Quantifying pesticide overuse from farmer and societal points of view: An application to Thailand

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Abstract

The rapid growth in pesticide use is a significant problem for Thailand, as it is in many other developing countries with an intensifying agriculture. The objective of this study was to quantify how much of the total quantity of pesticides is overused. The novelty of this research resides in the fact that it considered the social rather than the private optimum by including negative pesticide externalities in determining levels of overuse. Marginal benefits of pesticides are quantified by estimating Cobb-Douglas production functions with an exponential damage control specification. The marginal costs are calculated as the sum of private and external costs with the latter quantified using the Pesticide Environmental Accounting (PEA) tool. The method is applied using farm- and plot-level data from one intensive upland vegetable production system in northern Thailand. The findings show that about 80% of the applied pesticide quantity is used in excess of the social optimum, while the difference between the private and social level of overuse is small for this particular case study. Therefore results from the study area suggest that internalizing pesticide externalities into the price of pesticides would only have a small effect on reducing pesticide overuse.

Keywords: Damage control; externality; Pesticide Environmental Accounting (PEA); pesticide policy; production function; Southeast Asia.

1. Introduction

The intensification of crop production in many low and middle income countries is often accompanied by problems of pesticide overuse and misuse (Ecobichon, 2001; Schreinemachers and Tipraqsa, 2012). Farmers and consumers in these countries are particularly vulnerable to the health risk posed by pesticides, especially acute poisoning (Atreya, 2008; Snelder et al., 2008; Thapinta and Hudak, 2000), because of a lack of knowledge about safe and correct use. Policies in developing countries do not adequately address pesticide risk, as policy-makers fear that restricting pesticide use will harm food production (Carvalho, 2006). As a result, many developing countries have rules in place that give farmers incentives to use more pesticides.

Concerns that restrictions on pesticide use will put food production and food security at risk are, however, not usually based on empirical analysis. In fact, there are very few analytical tools available for making such an assessment (Falconer, 2000; Jacquet et al., 2011). 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 do not have a direct impact on crop yields, other than limiting the possible adverse effects of pests, and are extremely diverse with nearly a thousand active ingredients currently in use (Tomlin, 2009). Yet, in the absence of scientific analysis of the exact 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 common approach to quantifying optimal levels of pesticide use has been the estimation of an agricultural production function in which pesticides are included as a damage control agent (Lichtenberg and Zilberman, 1986). Scholars generally agree that the use of a damage control approach is necessary to avoid overestimating the marginal effect of pesticides. The exponential specification of the damage abatement term has given realistic results in a number of crop protection studies (Jah and Regmi, 2009; Pemsl et al., 2005; Praneetvatakul et al., 2003).These studies find that pesticide productivity is low for developing countries, such as Nepal, China and Thailand.

Production functions are generally estimated from farm-level data and therefore give an estimate of the optimum level of pesticide use from the point of view of a farmer (that is, a "private" optimum). Yet the use of pesticides creates negative externalities, such as health effects on farm workers and consumers as well as imbalances in the functioning of ecosystems. It has been shown that pesticides accumulate in soils, water and the food chain (Sangchan et al., 2012; Thapinta and Hudak, 2000). Beneficial organisms disappear and pest resistance increases, which can put the viability of farming systems at risk (Wilson and Tisdell, 2001). As the external effects are not transmitted to farmers through the price of pesticides, the private optimum level of pesticide use will be in excess of what is optimal from a societal point of view (Pretty et al., 2001). In other words, the "social" optimum would be below the private optimum if including the negative pesticide externalities. This social optimum level of pesticide use can be estimated by adding the external costs of pesticides to their purchase costs. Yet, no studies have previously done this, because there was no method available to quantify the external cost of an individual farmer's pesticide application. Economic analysis of the external costs related to pesticide use—for example, for the USA (Pimentel, 2005; Pimentel et al., 1993), the UK (Pretty et al., 2000) or Thailand (Jungbluth, 1996), has been carried out at the national level, i.e. estimating the combined cost of pesticides for a particular country. Studies on the impact of pesticide policies, which rely on mathematical programming models, consider external costs as the basis for designing taxes to internalize these costs (Falconer, 2000; Jacquet et al., 2011; Koleva et al., 2011). Skevas et al. (2013) use farm level data to examine the effect of pesticide spill-overs on the production environment of Dutch farmers, but do not consider external costs to determine optimal pesticide use from a societal point of view.

