THE PRODUCTIVITY OF PESTICIDE USE IN RICE PRODUCTION OF THAILAND: A DAMAGE CONTROL APPROACH[1]

S. Praneetvatakul[2], D. Kuwattanasiri[2] and H. Waibel[3]

[2] Department of Agricultural and Resource Economics, Faculty of Economics, Kasetsart University, Bangkok 10900 Thailand
[3] Institute of Economics in Horticulture, Faculty of Economics, University of Hannover, 30419 Hannover, Germany

KEYWORDS

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ABSTRACT

This paper follows the methodology proposed by Lichtenberg and Zilberman (1986) to treat pesticide productivity analysis in the context of a damage function. The implications of four alternative model specifications are examined to assess the marginal productivity of pesticides in rice in Thailand. The primary data are collected from five major rice producing provinces, namely Angthong, Chai-Nat, Kampaengpetch, Karasin and Udonthani. In these provinces rice cultivation is practiced intensively. A total of 241 rice farmers were interviewed. Production inputs and rice yields were collected on a recall basis of the interviewee using the foregoing season as a reference point.

Four production function specifications were developed generally comparing the conventional approach with several damage control specifications, i.e. to compare the conventional Cobb-Douglas with three alternative damage abatement function incorporations, namely exponential, logistic and Weibull.

Results showed that for the abatement function, all specifications gave a satisfactory fit with statistically significant coefficients. Results also showed a positive effect of pesticides on yield. When comparing the conventional Cobb-Douglas with the damage control approach, the Cobb-Douglas specification yields larger estimate of pesticide productivity as compared to the damage control specification. Hence, results support the hypothesis of pesticide overuse in rice cultivation.

This analysis of pesticide productivity in rice provides important information to policy makers who are challenged to improve pesticides policy as a component of other agri-environmental policies. Since the contribution of pesticides to productivity is lower than previously assumed more emphasis can be given to public concerns of chemical pesticide residues and ecological damage. Results of our analysis have also implications for the continuing debate on the role of chemical pesticides in maintaining food security and consequently the perceived need for biotechnology (e.g. Bt rice). Damage function results can help to establish a realistic reference systems for assessing the benefits of modern biotechnology.

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INTRODUCTION

Pesticides continue to be applied at high rates in Asian rice production. Such observations are contrary to research findings especially with regards to insect control where, several researchers have shown that high levels of insecticide use are not justified from an economic point of view (e.g. Herdt et al, 1984). Simulation studies based on pest observations from farmer trials showed that in fact insecticides may only be needed in exceptional years (Waibel, 1986). Studies referring to data from the Pest Surveillance Services in the Philippines and Thailand showed that the probability of the marginal revenue from insecticide treatments to exceed the costs of control is lower than 0.2 (Engelhardt and Waibel 1988). Rola and Pingali (1993), using a stochastic production function model that included human health effects of pesticides found that even in intensive irrigated rice, insecticide use is uneconomical altogether if health costs are included. Contrary to that, until to date farmers in many Asia countries continue to spray two to three times per season on average (Heong et al, 1997, Horstkotte-Wesseler, 1999). Agricultural policies that stimulate pesticide use and through a number of hidden and indirect subsidies may impede the diffusion of Integrated Pest Management (IPM) whose adoption rates have remained below expectations (Waibel 1990, Jungbluth 1996, Poangpasorn et al 1998). Some doubts have been raised whether the popular and on a pilot-scale quite successful Farmer Field School approach to IPM is feasible for an up-scaling to a national level program (Quizon et al 2001, CGIAR 2000).

One of the weaknesses of previous economic studies dealing with the productivity of pesticide use in rice is related to the methodology used in these studies. Overwhelmingly, in these studies either a production function or a partial budget approach was used. Applying partial budgets, the problem is that here the economics of pesticides depends on pre-determined treatments in experiments. These may not always reflect farmer's actual practices and such trials are often not a available over a sufficiently long period of time. On the other hand, production function analysis that treats pesticides as a yield-increasing variable ignores their true nature as damage abatement agents. As shown in previous studies this can lead to serious misspecifications of the effects of pesticides (Lichtenberg and Zilberman 1986; Carrasco-Tauber and Moffit 1992). Ignoring the true biological relationships in the standard production function, such as Cobb-Douglas, has consistently led to the result that conventional production function analysis leads to an overestimation of the marginal physical product of pesticides (Saha, Shumway and Havenner, 1997, Ajayi, 2000). Such overestimates in combination with the perceived risk-reducing nature of pesticides have resulted in a continuous high use of chemical pesticides in many crops including rice. Consequently, negative effects such as health and environmental hazards of pesticides have become a widely recognized problem. Therefore, it is important to accurately assess the productivity effects of pesticides applying an appropriate methodology.

