decisions on pesticide application. The approaches are: the economic threshold concept and the marginal analysis concept (based on a deterministic approach) and the decision theory concept (based on a probabilistic approach). In the deterministic model, uncertainty in various parts of the model is ignored. The model outcome is calculated using average values of model inputs and parameters. Application of these approaches results in a recommendation to a farmer, and as such the concepts are prescriptive. In contrast, the second approach is normative. It incorporates value judgements to prescribe what ought to be done. It does this by indicating that one strategy is better than another, according to specific, subjective criteria.

The use of synthetic chemical pesticides tends to be increasing, though many of them have a negative impact on human health, environment, and economic activities. Because of the negative impacts inherent in pesticides, it would seem that their use is excessive. Some studies (Headley 1968, and Campbell 1976) show that the value of marginal product of pesticides has exceeded its marginal factor cost. This indicates that pesticides have been under applied. These results have been particularly surprising since other evidence suggests that pesticide materials are overused in agriculture. Norgaard (1976) has argued that imperfect information and farmers' risk aversion have added the perceived uncertainty as a major factor in inducing pesticide use.

Norgaard stated that the farmers have applied pesticides beyond the point where the value of marginal product is equal to the marginal cost of the pesticides. In relation to this issue, Fox and Weersink (1995) have shown that the increasing returns to the damage control inputs can occur even when control and damage functions are concave. They suggest us to pay more attention on the functional form selection for the damage and control functions.

Some investigators have attempted to measure pesticide productivity econometrically. The focus of the studies includes contributions to harvest yield, estimation of production function and system of output and pesticide demand, and effectiveness of pesticide on quality of output (Babcock *et al*, 1992).

Lichtenberg and Zilberman (1986) argued that a key feature in explaining possible overvalue of pesticide productivity, in econometric studies, is the functional specification employed in these studies. They showed that the use of traditional specification (i.e. Cobb Douglas) leads to overestimation of the productivity of damage control inputs and underestimation of the productivity of other inputs. They developed an alternative model of production which involves damage control inputs to accommodate particular characteristics of such inputs. However, Blackwell and Pagoulatos (1992) argued that this study could not specify the correct form of the chemical damage abatement. By including the state variable, they discover that the effect of chemical damage abatement enter the model is as the proportion of damaging agents remaining. This is as opposed to the Lichtenberg and Zilberman assumption that it is proportion of damaging agent killed.

Carrasco-Tauber and Moffitt (1992) have shown that aggregate pesticide productivity estimates depend on the functional form chosen for the damage function. They compared a Cobb-Douglas production function with exponential, logistic, and Weibull damage-control specifications in estimating pesticide productivity in aggregate U.S. crop production.

Fox and Weersink (1995) further explore the relationship between the damage and control functions, and to illustrate the possibility of increasing returns in the use of damage control inputs. They develop a two-stage process involved with damage control inputs and evaluate seven alternative control and damage functions. The functional forms are: Pareto, exponential, logistic, Weibull, rectangular hyperbola, linear response plateau, and square root response plateau. Their results suggest that a small variation in functional form can have a profound impact on the economic analysis. The possibility of increasing returns increases when the relative curvature of the control function is less than that of the damage function.

Assessment on the issues of economic efficiency of pest management is incomplete without considering the existence of risk and uncertainty. This is because risk and uncertainty are important characteristics of decisions on pest management (Pannell, 1990 and 1991). A decision is said to be risky when its precise outcome is not known when the decision must be taken (Webster, 1977). In agricultural production such decisions are often unavoidable. It is thus a matter of importance to investigate the impact of uncertainty on decisions made by risk-averse farmers regarding pesticide use and the way it affects reaction to various changes.

Norgaard (1976) argued that a major motivation for pesticide applications is the provision of 'insurance' against damage; that is the existence of uncertainty in the pest-pesticide system. This reduction in the degree of uncertainty will increase the farmers' expected profits or utilities.

