Private and Social Levels of Pesticide Overuse in Rapidly Intensifying Upland Agriculture in Thailand

Christian Grovermann*, Pepijn Schreinemachers, Thomas Berger

Dept. of Land Use Economics in the Tropics and Subtropics (490d), Universität Hohenheim,

70593 Stuttgart, Germany

Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012

* Corresponding author.

Email: c.grovermann@uni-hohenheim.de

Tel.: +66-53-944-647; Fax: +66-53-893-099

Abstract

This study quantifies private and social levels of agricultural pesticide overuse by combining an abatement function approach to estimate the marginal benefits of pesticide use with the Pesticide Environmental Accounting (PEA) tool to estimate marginal social costs. We applied the method to one intensive vegetable production system in the mountainous north of Thailand by using farm and plot level survey data. We find that the exponential specification for the abatement effect of pesticides gives more realistic outcomes than the logistic specification. Based on an exponential specification, we estimate that private overuse is 78-79% of the applied quantify of pesticides, while social overuse is 79-80%. The difference between private and social overuse is small as the exponential form reaches an optimum at a relatively low level of pesticide use.

Keywords: Damage control; Externality; Pesticide Environmental Accounting (PEA); Southeast Asia.

1 Introduction

Farmers in low-income countries, although generally using much smaller quantities of agricultural pesticides than farmers in high-income countries, are much more vulnerable to the potential risks arising from their use. Policies in low-income countries do not adequately address these human and environmental risks, as policy-makers fear that restricting pesticide use will harm food production (Carvalho, 2006), in fact, many of these countries have policies in place that give farmers incentives to use more pesticides.

Fears that restrictions on pesticide use will reduce food production and harm food security are, however, not usually based on empirical analysis. In fact, there are very few analytical tools available for making such an assessment (Falconer, 2001). Unlike fertilizers or improved crop varieties, which have a more straightforward relationship to higher productivity and for which there are well-established methods and models that can be used to predict their effect on crop yields, pesticides are much more diverse with nearly a thousand active ingredients (Tomlin, 2009) and do not have a direct impact on crop yields other than limiting the adverse effects of pests. Yet, in the absence of scientific analysis of the costs and benefits associated with pesticides, debates about their use in developing countries have been prone to the influence of ideology and commercial interests.

The objective of this study is therefore to support the debate about pesticide overuse in low-income countries by quantifying how much pesticides are being overused in vegetable production, while explicitly considering the external costs not transmitted to farmers through input prices. Previous studies (Huang et al., 2002; Qaim and De Janvry, 2005; Jah and Regmi, 2009), which aimed at quantifying pesticide overuse, have focused on private costs only and might therefore have over-estimated the optimal levels of pesticide that can be applied.

Like other emerging economies with an export-oriented agricultural sector, such as Argentina, Brazil, Malaysia and Mexico, Thailand has very rapidly increased its agricultural pesticide use (Schreinemachers and Tipraqsa, 2011). Whereas Thai farmers used 1.2 kg of active ingredients per hectare in 1997, by 2010 they were using 3.7 kg/ha—an average increase of 9% per year (Praneetvatakul et al., 2011). Thai policymakers have been rather supportive of pesticide use, offering cheap credits to buy inputs, tax exemptions for agricultural pesticide imports and free distribution of pesticides during major pest outbreaks. Since the early 1990s, more efforts have been made to limit the increase in pesticide use by restricting the import of highly hazardous pesticides, while at the same time trying to reduce pesticide demand by promoting organic agriculture, running farmer field-schools and introducing the public certification of Good Agricultural Practices. Previous studies have shown that these demand side efforts have only limited success (Amekawa, 2009; Praneetvatakul et al., 2011; Schreinemachers et al., 2011).

The increase in pesticide use has been particularly strong in mountainous areas, which, favoured by a cooler climate and more rainfall, and due to recent improvements in infrastructure, have become important suppliers of temperate and sub-tropical fruits and vegetables. This study therefore uses farm-level data from one mountainous watershed area in northern Thailand. The adoption of cash crops by farmers in the study area, who until recently relied on growing rice for their own subsistence, has led to a high dependence on synthetic pesticides (Schreinemachers et al., 2011), a trend that has been observed in many Asian countries (Pingali, 2001).

The paper continues in the next section by providing information on how we quantified overuse for the study, and how we separated between the private and social costs of pesticide use, followed by an account of the selection criteria used when choosing the study area and details on the farm data that were collected. The subsequent section describes the results of the study, and we then end the paper with a discussion of these results.

2 Quantifying pesticide overuse

2.1 Conceptual background

In line with previous studies, we define pesticide overuse as the amount of pesticides used in excess of an economic optimum (Huang et al., 2002; Qaim and De Janvry, 2005; Sexton et al., 2007; Jah and Regmi, 2009). Making the simplifying assumption that farmers are motivated to maximize their profits, we can mathematically derive a private economic optimum level of pesticide use as being the point at which the marginal returns associated with pesticide use equal the farmers' purchase price for those same pesticides, and a social economic optimum as being where the marginal returns are equal to the sum of the marginal private costs, the purchase price, and the marginal external costs.

The marginal returns for pesticide use can be derived from a production function analysis. Lichtenberg and Zilberman (1986) argued that treating pesticides in the production function as a damage-control agent rather than a regular growth-stimulating input avoids overestimating the efficiency of pesticide use, a phenomenon confirmed by successive studies (Chambers and Lichtenberg, 1994; Lansink and Carpentier, 2001; Praneetvatakul et al., 2003). Following Lichtenberg and Zilberman (1986), for this study we thus specified crop output (Y) as a function of growth-stimulating inputs $F(Z)$ and damage control agents $G(X)$:

$$Y = F(Z)\, G(X) \tag{1}$$

The function $G(X)$, which takes values between zero and one, thus determines the magnitude of any damage and the effectiveness of the control with pesticides (X). Economic analysis of this type involves uncertainty surrounding the exact and appropriate functional form to use in order to specify the damage control function (Sexton et al., 2007), and might neglect intervening factors such as pest resistance. In the absence of precise entomological data though, the damage control approach provides a useful framework to capture pest pressure and abatement factors.