Leach and Mumford (2008, 2011) recently developed a method, which allows determining the externality associated with individual pesticides, called the Pesticide Environmental Accounting (PEA) tool. The PEA tool allows disaggregating pesticide externalities to the field or farm level. The novelty of the present study is to combine the PEA tool with a common production function framework to determine marginal costs and benefits of pesticides. The first objective is therefore to show how to quantify pesticide overuse from a societal rather than a private point of view by combining the PEA tool with a production function using a damage control specification. The second objective is to illustrate this method with data from a horticultural production system in northern Thailand.

Like other emerging economies with an export-oriented agricultural sector, Thailand has very rapidly increased its agricultural pesticide use (Schreinemachers and Tipraqsa, 2012). Whereas Thai farmers used 1.2 kg of active pesticide compounds per hectare in 1997, by 2010 they were using 3.7 kg/ha – an average increase of 9% per year (Praneetvatakul et al., 2013). 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. Efforts have been undertaken to limit some of the 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 a public certification programme of Good Agricultural Practices (Schreinemachers et al., 2012).

Against this backdrop, Praneetvatakul et al. (2013) tested the use of the PEA tool for estimating the external costs of pesticide use in Thailand. They applied the tool to the country as a whole as well as to two distinct agricultural systems of rice and intensive upland horticulture. They estimated the negative externalities (so-called average external costs) to be USD 27/ha for Thailand as a whole, USD 19/ha using a dataset of 224 rice farmers and USD 106/ha using a dataset of 295 farmers that practice intensive upland horticulture. This paper draws on the same farm-level data that were used for the upland horticultural system and quantifies pesticide overuse by combining the external cost estimates with an estimation of marginal benefits.

This 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. The paper ends with a discussion of these results and a conclusion.

2. Methodology

2.1. Conceptual frame

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

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; Praneetvatakul et al., 2003; Shankar and Thirtle, 2005). Following Lichtenberg and Zilberman (1986), for this study crop output (Y) is thus specified 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 has values between zero and one, thus determines the magnitude of any damage and the effectiveness of the control with pesticides (X). In accordance with the original framework of Lichtenberg and Zilberman (1986) and most of the related economic analysis involving pest damage, separability between potential output and losses is assumed. This assumption implies that damage does not depend on potential output, i.e. the effectiveness of damage control is independent of the mixture of direct inputs, and that $F(Z)$ exhibits constant returns to scale (Carpentier and Weaver, 1997; Kuosmanen et al., 2006).

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

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

Maximizing this function with respect to pesticides gives us the private economic optimum level of pesticide use:

$$\mathrm{d}\Pi/\mathrm{d}X= 0 \quad \text{or} \quad \mathrm{d}(pF(Z)G(X)\text{-}wZ\text{-}vX)/\mathrm{d}X = 0 \tag{3}$$

Not all costs associated with pesticides are transmitted through the price (v) that farmers pay for them. Being toxic by design, pesticides can harm organisms other than pests, such as beneficial insects and soil organisms, aquatic life and humans. Costs to society are incurred in the form of pest resurgence and pesticide resistance, in the form of chronic and acute health problems for applicators or pickers and for consumers ingesting pesticide residues as well as in the form of the contamination of water resources or the monitoring of pesticides by governments for example. These costs are called external costs (Praneetvatakul, 2013;Pretty, 2000). Including them in the price of pesticides will raise their overall cost and lower the optimum level of pesticide use. This is illustrated in Figure 1. Graphically, the private optimum is represented by the intersection of the marginal benefit of pesticide use, which can be derived from the production function analysis and is referred to as marginal value product, and the marginal private cost of pesticide use, which corresponds to the pesticide purchase price. The social optimum is given by the intersection of the marginal value product and the marginal social cost, i.e. the external marginal cost added to the private marginal cost. The PEA tool, as explained in Section 2.4 below, allows quantifying the marginal external cost such that it can be added to the marginal private cost in order to determine optimal use from a societal point of view.