Feder (1979) stated there are two types of uncertainties: uncertainty regarding the degree of infestation, and uncertainty regarding the effectiveness of pesticides. The first type of uncertainty is due to the inability of farmers to count the number of pest present at the beginning of the period. The second type of uncertainty is because the farmers have has no perfect knowledge of the relationship between pesticide and pest mortality. The increased effectiveness of the pesticide may be achieved either by obtaining information as to the proper way of its application, or by buying an improved variety of the chemical (Feder, 1979). Most studies assumed that the objective of decision makers is maximization of expected profit (Feder 1979, Moffitt *et al.* 1984, Babcock *et al.* 1992, and Chambers and Lichtenberg 1994). Evidence suggests that optimal pesticide decisions under expected profit maximization differ from decisions made under risk aversion (Pannell, 1990). Of those studies that assume risk-neutrality, the majority adopt a deterministic decision framework. This is why expected profit-maximizations are often referred to as 'risk neutral'.

Farmers choose between alternative decisions by considering not only expected profit, but also the risk associated with each decision (Rossing *et al.,* 1994). Farmers' attitude to risk associated with pest problems differ between individuals and, for one individual, change with time (Webster, 1987). Farmers, with respect to pest control decisions, have been found to show attitudes ranging from risk averse to risk loving. This indicates that farmers use information on the likelihood of various possible outcomes of a decision to arrive at subjectively best alternative. This constitutes another argument for taking a probabilistic, rather than a deterministic, approach to support decisions on pest control (Rossing *et al.,* 1994).

From the literature review, it can be concluded that: first, choice of functional form for the control and damage functions are an important factor in estimating pesticide productivity. Second, consideration of risk in pest control model could improve the prediction capability of the intensity of crop damage, output yield, and expected outcome. Third, farmers' attitudes toward risk in pest control decisions are important in determining the level of pesticide application.

3. CONCEPTUAL FRAMEWORK

The Concept of Economic and Action Thresholds

The economic threshold is defined by entomologists as "the population large enough to cause damages valued at the cost of practical control" (Edwards and Heath, 1964). Practically, it is interpreted as the minimum population level for which it is profitable to apply a pre-specified, fixed amount of pesticides, ordinarily a recommended or label dosage rate. Economists have treated dosage as a continuous decision variable in their models.

Headley (1972) defined the economic threshold as "the population that produces incremental damage equal to the cost of preventing that damage." It is not necessarily a zero level of damage, but the pest population level subsequent to application of a computed profit-maximizing dosage rate. Moffitt *et al* (1984) differentiated these two definitions as the “action threshold” and “economic threshold”, respectively. The action threshold has become popular in applied pest management due to its ease of use relative to the competing economic threshold.

Mumford and Norton (1984) defined damage threshold as the level of pest attack at which the benefit of control just exceeds its cost. In a deterministic model uncertainty in various parts of the model is ignored, thus it may lead to wrong recommendations. When acting according to the deterministic threshold, farmers will spray their crops too late, and on average, will incur avoidable loss (Rossing *et al*, 1994)

The Damage and Control Functions

In contrast to conventional inputs, damage control inputs act indirectly on output. Contribution of damage control inputs on production can be understood if one conceives of actual output as a combination of two components. The two components are potential output (the maximum quantity of product obtainable from any given combination of inputs) and losses caused by damaging agents (insects, weeds, bacteria, and viruses) presenting in the environment (Lichtenberg and Zilberman, 1986). Because of these characteristics, the damage control inputs are also known as *risk reducing inputs*.

Lichtenberg and Zilberman developed a simple model of yield response to pesticide application. The response to pesticide can be represented in a two-stage process. First, the effect of damage control input to damage agents. Second, the subsequent effect of the remaining damage agents on output. In the first stage, following Fox and Weersink (1995), pest density (Z) depends on the untreated pest incidence (Z_o) and the proportion of the damage agent which is controlled for a given level of treatment T. This is summarized by *the control function*, C(T).

This C(T) function is also called the "kill function", and T can also be seen as "control effort".

$$Z = Z_0(1 - C(T)) \qquad (1)$$

The control function C(T) represents the proportion of the destructive capacity of damage agent eliminated by the application of a level of control agent T. The control function has the properties of a cumulative probability distribution. It defined on the (0, 1) interval. When C(T)=0, denoting zero elimination i.e., maximum destructive capacity, the control agent has no impact on the damage agents ($Z = Z_o$). When C(T) = 1, corresponds to a complete eradication of the damage agent (Z = 0).

It is assumed that the proportion of damage agent remaining after treatment monotonically decreases with increases in the level of the control agent. This means that the first derivative of C with respect to T, i.e. marginal effectiveness of control input or marginal productivity, $C_T \geq 0$. Although there is a consensus that the marginal effectiveness of the control input is nonnegative, the rate of change in this marginal product is unknown (Fox and Weersink, 1995).

