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Abstract. This paper proposes a tax mechanism modelled for water extraction in a river system with upstream and downstream farmers. The tax mechanism is based on the regulator's own estimation of aggregate extraction and for that reason the tax addresses the problem of asymmetric information. It is demonstrated that the tax mechanism ensures approximately correct marginal extraction incentives for the individual farmer. Consequently, it is concluded that the tax mechanism proposed here has a practical application.

Keywords: Water extraction; River system; Tax mechanism; Upstream-downstream users

1. Introduction

Water scarcity and population pressures are increasing. In 2030, 47% of the world's population will be living in areas of high water stress (OECD 2008). To avoid potential water conflicts caused by increased competition, more countries are focusing on means of regulating water extraction (Johansson 2000). The request for water regulation especially arises in river basins with upstream-downstream communities, where the downstream community are exposed to an insufficient amount of water due to upstream extraction. Because the downstream community cannot force the upstream community to save water, or exclude the upstream community from extracting the water, the upstream community have no incentive to take into account the negative effects they impose on downstream communities as a result of their extraction. In the Chiang Mai Province in Northern Thailand, tensions occurred between upstream and downstream communities, as a consequence of water scarcity in the dry season. Downstream farmers blamed the upstream farmers for increasing their extraction to irrigate orchards, leaving very little water for the downstream community (Hares 2009).

In this paper we address problems of water extraction such as those faced by the Chiang Mai Province. Considering various pricing mechanisms[1], the methods of water pricing can be classified into volumetric pricing, non-volumetric pricing, and market-based methods (Johansson 2000; Dinar and Subramanian, 1997; Tsur and Dinar 1997). The volumetric pricing methods use various kinds of charges for irrigation water. These methods are typically based on the consumption of actual quantities of water and hence require a metering water facility. Non-volumetric methods can be used if the information concerning extraction quantities is inadequate. These methods charge for irrigation water based on a per output basis, a per input basis, or a per area basis. Finally, market-based mechanisms rely on market pressures and well-defined water rights to determine the irrigation water price.

[1] Other methods such as common governance, subsidies etc. can be used as well. See Sampath (1992) for an overview of irrigation pricing in developing countries.

However, when choosing a regulation method it is important to take the costs of implementing the regulation system into account, e.g. the metering system, as well as the problem of asymmetric information. In the case of water pricing, asymmetric information often appears in two forms: The farmer, typically, has complete information on his water extraction, but this information is private and unavailable to the regulator: Moreover, water production technologies, which depend on farmer characteristics, are unobserved by the regulator. Smith and Tsur (1997) use mechanism design theory to propose a water-pricing scheme, which depends only on observable outputs to deal with the problem of unobserved individual water intake, and the high costs of implementing a metering system. Similarly, Loehman and Dinar (1994) suggest a mechanism design based on a cooperative solution.

Pricing methods based on inputs or outputs may, however, distort input-output decisions (Tsur 2000). Therefore, in this paper a tax based on volumetric pricing[2] is suggested. The tax is based on aggregate consumption, and therefore requires a limited amount of information, taking into account the typical problem of asymmetric information. Moreover, suggesting a tax to regulate the problem between the upstream and downstream community, it is possible to internalise the negative externality, which the upstream community impose on the downstream community, thus, potentially avoiding tensions between the two.

The conditions for the tax mechanism are described in Section 2; In Section 3 the tax mechanism is set up; and in Section 4 the pros and cons of the tax are discussed and the conclusion is presented.

2. The extraction problem

Consider our river system with two communities; an upstream (u) and a downstream (d). The individual upstream farmer, $i = 1, \dots, m$, and the individual downstream farmer, $j = 1, \dots, n$,

[2] The tax mechanism is a revised version of Hansen's (1998) mechanism, applied to water extraction.

extract an amount of water, h ($h \in [h_i^u, h_j^d]$), which for the two communities can be summarised into aggregate water extraction, $H^u = \sum_i h_i^u$, and $H^d = \sum_j h_j^d$. Due to limited information, the regulator has no information regarding the individual's level of water extraction, h_i^u and h_j^d. However, by relatively simple hydrological calculations, the regulator is able to observe how much water the upstream community extracts in total, $H^u = \sum_i h_i^u$.