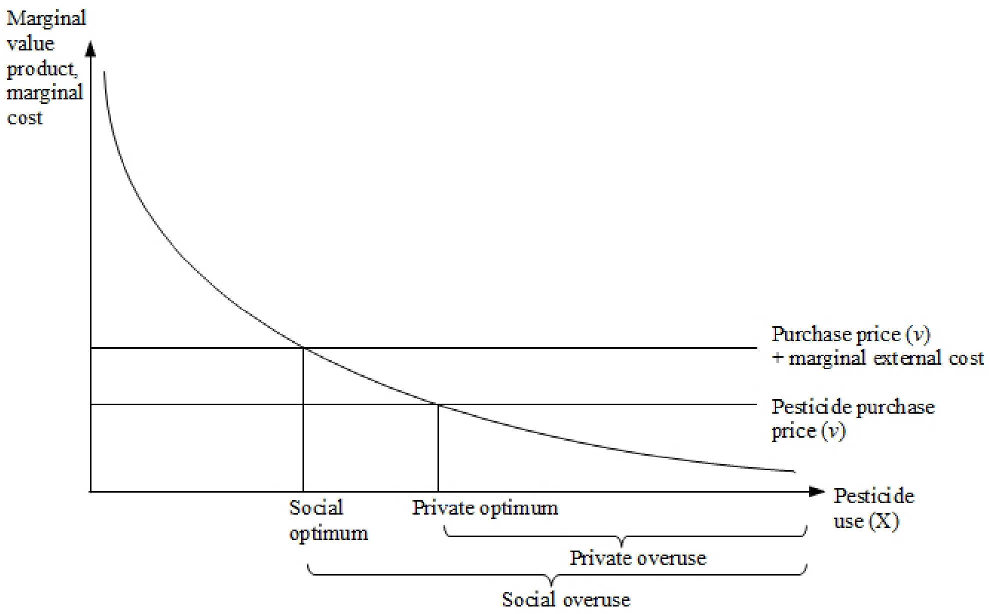

Figure 1: The private and social optimum level of pesticide use

2.2. *Specification of the production function*

The Cobb-Douglas and quadratic specifications are the most commonly used types of farm production functions, and have been shown to give similar results (Horna et al., 2008; Qaim and De Janvry, 2005). Unlike the Cobb-Douglas method, the quadratic form allows for decreasing total and negative marginal 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, there were few zero values but a relatively high variation in observed values. For the set of growth stimulating inputs in *F(Z)* it can be considered reasonable to assume diminishing, but not negative marginal returns. The curve of the total and marginal value product flattens out at higher levels of input, which may be a disadvantage if the economic optimum occurs at these high levels; however, our results suggest that this is not the case. The Cobb-Douglas function further assumes constant returns to scale as well as convexity to the origin, which implies some complementarity among inputs, but no full substitution. An F-test for restrictions was used to test the restricted Cobb-Douglas specification against a flexible translog specification, which nests the Cobb-Douglas function. Based on this test, the use of the Cobb-Douglas specification could not be rejected (F statistic of 0.830 ($p = 0.363$) for leafy vegetables and F statistic of 0.210 ($p = 0.649$) for greenhouse vegetables).

Various specifications have also been proposed for the damage abatement term *G(X)*, such as exponential, logistic, Pareto and Weibull (Lichtenberg and Zilberman, 1986). As several recent studies have shown that the exponential specification gives robust results (Jah and Regmi, 2009; Pemsl et al., 2005; Skevas et al., 2012a) this specification is employed in our analysis. It is defined as:

$$\ln Y = \alpha + \sum_i \gamma_i C_i + \sum_j \beta_j \ln Z_j + \ln[1 - \exp(-\lambda X)] + \varepsilon \qquad (4)$$

The constant α and the coefficients γ_i, β_j and λ for this function were estimated for two distinct land uses in the study area, these being, leafy vegetables and greenhouse vegetables, because these have very different output levels (Y) and use a different technology (open field vs. closed system). Within each land use management, growing period and pest problems are similar. The indicator variables C_i were introduced alongside growth-stimulating inputs Z_j and pesticides X to control for farm characteristics. These farm characteristics also included crop and location dummies that captured differences in crop management and agro-ecological conditions.

As explained above, the private optimum of pesticide use occurs at the point, where the marginal value product equals the purchase price of pesticides. However, in this study pesticides were expressed in monetary rather than physical quantities, which means that the purchase price was already included in the pesticide variable. As a consequence, the optimal private level of pesticide use occurs where the marginal value product equals unity. Likewise, the social optimum was obtained where the marginal value product equals unity plus the ratio of external costs to pesticide purchasing costs.