OBJECTIVE OF THE PAPER

This paper examines the productivity of insecticides use in rice production in two regions of Thailand. The methodology is based on four alternative damage control specification in the production function using survey data of 241 farmers across five provinces. The regression results are used to derive the marginal productivity of insecticides and assess the possible degree of insecticides overuse in rice production in Thailand

THEORETICAL FRAMEWORK AND METHODOLOGY

Theory of pesticide productivity

The methodology used for the economic assessment of pesticide productivity has made important advancements over the last decades. Initially, economists treated pesticides in a conventional production function framework, i.e. assuming them to be yield increasing factors like e.g. nitrogen fertilizer. Using a Cobb Douglas (C-D) function framework HEADLEY (1968) estimated the marginal productivity of aggregated pesticide use in US agriculture for the period from 1955 to 1963. He found that the marginal value of a one-dollar expenditure for chemical pesticides was approximately US$ 4, concluding that additional net benefits could be achieved from applying more pesticides. The figure derived in HEADLEY'S analysis has been widely cited and dominated the debate in the following decades. The productivity effects of pesticides were overestimated as neither the level of pests nor the effect of other damage control factors (e.g. agronomic practices) were attributed for.

LICHTENBERG and ZILBERMAN (1986) were among the first to point out the methodological problems when a standard production function framework is applied to pesticides. They provided a theoretical explanation why production function specifications, which ignore the damage reduction characteristics of pesticides and treat them as directly yield increasing inputs, can overestimate marginal pesticide productivity. The misspecification of the production relationships, the omission of pest population levels and other environmental factors and the use of pesticide expenditure as a variable instead of the total costs of abatement in previous analyses attributes productivity effects to pesticides which in reality are caused by other factors. As a remedy, LICHTENBERG and ZILBERMAN (1986) suggest to modify the conventional (logarithmic) specification of the C-D production function :

$$\ln Q = \alpha + \beta \ln Z + \gamma \ln X$$

with "Z" as productive inputs and "X" being pesticide inputs, by incorporating an abatement function: G(X) as follows:

G(X) with a distribution form of Pareto: $1 - K^{\lambda} X^{-\lambda}$

G(X) with a distribution form of Exponential: $1 - e^{-\lambda x}$

G(X) with a distribution form of Logistic: $[1 + \exp\{\mu - \sigma X\}]^{-1}$

G(X) with a distribution form of Weibull: 1-exp$\{X^{c}\}$

showing the proportion of the destructive capacity of the damaging agent eliminated by the application of a level of control agent "X", i.e. pesticides. They show that the marginal product (marginal effectiveness) of the damage control agent in the abatement function specification G(X) declines faster than the marginal product of pesticides in the C-D function (1/X) with a constant elasticity.

Empirical studies applying the LICHTENBERG and ZILBERMAN (LZ) framework confirmed their hypothesis. For example, BABCOCK et al. (1992) compared the marginal product derived from a conventional C-D function with a damage control specification, using data of North Carolina apple producersand found that the C-D results exceeded the damage function estimate by a factor of almost 10. Including state variables in their production process model, BLACKWELL and PAGOULATOS (1992) suggest that ignoring natural abatement factors may overestimate the marginal productivity of pesticides. CHAMBERS and LICHTENBERG (1994) applied a dual representation of the LZ damage control specification to an aggregate US agriculture data set. They concluded that the aggregate pest damage in US agriculture was lower than previous estimates suggested. Their model also hints at the important distinction between pesticides as single damage control agents and total damage abatement. The long run price elasticity of pesticides was found to be in the order of -1.5, while the elasticity of abatement subject to the prices of all other input factors was found to be consistently less than -0.1 suggesting that the contribution of pesticides to the economic outcome of pest control is overestimated.

On the other hand, it was also shown that the choice of the functional form influences the conclusion as regards pesticide productivity. For example, CARRASCO-TAUBER and MOFFIT (1992) used the LICHTENBERG/ZILBERMAN (LZ) framework to analyse 1987 cross-sectional data. They compared the conventional C-D function with three different specifications of the abatement function (Weibull, logistic and exponential). The exponential form in the damage control specification showed a marginal productivity of pesticides of less than unity suggesting pesticide overuse, while all other functional specifications showed results similar to those found by HEADLEY (1968). Although the exponential form is commonly used in pesticide kill functions (e.g. REGEV et al, 1976) there is no theoretical basis for choosing one functional form instead of the other.