During each rainy season, a certain amount of water, W, is added to the system. The amount of water available for extraction, F, depends on whether one is located upstream or downstream. For upstream farmers, this relation is assumed to be exogenous, while for downstream farmers, the relation depends on the amount of water left in the system after upstream extraction. An amount of water cannot, however, be used for extraction. This is the water base, $x \in [x^u, x^d]$, whereby the water base influences the amount of water available for extraction. Without the water base, the river is unable to renew itself and will dry out. Thus, it is assumed that $F'(x) < 0$. Consequently, in a steady-state equilibrium[3], the following resource restrictions are applicable:

(1) $F^u(x^u) = W - H^u$ and $F^d(x^d) = W - H^u - H^d$

Formulating the resource restriction in this way means that if $H^u = W$, there is no water for downstream users. In the following, however, only the situation in which $H^u < W$ is considered since, in most cases, it seems unlikely that upstream users will extract all the water available.

We assume that the extraction cost, $c = c(h, x)$, is a function of water extraction, h, and of the water base, x, with $dc/dx < 0$ and $dc/dh > 0$. The cost functions vary between the individual farmers, reflecting variations in technology and ease of water extraction. Thus, extraction costs for the individual upstream farmer and the individual downstream farmer can be expressed as:

[3] It is possible to generalise the model and analysis to a dynamic problem, but since dynamic problems often result in an analysis of steady-state, the problem is simplified from the beginning and the whole problem is analysed in a steady-state setting.

(2) $c_i^u = c_i^u(h_i^u, x^u)$, and $c_j^d = c_j^d(h_j^d, x^d)$

It is assumed that the individual farmer knows his own cost function, but that the individual farmer's cost functions are unknown to the regulator.

Defining the gross benefits of water for the individual farmer B_i^u and B_j^d, it is assumed that the gross benefit is a function of water extraction, $B(h)$, with $B^{'}(h) > 0$, $B^{'}{'}(h) < 0$ (see for example Neher 1990). Consequently, the net benefit for farmer i and farmer j, respectively, is:

(3) $\pi_i^u = B_i^u(h_i^u) - c_i^u(h_i^u, x^u)$, and $\pi_j^d = B_j^d(h_j^d) - c_j^d(h_j^d, x^d)$

Hence, the optimisation problems for farmer i and farmer j, respectively, are:

(4a) $\max_{h_i^u} \pi_i^u = (B_i^u(h_i^u) - c_i^u(h_i^u, x^u))$

s.t. $F^u(x^u) - W + H^u = 0$

and

(4b) $\max_{h_j^d} \pi_j^d (B_j^d(h_j^d) - c_j^d\left(h_j^d, x^d\right))$

s.t. $F^d\left(x^d\right) - W + H^u + H^d = 0$

This problem can be solved with a standard Lagrange method. The first-order conditions with respect to h_i^u and h_j^d are:

(5a) $\frac{\partial B_i^u}{\partial h_i^u} - \frac{\partial c_i^u}{\partial h_i^u} - \lambda_i^u = 0$ and

(5b) $\frac{\partial B_j^d}{\partial h_j^d} - \frac{\partial c_j^d}{\partial h_j^d} - \lambda_j^d = 0$

λ_i^u and λ_j^d are the user costs of the water base, that is, λ_i^u and λ_j^d denote the marginal increase in total extraction costs.

Having that $F'(x) < 0$, it is possible to reformulate the resource restrictions in such a way so that the steady-state water base relates to the amount of water available, and hence aggregated extractions (M). That is:

(6a) $x^u = F^{u^{-1}}(W - H^u) = M^u(W - H^u)$

(6b) $x^d = F^{d^{-1}}\left(W - H^u - H^d\right) = M^d\left(W - H^u - H^d\right)$

And because $F^{'}(x) < 0$ it follows that $\partial M/\partial h < 0$

By substituting (6a) and (6b) into (4a) and (4b), respectively, we get the following maximisation problem for the regulator:

(7) $$\max_{h_i^u, h_j^d} \sum_i^m \left(B_i^u(h_i^u) - c_i^u\left(h_i^u, M^u(W - H^u)\right)\right)$$
$$+ \sum_j^n \left(B_j^d(h_j^d) - c_j^d\left(h_j^d, M^d\left(W - H^u - H^d\right)\right)\right)$$

This gives the following first-order conditions with respect to h_i^u and h_j^d:

(8a) $\frac{\partial B_i^u}{\partial h_i^u} - \frac{\partial c_i^u}{\partial h_i^u} - \sum_i^m \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u}\frac{\partial H^u}{\partial h_i^u} - \sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^u}\frac{\partial H^u}{\partial h_i^u} = 0$ and