Thereby the marginal value product of pesticides describes the change in the value of output that results from spending one more monetary unit on pesticides. It is the first derivative of the production function in equation (4) and is specified as:

$$MVP_x = F(Z)*\lambda[\exp(-\lambda X)]/[(1-\exp(-\lambda X)] \quad (5)$$

Equation (5) shows that the marginal value product of pesticides is observation-specific, because it depends on the level at which all other inputs are applied. Therefore the total quantity of pesticide overuse was computed for the study area by summing differences between the actual pesticide use (X_a), as recorded in the survey, and the optimal pesticide use (X^*), as calculated from the observation-specific marginal value product:

$$\text{Total Overuse} = \sum (X_a - X^*) \quad (6)$$

2.3. Econometric estimation

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, it was necessary to control whether pesticides were an endogenous variable in the model, as several previous studies have found it to be correlated with the error term. A test for endogeneity was therefore conducted using a two-stage least-squares (2SLS) instrumental variable regression following Horna et al. (2008) and Huang et al. (2002), which provided no evidence that pesticide use was endogenously determined (Wu-Hausman F of 0.604 ($p = 0.438$) for leafy vegetables and Wu-Hausman F of 2.293 ($p = 0.132$) for greenhouse vegetables).

2.4. Estimating the external costs of pesticide use

The Pesticide Environmental Accounting (PEA) tool was developed by Leach and Mumford (2008, 2011). It is a cost-transfer approach that was calibrated from detailed actual cost studies carried out in Germany, the UK and the USA (Pretty et al., 2000; Pretty et al., 2001). Comprehensive information was available on the costs of monitoring pesticide use, of remedying damage to ecosystems and of treating pesticide-related health problems. These actual cost data are used as base values for external costs and then 'transferred' to other countries by adjusting for different application rates, toxicity of applied pesticides as well as economic conditions.

The tool allocates the external costs of pesticides to particular pesticide compounds based on application rates and potential risk. For potential risk it uses toxicological data on the harmful effects of pesticide compounds on applicators and pickers (farm workers), on groundwater leaching and pesticide residues on food (consumers), and on aquatic life, bees, birds and beneficial insects (the environment). These toxicological data come from the Environmental Impact Quotient (EIQ) tool developed by Kovach et al. (1992).[1]

Using two economic adjustment factors, Leach and Mumford (2008) then ‘transferred’ these costs to estimate the external costs of pesticide use for agricultural production systems in Spain, Turkey and Israel. Praneetvatakul et al. (2013) tested the use of the PEA tool for Thailand by comparing the PEA estimates at the national level to an accounting of actual pesticide costs for two years. Although the PEA tool overestimated actual costs in one year and underestimated the costs in the other year, on average over all years the estimates were in a similar order of magnitude.

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

$$\mathrm{TEC_p} = \mathrm{Rate_p} * \frac{\mathrm{Active_p}}{100} * \sum_{c=1}^{8} \left[\mathrm{EC_c} * \mathrm{F_c} * (\mathrm{F_{agemp}} | c = 1,2) \right] * \mathrm{F_{gdppc}} \quad (7)$$

$Rate_p$ is the application rate of a pesticide *p* in kg of formulated product per hectare, while $Active_p$ represents the percentage of active ingredient contained in the formulated product. The EIQ methodology uses eight categories (*c*=1,2,..8) to distinguish the eco-toxicological effects of active ingredients. EC_c denotes the base value of the external cost attributed to category *c* (*c*=1,2,..8). As pesticides with a higher potential risk should be associated with a higher external cost, the potential risk is divided into three categories. In doing so, lower, medium and upper values are multiplied with the external costs by a factor (F_c) of 0.5, 1.0 and 1.5, respectively. Leach and Mumford (2008) defined the three levels of factor (F_c) according to low, medium and high toxicity ranges based on the EIQ. F_{agemp} and F_{gdppc} are adjustment factors for the importance of employment in agriculture and the costs of pesticide monitoring and clean up, which are further explained below.

[1] EIQ base values are available from an online database: http://cceeiq-lamp.cit.cornell.edu/EIQCalc/input.php (accessed January 2011).