Furthermore, the restrictions of an output-oriented damage function were demonstrated by Carpentier and Waever (1997). They proposed instead a more general input damage abatement specification which was recently applied to panel data of Durch arable farms by Lansink and Carpentier (2001). However, the statistical evidence of pesticides on different productive impacts was found to be weak. Taking these findings into account lends support to the hypotheis that the origina LZ-specification of the damage abatement function may be the approriate methodology to be used in estinmating pesticide productivity. Furthermore, results from applying the damage abatement function not only confirm the results of farm level economic studies (e.g. Engelhardt and Waibel 1988) but also those of numerous casual observations of pest management specialists (e.g. Kenmore 1996) that insecticides in rice are oversused.

Data collection

The primary data are the main source of information used in this study. The data are gathered from the farm-household survey in the main area of rice cultivation in Thailand for the cropping year 1999/2000 and 2000/2001. Five provinces in three regions (Central Plains, North, and North-East) were purposively selected for the survey. The provinces of Angthong, Chai-Nat, Kampaengpetch, Karasin and Udonthani are major rice producing areas of Thailand. In total two hundred forty one farmers were selected at random in 2 villages per province and were interviewed as reagards their practices inputs and outputs of rice production during the wet season of the cropping year 1999/2000 and 2000/2001 (Table 1).

Table 1: Samples size by region and province

Region/-Province	Number of farmers interviewed
Central Plains	
- Angthong	50
- Chai-Nat	42
North-East	
- Udonthani	38
- Karasin	59
North	
- Kampaengpetch	52
Total	241

Econometric specification of the damage control functions

The typical production function form used to estimate productivity of external inputs is the Cobb-Douglas function. In the incorporation of a damage abatement function for the estimation of pesticide productivity alternative econometric specifications exist. In this analysis the exponential, the logistic and the Weibull functions were used. In mathematical terms the following specifications were utilized:

(1) Cobb-Douglas: $\ln Y = \ln A + \beta_i \ln Z_i + \ln X_i$

(2) Exponential: $\ln Y = \ln A + \beta_i \ln Z_i + \ln[1-\exp(-\lambda X)]$

(3) Logistic: $\ln Y = \ln A + \beta_i \ln Z_i + \ln[1+\exp(\mu-\sigma X)]^{-1}$

(4) Weibull: $\ln Y = \ln A + \beta_i \ln Z_i + \ln[1-\exp(-\lambda X^C)]$

where:
Y is the value of output in Baht per rai.
A is the constant value.
Z_i are the production inputs such as seed, fertilizer, and labor.
X_i are the damage control agents i.e. pesticides.

The marginal productivity can be estimated using the following formula.
For the input Z_i, the marginal value product of Z_i is

$$MVP(Z_i) = \frac{\partial Y}{\partial Z_i} = \beta_i \frac{Y}{Z_i}$$

For the input X_i, the marginal value product of X_i is

$$MVP(X_i) = \frac{\partial Y}{\partial X_i} = \frac{Y}{D(X)} * \frac{\partial D(X)}{\partial X_i}$$

where; D(X) is the specification form of damage control agent i.e. exponential, logistic or Weibull.

RESULTS

Three models were used to estimate production coefficients for the input variables of rice production. The first model is based on data from all five provinces for the crop year 1999/2000 (Table 2) while the second one represents cropping year 2000/2001 (Table 3). Finally, a separate production function was estimated for the Central Plains of Thailand (Table 4) because it is there where rice cultivation is most intensive. Input variables include inputs such as fertilizer, seeds, labor, and pesticides, generally believed to be important determinants of rice output. Most of the variables have the expected signs.

The equations were selected based on the goodness of fit and the significance of the regression coefficients and the general significance of the regression equation. The coefficient of multiple determination (R^2) of all models range from 0.19 to 0.50 implying that there are also other factors that explain the value of rice output. However, the important quantifiable factors were included. They generally showed the expected signs and the coefficients were statistically significant. (see Tables 2, 3 and 4).

In terms of the individual variables, *fertilizer* showed the expected positive effect on rice production in all equations. However, this only holds for urea but not for the phosphorous fertilizer 16-20-0. Based on anecdotal evidence improper use of 16-20-0 is widely found in the Central Plains of Thailand where farmers often apply excessive amounts of 16-20-0 in the early period of rice cultivation.