In the second stage, the effect of the remaining pest can be represented as

$$Y = Y_0(1 - D(Z)) \qquad (2)$$

where Y is the actual level of production for a given level of damage agent, Z, and Y_o is the level of production that would be forthcoming if no damage agent were present.

Damage function D(Z) represents the proportion of output loss at pest density Z. D(Z) depends on a range of factors and varies for different pests and different crops or pastures. It is assumed that the damage agent only act to reduce yield, although other damages may result such as a reduction in product quality.

This simple model illustrates the major components of the pest control problem. However, it can be used as the basis for a range of different types of analysis to find the threshold pest density above which application of a fixed recommended pesticide dosage would produce benefits greater than costs. Alternatively, marginal analysis could be used to determine the optimal pesticide dose.

4. THE FRAMEWORKS FOR ANALYSIS OF RISK

Risk and Uncertainty

Agricultural production is a risky business. Farmers face price, yield and resource risks that make their incomes unstable from year to year. In many cases, farmers are also confronted by the policy risks and risk of catastrophe. In a risky world, farm plan no longer has a known income each year. Rather, there are many possible income outcomes. Each possible outcome depend on a state of nature correspond to it. Not all states of nature need be equally likely. Knight (1921) distinguished between risk and uncertainty on the basis of the state of knowledge about such probabilities. Knight stated that if the probabilities are known, the decision problem is one of risk. In contrast, if the probabilities are unknown, the problem is one of uncertainty. However, according to Hazell and Norton (1986) this distinction is not particularly useful in agricultural planning since data for estimating income distributions are usually restricted to relatively small time series sample, or to subjective anticipations held by the farmer.

Farmers' Risk Preferences: Risk Neutrality versus Risk Aversion

During the year, farmers are faced with the decision whether or not they should spray. Uncertainties surrounding the decision include the likely build-up of disease and the efficiency with which the spray will control the pests (Webster, 1977). There are some uncertainties that affect farmers' decision making for pest control. They include pest density, yield loss per pest, pesticide effectiveness, pesticide damage to crops, pest-free crop yield, and output price (Pannell, 1991).

Feder (1979) argued that the existence of uncertainty in the pest-pesticide system is by itself a factor leading to a higher and a more frequent use of pesticides. Suppose that pest population is Z_o. The damage caused by a single pest is ***d*** (it is marginal damage effect which is assumed to be independent of the population of pests). By increasing pesticide application (T) farmers reduce the level of risk at the margin due to the change in the probability of risk distribution. Let there are two different distributions (p_1 and p_2) with an identical mean ($Z_{\ddot{o}}$). Distribution p_2 is more dispersed and implies a higher degree of risk relative to distribution p_1. These two alternative distributions for each of marginal damage are presented in Figure 1. The relationships between optimal pesticide level and the degree of infestation corresponding to the two pest densities are presented in Figure 2. Since the variability in pest infestation associated with distribution p_2 is greater than one with distribution p_1, the response function $x(p_2)$ lies to the left of $x(p_1)$, implying higher pesticide applications for any infestation level above the threshold population Z^*_2. In particular, the threshold population corresponding to p_2 is lower than the threshold level under p_1 ($Z^*_2 < Z^*_1$). This verifies that with a higher level of uncertainty there will be a more frequent use of pesticide.