The effects of pesticides on applicators and pickers (i.e., farm workers) are likely to be greater in low-income countries due to the fact that relatively more people are employed in agriculture and thus come into direct contact with pesticides. Whereas Leach and Mumford (2008) proposed the proportion of GDP taken up by agriculture as a proxy for health-related externalities, Praneetvatakul et al. (2013) preferred using the share of agriculture in employment terms. It is considered to better reflect the number of people who tend to be exposed to pesticides on farms. The external costs for applicators and pickers (c=1,2) are thus multiplied 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). The authors point out that this approach does not capture the fact that pesticide use in low-income countries is far more hazardous, because of a lack of sufficient protection. On the other hand, as lower labour costs reduce expenditures of monitoring and clean-up, low-income countries are supposed to incur fewer external costs. Therefore Leach and Mumford (2008) resorted to the adjustment factor F_{gdppc}, which is 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). Multiplying the total external costs with this factor thus allows taking into account that labour is cheaper in a developing country.

Praneetvatakul et al. (2013) applied the PEA tool to the same site as in this study, using the same farm-level data. Based on an average application rate of 13 kg of active pesticide compounds per hectare in 2010, they estimated an average external cost of USD 106/ha, which compares to average pesticide expenditures of USD 963/ha. They estimated that internalizing the external costs into the price of pesticides would increase the price of pesticides by about 32% in the study area. For more details, refer to Praneetvatakul et al. (2013) as the methods and data are exactly the same.

The external costs quantified with the PEA tool are an essential part of analysing pesticide overuse from a societal point of view. As explained in section 2.1, external costs are required to obtain the social costs of pesticide use and to then derive their marginal social costs. At the point where the latter are equal to the marginal value product, the optimal level of pesticide use can be determined. Pesticides were expressed in monetary units rather than physical quantities, so that the social optimum was in fact computed where the marginal value product equals unity plus the ratio of external costs to pesticide purchase price. For further explanations see sections 2.1 and 2.2.

3. Data

3.1. Study site selection

The Mae Sa watershed area in northern Thailand was selected as our primary data collection area. It is an upland area that has experienced a rapid intensification of agriculture. Favoured by a cooler climate and more rainfall, and stimulated by recent improvements in infrastructure, upland areas such as this watershed have become important suppliers of temperate and sub-tropical fruits and vegetables in Thailand.

The study area 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. 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 compounds 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).

There are strong indicators of heavy pesticide use in the study area. For instance, more than half of all farmers in the study area are experiencing serious health problems after spraying and three fourth of all farmers in the study area are concerned about high expenditures for pesticides. Rivers are heavily contaminated with pesticide residues, especially during the rainy season (Sangchan et al., 2012). While half of the leafy and greenhouse vegetable growers in the study area use less than 1 kg/ha/month of pesticides, one fifth of farmers vastly exceed recommended input levels and apply more than 5 and up to 20 kg/ha/month. Schreinemachers et al. (2011) observed that farmers growing bell peppers used on average 3 times more pesticides than Spanish farmers and 52 times more than Dutch farmers to produce the same quantity of output.

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 relative profitability of these crops (Schreinemachers et al., 2009; Schreinemachers et al., 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.

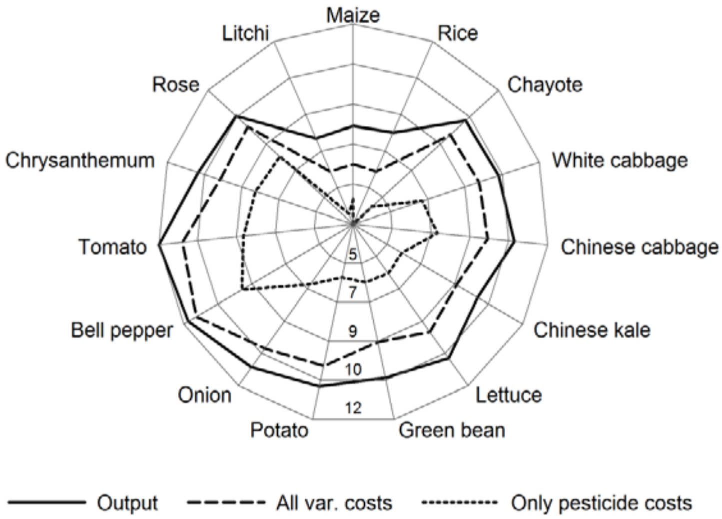

Figure 2: Crop output, total costs and pesticide costs for 15 crops in the Mae Sa watershed area, 2010 (in log baht/ha/month)

The great diversity of land-use activities proved a challenge for our empirical analysis. Production functions are ideally estimated separately by crop, as different crops have a different response to fertilizers and other inputs, and are differently affected by pests. However, aggregate production functions, estimated at the farm, regional or even the country-level are also common in the literature (Carrasco-Tauber and Moffitt, 1992; Mundlak et al., 1997) . As there were not enough observations to estimate separate production functions for each crop, crops were aggregated into two land-use groups by their similarity in terms of length of growing period, pest problems and pest management activities. One group was greenhouse vegetables (including bell peppers and tomatoes) and the other leafy vegetables (cabbages, kale and lettuce). Flowers were excluded from the analysis.