By introducing prices for output (*p*) and inputs (*w* for growth-stimulating inputs and *v* for pesticides), we can specify the farm-level profit function as:

$$\Pi = pY - wZ - vX \tag{2}$$

Maximizing this function with respect to pesticides gives us the private economic optimum level for pesticide use, which shows that optimum levels of use not only depend on the prices of outputs and pesticides, but also on the levels at which all other inputs are applied:

$$\frac{\partial \pi}{\partial X} = 0 \text{ or } \frac{\partial pF(Z)G(X) - wZ - vX}{\partial X} = 0 \tag{3}$$

Not all costs associated with pesticides are transmitted through the prices that farmers pay for them. There are also the external effects of pesticides on ecosystems and the health of applicators and pickers, as well as on consumers ingesting pesticide residues. Including these externalities in the price of pesticides will raise their cost and lower the optimum level of pesticide use, as illustrated in Figure 1. Graphically, the economic optima can be represented by the intersection of the private and social marginal cost functions, shown as horizontal lines in the figure, and the marginal value product (MVP) curve.

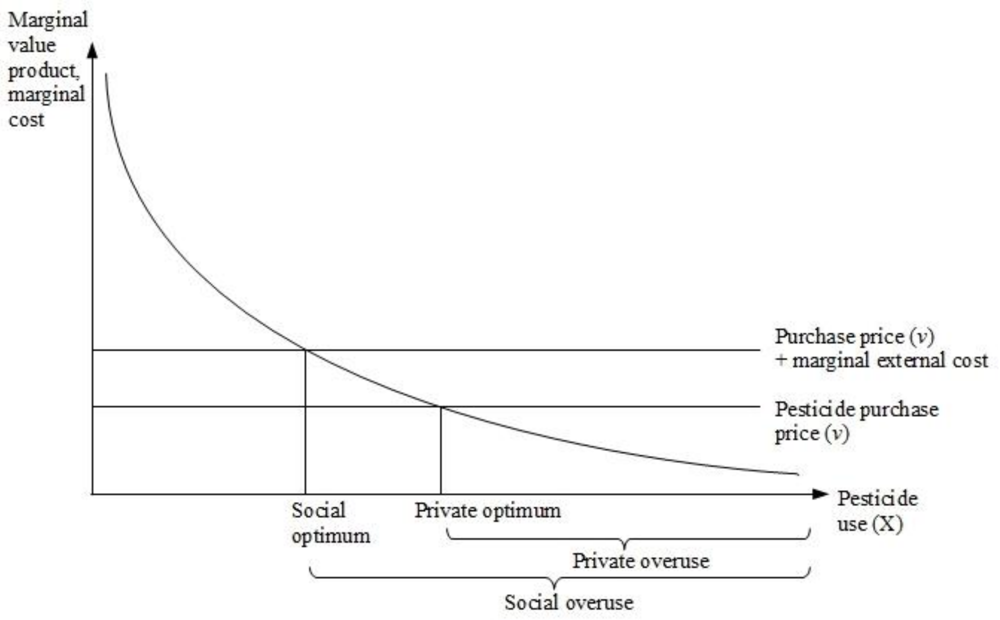

Figure 1: The private and social optimum level of pesticide overuse

2.2 Econometric estimation

The Cobb-Douglas and quadratic specifications are the most commonly used types of farm production functions, and have been shown to give similar results (Qaim and De Janvry, 2005; Horna et al., 2008). Unlike the Cobb-Douglas method, the quadratic form allows for decreasing returns and can handle zero values for input or output variables, yet multi-collinearity is a frequently encountered problem. The Cobb-Douglas function, on the other hand, tends to give better results if inputs and outputs have a high variation, as the logarithmic transformation reduces the spread in values. In this study, we had relatively few zero values but a relatively high variation in observed values, and we therefore chose the Cobb-Douglas form for *F(Z)*.

Various specifications have been proposed for the damage abatement element *G(X)*, such as exponential, logistic, Pareto and Weibull specifications (Lichtenberg and Zilberman, 1986). Previous studies have shown that results tend to be sensitive to the choice of damage control term used (Carrasco-Tauber and Moffitt, 1992; Praneetvatakul et al., 2003; Pemsl, 2006; Jah and Regmi, 2009). These studies have found that an exponential term gives smaller estimates for the marginal benefit of pesticides than do other specifications such as logistic or Weibull.

Due to uncertainty over the exact and appropriate specification to use, Sexton et al. (2007) suggested finding the right specification by using a variety of functional forms and complementing the analysis with agronomic insights. For this study, we selected the exponential and the logistic specification for *G(X)*, as these were the most commonly used methods in the above mentioned studies, and we compared them with a conventional Cobb-Douglas production function *F(Z,X)* without a damage control specification. The three production function specifications used in our analysis are as follows:

With exponential specification

$$lnY = \alpha + \sum_i \gamma_i C_i + \sum_j \beta_j lnZ_j + ln\left[1 - exp(-\lambda X)\right] + \varepsilon \qquad (4)$$

With logistic Specification $$lnY = \alpha + \sum_i \gamma_i C_i + \sum_j \beta_j lnZ_j + ln\left[1 + exp(\mu - \sigma X)\right]^{-1} + \varepsilon \quad (5)$$

Without damage control specification $$lnY = \alpha + \sum_i \gamma_i C_i + \sum_j \beta_j lnZ_j + \beta lnX + \varepsilon \quad (6)$$

In the equations, indicator variables C_i were introduced alongside growth-stimulating inputs Z_j and pesticides X to control for farm characteristics, individual crops and location. Individual crop dummies and area dummies were introduced, because we estimated the functions over several crops and villages located at different altitudes. In addition, irrigation practices, the spraying habits of farmers (preventive vs. responsive) and their education levels were taken into account. Crop output, fertilizer amounts, other inputs and pesticide amounts were expressed in monetary terms, in baht per hectare per month (1 USD ~ 31 Thai baht).

