

# Pollution taxes and poverty-reducing transfers in developing countries: theory and evidence from a Philippine watershed\*

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## Abstract

Poverty and resource degradation are twin scourges of upland farming in the developing world. Yet many poverty alleviation programs promote faster resource depletion, while conservation measures often demand uncompensated sacrifices from the poor. We propose a market-based approach to environmental policy, taking into account the prevalence of poverty. Because farm households are heterogeneous in income and the physical characteristics of land they operate, we develop a non-linear programming model to design spatially differentiated environmental policy. An application with Philippine data confirms the ex ante benefits of differentiated policies, and helps identify conditions under which pollution taxes can finance poverty-reducing transfers.

Key Words: Pollution tax, poverty, Philippines, watershed, erosion

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## 1. Introduction

Rural populations in the uplands of developing countries are typically both very poor and also heavily dependent on natural resources as the basis for their livelihoods. Poverty alleviation measures for people at the cultivated margin are typically build around on agricultural growth, which implies expanded or intensified use of soils and accompanying water and forest resources. In the tropics, however, upland and steep-land ecosystems are usually fragile; soils are highly vulnerable to depletion, and watersheds are easily (and frequently) subjected to severe damage associated with soil erosion and loss of key ecosystem features (such as forest cover) that regulate the flow of water across the landscape. Soil erosion and its downstream effects are among the most important environmental externalities in the developing world (Shively, 2006). In the past, land use planning and other regulatory approaches have had at best localized and project-dependent success (Tomich et al. 2004); there is a need for more cost-effective and longer-lasting solutions. Economists have long advocated market-based approaches to problems of this nature, but the design of cost-effective market-based instruments faces severe data constraints and many practical problems of implementation. This study has a unique advantage in that the analysis is based on GIS data overlaid on a decade of farm household data from a Philippine upland watershed, with farm plots being geo-referenced. The data constraint relaxed, we are able to explore implementable policies for watershed management.

For many developing countries, the design of suitable watershed protection policies is complicated by the fact of severe poverty in the same areas. Polluter-pays and command-and-control policies for watershed protection often meet with resistance from local communities, as well as from external groups concerned for their economic welfare. When poverty is a concern,

there is a need to find alternative measures to attain environmental protection goals. One means to do this is to exempt the poor from pollution reduction efforts. However, such a measure is obviously suboptimal when the actions of poor farmers and others have significant influence on watershed degradation. Another approach, popularized as ‘Payments for Environmental Services (PES)’, is to offer rewards to the poor in return for their adoption of less damaging practices (Kerr 2002). In this approach either the beneficiaries of improved environmental quality, or government and external donors, will have to finance the payments required. If beneficiaries are in a position to pay, the role of the regulator will be limited to facilitating the creation of market for the environmental services (see Pagiola 2002 for case studies).

There are several difficulties with the PES approach. There is no guarantee that downstream beneficiaries are not themselves poor. Reliance on outside financing, from NGOs or foreign donors, will not be sustainable in the long run. More generally, when access to land is not restricted, PES may create incentives for outsiders to move in and start production, so exacerbating land degradation (Pagiola 2005). Finally, PES assumes that all polluters are poor, even though such an assumption is almost never robust. Any alternative mechanism that can target payments both by the value of the environmental services they assure and by the utility value to heterogeneously poor households merits exploration. In this paper we propose a mechanism that can address poverty alleviation and also serve as a cost-effective environmental policy. Under the right conditions, it may be possible to utilize pollution tax revenues as a means of combating upland poverty.

The literature has contributed quite significantly to our understanding of on-site incentives to adopt improved land management practices in a dynamic context (Burt 1981, McConnell 1983; Barbier 1990, Barrett 1991; LaFrance 1992; Demeke et. al. 1998). The

problem of offsite damages from runoff has also received significant attention, albeit mostly in wealthy countries. Onsite impacts of soil erosion are not usually sufficient to induce adoption of socially optimal land management practices when off site impacts are significant. Increasing incidence and costs of downstream damages has raised interest in regulating pollution delivered from agricultural sources through runoff. Initiatives aimed at reducing these forms of agricultural externalities often need to have significant spatial components (Hochman and Zilberman 1977, Shortle and Horan 1998, Schwabe 1999).

This study has two objectives: to design spatially explicit efficient environmental policy at a landscape scale, following methodologies used in economic studies of non-point source pollution; and to identify conditions under which environmental policy could aid in addressing poverty reduction. Uniform targeting policies to address agricultural runoff externalities are not economically efficient,<sup>i</sup> since the environmental damage associated with soil erosion from a given agricultural field depends on many characteristics unique to that field: its location, slope, land use, and so on. Given that producers respond to price incentives, the empirical questions that follow are: i) What policies should be used to efficiently limit the level of environmental degradation to an acceptable level? ii) How large is the benefit of heterogeneous as opposed to uniform policies? iii) What mix of land use and conservation measures should be adopted for each type of land in a watershed in order to maximize economic returns at the watershed scale? iv) To what extent can environmental taxes be used to finance poverty reduction?

We use a decade-long household survey data set along with topographic information from an upland watershed in the southern Philippines to estimate technology parameters corresponding to each part of the watershed. This paper therefore contributes to a growing literature on the economics of non-point source pollution, and to a much smaller empirical

literature on watershed-level policies in developing countries. To our knowledge this is the first study to integrate the design of a spatially explicit environmental policy with poverty reduction goals. Although water pollution and other downstream effects of agriculture are increasingly important problems in developing countries, the literature on non-point source pollution remains focused on developed country agriculture. Poverty, weak institutions, and incomplete markets are some well-known challenges to sustainable resource use and environmental decision-making in developing countries. Hence, policies aimed at changing the production environment will most likely have consequences for poverty. Our model incorporates many of these features of a typical developing country decision-making environment.

The remainder of the paper is organized as follows. Section 2 reviews relevant work on non-point source pollution. In section 3 we present an economic model of pollution control policy that takes poverty alleviation into account. In section 4 we present a spatial model of the study site. In section 5 we provide details of the empirical model. Section 6 presents empirical results, and section 7 provides conclusions and policy implications.

## **2. Policies to reduce agricultural externalities: review of the literature**

Economists have long promoted market mechanisms to address pollution externalities, and there is a growing interest by policy makers in the US, Europe, and in some developing countries to use such instruments (Shortle and Horan 2001). In theory, market-based mechanisms equalize marginal abatement costs between polluting firms, thereby allocating the control of emissions at least cost. Despite the ex ante efficiency advantage of economic instruments, however, developing-country authorities commonly prefer command and control, often for practical reasons (lack of data for policy design; implementation and enforcement costs).

There is an extensive literature on environmental externalities and on policies to minimize their effects. By definition, the existence of such an externality creates a mandate for government intervention in order to improve social welfare (Baumol and Oates 1971; Hochman and Zilberman 1978). The first-best remedy is a Pigovian emission tax, set at a rate that equates the marginal benefit from production to marginal social damage. Even though such taxes produce Pareto-optimal resource allocations, however, they are rarely used, in part due to the difficulty of measuring environmental damage. A practical alternative cited in much of the environmental economics literature is to set a desired environmental quality standard and then impose a tax to attain it (e.g. Baumol and Oates 1988; Griffin and Bromley 1982; Ribaudo, Horan and Smith 1999). Such a policy, though less efficient overall, can in principle attain the standard at a minimum cost to society. Equally efficient remedies, under some conditions, are marketable pollution permits and subsidies (Baumol and Oates 1988; Griffin and Bromley 1982). The cost effectiveness methodology that we will adopt has also been widely used in air pollution literature (e.g. Atkins and Lewis 1974; Tietenberg 1995; Newell and Stavins 2003).