3.3. Farm data collection

A structured questionnaire survey was carried out in the Mae Sa watershed area. The area comprises 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. The data set is hence rather unique in that it provides detailed farm-level information on quantities of active ingredients, which are required for using the PEA tool. External costs could thus be calculated for each individual active ingredient and then be aggregated to an overall external cost estimate.

For the regression analysis, pesticide amounts as well as crop output, fertilizer amounts and other inputs were all expressed in Baht per hectare per month (1 USD ~ 31 Thai Baht). Just like the pesticide data, all output and other variable input data were recorded for each plot and each crop that farmers were growing. The variable 'Fertilizers' comprised data on the quantity of mineral and organic fertilizer valued by their price. The variable 'Other inputs' included seed or seedlings, plant hormones as well as planting material valued by the respective price.

Other explanatory variables were crop dummies, village dummies, irrigation, education and the spraying habit of farmers. In the production function analysis for leafy vegetables, crop dummies included white cabbage, Chinese cabbage and kale, for greenhouse vegetables a tomato dummy was used. Other variables control for farm and farmer characteristics, such as the ethnicity and location of the village related to a particular observation, because data were collected from structurally different Thai and Hmong villages at middle and high altitudes. As no data were available on the amount of irrigation water, a dummy was included indicating whether irrigation was used or not. As education levels differed among farmers, which might impact on production, the education dummy 'Low education' specified if farmers attended at most primary school. Likewise, the spaying habit of farmers differed. Here, data were recorded on the predominant pesticide application strategy of farmers, preventive versus curative. Table 1 summarizes for each group the variables used in the analysis.

Table 1: Summary statistics of variables used in the analysis

Variables	Leafy Vegetables		Greenhouse Vegetables	
	Mean	SD	Mean	SD
Spraying method (1=preventive)	0.59	0.49	0.51	0.50
Education (1=low)	0.46	0.50	0.48	0.51
Irrigation (1=using)	0.47	0.50	1.00	0.00
Location 1 (1=Thai villages at high altitude)	0.06	0.23	0.16	0.37
Location 2 (1=Hmong villages at high altitude)	0.09	0.29	0.20	0.40
Location 3 (1=Hmong villages at high altitude)	0.76	0.43	0.09	0.29
Output (1000 baht/ha/month)	46.05	39.80	213.47	187.21
Labour (hrs/ha/month)	95.77	96.32	246.88	219.22
Fertilizers (1000 baht/ha/month)	7.10	4.54	53.18	39.79
Other (1000 baht/ha/month)	1.77	1.26	36.72	24.55
Pesticides (1000 baht/ha/month)	1.71	1.67	15.16	14.82
External costs (1000 baht/ha/month)	0.49	0.59	3.21	3.56

Notes: Omitted location dummy is Thai villages at middle altitude. The crop dummies are not shown.

4. Results

Table 2 shows the coefficients of the production functions for the two types of land use. The adjusted R-squared was 0.41 for leafy vegetables and 0.30 for greenhouse vegetables, which is comparable to previous studies in China and Thailand that used the same functional form (Huang et al., 2002; Pemsl et al., 2005; Praneetvatakul et al., 2003). The dummy variable identifying whether farmers' spraying was mainly preventive, as opposed to responsive spraying, had a positive and significant effect on output, while the effect of having a low education was insignificant. The use of irrigation had a significant negative effect on output, which suggests an intervening effect of seasonality or management as yields in the dry period are generally lower. The effect of all growth-stimulating inputs was positive and significant, with labour having the highest coefficient.