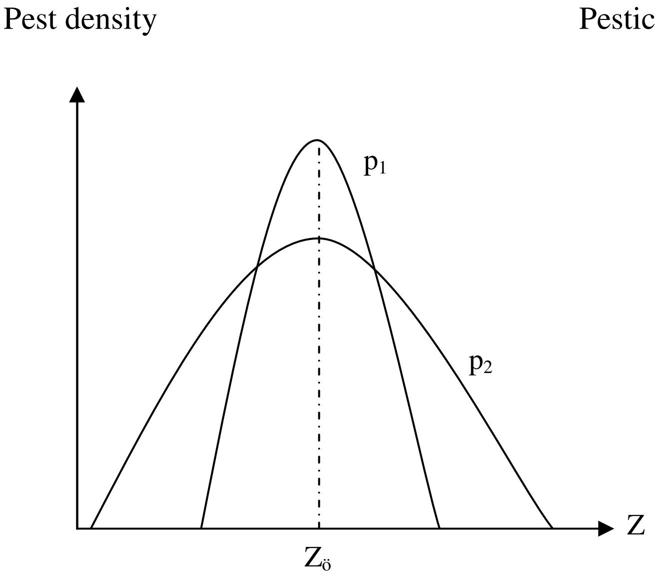

Figure 1. The two alternative distributions of the damage per pest

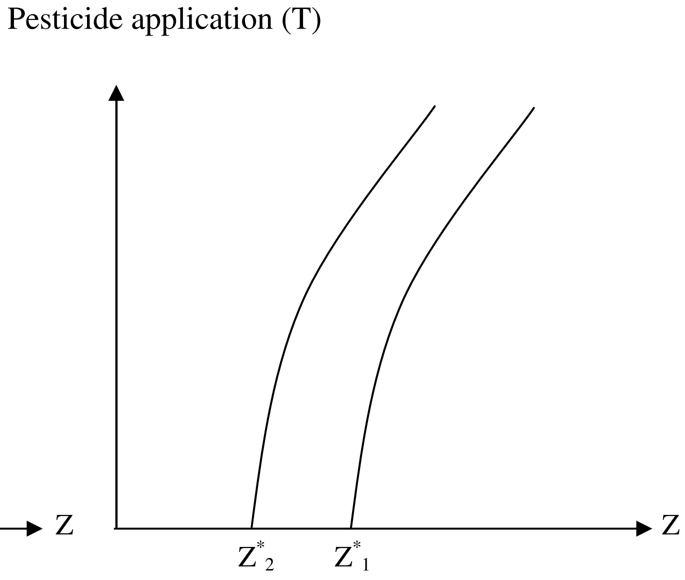

Figure 2. The Relationships between pesticide rate and the degree of infestation

Farmers' attitudes to risk associated pest problems differ between individuals and change with time (Webster, 1987). With respect to pest control decisions, farmers have been found to show attitudes ranging from risk-averse to risk-loving. The assumptions that risk increases pesticide usage and that the pesticide usage reduces risk are widely accepted. Feder (1979) established the theoretical basis for the presumed positive relationship between degree of risk and level of pesticide usage. Feder shown that under risk aversion, uncertainty about the level of pest infestation increases the optimal level of pesticide use.

The assumption of risk neutrality is often made for simplicity and tractability (Moffitt *et al*, 1984). Webster (1977) found that for a fungicide-spraying problem, the decision of whether or not to spray was very insensitive to the degree of risk aversion. Pannell (1990) found that when a range of sources of uncertainty was considered, the variance of income was almost unchanged over a wide range of herbicide dosage. This indicates that the optimal herbicide dosage would not be affected by risk aversion.

In addition to these indications that risk aversion may have little impact on pest control decisions, there is also evidence that many farmers are approximately risk-neutral or only slightly risk-averse (Pannell, 1991). Carlson (1984) has suggested that risk may not be an important consideration in farmers' decisions on pest control. These findings appear to provide some support for use of a risk-neutral framework.

There are three possibilities where risk can affect the decision of risk-neutral decision makers in maximizing expected profit (Pannell, 1991). The first problem is convexity of relevant function. Auld and Tisdell (1987) argued that because of convexity of the relationship between weed density and crop yield, uncertainty about weed density reduces expected yield loss. This has increased the economic threshold and reducing the overall level of pesticide use. The second problem is dynamics. Zacharias *et al.* (1986) found modest support for the hypothesis, with small differences between the results of their deterministic and stochastic models. The last problem is when the decision maker is subject to a progressive marginal taxation rate. Taylor (1986) showed that the effect of this on decision making is essentially the same as the effect of risk aversion.

Farmers' Decision Making in a Risky Situation

Numerous empirical studies have demonstrated that farmers typically behave in a risk-averse way (Binswanger, 1980). As such, farmers often prefer farm plans that provide a satisfactory level of security even if this means sacrificing income on average. More secure plans may involve producing less of risky enterprises, diversifying into a greater number of enterprises to spread risks, or using established technologies (Hazell and Norton, 1986). In relation to risk reducing inputs, such as pesticide, farmers will apply more pesticide to reduce the variability of output and profit.