(8b) $\frac{\partial B_j^d}{\partial h_j^d} - \frac{\partial c_j^d}{\partial h_j^d} - \sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d}\frac{\partial H^d}{\partial h_j^d} = 0$

and having a number of farmers extracting water at the same time, it is assumed that individual water extraction h is not fully observed. Thus, it is assumed that the individual farmer has Nash-Cournot conjectures ($\frac{\partial H}{\partial h} = 1$). This means that equation (8a) and (8b) can be reduced to:

(9a) $\frac{\partial B_i^u}{\partial h_i^u} - \frac{\partial c_i^u}{\partial h_i^u} - \sum_i^m \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u} - \sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^u} = 0$ and

(9b) $\frac{\partial B_j^d}{\partial h_j^d} - \frac{\partial c_i^d}{\partial h_j^d} - \sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d} = 0$

In equation (9a), $-\sum_i^m \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u}$, is the marginal increase in water costs, which upstream users impose on other upstream farmers through their aggregated extraction. A similar condition is found for downstream farmers, $-\sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d}$. These elements are denoted as an “internal externality". Moreover, for upstream farmers, $-\sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^u}$, is the marginal increase in extraction costs, which upstream farmers impose on downstream farmers through their aggregated extraction, hence an "external externality" or "upstream-downstream externality". Comparing equation (9) with equation (5), it is apparent that the elements; $-\sum_i^m \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u}$ and $-\sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^u}$, and $-\sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d}$ are similar to λ_i^u and λ_j^d. And because upstream farmers do not take the costs they impose on downstream farmers into account, regulation must consequently compensate for this. Moreover, regulation must compensate for the condition that farmers within the same community do not take into account the costs they impose on each other[4], in order to avoid the over-utilisation of the resource.

3. Imposing a regulatory tax

A regulatory tax is suggested, which is a function of water extraction, due to the situation in which very little water is left for the downstream farmers, because upstream farmers do not take into account that they impose costs on downstream farmers through extraction. In fact, two types of taxes are suggested in order to capture the internal externality within the communities and the external externality between the communities: That is an internal tax (IT) aimed at regulating the internal externality; $IT(h) \in [IT_i^u, IT_j^d]$, and an external tax (ET), to regulate the external externality; $ET(h) \in [ET_i^u, ET_j^d]$. The external tax is, naturally, only valid for upstream farmers. Consequently, in the steady-state equilibrium, the individual upstream and downstream farmer, respectively, faces the following profit maximisation problem (defined in equation (4)):

$$\text{(10a)} \qquad \max_{h_i^u}\left(B_i^u(h_i^u) - c_i^u\big(h_i^u, M^u(W-H^u)\big) - IT_i^u(h_i^u) - ET_i^u(h_i^u)\right)$$

[4] The simple version is considered here in which farmers within the community extract water from the same waterhole. A more correct version would also involve an upstream-downstream condition within the individual communities, meaning that a number of waterholes along the river exist from which the farmers extract water. This specification is rather easy to implement in the model although not necessary for the objective.

(10b) $\max_{h_j^d} \ (B_j^d(h_j^d) - c_j^d\left(h_j^d, M^d\left(W - H^u - H^d\right)\right) - IT_j^d(h_j^d))$

This gives the following first-order profit maximisation condition for the two groups of farmers:

(11a) $\frac{\partial B_i^u}{\partial h_i^u} - \frac{\partial c_i^u}{\partial h_i^u} - \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u} - \frac{\partial IT_i^u}{\partial h_i^u} - \frac{\partial ET_i^u}{\partial h_i^u} = 0$ and

(11b) $\frac{\partial B_j^d}{\partial h_j^d} - \frac{\partial c_j^d}{\partial h_j^d} - \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d} - \frac{\partial IT_j^d}{\partial h_j^d} = 0$

In the case without regulation, $\frac{\partial IT}{\partial h} = \frac{\partial ET}{\partial h} = 0$, the individual farmer sets his extraction of water to maximise profit without taking into account the fact that he affects the other farmers' extraction costs. Thus, the free-rider problem occurs and the resource is over-utilised. Efficiency requires that the farmers take into account the resource constraint effect on the costs of their own community, $\sum_i^m \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u}$ and $\sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d}$, but also that the upstream farmers take into account the resource constraint effect of the costs of the downstream community, $\sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^u}$.