Table 2: Production function estimates with abatement specification

Variable	Leafy Vegetables		Greenhouse Vegetables	
	Coeff.	SE	Coeff.	SE
Spraying method (1=preventive)	0.301***	3.47	0.295**	2.05
Education (1=low)	-0.102	-1.06	0.054	0.41
Irrigation (1=using)	-0.464***	-4.76		
Location 1 (1=Thai villages at high altitude) [1]	0.176	0.64	-0.270	-1.49
Location 2 (1=Hmong villages at middle altitude) [1]	0.046	0.19	-0.081	-0.43
Location 3 (1=Hmong villages at high altitude) [1]	0.599***	2.89	0.585**	2.13
Labour (baht/ha/month, ln)	0.346***	4.83	0.251***	2.69
Fertilizers (baht/ha/month, ln)	0.130**	2.02	0.355***	3.84
Other inputs (baht/ha/month, ln)	0.065	1.23	0.121*	1.70
Constant	7.086***	12.99	5.422***	5.71
Damage abatement effect (λ) of pesticides (baht/ha/month)	0.0182***	3.28	0.0019**	2.18
N	265		188	
Adj. R^2	0.41		0.30	

Notes: Dependent variable is output in ln(baht/ha/month). Omitted location dummy is Thai villages at middle altitude. The crop dummies are not shown. Significance levels: * P < 0.10, ** P < 0.05, *** P < 0.01.

The regression coefficient for pesticides was positive and significant for both land uses. Figure 3 shows the functional shape of the damage abatement term. It shows that the abatement effect reaches 100% and levels off at a relatively small quantity of pesticide. The shape is similar for land use groups but the x-scale is different as farmers use much higher amounts of pesticides on greenhouse vegetables.

The marginal value product of pesticides was estimated for each farmer in the sample. The marginal value product is the value of output resulting from one additional baht spent on pesticides. Values above unity hence point at the underuse of pesticides from a private point of view while values below unity point at overuse. The marginal value product was below unity for 86.1 % of the observations for leafy vegetables and 88.7% of the observations for greenhouse vegetables. While up to the 75th percentile the marginal value product was close to zero, the average marginal value product was greater at 0.39 and 0.56 for leafy and greenhouse vegetables respectively due to a few outlying data points well above unity.

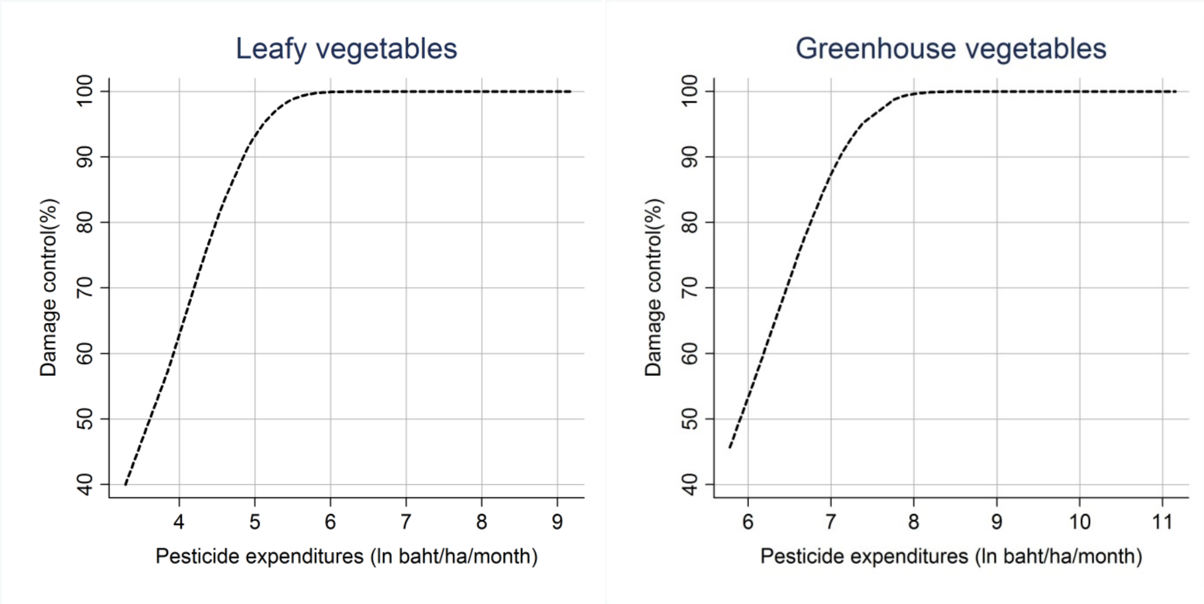

Figure 3: Effect of pesticide use on crop yields for leafy and greenhouse vegetables

Optimal levels of pesticide use were determined for each observation, depending on the costs associated with the applied pesticides as well as on the use of other inputs. Table 3 shows that the average optimal levels of pesticide use were relatively small and the levels of overuse relatively high. 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 leafy vegetables and 78% for greenhouse vegetables could thus be categorized as overuse from a private point of view. Because of the relative steepness of the exponential damage control function, as shown in Figure 3, adding external costs to the private costs only had a minor effect on the quantity of overuse.