For *seeds*, the positive impact of seed on the value of rice production occurred in all models, indicating that with an overview picture of Thailand, an increase in amount of seed, the increase in value of rice products will obtain.

Labor showed a positive effect on the value of rice production occurred in all models.. However, when considering the labor use in central region of Thailand, the negative impact of labor on rice production occurred. This is because there is a high labor use in this area due to an over-application of several inputs such as pesticides and fertilizers (as already mentioned above) (Table 2, 3 and 4).

Pesticides had a positive impact on the value of rice production in all three models. However, the derived production elasticity is low, i.e. the value of rice production is not much responsive to the amount of pesticide application. In the conventional Cobb-Douglas function form, the coefficient of pesticides shows that a 1 % increase in pesticide expenditure in rice fields will increase rice output by only 0.019 % and 0.024 % for the rice production in Thailand for the cropping season 1999/2000 and 2000/2001 respectively (Table 2, 3 and 4). It is must be mentioned that in the Cobb Douglas production function for the Central Plains insecticide and herbicide were defined as separate variables but only the latter was statistically significant.

Table 2: Production coefficients of Cobb-Douglas and Damage function specification of rice cultivation in Thailand, the cropping year 1999/2000

Independent Variables	Cobb-Douglas	Damage function specification		
		Exponential	Logistic	Weibull
Constant	6.3054	6.1828	6.0089	6.7421
Nitrogen	0.0395 (1.90)*	0.0467 (2.24)**	0.0557 (2.75)***	0.0406 (1.96)*
Phosphorus	0.0540 (7.12)***	0.0541 (6.94)***	0.0513 (6.70)***	0.0539 (7.09)***
Seed	0.2123 (5.15)***	0.2454 (6.31)***	0.2685 (7.36)***	0.2172 (5.32)***
Labor	0.0188 (1.84)*	0.02126 (2.07)**	0.0234 (2.28)**	0.0192 (1.88)*
Pesticide	0.0199 (2.76)***			
Lambda λ		232.5093 (4.00)***		
Sigma σ			-0.0931 (-11142)***	
μ			-457.027 (-72148)***	
C				0.0319 (2.56)**
N R-square F-statistic	241 0.4971 46.45***	241 0.4865 44.53***	241 0.4807 36.10***	241 0.4960 46.25***

Note: the value in bracket are t-value
* means statistical significant at 90%
** means statistical significant at 95%
*** means statistical significant at 99%

Table 3: Production coefficient of Cobb-Douglas and Damage function specification of rice cultivation in Thailand, the cropping year 2000/2001

Independent Variables	Cobb-Douglas	Damage function specification		
		Exponential	Logistic	Weibull
Constant	6.6657	6.5582	7.2162	7.1079
Nitrogen	0.0555 (1.71)*	0.0684 (2.11)**	0.0432 (1.32)	0.0571 (1.76)*
Phosphorus	0.0450 (4.13)***	0.0477 (3.86)***	0.0436 (3.65)***	0.0498 (4.09)***
Seed	0.1124 (2.48)**	0.1433 (3.29)***	0.0664 (1.35)	0.1165 (2.59)***
Labor	0.0244 (1.99)**	0.0260 (2.11)**	0.0212 (1.72)*	0.0246 (2.01)**
Pesticide	0.0240 (2.64)***			
Lambda λ		218.9042 (3.48)***		
Sigma σ			0.1032 (1.50)	
μ			-0.8216 (-2.14)**	
C				0.0391 (2.48)**
N R-square F-statistic	241 0.2726 17.62***	241 0.2581 16.35***	241 0.2890 15.85***	241 0.2715 17.51***

Note: the value in bracket are t-value
* means statistical significant at 90%
** means statistical significant at 95%
*** means statistical significant at 99%

Table 4: Production coefficient of Cobb-Douglas and Damage control function specification of rice cultivation in Central Plains of Thailand, the cropping year 1999/2000

Independent Variables	Cobb-Douglas	Damage control function specification		
		Exponential	Logistic	Weibull
Constant	8.4953	8.9803	9.0565	9.3131
Urea (46-0-0)	0.0702 (1.28)	0.1044 (1.95)*	0.0901 (1.66)	0.0803 (1.44)
Fertilizer 16-20-0	-0.1817 (-3.68)***	-0.1679 (-3.43)***	-0.1695 (-3.47)***	-0.1797 (-3.62)***
Labor	-0.0836 (-1.79)*	-0.0955 (-2.07)**	-0.0918 (-2.01)***	-0.0695 (-1.52)
Herbicide	0.1075 (2.25)**			
Insecticide	0.0391 (1.04)			
b_5		0.0709 (4.72)***	0.0556 (2.15)**	0.2186 (0.58)
b_6		0.1534 (2.10)**		0.0947 (0.67)
b_7			0.1369 (0.23)	
N R-square F-statistic	111 0.1927 5.01***	111 0.2097 5.67***	111 0.2223 6.00***	111 0.1872 4.84***