Because equation (11) is the objective first-order condition for profit maximisation, it is unclear to what extent the farmers realise that their own extraction affects the common costs, that is the costs they impose on other farmers within their community. In most cases, the extent to which farmers realise that their own extraction affects the common costs may depend on the functioning of the community. In order to capture variations in community cultures, a parameter, β, $\beta \in [\beta_i^u, \beta_j^d]$, is introduced, affecting the internal externality: $-\beta_i^u \sum_i^m \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u}$ and $-\beta_j^d \sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d}$ for the upstream and downstream farmers, respectively, where β may attain values between 0 and 1. It is argued that if $\beta = 1$ the community is fully able to internalise the costs they impose on other farmers through extraction. If, however, $\beta = 0$, the community is unable to internalise the costs they impose on the others through extraction. Irrespective of the value of β, the resource will, however, be over-utilised. This is because the upstream farmers do not take the increased downstream extraction costs into account. Consequently, a regulatory tax is needed.

3.1 Information assumptions

Consider the information upon which the regulator can base the taxes. The regulator has no information about the individual cost functions, $c(\cdot)$, or about individual water extractions, h_i. The regulator is, however, able to estimate the aggregate cost functions for the upstream and downstream water users, respectively, $\sum_i^m c_i^u(\cdot)$ and $\sum_j^n c_j^d(\cdot)$. In most cases, the regulator has an idea of the aggregate costs, based on knowledge of average extraction costs and the number of users. Similarly, the regulator has an idea of the aggregated benefit functions $B_i^u(\cdot)$and $B_j^d(\cdot)$ based on knowledge of crops grown in the irrigated areas. It is, moreover, assumed that the regulator is able to estimate how much water enters the system, W, and how much water upstream users leave for downstream extraction. Therefore, the regulator can estimate the aggregated water extraction (H) by measuring $M^u(\cdot)$ and $M^d(\cdot)$. Given knowledge of $\sum_i^m c_i^u(\cdot)$ and $\sum_j^n c_j^d(\cdot)$, $M^u(\cdot)$, and $M^d(\cdot)$ [5], the regulator can solve the following problem:

$$(12)\quad \max_{H^*}(B_i^u(H^u) - \sum_i^m c_i^u\left(H^u, M^u(W - H^u)\right) + B_j^d\left(H^d\right) - \sum_j^n c_j^d\left(H^d, M^u\left(W - H^u - H^d\right)\right))$$

Equation (12) implies that the optimal aggregate steady-state extraction, H^*, is known by the regulator, where $H^* = \sum_{i=1}^n h_i^{u*} + \sum_{j=1}^n h_j^{d*}$.

[5] Gross benefits, B_i^u and B_j^d, are not assumed to differ significantly between the two communities. The reason is that they are located in the same region. Hence, crops produced and crop prices may be alike.

3.2 The Tax Scheme

Now imposing an internal and an external tax, a tax based on aggregate cost functions and measured aggregate water extraction is suggested, thereby avoiding the problem of asymmetric information. Thus, the internal tax to be paid by the individual water user (i, j) to capture the internal externality is:

(13a) $IT_i^u = \sum_i^m c_i^u\ (H^{*u}, M^u(H^u))$ and $IT_j^d = \sum_j^n c_j^d\ (H^{*d}, M^d(H^d))$

And the external tax to be paid by the individual upstream farmer (i) to capture the external externality is:

(13b) $ET_i^u = \sum_j^n c_j^d\ (H^{*u}, M^d(H^u))$

Forming the taxes this way means that the taxes are a function of optimal aggregate extraction calculated by the regulator, H^*, and actual aggregate extraction measured by the regulator. Basing the taxes on the aggregate steady-state extractions means that the taxes in optimum are equal to the total extraction costs.

3.3 Nash Equilibrium under Tax Regulation

Having now two types of taxes, as defined in equation (13), the individual farmer and his maximisation problem is considered once more. By substituting the taxes for the individual farmer's maximisation problem (equation (4)), the farmer i, j now solves the following problem depending on whether he is an upstream or a downstream farmer:

(14a) $\max_{h_i^u}(B_i^u(h_i^u) - c_i^u\big(h_i^u, M^u(W - H^u)\big) - \sum_i^m c_i^u\ (H^{*u}, M^u(H^u)) -$
$\sum_j^n c_j^d\ (H^{*u}, M^d(H^u)))$

and

(14b) $\max_{h_j^d}(B_j^d(h_j^d) - c_j^d\left(h_j^d, M^d\left(W - H^u - H^d\right)\right) -$

$\sum_j^n c_j^d\,(H^{*d}, M^d(H^d)))$

The respective first-order profit maximisation condition for the individual upstream water user and downstream farmer is:

(15a) $\frac{\partial B_i^u}{\partial h_i^u} - \frac{\partial c_i^u}{\partial h_i^u} - \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u} - \beta_i^u \sum_i^m \frac{\partial c_i^u}{\partial M^u}\frac{\partial M^u}{\partial H^u} - \sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^u}$ and

(15b) $\frac{\partial B_j^d}{\partial h_j^d} - \frac{\partial c_j^d}{\partial h_j^d} - \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d} - \beta_j^d \sum_j^n \frac{\partial c_j^d}{\partial M^d}\frac{\partial M^d}{\partial H^d} = 0$

And the individual farmer is able to solve this problem as he knows his own cost function and is informed of the tax formula.