Table 3: Private and social levels of optimal pesticide use and overuse

	Leafy Vegetables		Greenhouse Vegetables	
	Private	Social	Private	Social
Av. optimal use (1000 baht/ha/month)	0.34	0.32	2.89	2.77
Total overuse (1000 baht)	336	340	1,287	1,302
Overuse (as % of total quantity)	79	80	78	79

Notes: Overuse determined for each observation as the difference between actual and the private/social optimal pesticide use. Total overuse for the whole watershed is the sum of these individual differences.

5. Discussion

The novelty of this paper is to include pesticide externalities in quantifying levels of pesticide overuse. The PEA tool is straightforward to apply if farm-level data on active pesticide ingredients are available. To our knowledge, the PEA tool is the only available tool to do this although several weaknesses to the methodology need to be considered, as discussed in Praneetvatakul et al. (2013). Hence there is room for improvements to this methodology.

The production function approach is based on standard micro-economic theory and assumes that farm decision-making is guided by a profit-maximizing motive. There are other motivations for farm decision-making in reality, but including these would make the calculation of economic optima very complex and require an unrealistically high amount of farm-level data. The idea of profit maximization is therefore a necessary simplifying assumption for the ease of computability.

It was found that 78-79% of the total quantity of pesticides applied can be labelled as overuse from a private point of view. This implies that farmers, even without considering externalities, are spraying excessively and inefficiently and could increase their profits by applying fewer pesticides. The marginal value product was estimated to be close to zero for the majority of observations, which confirms results of Praneetvatakul et al. (2003) who used the same functional form and also found the marginal value product of pesticide use in rice farming to be close to zero. Studying pesticide overuse by vegetable farmers in Nepal, Jah and Regmi (2009) likewise used a Cobb-Douglas function with exponential abatement specification and found that 70% of pesticide use was above the private optimum, which is similar to our finding.

The analysis found only a one percentage difference between private and social levels of overuse for this case study of upland horticulture, which appears surprising at first glance. This difference is small, because the optimum level of control is reached at a relatively low level of pesticide use; that is, the function is steep as was illustrated in Figure 3. Most farmers are producing at the flat-end of the production function where the marginal value product approaches zero. It is not possible to conclude from this result that including pesticide externalities is not important. The results do however suggest that for situations where pesticide overuse is dramatic, internalizing pesticide externalities into the retail price of pesticides, for instance through an environmental tax on pesticides, might not be an effective policy instrument. In other words, a marginal value product of pesticides that approaches zero suggests that farmers are not much influenced by the costs and returns of pesticides in deciding on their use; if they were, they would bring the marginal value product closer to unity. Though our finding is from one location only and at this stage of research cannot be generalized to Thailand as a whole, it confirms previous studies that showed the demand for pesticides to be very inelastic (Falconer, 2000; Pina and Forcada, 2004; Skevas et al., 2012a).

A possible explanation for the high rate of pesticide use is that farmers in the study areas 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. Government policies, such as tax exemption and subsidized credit for chemical inputs for agriculture, keep the price of pesticides low and contribute to application rates above optimal levels. Farmers are also 'locked in' the system of unsustainable pest control, because of the real or perceived economic losses of switching growing practices (Wilson and Tisdell, 2001Wilson and Tisdell, 2001). 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 in Thailand and investment in these might have a more substantial and long-term effect on reducing pesticide use than simply removing pesticide subsidies or introducing a tax alone. Further research is needed to test the validity of this statement.

6. Conclusion

This study 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. Applying the method to intensive upland horticulture in Thailand, it was found that 78-79% of the applied pesticide quantity is overuse from a private point of view, while 79-80% can be labelled as overuse from a societal point of view. The small difference between the two can be explained by the shape of the abatement function and the fact that the average marginal value product of pesticides approaches zero. The findings suggest that for this case study, internalizing pesticide externalities in the price of pesticides might be ineffective as a stand-alone policy instrument to address the problem of overuse.

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