Farmers choose amongst risky prospects (i.e. courses of action whose outcomes are uncertain) in attempt to maximize their utility. Anderson *et al* (1977) stated that the dominant paradigm for risk analysis in economics has been expected utility maximization. Alternatively, some studies (Moffitt *et al.* 1984, and Pannell 1990) model the objective of the decision maker is to maximize expected profit.

Decision making under uncertainty involves the trade-off between risk and return (or profit or utility). The trade off can be illustrated graphically with an E-V frontier or expected value variance frontier (Figure 3). The E-V frontier describes the complete set of efficient farm plans under uncertainty. Movement along the frontier away from the origin implies farm plan with more risk. The slope of the frontier is increasing at decreasing rate which suggests that the rate at which income is traded for risk decreases. This is not surprising since the point at which the slope equals zero is the risk neutral solution. The E-V frontier is also referred as the efficient frontier, because no feasible plan exists which dominates solutions on the frontier (Turvey, 1995).

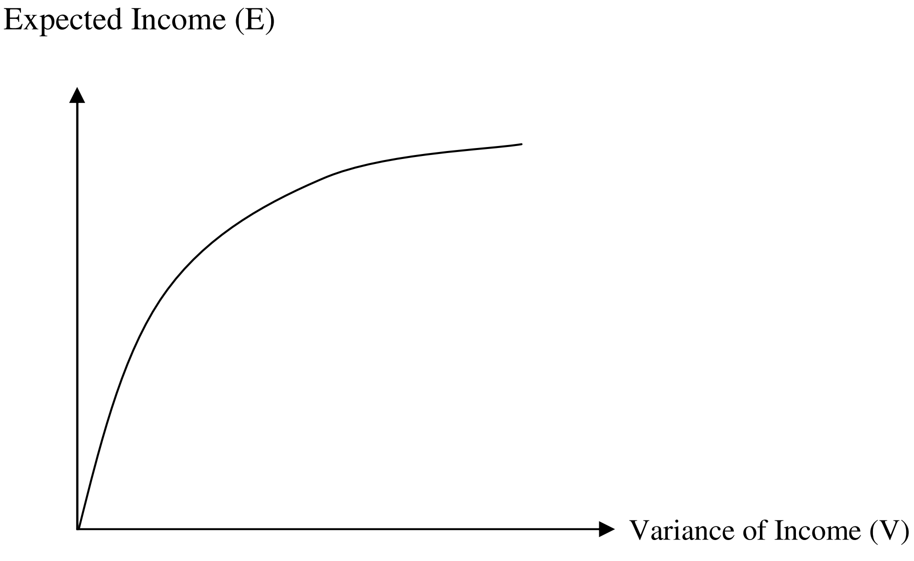

Figure 3. The E-V Frontier

In pest management problem, farmers' risk attitude has been accounted for in two ways. If the decision support approach is deterministic, the recommendation is adjusted so that it is 'on the safe side', i.e. biased toward pesticide control (Rossing *et al*, 1994). Alternatively, if the decision support approach is probabilistic, the risk attitude of a farmer is described as a subjective utility function, that is used to calculate the recommendations (Lazarus and Swanson, 1983). These prescriptive approaches ignore the danger of further bias when a farmer superimposes his risk attitude upon the recommendation.

Pannell (1990) examined a range of uncertain variables in model of yield response to herbicides under expected profit maximization. He found that uncertainty about each of variables considered (initial weed density, weed kill, weed competitiveness, herbicide dosage, and weed-free yield) reduced the profit maximizing herbicide dosage and increased the threshold density for herbicide treatment.

Simple Model of Risk Consideration in Pest Control and its Implication

Suppose that the control function is exponential and the damage function is linear. The exponential control function, equation (3), implies that the controlled pest-density increases (at decreasing rate) with pesticide application. This relationship is presented in Figure 4. In this figure it is assumed that the coefficient of effectiveness of pesticide (c) is 0.2.