Because pesticides were expressed in monetary units rather than physical quantities, the optimal private level of pesticide use occurred where the marginal value product equalled unity. Likewise, the social optimum was obtained where the marginal value product equalled one plus the ratio of external costs to pesticide purchasing costs. The marginal value product of pesticides was the first derivative of the production functions specified above:

With exponential specification $$MVP_x = \mathrm{F(Z)} * \frac{\lambda[\exp(-\lambda X)]}{[1-\exp(-\lambda X)]} \quad (7)$$

With logistic specification $$MVP_x = \mathrm{F(Z)} * \frac{\sigma[\exp(\mu-\sigma X)]}{[1+\exp(\mu-\sigma X)]^2} \quad (8)$$

Without damage control specification $$MVP_x = \beta \frac{\mathrm{F(Z,X)}}{X} \quad (9)$$

Parameters were estimated using non-linear least squares regressions with robust standard errors. The Variance Inflation Factor was found to be well below 10 for each regression, suggesting that multi-collinearity might not be a problem here. In addition, we tested whether pesticides were an endogenous variable in the model, as several previous studies have found it to be correlated with the error term. We tested for endogeneity using a two-stage least-squares (2SLS) instrumental variable regression following Horna et al. (2008). Based on the result of the Wu-Hausman test we could reject the null hypothesis of endogeneity (p = 0.311).

2.3 External costs of pesticide use

Using an actual cost method, Jungbluth (1996) estimated the external cost of agricultural pesticide use in Thailand to be 5.5 billion baht in 1996 (267,7 million USD at 2010 exchange rate and prices). Her results suggested that every baht spent on pesticides created roughly one baht in external costs—implying a 100% difference between the private and social costs of pesticide use. However, it is not possible to use this national figure to assign a specific external cost to an individual pesticide or active ingredient, as would be needed for our analysis.

For our study, we therefore complemented Jungbluth's estimates with the Pesticide Environmental Accounting (PEA) tool, which estimates external costs based on observed amounts of pesticide use, and can estimate the external costs of a particular cropping cycle (Leach and Mumford, 2008). The PEA tool approximates external costs for particular active ingredients depending on the application rate and potential risk, with potential risk data coming from the Environmental Impact Quotient (EIQ) tool developed by Kovach et al. (1992; 2008). The EIQ method gives a relative estimate of the potential risk to farm workers (applicators and pickers), consumers (groundwater leaching and food consumption) and the environment (aquatic life, bees, birds and beneficial insects). Making a number of assumptions, Leach and Mumford assigned the external cost estimates produced by Pretty et al. (2000; 2001) for Germany, the UK and the USA to the six sub-categories of the EIQ tool.

Based on the PEA method, the total external cost (TEC) of a pesticide *p* is calculated as:

$$\mathrm{TEC_p} = \mathrm{Rate_p} * \frac{\mathrm{Active_p}}{100} * \sum_{c=1}^{8}\left[\mathrm{EC_c} * \mathrm{F_c} * (\mathrm{F_{agemp}}|\mathrm{c} = 1{,}2)\right] * \mathrm{F_{gdppc}} * \mathrm{F_{adj}} \quad (10)$$

In which $Rate_p$ represents the application rate of a pesticide *p* in kg of formulated product per hectare, and $Active_p$ is the percentage of active ingredient contained in the formulated product. EC_c is the external cost of category *c* (*c*=1,2,..8), which is a fixed parameter in the EIQ tool. As pesticides with a higher potential risk should bear a higher external cost, Pretty et al.

divided the potential risk into three categories of lower, medium and upper values, and multiplied the external costs by a factor (F_c) of 0.5, 1.0 and 1.5, respectively.

The effects of pesticides on applicators and pickers (i.e., farm workers) are likely to be greater in low-income countries, as relatively more people engage in agriculture and therefore come into direct contact with pesticides. Leach and Mumford (2008) suggested using the proportion of GDP taken up by agriculture as a proxy for health-related externalities, but we think that the share of agriculture in employment terms is preferable, because it better reflects the number of people who are likely to come into direct contact with pesticides on farms. We therefore multiplied the external costs for applicators and pickers (c=1,2) by a factor F_{agemp}, calculated as the ratio of a country's share of employment in agriculture to the average share of agricultural employment in Germany, the UK and the USA (weighted by GDP). We should note that although this factor captures the fact that in low-income countries more people come into direct contact with pesticides, it does not capture the fact that pesticide use in low-income countries is far more hazardous, because farm workers do not sufficiently protect themselves.

On the other hand, low-income countries are also likely to have lower external costs, because lower labour costs also reduce the costs of monitoring and clean-up. Leach and Mumford therefore suggested adjusting the total external costs by multiplying them by the factor F_{gdppc}, calculated as the ratio of a country's per capita GDP to the average per capita GDP in Germany, the UK and the USA (weighted by GDP).

Applying the PEA tool to Thailand, Praneetvatakul et al. (2011) found that it gave an external cost estimate that was about 53% lower than Jungbluth's estimate. Because Jungbluth's estimate, based on empirical research in Thailand, is more reliable, we amended the PEA tool by including an adjustment factor (F_{adj}=2.15) in Equation 10 that calibrated the PEA tool to Jungbluth's estimate. We should note however, that both the PEA and Jungbluth's study are based on actual cost-accounting methods and these have been shown to give lower cost estimates than hypothetical willingness-to-pay studies (Harrison, 2006). This is because the adverse effects of pesticides on the environment and human health do not always create direct financial costs, at least in the short term. For instance, pesticide applicators falling ill because of spraying might not actually visit a doctor, the long-term effect of pesticide residues on humans might not be diagnosed initially, and there are no direct payments made when beneficial insects disappear from ecosystems.