Note: the value in bracket are t-value
* means statistical significant at 90%
** means statistical significant at 95%
*** means statistical significant at 99%

The derived *marginal value product* (*MVP*) *of pesticides* was found to be greater than unity in the Cobb-Douglas function, whereas those derived from the damage control function specifications show lower values. In the first place this confirms the hypothesis of Lichtenberg and Zilberman (1986) of an overestimation of pesticide productivity. However, as also found in previous studies (e.g. Carrasco-Tauber and Moffit 1992), results depend on the damage function specification. For example, the MVP derived from the logistic function is similar to those of the Cobb Douglas specification (Table 5).

Based on the statistical quality of the regression results the exponential model was used as basis for comparison (Table 6 and 7). The MVP from the exponential model in both cropping season of rice cultivation in Thailand and Central plain range from 0.000 to 0.002, whereas, the MVP of the Cobb-Douglas ranges from 1.49 to 5.24 (Tables 5 and 6).

In general, the results confirm that the treatment of pesticides in the traditional specification of a production function leads to overestimation of their productivity effects. Likewise this may imply a slight underestimation of the productivity of the standard inputs (e.g. labor, fertilizer).

Table 5: Marginal Value Product of Pesticide and other farm inputs of rice cultivation in Thailand , cropping year 1999/2000

Inputs	Cobb-Douglas	Damage function specification		
		Exponential	Logistic	Weibull
Nitrogen (Baht/rai)	1.7192	2.0959	1.7779	2.4265
Phosphorus (Baht/rai)	20.0323	20.6426	20.1046	19.0697
Seed (Baht/rai)	4.9015	5.8278	5.0327	6.2008
Labor (Baht/rai)	0.1507	0.1757	0.1545	0.1878
Pesticide (Baht/rai)	5.2409	0.0000	4.7239	0.0000

Table 6: Marginal Value Product of Pesticide and other farm inputs of rice cultivation in Thailand, cropping year 2000/2001

Inputs	Cobb-Douglas	Exponential damage control function
Nitrogen (Baht/rai)	2.1312	2.6819
Phosphorus (Baht/rai)	9.5836	9.3680
Seed (Baht/rai)	3.2583	4.2449
Labor (Baht/rai)	0.1929	0.2102
Pesticide (Baht/rai)	4.5359	0.0000

Table 7: Marginal Value Product of Pesticide and other farm inputs of rice cultivation in central region of Thailand, cropping year 1999/2000

Inputs	Cobb-Douglas	Exponential damage control function
Urea	1.3544	2.0828
Fertilizer 16-20-0	-2.7892	-2.6650
Labor	-0.9192	-1.0858
Herbicide	5.0491	2.1392
Insecticide	1.4996	0.0021

CONCLUSIONS AND RECOMMENDATION

Unlike directly productive inputs e.g. land, labor and capital, pesticides are damage control inputs and therefore do not increase the output directly. Their contribution depends on their ability to increase the share of potential output that farmers realize by reducing damage from pests (Lichtenberg and Zilberman, 1986). Thus, the functional specifications for damage control agents are different from the typical production function like Cobb-Douglas. The results found in this study confirm that the types of production function specifications used most commonly (i.e. Cobb-Douglas) to estimate factor productivity overestimate the productivity of pesticide inputs. Hence, it is recommended that a more sophisticated approach to damage abatement in production like Exponential, Logistic or Weibull should be incorporated into the economic work for future planning on the damage control agents like pesticides.

Results of this study may be useful for decision makers that are challenged with the reform of crop protection policy in Thailand towards reducing the dependence on chemical pesticides. In designing policy incentives to increase the productivity of rice production, policy makers should avoid distortions in favor of pesticide use, not only because of their demonstrated and assumed negative externalities (e.g. Jungbluth 1996) but also because of their lower than expected productivity effects. The results of this study also underline that in determining the need for biotechnology of crop protection in rice (e.g. Bt rice) it is important to first establish a realistic reference system (Zadoks and Waibel 2000) if wrong expectations as regards the benefits of such technologies is to be avoided.

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