Several studies have considered spatial aspects of agricultural pollution externalities. Hochman, Pines and Zilberman (1977) developed a theoretical model to address the spatial nature of pollution. They considered a rectangular river basin used for agricultural production along the river, with a city at the bottom of the basin that suffers from agricultural pollutants. With transportation costs increasing with distance from the city, and absent any environmental policy, their model predicts that both intensity of cultivation and land rents are decreasing functions of distance from the city—the standard von Thünen result. However, they show that this result can be reversed by adoption of an optimal pollution tax with the rate of tax increasing with distance from the city—hence offsetting the effects of transportation cost in the von Thünen

prediction. More recent developments in the study of agricultural non-point pollution policies emphasize the use of site-specific heterogeneous tax policies (e.g. Fleming and Adams 1996, Schwabe 1999; Braden et al. 1989, Coxhead 2002; Khanna et al. 2003).

Though the efficient pollution tax can be found in theory, in practice it is difficult (and in some settings impossible) to assess the exact cost of externalities and/or to measure emissions from individual firms. To overcome this problem, Griffin and Bromley (1982) proposed the use of inputs and crop choices that are correlated with emissions. For non-point-source pollution, market based policies can then be directed at pollution-generating activities or inputs, and with appropriate policy design, efficiency can be attained just as for point-source pollution. The degree of efficiency, of course, depends largely on how well input choices, output levels and crop choices predict pollution. The high costs of acquiring information on farm-level characteristics and transaction costs have led to the favoring of such second best policy instruments (e.g. Cabe and Herriges 1992; Helfand and House 1995; Wu and Babcock 1996).<sup>ii</sup>

The empirical literature on the use of spatially explicit watershed policy is also expanding. Several studies have concluded that highly targeted information-intensive strategies outperform uniform strategies in the design of non-point control policies (Braden et al. 1989; Babcock et al. 1997; Schwabe 1999, Classen and Horan 2001; Khanna et al. 2003). For example, the study by Khanna et al. of the Illinois land retirement reserve program finds that the costs of achieving an abatement goal are much lower with differentiated standards than with uniform standards. In contrast, other empirical studies suggest that that the benefits of heterogeneous policies over uniform policies are not very significant. For example, a study of spatial variability in the design of tax policy to control groundwater nitrate concentration from irrigated agriculture indicates that a detailed accounting of spatial heterogeneity had little effect on the selection of a

cost effective tax policy (Fleming and Adams 1997). Another study compares instruments to reduce nitrate leaching from soils used for lettuce production in California (Helfand and House 1995), and finds that that while differentiated policies are slightly more cost-effective than uniform policies, the difference is small.

In general, the magnitude of the gains from differentiated policies generally depends on the extent of spatial heterogeneity in the watershed under consideration.<sup>iii</sup> However, when there is significant spatial variation in terms of pollution contribution, due to physical characteristics of individual farms and land management, use of a uniform policy is known to be inefficient (Shortle and Horan 2001). Thus, whether the benefits of differentiated policies are large enough to warrant spatially-specific policies is an empirical question whose answer depends on the characteristics of the watershed under consideration.

Most empirical contributions have been confined to the use of data from North America and Western Europe (Shortle and Horan 2001). Uplands of developing countries typically exhibit a very high degree of spatial heterogeneity. In such areas, therefore, the finding that returns to differentiated policies are small may not hold. Moreover—as already discussed—policy design for developing countries faces an additional constraint, the need to ensure that poor households are not made worse off. In the next section we present a conceptual model addressing these issues.

### 3. Conceptual Framework: Pollution Control Policy and Poverty Reduction

Consider a watershed consisting of farms that release erosion sediments to a downstream receptor point. Assume that there are  $J$  unique areas (or land zones) in the watershed, each with its corresponding biophysical attributes, and each operated by a number of identical farmers. Let

the  $j^{\text{th}}$  farmer's vector of netputs be denoted by  $\mathbf{y}^j$ , with  $y_i^j$  being the  $i^{\text{th}}$  element of the vector.

The production function is given by  $f(\mathbf{y}^j) \leq 0$  with corresponding aggregate pollution function

$$(1) \quad d^j = g^j(\mathbf{y}^j).$$

The regulator's objective is to find the least-cost means of reducing detrimental externalities.

This can be written as a social planner's problem, to maximize the sum of current profits consistent with a targeted pollution level, or

$$(2) \quad \text{Max}_{\mathbf{y}^j} \sum_j \mathbf{p}\mathbf{y}^j$$

subject to a constraint on total pollution.

$$(3) \quad \sum_j d^j \leq \bar{d}$$

where  $\mathbf{p}$  is a vector of prices and  $\mathbf{p}\mathbf{y}^j$  represents profit for the  $j^{\text{th}}$  farmer.

Following the literature on non-point source pollution, we assume that farmers' decisions are static. With weak property rights that are characteristic of land in developing countries, there may be little incentive for forward-looking behavior. Thus for our purposes a static model is sufficient to highlight the major elements of the analysis. Assuming concave production functions and that all constraints bind, the Lagrangian of the problem is given by:

$$(4) \quad L = \sum_j \mathbf{p}\mathbf{y}^j - \sum_j \psi_j f(\mathbf{y}^j) + \lambda \left( \bar{d} - \sum_j g^j(\mathbf{y}^j) \right),$$

where  $\psi_j$  and  $\lambda$  are the Lagrange multipliers for the production function and allowable emission level respectively. The multiplier  $\lambda$  is the shadow price of the allowable pollution constraint in equation (3), or the extra profit a farmer would earn were one more unit of pollution allowed.

The first order conditions for interior solutions with respect to  $y_i^j$  are:<sup>iv</sup>

$$(5) \quad \partial L / \partial y_i^j = p_i - \psi_j f_i^j - \lambda g_i^j = 0 \quad \text{for all } i \text{ and } j$$

$$(6) \quad \partial L / \partial \lambda = \bar{d} - \sum_j g^j(\mathbf{y}^j) = 0$$

$$(7) \quad \partial L / \partial \psi_j = f(\mathbf{y}^j) = 0 \quad \text{for all } j$$

The system of equations (1) through (7) defines the optimal solution to the problem. After rearranging, (5) states that the marginal value product of input  $i$  is equal to its price (the value of its marginal product) plus the value of marginal pollution associated with its use. By comparison with the case of unrestricted pollution, the model implies lower use of input  $i$  if pollution increases with its use. Absent any environmental policy, producers will maximize profit by setting  $\lambda$  to zero. However, when the social planner aims to limit total pollution to a level below the private optimum, the constraint in (3) becomes part of the maximization problem. The solution to the planner's problem then requires higher abatement efforts from high-pollution agents. With spatially distinct pollution characteristics, the solution to the social planner's problem will be a unique tax rate for each land area—that is, spatially differentiated targeting of abatement policies. The optimal per-unit emission tax  $\tau$  can be found by choosing a tax equal to  $\lambda$  for each unit of pollution reaching the receptor site.