$$C(T) = 1 - e^{-c\,T} \qquad (3)$$

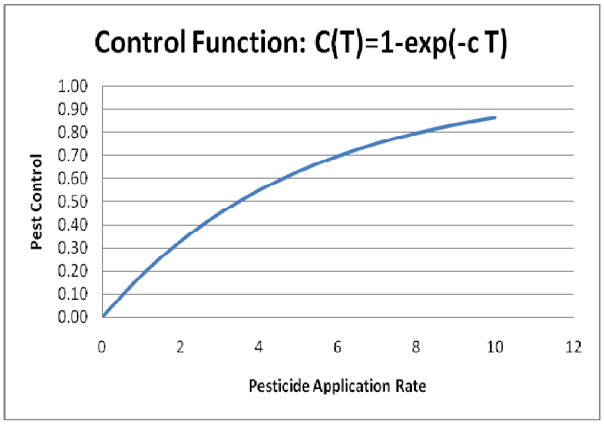

Figure 4. The Exponential Control Function

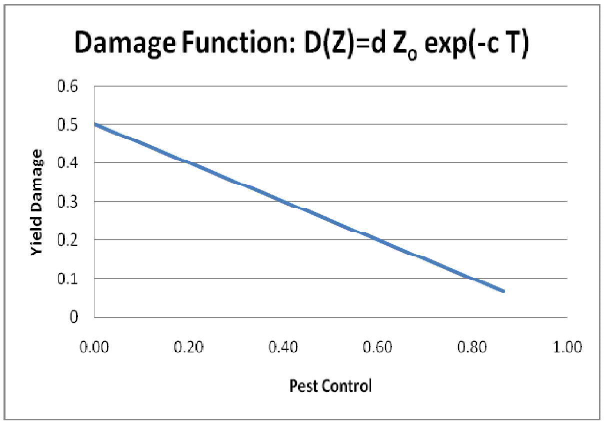

Figure 5. The Linear Damage Function associated with the Exponential Control Function

The proportion of pest remaining after treatment is presented in equation (4). It is assumed that the proportion of pest after the treatment (Z) monotonically decreases with increases in the level of pesticide application. Although there is a consensus that the marginal effectiveness of pesticide is non-negative, the rate of change in this marginal product (C_T) is unknown (Fox and Weersink, 1995).

$$Z = Z_0\, e^{-cT} \qquad (4)$$

A linear damage function, equation (5), indicates that the proportion of crop damage linearly decreases as the controlled pest-density increases. Graphical presentation of this damage function is presented in Figure 5. In this figure it is assumed that the marginal damage effect (d) is 0.5.

$$D(Z) = d\,Z \qquad (5)$$

The damage function associated with such control function is determined by substituting the equation (4), the pest remaining after the control, into equation (5). This damage function is presented in equation (6). The function shows that proportion of crop damage increases with marginal damage effect (d) and initial pest density (Z_o), and decreases with the coefficient of pesticide effectiveness (c), and level of pesticide application (T).

$$D(Z) = d\,Z_0\,e^{-cT} \qquad (6)$$

Actual yield associated with the exponential control and linear damage functions will be equal to:

$$Y = Y_0\left(1 - d\,Z_0\,e^{-cT}\right) \qquad (7)$$

This equation indicates that the actual yield is equal to the pest-free yield (Y_o) minus the proportion of yield damage which is represented by the damage function. The actual-yield level (Y) in equation (7) is a function of the pest population (pest density) and reflects the damage inflicted by the pest. Assuming that c = 0.2 and d = 0.5, the graphic of the actual yield is presented in Figure 6. Figure 6 shows that the actual yield monotonically increases with the pesticide application. A zero pesticide application will result in an actual yield of only 50 per cent from its potential yield. Marginal productivity of pesticide decreases with its application rate.

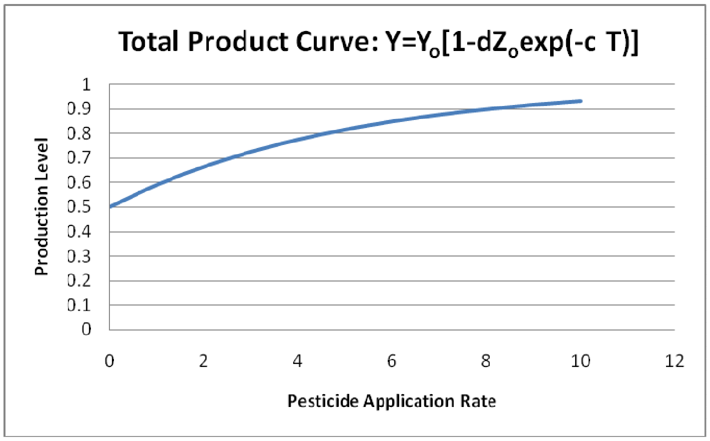

Figure 6. The Actual Yield associated with the Control and Damage Functions

Based on equation (7), the profit equation for this model is:

$$\pi = p_y\,Y_0\left(1 - d\,Z_0\,e^{-cT}\right) - p_t T - A - F \qquad (8)$$

where p_y is output price, p_t is pesticide price per unit of application, A represents fixed pesticide application costs, and F is other production costs. Equation (8) expresses profit as a function of prices of input and output, pesticide application rate, coefficients of pesticide effectiveness and marginal damage effect, and yield.