3 Data basis and levels of pesticide use

3.1 Study site selection

We selected the Mae Sa watershed area in northern Thailand as our primary data collection area, as this area has experienced a very rapid intensification of agriculture and consequent increase in pesticide use (Schipmann and Qaim, 2010). The watershed is located about 30 km northwest of the regional capital Chiang Mai, and is characterized by good market access and intensive upland agriculture. It covers an area of 140 km^2, with altitudes ranging from 400 m to 1,200 m above sea level. Farmers grow a wide variety of cash crops, of which the key crops are bell peppers, tomatoes, cabbages, lettuce, onions, potatoes, chayote, maize, rice, chrysanthemums, roses and litchi trees. Cropping patterns vary according to the village location, the elevation and slope, which results in a spatially diverse agricultural land-use mix, with particular crops such as litchi being locally concentrated. The increase in production of high-value crops has been accompanied by heightened pest pressure and the build-up of pest resistance, which has led farmers to increase the frequency and intensity of pesticide applications.

3.2 Farm data collection

A structured questionnaire survey was carried out in the Mae Sa watershed area. The watershed area has twelve villages that practice agriculture, and 20% of the farm households in each of these villages were randomly selected, which gave us a total of 295 farm households. A one-year recall period, from April 2009 to March 2010, was used for the face-to-face interviews. For each plot and each crop respondents were asked about their pest problems and how they have tried to control them. If using a pesticide, respondents were asked to give its common name, the number of times they sprayed it, the quantity of undiluted chemical they used, and the price and volume per container. For each recorded pesticide data were collected on the active ingredients from traders, shops and producers.

3.3 Pesticide use

Drawing on the same farm survey data as used in this study, Schreinemachers et al. (2011) estimated that farmers apply synthetic pesticides at a rate of 13 kg of active ingredients per hectare, the majority of which are fungicides and insecticides. Farmers in the area very much depend on synthetic pesticides for their pest control activities, with non-synthetic methods being practiced on only 6% of the planted area. However, on 17% of the planted area, no pest control takes place at all, either because of the low market value of the crop (*e.g.* litchis), because the crop is used for own-consumption (*e.g.* upland rice), or due to a lack of severe pest problems (*e.g.* chayote).

Pesticide use, as well as production costs and output, vary greatly among the various agricultural land-uses. The diffusion of greenhouse vegetables and the decrease in litchi areas can largely be explained by the profitability of these crops (Schreinemachers et al., 2009; 2010). Greenhouse crops, such as bell peppers, generate a high output but entail high costs and require substantial applications of pesticides. As can be seen from Figure 2, farmers apply greater amounts of pesticides on crops with relatively higher revenues.

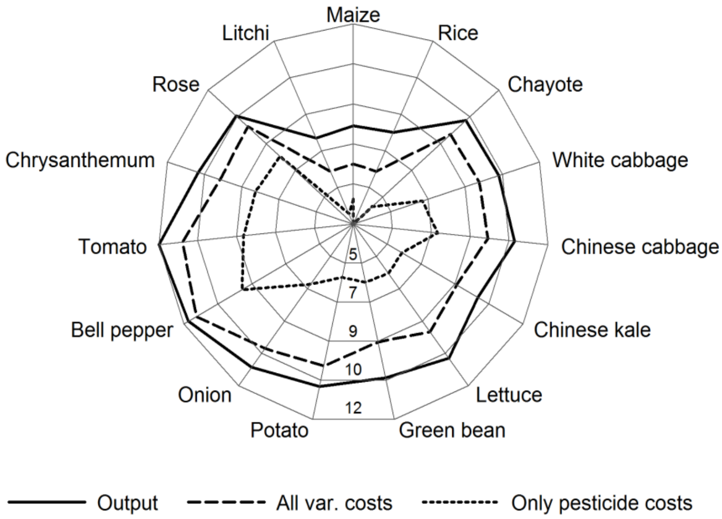

Figure 2: Crop output, total costs and pesticide costs for 15 crops in the Mae Sa watershed area, 2010 (in log baht/ha/month)

The great diversity of land-use activities proved a challenge for the analysis. Production functions are usually estimated separately by crop, as different crops have a different response to fertilizers and other inputs, and are differently affected by pests. However, because of the diverse land-use activities, there were not enough observations to estimate separate production functions for each crop, so we had to group crops by their similarity in terms of length of growing period, pest problems and pest management activities, which produced two separate land-use groups: greenhouse vegetables (including bell peppers and tomatoes) and leaf vegetables (cabbages, kale and lettuce). The analysis of these two groups was compared to a combined analysis of all major vegetables (greenhouse vegetables, leaf vegetables, onions, potatoes and chayote). We also tried to estimate a damage control function for flowers, but parameters were not significant, which we reasoned was due to the fact that the spraying of flowers is mostly preventive and has no significant and clear relationship to output. Table 1 summarizes the main variables used in the analysis. Other explanatory variables included crop dummies, village dummies, irrigation, education and the spraying habit of farmers.

Table 1: Summary statistics of the main variables used in the analysis (1000 baht/ha/month)

Variables	Leaf Vegetables		Greenhouse Vegetables		All Vegetables	
	Mean	SD	Mean	SD	Mean	SD
Output	46.05	39.80	213.47	187.21	106.09	139.75
Labour (hrs/ha/month)	95.77	96.32	246.88	219.22	154.41	165.66
Fertilisers	7.10	4.54	53.18	39.79	22.71	32.49
Other	1.77	1.26	36.72	24.55	14.62	21.88
Pesticides	1.71	1.67	15.16	14.82	6.28	10.95
External costs	0.49	0.59	3.21	3.56	1.44	2.51

4 Results

4.1 Production function estimates

Table 2 shows the coefficients of the production functions with the exponential specification (Exp.), the logistic specification (Log.) and without abatement specification (Without), which were estimated for three different land-use groups. The adjusted R-squared for the exponential specification was 0.41 for leaf vegetables, 0.30 for greenhouse vegetables and 0.55 for all vegetables, which is comparable to similar studies in China and Thailand (Huang et al., 2002; Praneetvatakul et al., 2003; Pemsl, 2006). The dummy variable identifying preventive spraying (1=preventive) had a clear and positive effect on output, while the effect of education (1=low) was generally small. Surprisingly, irrigation had a highly significant negative coefficient, suggesting an intervening effect related to seasonality or management. With regard to growth-stimulating inputs, all had positive and significant effects, with labour being the most important. In each land-use group, regressions produced similar results for the different specifications in terms of explained variances and the significance of the parameters. Pesticides produced a positive sign in all instances.