Of course, the policy just defined requires measurement of pollution reaching the receptor site from each agent—a practical impossibility. However, so long as production technologies vary little across the landscape, optimal policy can be approximated using information on technology and on the location and biophysical characteristics of farm plots. When there is a known functional relationship between input and output choices and emissions, it is possible to design incentives based on these choices rather than on the emissions themselves. Because of variation in biophysical characteristics among farm plots in any given watershed, the

marginal incentive for each farmer operating at each site is unique. Without loss of generality, assume that the  $J$  unique areas are ordered (from low to high) in terms of their erosion potential—such as field slope and/or distance to a stream. Denote the erosion potential by  $r(j)$ , with  $r'(j) > 0$ . For simplicity, assume that pollution is a linear function of area planted for any given  $j$ . Redefine the pollution function as:

$$(8) \quad d^j = r(j)A^j$$

It is straightforward to show that tax per unit of area planted,  $\tau r(j)$ , increases with  $j$ .

Once we find the least cost tax, the next question is how this tax policy affects poverty. We are especially interested in whether pollution tax revenues would be sufficient to alleviate poverty. We use a marginal abatement cost graph to illustrate the tax policy under discussion. Consider two farms having the same scale of operation but with different biophysical characteristics, such as slope. Assume that the farmers face linear aggregate marginal abatement cost (MAC) function given by  $MAC = \gamma - \phi d$ , where  $d$  represents the level of pollution.

{Insert Figure 1 here}

The dissimilar biophysical characteristics of farms will result in different pollution levels, even if their profits in the absence of environmental regulation will be the same. That means that the area under the two MACs will be the same. Given differences in their physical characteristics, a cost-minimizing tax policy requires that the farm with higher pollution intensity pay more in taxes, as represented by the two shaded areas in figure 1. The less pollution-intensive farm will pay only the shaded area shown on the left side. Thus, a cost minimizing tax policy implies the use of different tax rates, even though farms grow similar crops using similar technologies.

{Insert Figure 2 here}

Figure 2 shows a simple aggregate marginal abatement cost (MAC) story with farms aggregated into two groups, poor and non-poor. In this case, the poor are households earning less than a specified level of per capita income. Their income is derived based on profit maximizing behavior subject to resource constraints on capital, land, and labor and production technology. The non-poor in general have better access to capital, own large sized farms and have access to better technologies. In figure 2, the left panel (with subscript  $p$ ) shows the MAC for the poor, and the right panel (with subscript  $n$ ) that for the non-poor. The parameters of MAC on the graph represent a combination of pollution intensity, scale of operation, number of farms in the group, and/or production technology employed by the farmers.

Using the MAC for the poor as an illustration, a lower  $\phi_p$  represents a higher level of operation or a larger number of farmers in the group, other things equal. Since the aggregate MAC is a horizontal summation of individual MACs, a lower  $\phi_p$  shifts the x-intercept to the right, and thus could be interpreted as implying a larger number of poor farmers. Other things equal, higher  $\gamma_p$  could be interpreted as farms using better production technology since the area under MAC represents gross margin.

To interpret the parameter difference as pollution intensity difference, we can think of two groups of farms with otherwise similar scales of operation but with different pollution intensities. By similar scale of operation, we mean that absent any environmental policy, each group would earn the same profits. This situation is represented by two distinct MACs, but with the condition that the areas under the two MACs remain the same (see figure 1). Thus, with a linear MAC, in order to keep the area under MAC constant for the two groups, if  $\gamma_p$  is multiplied by constant  $m$ , then  $\phi_p$  needs to be multiplied by  $m^2$ . Higher pollution intensity is therefore

represented by  $m < 1$ , representing flatter MAC. Thus, when pollution is not restricted by any policy, pollution intensive farms pollute more than less-pollution intensive farms as long as the scale of operation of the two groups remain the same.

The parameters of the MAC also determine how well the tax instrument attains the two targets, poverty alleviation and pollution reduction. In other words, the degree to which the tax revenue collected from the non-poor compensates the poor depends on the relative size of the two groups, the types of production technology employed by the poor versus the non-poor, and the relative pollution intensity of the two groups.

To show this formally, consider the cost of tax policy on the poor and tax revenue collected from the non-poor. In order to maximize profit, polluters set their MAC equal to the tax rate ( $\tau$ ). From the linear MAC curves in figure 2, the level of pollution corresponding to a given tax rate is therefore given by

$$(9) \quad d_p(\tau) = \left( \frac{\gamma_p - \tau}{\phi_p} \right) \quad \text{and} \quad d_n(\tau) = \left( \frac{\gamma_n - \tau}{\phi_n} \right)$$

Total tax revenue from the non-poor (assuming that none fall into poverty)<sup>v</sup> is given by (10):

$$(10) \quad TR = \tau d_n(\tau) = \tau \left( \frac{\gamma_n - \tau}{\phi_n} \right)$$

Total tax revenue ( $TR$ ) from the non-poor depends on the parameters of the aggregate MAC and is not monotonic. Given the functional form of  $TR$ , it is straightforward to show that tax revenue has a parabolic shape with its maximum at  $\tau = \frac{\gamma_n}{2}$ . Other things equal,  $TR$  increases with  $\gamma_n$  but decreases with  $\phi_n$  since  $\tau \leq \gamma_n$ . Higher  $\gamma_n$  shifts the MAC to the right. This shift could represent a combination of either of the following situations: better production technology,

or higher profitability due to higher output price or lower input prices. Thus, if the rich use superior technology or are highly profitable, pollution tax revenue would be much higher. On the other hand, lower values of  $\phi_n$  would indicate that the number of rich is high or the rich operate at a larger scale, such as in terms of land area. Intuitively, if there are many non-poor farmers, the tax revenue would be higher.

What is the effect of pollution intensity on the level of tax revenue generated? To answer this question, imagine two identical non-poor farmers that generate the same profit absent any policy, but with differing total pollution, as in figure 1. As illustrated above, we multiply  $\gamma_n$  by constant  $m$  and  $\phi_n$  by  $m^2$ , with  $m < 1$  representing higher pollution intensity. It can be shown that revenue will be higher from a pollution-intensive farm at a tax rate lower than the point where the two MACs cross (i.e.  $\tau = \frac{m\gamma_n}{1+m}$ ), and lower for any higher tax rate. Thus, the effect of pollution intensity on the revenue generated depends on the stringency of the pollution taxes imposed. For our purpose, assuming the stringency of the policy to be on the lower side, pollution intensive non-poor farmers will boost pollution tax revenue.

Now we turn to losses borne by the poor. In figure 2, the area of the triangle to the right of  $d_p$  represents the cost of the tax to the poor, after 100% tax rebate. Analytically, this cost, after substituting from (9), will be:

$$(11) \quad [\pi(0) - \pi(\tau)]_p = 0.5\tau \left[ \frac{\gamma_p}{\phi_p} - d_p(\tau) \right] = 0.5 \frac{\tau^2}{\phi_p}$$

Notice that the losses of the poor increase with the square of tax rate. For any given tax rate, assuming an interior solution, the cost (or profit loss) borne by the poor is decreasing with the slope of MAC curve,  $\phi_p$ , irrespective of the size of  $\gamma_p$ . However, for a corner solution, where the

tax rate is high enough to force farmers out of business, the MAC with higher  $\gamma_p$  will be associated with a relatively larger loss. In addition, if the number of poor farmers is large, then the cost of a tax on the poor will also be large. Moreover, if the pollution intensity of poor farmers is high, then the loss to be borne by the poor will also be large. In summary, if the number of poor farmers is large or if they are more pollution-intensive, then losses by the poor will be larger.