According to Pannell (1991) there are a number of parameters in the model that are likely to be stochastic. Pest density may be uncertain as a result of uncertainty about the initial pest density, the proportion of pests killed or the pesticide dosage actually applied. Yield will be uncertain due to uncertainty about pest-free yield, the level of damage and the final pest density. Profits are most likely to be affected by variance in yield and output price.

In this model, only one out of three types of uncertainties are considered, that is pest density. The model will explain the way this source of uncertainty affect the variance of income. Uncertainty about the level of pest density will affect proportional yield loss, actual yield and, finally, profits. Suppose that the probability density functions for the pest density variable is:

$$Z_0 \sim \mathrm{N}\left(\ddot{\mathrm{Z}}_0, \sigma^2_{z_0}\right) \qquad (9)$$

where $\ddot{\mathrm{Z}}_0$ is the average pest density and $\sigma^2_{z_0}$ is its variance.

Substituting the output equation (7) into the profit equation (8) and incorporating the probability distributions of the stochastic variable (9) results in the following expected profit function:

$$E(\pi) = E\left(p_y\, Y_0 \left(1 - d\, \ddot{Z}_0\, e^{-cT}\right) - p_t T - A - F\right) \qquad (10)$$

Variance of the profit, Var(π), is:

$$Var(\pi) = \left(p_y\, Y_0\, d\, \ddot{Z}_0\, e^{-cT}\right)^2 \sigma^2_{Z_0} \qquad (11)$$

Therefore, certainty equivalent of profit, CE(π), is written as:

$$CE(\pi) = p_y\, Y_0 (1 - d\, \ddot{Z}_0\, e^{-cT}) - p_t T - A - F - 0.5\, \alpha \left(p_y\, Y_0\, d\, e^{-cT}\right)^2 \sigma^2_{Z_0} \qquad (12)$$

The certainty equivalent of profit measures a level of certain profit with which the farmer would be indifferent to the expected stochastic profit E(π). It is determined by the difference between expected profit E(π) and risk premium. Risk premium is the dollar amount by which the farmer must be compensated for undertaking the risky action. The premium is determined by the degree of risk aversion (α) and the probability distribution of risky outcomes, ½ α Var(π) (Turvey, 1995). For the risk neutral individual the risk premium is zero. As risk aversion increases, so does the premium.

There is only one control variable for this problem, pesticide application rate, T. However, there are some parameters and important economic terms can be derived from the certainty equivalent profit equation. For example, the optimal pesticide rate, the threshold pest density, and change in pesticide application with respect to change in farmer's risk aversion.

The Optimal Pesticide Application and Economic Pest Threshold

The optimal pesticide rate is the first derivative of the CE(π) with respect to pesticide application rate (∂CE(π)/∂T).

$$\frac{\partial CE(\pi)}{\partial T} = c\, p_y\, Y_o\, d\, e^{-cT}\left[\alpha\,\sigma^2_{Z_0} + Z_o\right] - p_t = 0 \qquad (13)$$

Equation (13) suggests that the pesticide is applied until the proportion of reduction in profit variability due to uncertain pest damage weighted by the risk aversion coefficient (α) plus the expected loss reduction just equals the cost of additional unit of pesticide application (p_t). This result is different from the conventional rule which suggests that the pesticide use is based on the equality between its marginal factor cost and its marginal value product.

The optimal level of pesticide application can be derived from equation (13). The optimum pesticide rate is:

$$T^* = [\ln(cp_yY_od(\alpha\sigma_{Zo}{}^2+Z_{\ddot{o}})) - \ln(p_t)] / c \qquad (14)$$

Equation (14) suggests that the pesticide rate increases with the price of output and initial pest density, and decreases as price of pesticide rises. Farmers' risk aversion coefficient also determines the application rate. The more risk averse farmers tend to increase the rate of pesticide application. In general, the existence of risk associated with pest density will induce farmers to apply more pesticide, as presented in Figure 7. When there is no risk associated with pest density, the farmer will apply T^o of pesticide. When the risk exists, the farmers will apply more pesticide, T^1. The difference in the two application rates depends on the initial pest density and farmers' risk aversion. When the pesticide price (marginal factor cost) declines, from MFC^0 to MFC^1, the farmer will apply more pesticide and – under this new condition – the optimal application rate (T^1) is associated with that of without risk condition.