Table 2: Production function estimates, with and without abatement specification

	Leaf Vegetables			Greenhouse Vegetables			All Vegetables		
	Exp.	Log.	Without	Exp.	Log.	Without	Exp.	Log.	Without
Constant	7.086***	8.438***	6.533***	5.422***	6.739***	4.095***	6.611***	7.883***	6.059***
	[12.99]	[14.60]	[13.54]	[5.71]	[6.85]	[4.82]	[10.82]	[12.25]	[11.30]
Irrigation	-0.464***	-0.393***	-0.414***				-0.361***	-0.291***	-0.296***
	[-4.76]	[-4.22]	[-4.38]				[-3.92]	[-3.24]	[-3.33]
Education	-0.102	-0.089	-0.084	0.054	0.052	0.053	-0.033	-0.027	-0.030
	[-1.06]	[-0.97]	[-0.92]	[0.41]	[0.46]	[0.41]	[-0.44]	[-0.37]	[-0.41]
Preventive	0.301***	0.276***	0.270***	0.295**	0.200	0.194	0.196***	0.139*	0.134*
	[3.47]	[3.24]	[3.16]	[2.05]	[1.39]	[1.34]	[2.66]	[1.92]	[1.83]
Location1	0.176	0.215	0.334	-0.270	-0.307*	-0.295*	0.013	-0.015	0.033
	[0.64]	[0.77]	[1.20]	[-1.49]	[-1.76]	[-1.68]	[0.09]	[-0.11]	[0.23]
Location2	0.046	-0.008	-0.015	-0.081	-0.084	-0.086	0.078	0.074	0.086
	[0.19]	[-0.03]	[-0.06]	[-0.43]	[-0.46]	[-0.47]	[0.55]	[0.54]	[0.62]
Location3	0.599***	0.553***	0.519**	0.585**	0.658**	0.640**	0.582***	0.647***	0.577***
	[2.89]	[2.73]	[2.47]	[2.13]	[2.56]	[2.49]	[4.18]	[4.80]	[4.23]
Labour	0.346***	0.318***	0.322***	0.251***	0.247***	0.253***	0.292***	0.280***	0.268***
	[4.83]	[4.56]	[4.50]	[2.69]	[2.66]	[2.73]	[3.80]	[2.62]	[2.84]
Fertilizers	0.130**	0.089	0.070	0.355***	0.273***	0.286***	0.209***	0.154***	0.159***
	[2.02]	[1.41]	[1.09]	[3.84]	[2.99]	[3.13]	[3.80]	[2.62]	[2.84]
Other	0.065	0.068	0.052	0.121*	0.118*	0.110	0.131***	0.124***	0.119***
	[1.23]	[1.29]	[1.99]	[1.70]	[1.73]	[1.62]	[2.82]	[2.72]	[2.61]
Pesticides			0.200***			0.238***			0.173***
			[5.42]			[3.60]			[5.31]
λ	0.0182***			0.0019**			0.0263**		
	[3.28]			[2.18]			[2.49]		
μ		0.7375*			0.5534			0.7407***	
		[1.76]			[1.51]			[2.61]	
σ		0.0003**			0.0001**			0.0001***	
		[2.42]			[2.26]			[3.76]	
N	265	265	265	188	188	188	533	533	533
F			25.17			13.89			46.03
Adj. R^2	0.41	0.46	0.45	0.30	0.34	0.34	0.55	0.57	0.57

Notes: Dependent variable is output in ln(baht/ha/month). T-values in brackets. The nine crop dummies are not shown. The independent variables (Pesticides, Fertilizers, Other inputs) expressed in baht/ha/month. Significance levels: ∗P < 0.10, ∗∗P < 0.05, ∗∗∗P < 0.01.

Table 3 shows the marginal value product of pesticides estimated at the individual input levels of each observation. As the MVP is here defined as the value of output resulting from one additional baht spend on pesticides, values above unity, such as in the logistic form, point at an underuse of pesticides. With an exponential damage control specification, the MVP of pesticides at the median level of pesticide use was close to zero for all land–use groups. If using a logistic specification, the MVP at the median was 5.07 for leaf vegetables and 3.12 for greenhouse vegetables. Results without abatement specification are in a similar order of magnitude as those for the logistic specification.

Table 3: Marginal Value Product (MVP) at percentiles of pesticide use observations

Percentile of observations	Leaf Vegetables			Greenhouse Vegetables			All Vegetables		
	Exp.	Log.	Without	Exp.	Log.	Without	Exp.	Log.	Without
10% highest	<0.01	3.15	2.03	<0.01	0.83	1.36	<0.01	1.62	1.56
50%	<0.01	4.85	5.07	<0.01	4.14	3.12	<0.01	2.98	5.08
90%	11.56	6.61	18.69	1.10	7.70	8.63	1.58	6.45	22.14

The results also reveal that the pesticide and damage control coefficients were different for leaf vegetables, greenhouse vegetables and all vegetables combined. It was greater for leaf vegetables than for greenhouse vegetables. In the following section, we aim to shed more light on the optimal pesticide use and overuse levels for each different production function specification and land-use group.