In order for environmental tax revenues to render poverty reduction feasible, tax revenues from the non-poor must exceed losses by the poor. Note that losses by the poor are increasing at an increasing rate with respect to the tax. Figure 3 shows tax revenues and losses of the poor. In this figure,  $PG$  represents a poverty gap (the total amount of money required to lift all households towards a specified poverty line) before imposition of an environmental tax. As the tax rate increases, the poverty gap also rises. As can be seen in the figure poverty cannot be eliminated at a low tax rate even if all the revenues are used to compensate the poor. But as the tax rate rises it becomes possible to alleviate poverty; specifically when the tax rate is in the range  $a$  to  $b$ . This representation indicates the case when the total revenue curve lies above the  $[\pi(0) - \pi(\tau)]_p + PG$  curve. When the tax rate is higher than  $b$ , tax revenue from the non-poor is insufficient to alleviate poverty since the TR curve lies below the  $[\pi(0) - \pi(\tau)]_p + PG$  curve. In general, for fixed  $\gamma_p$  and  $\gamma_n$ , the likelihood of alleviating poverty rises as  $\phi_n$  decreases and as  $\phi_p$  increases. Similarly for fixed  $\phi_n$  and  $\phi_p$ , the prospect of alleviating poverty rises as  $\gamma_n$  increases and  $\gamma_p$  decreases. If the number of poor is small or if the number of non-poor is large, or if the technology used by the non-poor is better; or if the poor are relatively more less-pollution intensive, then it is possible to alleviate poverty for a certain range of tax rates.

Poverty alleviation may not always be feasible with the scheme described here. It is actually possible that the  $TR$  curve in figure 3 could lie entirely below the  $[\pi(0) - \pi(\tau)]_p + PG$  curve, in which case the revenue will never be sufficient to alleviate poverty, though poverty could still be reduced. We could also find a tax rate that maximizes poverty alleviation based on the function  $TR_n - ([\pi(0) - \pi(\tau)]_p + PG)$ .

#### 4. Empirical Application

##### The Philippine study site

We draw case study data from the municipality of Lantapan in the southern Philippines. Lantapan is located in the upper watershed of the Manupali River, a major tributary of the Pulangi river, one of the largest in Mindanao Island (see figure 4). Lantapan itself contains five sub-watersheds. The northern boundary of the municipality is the southern perimeter of an important Philippine nature reserve (the Mount Kitanglad Range Nature Park). The watershed enclosing the study area climbs from river flats (400-600m) through to high altitude, steeply sloped mountainside (1100-2200m). At the lower edge of the study area, the Manupali flows through an irrigation diversion dam and ultimately drains into the Pulangi River a few kilometers upstream from one of the six largest hydropower-generating plants in the country.

For several decades, agricultural growth in Philippine uplands has been fueled by population growth and internal migration, lack of growth of productive non-agricultural jobs, and more or less unrestricted access to forest margin areas for conversion, due to ill-defined property rights. Conversion of uplands from forest and long-term crops such as coffee to highly erosive seasonal crops has been encouraged by policies—including trade restrictions targeting import

substitution and self-sufficiency— that provide incentives for upland farmers to plant vegetables and corn rather than perennials (Coxhead 2003). All of these factors have been highly influential in the study area (Rola and Coxhead 2008).

Trends in watershed function capture the combined effects of deforestation and upland land degradation in Manupali. Data from the study site show that land clearing and conversion of cleared land to agriculture are strongly associated with decreased overall stream flows, increased seasonal fluctuations, and higher loadings of sediments as well as pollutants introduced by cropping activities (Deutsch et al. 2001). The effects of deforestation and upland land degradation are not confined to upper-watershed areas; water pollution and soil transport contribute to sedimentation in the irrigation dams and its distribution canals, accelerated wear on hydro-power generation infrastructure, and increased health costs for downstream population (Deutsch et al. 2001). A variety of interventions have been attempted to reduce land-clearing and erosive uses of land; these have included official bans on deforestation and some incentives for agro-forestry initiatives. These, however, have been insufficient to offset the incentives for land-clearing and agricultural intensification created by the agricultural development policies referred to in the previous paragraph.

Lantapan is a poor municipality, and this is reflected in our survey data. Analysis of the data from years 1999 and year 2000 reveal that median per capita income in Lantapan was about PHP 10,000 per year. That amounts to just about \$0.50 per day. The minimum per capita income was PHP 2,400, while the maximum was PHP 48,000, and the mean is 13,500. These show the prevalence of poverty in the watershed, accompanied by a significant income disparity among households. Hence, it is important to consider the welfare of the poor when considering any environmental policy intervention.

### Zoning the watersheds, household characteristics and production function.

To account for spatial variability within the watershed we take the following steps to arrive at the final data set used for modeling. Using data generated from a 30X30 meter resolution Digital Elevation Model (DEM), we create sub-watersheds and locate the streams. We then subdivide the sub-watersheds by slope, distance to the nearest stream, and elevation to identify zones representing fairly uniform areas in a watershed. Even though the municipality is composed of 5 major sub-watersheds, our analysis focuses only on the three for which we have geo-referenced household data, the Alanib, Maagnaw and Tugasan watersheds (see figure 4). We identify 149 distinct zones with a total area of 7421 hectares of cultivable land. Tables 1 and 2 present the physical characteristics of the watershed. After subdividing the watershed into uniform sections, we associate household characteristics with those subdivisions of the watershed. We use the household survey information linked to geo-referenced farm plots to populate the watershed. Table 3 presents household characteristics in the watershed. Populating the watershed with heterogeneous household characteristics adds additional variation.

We also estimate Cobb-Douglas production functions using household data for the three main crops in the watershed- corn, vegetables and coffee (see table 4). In addition to inputs used (land, labor, fertilizer), the production is affected by field slope, distance to national road, elevation, and distance to stream.

## 5. The Economy-Environment Programming Model

At its most basic level, an economy-environment model is an abstract representation of the biophysical, social, and economic features of a well-specified geographical landscape (Shively and Coxhead 2004). At its most detailed level, an economy-environment model links people with

the spatial landscape they cultivate. Modeling efficient least-cost watershed pollution control policy requires a large-scale economic model capable of estimating the costs of alternative land uses on spatially heterogeneous land, combined with the capacity to estimate the environmental effects of alternative land uses at the watershed scale (Tanaka and Wu, 2004). With increasing availability of GIS data and the development of physical models that can predict environmental outcomes, site-specific models are increasingly popular. We use as detailed information as is available to link actors to the landscape. We then build an economic model based on the characteristics of households in the distinct zones we have identified. The integrated economy-environment model developed here is a spatially explicit non-linear programming model consisting of two components, dealing with economy and environment.

In the economy sub-model, households choose land use, labor, fertilizer and soil conservation measures to maximize current period returns given an exogenously imposed environmental policy. Following the conceptual model developed earlier, the per period returns to be maximized are:

$$(12) \quad \max_{v,A} \sum_i^N [p^i f^i(A^i, v^i) - wv^i - t \sum_i^N d_i]$$

where  $A^i$  is area allocated to crop  $i$ ,  $v$  is variable inputs such as fertilizer and labor,  $p$  and  $w$  are the prices of outputs and inputs respectively,  $t$  is tax rate for sediment, and  $d_i$  is the soil loss reaching the downstream in the form of sediments. We assume that farmers have access to limited land resources as shown in equation (13).

$$(13) \quad \sum_i^N A^i \leq \bar{A}$$

Additional constraints are imposed by family labor and capital endowments, which vary depending on our assumptions concerning the functioning of labor and capital markets. Since we have distributed the households to unique zones, these constraints are unique to each zone.