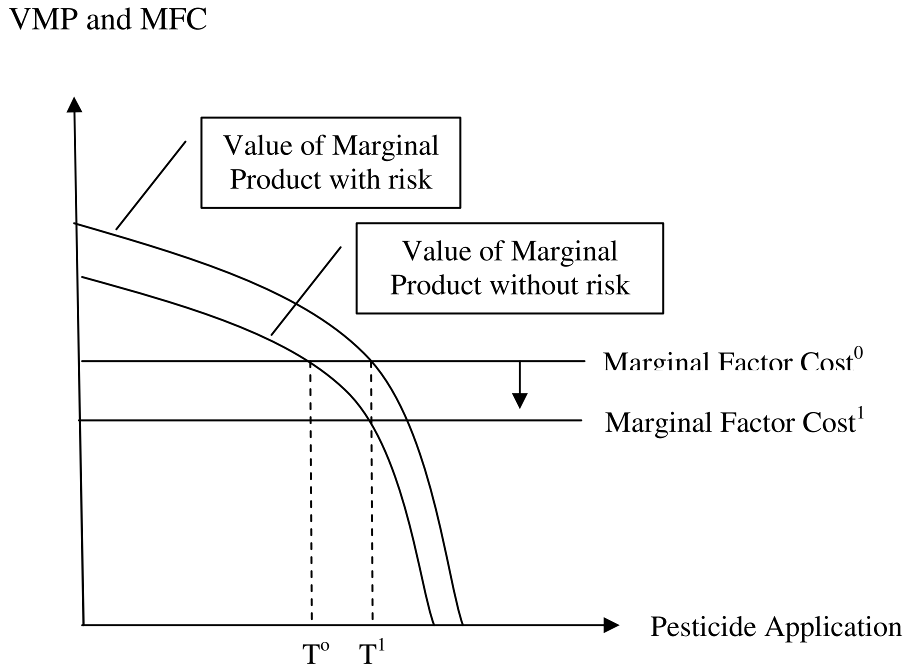

Figure 7. Optimal level of pesticide application

The threshold pest density (Z_o^T) is determined by set up T in the equation (12) by zero, and solve for Z_o^T. The threshold pest density function is:

$$Z_o^T = [p_t - \alpha \ c p_y Y_o d \ \sigma_{Zo}^2] / c d p_y Y_o \qquad (15)$$

The threshold pest density increases with the cost of pesticide (p_t), and decreases with output price (p_y), coefficients of pesticide effectiveness (c) and marginal damage effect (d), variance of pest density (σ_{Zo}^2), and risk aversion coefficient (α).

Change in pesticide application due change in farmer's risk aversion ($\partial T/\partial \alpha$) is as follow:

$$\partial T/\partial \alpha = c(\alpha \sigma_{Zo}^2 + Z_{\ddot{o}}) / \sigma_{Zo}^2 \qquad (16)$$

In general, $\partial T/\partial \alpha$ is non-negative. This suggests that the more risk-averse the individual decision maker, the greater his application of pesticide. This result is consistent with equation (15) that suggests that the more risk-averse decision maker, the lower the economic threshold of pest population at which pesticide application is begun.

CONCLUSIONS

Pest control program is required in maintaining crop production. Raising damage on more intensive cropping system in both developed and developing countries has contributed to this pest control program. Existence of risk associated with the pest density requires good information and monitoring system on pest control program.

The simple model applied in this paper shows that the existence of risk associated pest density will affect the optimal pesticide applications and the economic pest thresholds. These two outcomes depend on the prices of output and input (pesticide), coefficients of pesticide effectiveness, marginal damage effect, variance of pest density initial pest density, and farmers' risk aversion.

Economists need to collaborate with agronomist, plant pathologists and entomologists to investigate the long range risk problems associated with various cropping patterns and their impacts on crop productions. Economist can assist in the evaluation and design of alternative approaches to pest management.

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