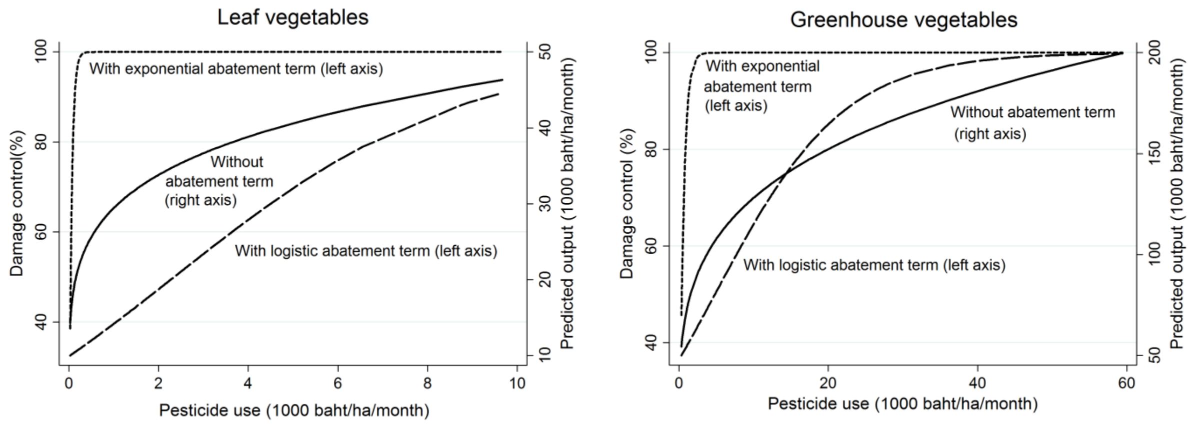

Figure 3: Effects of pesticides with and without abatement term

As Figure 3 illustrates, the shape of the response to pesticides is radically different depending on how pesticides were specified in the production function. For leaf vegetables, the relationship between pesticides was close to linear, and full damage control (100%) was not achieved if using a logistic specification. If treating pesticides as a regular direct input, the productivity effect gradually increased with increasing levels of pesticide use, but if treating pesticides as an exponential damage control agent, the abatement effect quickly levelled off at relatively small amounts of pesticide use. For greenhouse vegetables, where much higher amounts of pesticides are applied than for other land-uses, the regular Cobb-Douglas functions and the exponential functions described a similar relationship as for leaf vegetables, but on a different scale. However, the logistic abatement specification was markedly different, and its shape was a combination of the other two specifications, levelling off and reaching full damage control potential at a relatively high level of pesticide use.

4.2 Pesticide overuse

Optimal levels of pesticide use were determined for each individual observation, depending on the costs associated with the applied pesticides as well as on the use of other inputs. Overuse of pesticides was then calculated for each observation as the difference between actual pesticide use and optimal use and eventually summed up. In case of many pesticide use observations below optimal use values, overall overuse figures then turn out to be negative, indicating underuse.

Table 4 shows that the optimal levels of pesticide use were relatively small and the levels of overuse relatively high if using an exponential damage control specification. This applied to both private and social levels of overuse, the difference between the two being relatively small though. As a consequence of the consistently low marginal productivity shown for the majority of pesticide use observations, a very substantial amount of pesticides, 79% for leaf vegetables, 78% for greenhouse vegetables and 94% for all vegetables could thus be categorized as overuse from a private point of view. Because of the steepness of the exponential damage control function, adding external costs to the private costs only had a minor effect on the quantity of overuse.

The results for the logistic specification strongly contradict those of the exponential specification. These results suggest there is hardly any overuse, but farmers could increase their output by using more pesticides. For leaf vegetables, they could increase the amount up to five times, while for greenhouse vegetables they could more than double the amount. These results are somewhat similar to the results of the regular Cobb-Douglas function without damage control specification, which also produce underuse rather than overuse.

Table 4: Private and social levels of optimal pesticide use and overuse

	Leaf Vegetables		Greenhouse Vegetables		All Vegetables	
	Private	Social	Private	Social	Private	Social
With the exponential abatement term						
Optimal use (1000 baht/ha/month)	0.34	0.32	2.89	2.77	0.28	0.27
Total overuse (1000 baht)	336	340	1,287	1,302	2,029	2,034
Overuse (as % of total quantity)	79	80	78	79	94	94
With the logistic abatement term						
Optimal use (1000 baht/ha/month)	11.59	10.55	30.77	28.51	24.09	21.40
Total overuse (1000 baht)	-2,535	-2,257	-2,195	-1,887	-8,735	-7,342
Overuse (as % of total quantity)	-598	-532	-133	-114	-404	-340
Without the abatement term						
Optimal use (1000 baht/ha/month)	6.33	4.98	37.08	30.35	15.19	12.15
Total overuse (1000 baht)	-1,072	-761	-2,538	-1,784	-3,664	-2,494
Overuse (as % of total quantity)	-253	- 180	-158	-108	-170	-116

Note: Overuse determined for each observation as the difference between actual and optimal pesticide use. Total overuse for the whole watershed is the sum of these individual overuse values, negative values indicate underuse.

5 Discussion

The MVP estimates of this study are in line with results of Praneetvatakul et al. (2003), who studied pesticide use in rice farming in Thailand; they also estimated an MVP near zero if using an exponential term, an MVP of 4.72 if using a logistic damage control term (we estimated it to be 4.14 for leaf vegetables and 4.85 for greenhouse vegetables), and 5.24 if not using a damage control term (we estimated it to be 5.07 for leaf vegetables and 3.12 for greenhouse vegetables). Our results also confirm the findings of other studies that demonstrated that the exponential form produced much lower marginal returns to pesticide use than when treating pesticides as a regular input or if using a logistic abatement term (Carrasco-Tauber and Moffitt, 1992; Praneetvatakul et al., 2003; Jah and Regmi, 2009). Using an exponential specification, Jah and Regmi (2009) estimated that 70% of pesticide use by vegetable farmers in Nepal is above the optimum, which is about the same order of magnitude as in our study.