The environment sub-model describes the relationship between alternative land use choices and sediment delivery (soil loss), for a given spatial location. Thus, choices in the economic sub-model are inputs to the environment sub-model. The environmental sub-model links households' economic decisions to environmental degradation. To compute soil erosion from sites within the watershed, we use the Universal Soil Loss Equation (USLE) adapted to Philippine data. The USLE is given as:

$$(14) \quad d = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where  $d$  is soil loss in t/ha/yr,  $R$  is a rainfall-erosivity index,  $K$  is a soil erodibility index,  $L$  is slope length,  $S$  is the slope steepness factor,  $C$  is a land cover management factor, and  $P$  is a supporting practices factor. Since the USLE does not account for the deposition of detached soil along hillslopes, we augment it by assuming that plots farther away from streams have lower sediment delivery ratios.<sup>vi</sup> Most of the USLE parameters are from David (1988).

#### The social planner's approach

In order to solve for the optimal tax, the planner solves the problem given in (12) and (13) without the taxes imposed, but with a target abatement level. As in the conceptual model in equations (1) through (8), the planner maximizes net profits, taking account of resource constraints faced by each household. The equilibrium for all households in the watershed will match the planner's problem when, for each household, the planner imposes a tax rate that is equivalent to the shadow price of the abatement target—a target that limits the sediment reaching

a receptor site. The model predicts that for a given crop choice, technology, and distance to the stream, taxes will increase as slope increases. In addition, we expect taxes to decrease as distance increases, holding other variables constant. Consider the grid of a rectangular region representing a watershed, as shown in figure 5. The cells depicted by **R** represent streams. The first element in any cell represents distance to stream, while the second element represents slope; in each case, higher numbers imply higher values. Our economic model predicts that the abatement responsibility of (1,4) is greater than that of (1,1), and so the former pays more tax than the latter for a given land use. Notice also that these two cells are equidistant from the stream. Moving up the columns, the model also predicts that cell (4,1) pays less tax than, for example, cell (2,1). Within a given cell, if a household adopts soil conservation measures, then the tax payment is less. Similarly a farmer will pay higher taxes on erosive crops than on less erosive crops.

The policy simulation is undertaken by restricting the total allowable level of sediment delivered to the receptor site located at the lower end of the watershed, where it is assumed to cause externality costs. Our model predicts differentiated land use taxes to attain the desired environmental. Using this methodology, a policy maker could in principle charge a differentiated tax for each zone, each land use and each conservation measure adopted.

## 6. Results and Policy Simulations

We run the model using GAMS-Minos5 non-linear programming solver. We construct scenarios for uniform and for differentiated tax policies. We solve the problem for a range of abatement targets. We start from no environmental policy (i.e. zero abatement target) and progressively increase the abatement target by increments of 10 percent up to a maximum of 50 percent reduction in soil loss.

### The cost of environmental protection

Table 5 shows a sample of efficient tax rates for different land uses, slope classes and distance from the streams. Taxes increase with slope and decrease with distance from the streams. In addition, farms with conservation measures are required to pay less tax per hectare. Vegetables (the more erosive crop) are associated with the highest tax rate, other things equal.

The private cost of environmental policies is measured in the reallocation of resources from activities that were most profitable without the policies. Table 6 presents estimates of the economic costs of tax policies designed to attain abatement targets reducing sediment delivery by 10% to 50%. The results reveal that when tax revenues are returned to households as a lump-sum rebate, environmental targets can be met at a modest cost to society. For example, the 50% reduction is attained at the cost of a loss in average income of about 6.5%. This is because there are some inexpensive conservation measures that can easily be adopted by households, resulting in significantly lower soil erosion. One such measure is Natural Vegetative Strips (NVS), which have become increasingly popular in the Philippines. These are buffer strips placed along the contour, in which natural vegetation is allowed to re-grow into a protective cover that eventually forms a hedgerow (Mercado et al. 2001).<sup>vii</sup> The cost attractiveness of NVS implies that, without altering crop choices, it is possible to attain a significant reduction in soil loss. Thus the costs of the policies are quite modest as long as the tax revenues are returned to households in the form of a lump sum rebate. However, the loss to households could be much higher, reaching up to 18% of base income, when tax revenues are not returned. Losses stem directly from payment to the regulator, and indirectly through reallocation of resources away from more profitable activities. Note that the losses reported in the table are averages; for households operating in the most fragile sections of the watershed, actual losses are expected to be much higher than 18%. Figure

6 depicts the marginal cost of conservation through taxes. As can be seen, the marginal cost curve is upward sloping: additional units of sediment loss are increasingly costly to attain.

#### Uniform versus differentiated policies

The uniform abatement standard restricts the allowable soil loss per hectare to be the same across all zones. The last line of Table 6 provides results for a uniform standard targeting a 10% abatement goal. Comparison of the results reveals that even for a moderate sediment reduction goal, targeting has a significant impact on economic efficiency. From table 6, we compute the cost saving to be (PHP)<sup>viii</sup> 13.42 million for the whole watershed, which is 7.4 thousand hectares (see table 1). This is equivalent to PHP 1.82 thousand per hectare. With a differentiated policy, even the 50% abatement target is attained at lower cost than the 10% target using a uniform policy. Given the extent of heterogeneity in the watershed, there is clear potential for spatial targeting of tax policies to mitigate degradation the watershed.

#### Poverty versus the environment

As shown in the theoretical section of this paper, the feasibility of using an environmental tax to alleviate poverty depends on a number of factors, including the severity of poverty, the proportion of households below the poverty line, and the incomes of those above it. In addition, the answers also depend on relative contributions to pollution, and on relative pollution intensity differences between poor and non-poor. If poor households are also those that cultivate the most fragile part of the watershed, for example, it is unlikely that environmental tax revenues will be sufficient to compensate them for income lost as a result of the same taxes. Conversely, a larger percentage of households with incomes above the poverty line increases the likelihood that the proceeds from the tax will be sufficient to meet the poverty reduction goal.

We measure poverty as the aggregate income required to enable the poor to reach a poverty line. The UN determines \$1/day as a conservative poverty line; however, we have used the maximum per capita income of the lowest three deciles of households (before introducing any environmental policy) as the poverty line. That income is about PHP 11,500 per capita or about \$0.60/day, resulting in a highly conservative poverty measure. The poverty line figure is slightly higher than the median per capita income of the sample households, mainly due to aggregation by zones, and also due to random production outcomes. The sample households' incomes exhibit more dispersion than the value of incomes we obtained after running the optimization model. Our analysis looks at the possibility of lifting people who are in the tail of the income distribution. Thus, we compare the environmental tax revenue with the total income needed to bring every individual in the watershed to a level of income equal or greater than the poverty line. The results, presented in table 7, reveal such a possibility. Revenues from taxes at 10%, 20% and 30% abatement levels are sufficient to cover the costs of lifting the poor to above the poverty line. With a 40% target however, the tax revenue is not sufficient to cover the income loss. At this level, the taxes cause more people to fall below the poverty line and also exacerbate the severity of existing poverty. Thus, the results demonstrate that moderate abatement targets can be met without increasing poverty; however, for more ambitious targets, poverty will increase when environmental taxes are the sole instruments. At high target levels of abatement, therefore, there is a clear tradeoff between poverty reduction and environmental protection. For more modest abatement targets, there is less conflict between the two goals—but then the environmental gains are also less ambitious. This tradeoff is an illustration of the “two targets, one instrument” dilemma; a policy designed to reduce pollution could also optimally reduce poverty only under exceptional circumstances.