Although there is no clear theoretical basis for preferring one damage control specification over another (Sexton et al., 2007), the results of the logistic specification clearly contradict our field observations of pesticide overuse. At 13 kg/ha, pesticide use in the study area is 3.5 times above the Thai national average and above nearly any other country in the world. Schreinemachers *et al.* (2011) estimated that the average bell pepper grower in this study area uses 3 times as much active ingredient per ton of bell peppers as the average Spanish grower, and 52 times as much as the average Dutch grower. The results of the exponential damage control function are therefore much more credible to us and are in line with other authors who have preferred using an exponential damage control specification (Huang et al., 2002; Jah and Regmi, 2009).

Resulting overuse numbers in the range of 80% are alarming, it implies that farmers are spraying excessively and inefficiently. Earlier research on pesticide overuse in Thailand in the early 1990s also showed that farmers are overusing pesticides by as much as a factor eight (Waibel and Setboonsarng, 1993). Farmers could therefore increase their profits by reducing pesticide expenditures.

In terms of separating between private and social levels of overuse, this paper made a methodological contribution by combing the damage control approach with the Pesticide Environmental Accounting tool. As the exponential damage control function reaches the optimal level of control at a relatively low level of pesticide use (i.e. the function is steep), the difference between the private and social optima is small for all land uses. The logistic and regular Cobb-Douglas functions are less steep and the difference between private and social optima are therefore more substantial.

Our results suggest that it is important to estimate damage control functions for consistent categories of crops. Levels of pesticide use were substantially greater for greenhouse vegetables than for leaf vegetables grown in open fields. When combining all vegetables in one regression, the estimated optimum level is lower and overuse is consequently higher than when estimating overuse for the two categories separately.

Although useful for quantifying the magnitude of pesticide overuse, the damage control approach falls short of adequately portraying the complex relationship between crop pests and crop yields as well as the effect of pesticide use on the development of pesticide resistance and on the loss of beneficial insects. An additional drawback is that all pesticide products were aggregated in this analysis and pest problems were not explicitly considered.

A possible explanation for the high rate of overuse is that farmers currently have few alternatives to synthetic pesticides because of a lack of knowledge about available alternatives that could be used to manage pests in an integrated manner. Schreinemachers et al. (2011) previously showed, for the same study area, that non-synthetic methods of pest control were only applied on 8% of the planted area, with 77% of the farms solely depending on synthetic pesticides. The development and dissemination of integrated pest management is in its infancy and will need more investment, but Thai policy makers seem to have given low priority to IPM and have instead focused on pesticide reductions through the voluntary, public certification of Good Agricultural Practice (Schreinemachers et al., under review).

Internalizing the external costs of pesticides by taxing pesticide use might have only a small effect in bringing down current levels of pesticide use to optimum levels as various studies have shown that the demand for pesticides is very inelastic (Falconer, 2000; Pina and Forcada, 2004) and our data, though not shown here, confirm this. Since there are currently few alternatives to synthetic pesticides available to farmers, if investing the revenues of a possible pesticide tax into the development and dissemination of IPM methods, it might have a more substantial and long-term effect on reducing pesticide use than a tax alone. Further research is needed to test the validity of this statement.

6 Conclusion

This study made two methodological contributions to the current literature on pesticide economics. First, we showed how to separate between private and social levels of pesticide overuse by combining a damage abatement approach to estimate the marginal benefits of pesticide use with the Pesticide Environmental Accounting (PEA) tool to estimate marginal social costs. Second, we compared the exponential and logistic abatement specification for pesticides and showed that these led to opposing conclusions with respect to the extent of pesticide overuse. Based on our empirical observations, we concluded that the exponential term is to be preferred. Using the exponential abatement specification we estimated that of the current quantify of applied pesticides in leaf vegetables and greenhouse vegetables, respectively 79% and 78% is private overuse while respectively, 80% and 79% is social overuse. The small difference between private and social levels of overuse is due to the fact that the exponential form reaches an optimum at a relatively low level of pesticide use.

Acknowledgements

The authors would like to acknowledge the Deutsche Forschungsgemeinschaft (DFG) for financially supporting this research study, which was carried out under Project SFB-564 (the Uplands Program). We would also like to thank Aer Sirijinda, Sureeporn Sringarm and Suwanna Praneetvatakul for their help at various stages of the research.

References

Amekawa, Y. "Reflections on the Growing Influence of Good Agricultural Practices in the Global South." *Journal of Agricultural and Environmental Ethics*, Vol. 22, (2009) pp. 531-557.

Carrasco-Tauber, C. and L.J. Moffitt "Damage Control Econometrics: Functional Specification and Pesticide Productivity." *American Journal of Agricultural Economics*, Vol. 74, (1992) pp. 158-162.

Carvalho, F.P. "Agriculture, pesticides, food security and food safety." *Environmental Science & Policy*, Vol. 9, (2006) pp. 685-692.

Chambers, R.G. and E. Lichtenberg "Simple Econometrics of Pesticide Productivity." *American Journal of Agricultural Economics*, Vol. 76, (1994) pp. 407-417.

Falconer, K., Hodge, I. "Using economic incentives for pesticide usage reductions: responsiveness to input taxation and agricultural systems." *Agricultural Systems*, Vol. 63, (2000) pp. 175-194.

Falconer, K., Hodge, I. "Pesticide taxation and multi-objective policy-making: farm modelling to evaluate profit:environment trade-offs." *Ecological Economics*, Vol. 36, (2001) pp. 263 - 279.

Harrison, G. "Experimental Evidence on Alternative Environmental Valuation Methods." *Environmental and Resource Economics*, Vol. 34, (2006) pp. 125-162.