Further research is needed to establish whether alternative environmental policies might more efficiently serve both policy objectives. Marketable permits, for example, are alternatives to taxes that lead to the same efficient environmental outcome. Marketable permits, however, do not require the knowledge of abatement costs of each individual. Poverty considerations could then be included as permit allocation criteria in such a way that more permits go to the poor.

## 7. Conclusions and policy implications

In developing countries, upland agriculture is one important arena in which environmental damages and severe poverty coexist and interact, yet to date, policies addressing poverty have largely had deleterious environmental impacts, and conservation measures have often adversely affected poor households. In this study we pursue the potential for an environmental tax plus redistributive mechanism to achieve simultaneous poverty alleviation. We exploit the knowledge that propensity for pollution is spatially differentiated to design tax policies that are more efficient than a one-size-fits-all approach.

In an application to Philippine data, we find that an environmental tax with transfers is complementary with poverty reduction but only when targets in either are modest. This is because many households are poor, and the spatial distribution of households at different levels of economic well-being is such that more ambitious environmental targets quickly begin to impact on poverty in a large fraction of the population.

At the local scale, however, an economy-environment model of the kind we have developed seems to present the most efficient way of attaining any environmental quality goal at the minimum cost to economic development. Setting environmental goals is the task of the policy maker; the model provides alternative solutions given these goals. If the objective is to

protect the environment without considering implications for poverty or distribution, the model predicts that those farmers operating on highly erodible lands will have to pay higher taxes regardless of their income losses or initial poverty. For the most part a significant reduction in soil erosion rate can be attained at a reasonably low cost to society, especially when the taxes imposed are differentiated by propensity to contribute to pollution loading. When environmental outcomes can be estimated or approximated from observable choices, targeted environmental policies are useful to reduce the costs of protecting the environment.

With growing income disparities among rural households and with continuing prevalence of acute poverty, environmental policy cannot be made in isolation, and indeed could be used to address broader welfare problems. Our empirical results confirm that, for moderate environmental abatement targets, revenues from differentiated taxes could cover the costs of alleviating the most severe poverty. When such possibilities exist, the policy has “double” benefits of protecting the environment with reduced poverty.

Our model is capable of generating efficient subsidy/tax incentives to protect watersheds when appropriate transfers can be designed to shield the poor from the impacts of environmental taxes. Of course, our results depend on the assumptions built into the model. Soil erosion estimates based on USLE overstate downstream impacts, so the model may set taxes per unit of area planted too high. For this and other reasons, more detailed work would be merited before policies were adopted for implementation. However, our use of household survey panels and GIS data sets means that many of the behavioral and technical parameters of the model are drawn from real data rather than from model assumptions, and in this respect our model is more robust than many of its predecessors.

The limitations of this work point to promising areas for future research. Even when it is possible to use state of the art erosion models, there remain other sources of uncertainty that could only be resolved through costly information collection. Monitoring and enforcement costs will be high when policies are disaggregated according to spatial location. Also, when production technology and other farm-level variables are not known with certainty, policies based on such information will not be efficient. The literature on non-point source pollution has long acknowledged the significance of information asymmetry and transaction costs in determining the efficiency of alternative policies (e.g. Cabe and Herriges 1992; Helfand and House 1995; Wu and Babcock 1996). In practice, information administration and enforcement costs essentially require that the tax/subsidy base be truncated to a subset of choices that are both relatively easy to observe and correlated with ambient impacts, and tax rates that are relatively uniform within jurisdictions (Shortle and Horan 2001). Information problems and enforcement costs are magnified in developing countries, due to weak institutions and the limited budgets available to regulators. The level of disaggregation in setting environmental taxes and poverty-alleviating transfers in such conditions will thus depend on the costs of enforcement and information acquisition; in general, the optimal level of disaggregation will decrease as transaction costs increase. In the absence of suitable data we leave further discussion and the measurement of transactions costs for future research.

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**Table 1: Land area (ha) by watershed and distance from national highway**

	Alanib	Maagnaw	Tugasan
0-1km	1967	476	866
1-2km	1407	395	667
2-3km	677	358	237
3-4km	141	148	80
4-5km	0	4	0

Source: survey data.

**Table 2: Land Area (ha) by slope and distance to streams**

Distance to stream (m)	Slope (%)				
	0-10%	10-20%	20-30%	30-40%	40-50%
0-200	1,207	761	265	96	55
200-400	1,209	641	152	38	14
400-600	737	463	96	14	7
600-800	441	267	77	10	7
800-1000	193	162	50	10	9
>1000	130	164	70	12	3

Source: survey data.

**Table 3: Household characteristics by watershed attributes**

	Farm size	Coffee area share	Vegetable area share	Corn area share	Education	Family Size
Distance to						
stream						
0-200	2.97	0.12	0.17	0.41	7.38	6.27
200-400	2.65	0.14	0.19	0.36	7.37	6.23
400-600	2.63	0.18	0.20	0.33	7.64	6.15
600-800	2.64	0.21	0.21	0.32	7.68	6.12
800-000	2.79	0.25	0.20	0.29	7.98	6.06
>>1000	2.62	0.36	0.22	0.23	7.95	6.16
Slope (%)						
0-10	2.99	0.21	0.17	0.34	7.80	5.80
10-20	2.96	0.21	0.17	0.34	7.75	6.00
20-30	2.66	0.19	0.20	0.33	7.55	6.29
30-40	2.32	0.16	0.23	0.33	7.25	6.59
40-50	2.14	0.18	0.27	0.29	7.55	6.91

Source: survey data.

**Table 4: Production function parameters**

	Corn		Vegetables		Coffee	
	Coefficient	P>t	Coefficient	P>t	Coefficient	P>t
Log(land)	0.590	0.000	0.539	0.000	0.625	0.000
Log(labor)	0.202	0.000	0.439	0.000	0.298	0.000
Log(fertilizer)	0.034	0.000	0.071	0.000	0.032	0.053
Log(slope)	0.095	0.183	0.088	0.611	-0.073	0.677
Log(D_Hwy), km	-0.022	0.577	-0.227	0.009	0.123	0.151
Log(D_stream), km	0.063	0.070	-0.144	0.151	0.108	0.075
Log(elevation), km	-0.240	0.256	2.087	0.054	-1.082	0.045
Variety (Dummy)	0.180	0.048				
Log(Education), Yr	0.055	0.123	0.033	0.676	0.024	0.705
Year98 (Dummy)	-0.493	0.000	0.115	0.666	-0.247	0.223
Intercept	-0.930	0.001	-0.512	0.459	-2.710	0.000

Source: estimated from survey data.

**Table 5 Tax rates by distance to stream and slope for a 10% abatement target**

		Tax/Ha ('000 peso) for 200 m distance to stream				
Land Use ↓	Slope(%) →	0-10%	10-20%	20- 30%	30- 40%	40-50%
Corn		1.29	3.20	5.47	8.02	10.79
Corn with NVS		0.64	1.60	2.74	4.01	5.40
Vegetables		1.93	4.80	8.21	12.03	16.19
Vegetables with NVS		0.97	2.40	4.11	6.02	8.09
Coffee		0.26	0.64	1.09	1.60	2.16
		Tax/Ha ('000 peso) for 1000 m distance to stream				
Corn		0.71	1.78	3.04	4.46	6.00
Corn with NVS		0.36	0.89	1.52	2.23	3.00
Vegetables		1.07	2.67	4.56	6.68	8.99
Vegetables with NVS		0.54	1.33	2.28	3.34	4.50
Coffee		0.14	0.36	0.61	0.89	1.20
		0.13	0.31	0.53	0.78	1.05

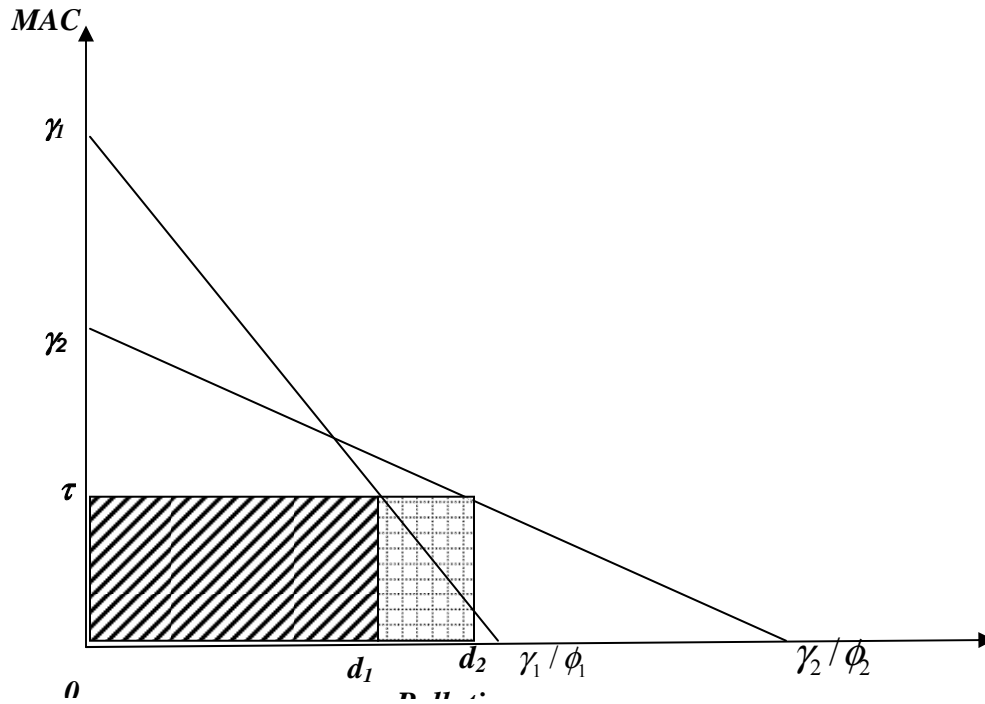
**Table 6: Costs of environmental policy without transfer**

Abatement Target	Income (000 Peso)	Total tax revenue	Total HH income	Total cost (% income)	Cost to HH (% income)
0%	169,953	0	169,953	0.0	0.0
10%	168,451	14,803	153,647	-0.9	-9.6
20%	166,654	15,256	151,398	-1.9	-10.9
30%	164,540	15,846	148,693	-3.2	-12.5
40%	162,063	16,117	145,946	-4.6	-14.1
50%	158,846	20,151	138,694	-6.5	-18.4
Uniform, 10%	155,035	17,095	137,940	-8.8	-18.8

**Table 7: Poverty and environmental taxes with targeted transfer**

Abatement Target →	0%	10%	20%	30%	40%	50%
Tax revenue ('000 Peso)	0	14,805	15,258	15,848	16,118	20,150
Poverty Gap ('000 Peso)	3,850	11,596	13,000	14,728	16,605	21,936
Possible to alleviate poverty?	No	Yes	Yes	Yes	No	No

Figure 1 Two identical farms with different pollution intensity



**Figure 2: Aggregate MAC for the poor (left) and MAC for the non-poor (right)**

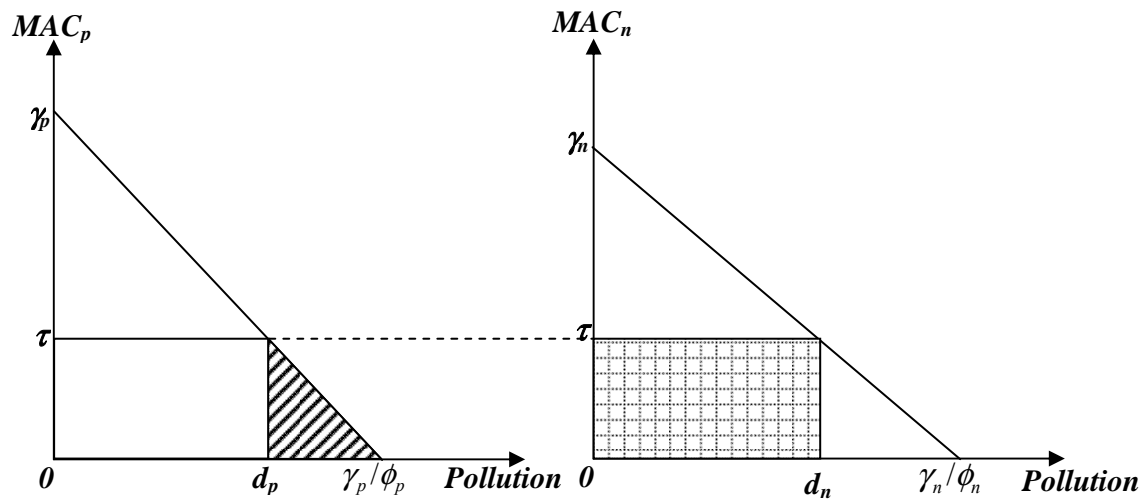
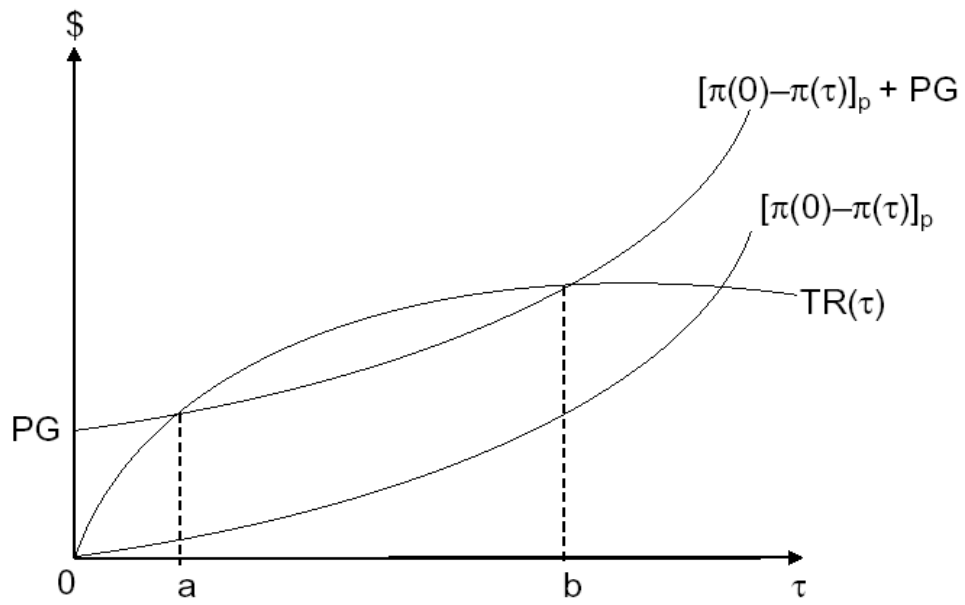
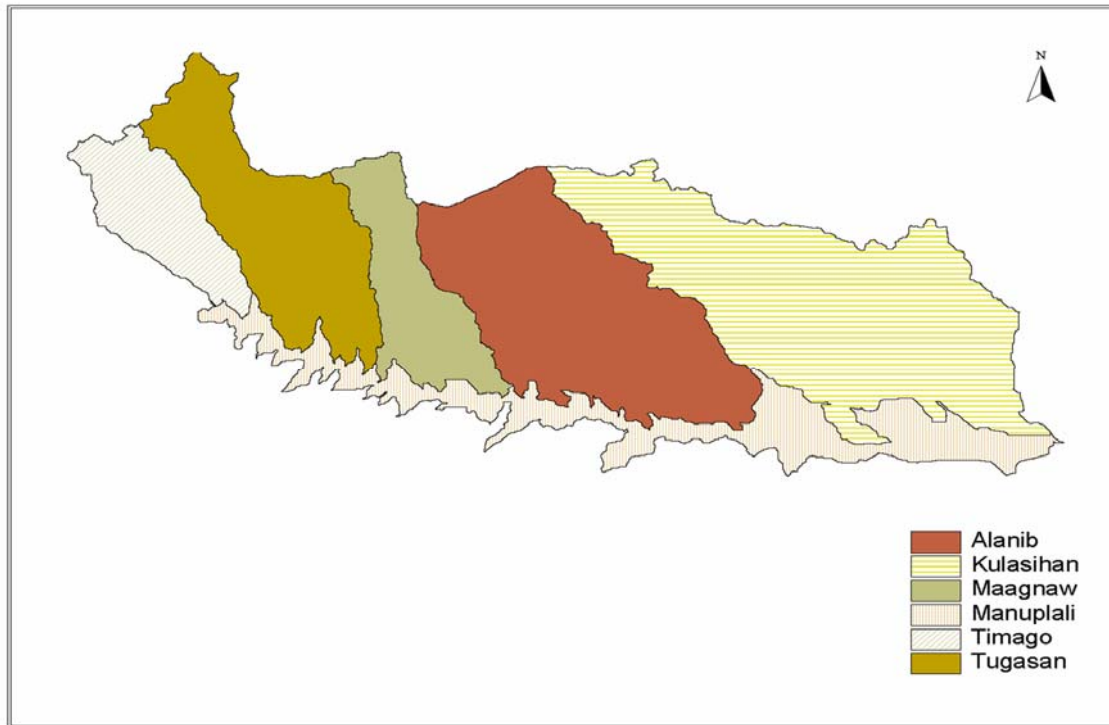