Horna, D., M. Smale, R. Al-Hassan, J. Falck-Zepeda and S.E. Timpo "Insecticide use on vegetables in Ghana", in I.F.P.R. Institute (ed.), *IFPRI Discussion Paper* (Washington, 2008).

Huang, J., R. Hu, S. Rozelle, F. Qiao and C.E. Pray "Transgenic varieties and productivity of smallholder cotton farmers in China." *Australian Journal of Agricultural and Resource Economics*, Vol. 46, (2002) pp. 367-387.

Jah, R.K. and A.P. Regmi "Productivity of pesticides in vegetable farming in Nepal", *SADEE Working Paper* (Katmandu, Nepal: South Asian Network for Development and Environmental Economics, 2009).

Jungbluth, F. "Crop Protection Policy in Thailand: Economic and Political Factors Influencing Pesticide Use", in H. Waibel (ed.), *Pesticide Policy Project Publication Series No. 6*: Institute of Development and Agricultural Economics, University of Hannover, 1996).

Kovach, J., C. Petzoldt, J. Degni and J. Tette "A method to measure the environmental impact of pesticides." *New York's Food and Life Science Bulletin 139, New York Agricultural Experiment Station, Cornell University, Ithaca, NY, 8 pp*, (1992).

Kovach, J., C. Petzoldt, J. Degni and J. Tette "A Method to Measure the Environmental Impact of Pesticides": Cornell University, New York State Agricultural Experiment Station Geneva, New York 2008).

Lansink, A.O. and A. Carpentier "Damage Control Productivity: An Input Damage Abatement Approach." *Journal of Agricultural Economics*, Vol. 52, (2001) pp. 11-22.

Leach, A.W. and J.D. Mumford "Pesticide Environmental Accounting: A method for assessing the external costs of individual pesticide applications." *Environmental Pollution*, Vol. 151, (2008) pp. 139-147.

Lichtenberg, E. and D. Zilberman "The Econometrics of Damage Control: Why Specification Matters." *American Journal of Agricultural Economics*, Vol. 68, (1986) pp. 261-273.

Pemsl, D.E. "Economics of agricultural biotechnology in crop protection in developing countries: The case of Bt-cotton in Shandong Province, China", in H. Waibel (ed.), *Pesticide Policy Project Publication Series No. 11*: Institute of Development and Agricultural Economics, University of Hannover, 2006).

Pina, C.M. and S.A. Forcada "Effects of an environmental tax on pesticides in Mexico." *Industry and Environment*, Vol. 27, (2004) pp. 34 - 38.
Pingali, P.L. "Environmental consequences of agricultural commercialization in Asia." *Environment and Development Economics*, Vol. 6, (2001) pp. 483-502.
Praneetvatakul, S., S.D. Kuwattanasiri and H. Waibel "The Productivity of Pesticide use in rice production of Thailand: A damage control approach." *Thai Journal of Agricultural Economics*, Vol. 22, (2003).
Praneetvatakul, S., P. Schreinemachers, P. Pananurak and P. Tipraqsa *Economic Impact of Chemical Pesticide Use in Agriculture* (Bangkok, Report prepared for the Thai Health Promotion Foundation. Kasetsart University, 2011).
Pretty, J., C. Brett, D. Gee, R. Hine, C. Mason, J. Morison, M. Rayment, G.V.D. Bijl and T. Dobbs "Policy and practice: policy challenges and priorities for internalizing the externalities of modern agriculture." *Journal of Environmental Planning and Management*, Vol. 44, (2001) pp. 263-283.
Pretty, J.N., C. Brett, D. Gee, R.E. Hine, C.F. Mason, J.I.L. Morison, H. Raven, M.D. Rayment and G. van der Bijl "An assessment of the total external costs of UK agriculture." *Agricultural Systems*, Vol. 65, (2000) pp. 113-136.
Qaim, M. and A. De Janvry "Bt cotton and pesticide use in Argentina: economic and environmental effects." *Environment and Development Economics*, Vol. 10, (2005) pp. 179-200.
Schipmann, C. and M. Qaim "Spillovers from modern supply chains to traditional markets: product innovation and adoption by smallholders." *Agricultural Economics*, Vol. 41, (2010) pp. 361-371.
Schreinemachers, P., T. Berger, A. Sirijinda and S. Praneetvatakul "The diffusion of greenhouse agriculture in Northern Thailand: Combining econometrics and Agent-Based Modeling." *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, Vol. 57, (2009) pp. 513-536.
Schreinemachers, P., C. Potchanasin, T. Berger and S. Roygrong "Agent-based modeling for ex-ante assessment of tree crop technologies: litchis in northern Thailand." *Agricultural Economics*, Vol. 41, (2010) pp. 519-536.
Schreinemachers, P., I. Schad, P. Tipraqsa, P. Williams, A. Neef, S. Riwthong, W. Sangchan and C. Grovermann "Can Public GAP Standards Reduce Agricultural Pesticide Use? The Case of Fruit and Vegetable Farming in Northern Thailand." *Agriculture and Human Values*, (under review).
Schreinemachers, P., S. Sringarm and A. Sirijinda "The role of synthetic pesticides in the intensification of highland agriculture in Thailand." *Crop Protection*, Vol. 30, (2011) pp. 1430-1437.
Schreinemachers, P. and P. Tipraqsa "Agricultural Pesticides and Land Use Intensification in High, Middle and Low Income Countries." *Food Policy*, Vol. Under review, (2011).
Sexton, S., L. Zhen and D. Zilberman "The Economics of Pesticides and Pest Control." *International Review of Environmental and Resource Economics*, Vol. 1, (2007) pp. 271-326.
Tomlin, C.D.S. *The pesticide manual: A World compendium* (Alton, U.K., British Crop Protection Council (11th Revised edition), 2009).
Waibel, H. and S. Setboonsarng "Resource Degradation Due to Chemical Inputs in Vegetable-Based Farming Systems in Thailand." *Journal of Asian Farming System Association*, Vol. 2, (1993) pp. 107-120.