Figure 3: Comparison of tax revenue from the non-poor and poverty gap



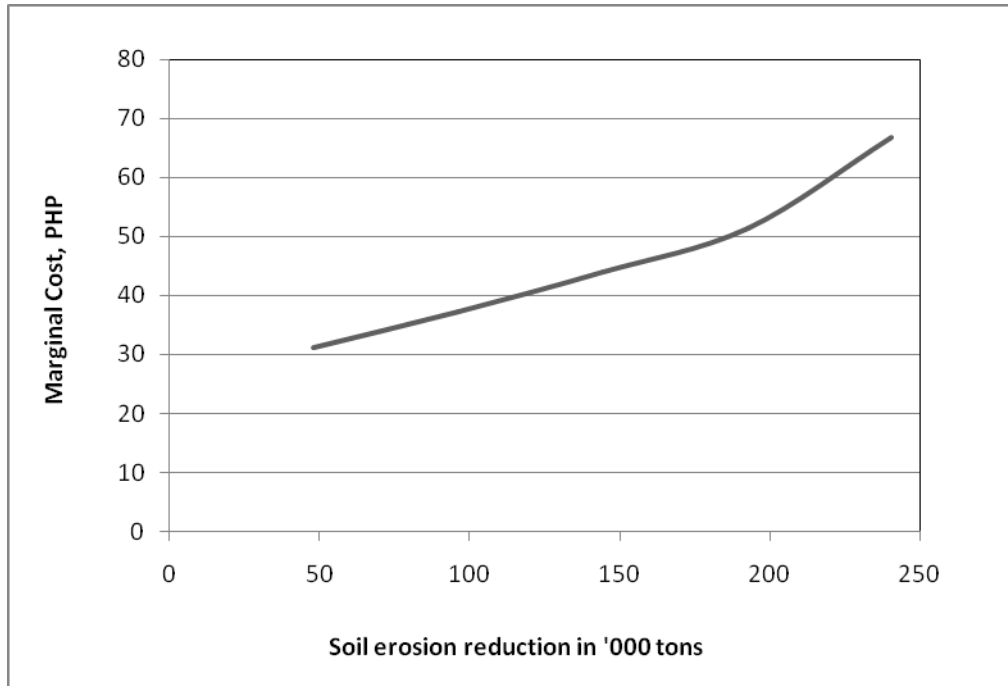
**Figure 4 Manupali Sub-Watersheds**



**Figure 5: Visual representation of hypothetical cells in a watershed**

	Slope →			
Distance to stream ↑	4,1	4, 2	4, 3	4, 4
	3,1	3, 2	3, 3	3, 4
	2,1	2, 2	2, 3	2, 4
	1,1	1, 2	1, 3	1, 4
Stream	R	R	R	R

**Figure 6 Marginal Abatement Cost Curve**



## Notes

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<sup>i</sup> By economic efficiency, we mean ability to attain a given environmental quality at least cost.

<sup>ii</sup> Other policy instruments proposed for controlling agricultural pollution include ambient taxes, random fines, and type-specific contracts (Shortle and Dunn 1986; Segerson 1988; Xepapadeas 1992; Cabe and Herriges, 1992).

<sup>iii</sup> For example, Fleming and Adams (1997) classified their study area into 4 sub-areas based on soil type. Their analysis suggests that the gains from differentiated policies were limited; however this may be a function of the classification.

<sup>iv</sup> The subscripts on the functions  $g$  and  $f$  represent first derivatives.

<sup>v</sup> Note that this assumption is not necessary for the result we present, but will greatly simplify the analysis; this gives a simplified result for the best-case scenario only. In the empirical application, we will relax this assumption so that some farmers fall into poverty due to the taxes imposed. In general, the number of the non-poor that fall into poverty depends on the distribution of income among non-poor prior to introduction of tax.

<sup>vi</sup> For a discussion of how slope length and the size of the watershed considered for analysis affects predicted soil erosion, see Amore et. al. 2004

<sup>vii</sup> NVS are constructed during land preparation by leaving uncultivated a band about 0.5 wide. Unlike conventional hedgerows, the labor required to establish and maintain NVS is quite modest: the largest labor requirements are for pruning, and to a lesser extent for laying out the contour. The average cost of establishing and maintaining NVS is estimated to be about 30 man days/ha/year for strips spaced about 6 meters apart (Mercado et al. 2001). The area lost to NVS is also moderate when constructed at about the recommended 2-3 meters vertical drop. For example, on a parcel with 50% slope and 0.5m wide of the NVS, less than 8% of planted area would be lost.

<sup>viii</sup> USD 1.00 = PHP 56 at the time the data were gathered.