By comparing equation (15) in which the farmer optimises his water extraction under the proposed tax scheme, with equation (9), the optimal water extraction, we see that the upstream farmer takes the full upstream-downstream externality into account. Hence, the tax we have suggested corrects for the upstream-downstream externality. Moreover, the internal tax is able to capture the internal externality, if β is known. The tax results in correct marginal incentives if $\beta = 0$, but "over-corrects" if $\beta > 0$. The tax also corrects for the external water base effect of the farmers' water extraction on other farmers within the community, $\sum \frac{\partial c_i}{\partial M}\frac{\partial M}{\partial H}$, as it should, but also for the perceived part of the water base effect on farmer i himself, $\frac{\partial c_i}{\partial M}\frac{\partial M}{\partial H}$, which is an internal effect that farmer i already takes into account. Moreover, an additional problem arises if $\beta > 0$. In this case, it is not possible to argue that the individual users have Nash-Cournot conjectures. One way to handle this condition is to decrease the internal tax, thereby moving closer to the optimal water extraction level.

If a situation in which β is unknown is considered instead, it becomes more problematic for the regulator to set a tax which neither over, nor under-corrects the internal externality. If the internal tax is set too low, the upstream farmers will extract too much water, affecting downstream conditions negatively. However, if the internal tax is set too high, upstream conditions are affected negatively. For this reason it may be beneficial for the regulator to support the functioning of the community, e.g. by subsidising, providing technical aid or other methods, in order to improve the functioning of the tax system. Also, the regulator may invest in revealing costs and benefits by developing new technologies, or by implementing mechanism design tools. However, independent of the knowledge of the functioning of the communities, a tax is suggested which is able to incorporate the upstream-downstream externality, which is often the root of upstream-downstream tensions.

4. Discussion and Conclusion

A tax mechanism in which the regulator simply bases the tax on the aggregate water extraction is simple and cheap. This means that the tax mechanism can be functional in areas where volumetric pricing methods may be too expensive to implement. The paper is concluded with a discussion of the pros and cons of the mechanism, focusing on how the proposed tax mechanism will work in reality.

First, in the paper we assume that the farmers have Nash-Cournot conjectures. Whether this is a reasonable assumption for all the farmers can be questioned, especially when considering the individual communities. It seems reasonable to assume, however, that that individual water extraction, h, is not fully observed between the two communities. Hence, Nash-Cournot conjectures between the communities can be assumed. Moreover, as the size of the communities increase, Nash-Cournot conjectures within the communities may become more reasonable. For this reason, Nash-Cournot conjectures may not be perfect, but can be rationalised.

A second aspect to consider is information requirements. Often the farmer has private information which is unavailable to the regulator. In this situation, the tax mechanism gives rise to at least two requirements. Firstly, the regulator must have information about the amount of water entering the system (W). Although it can be difficult to collect precise figures, it is not impossible for the regulator to obtain such information through surveys. Moreover, this problem is similar to problems of information requirements in the case of quota, or self-governing regulation. Secondly, the tax mechanism does not work without reliable cost data. However, information about the individual's cost function is not needed, in contrast to the mechanism proposed by Segerson (1988). The tax mechanism is functional when only information about the aggregate cost functions for the two groups of farmers is available. However, this can also be difficult for the regulator to collect, especially because farmers may underestimate their costs if they know the data will be used to calculate a tax. The information requirement for the tax mechanism proposed here is, however, similar to the requirement in the mechanism proposed by Hansen (1998). For this reason, it must be assumed that it is a general, but manageable, information problem.

Thirdly, it is often mentioned that it is important that a tax mechanism secures a budget balance. A tax mechanism is of a budget-balancing type if the total payments equal the society's value of conservation. The tax mechanism proposed here does not secure a budget balance and neither does the mechanism proposed by Segerson (1988). To solve non-point pollution problems, Xepapadeas (1991) proposes a random penalty mechanism which secures a budget balance. One might argue, however, that a budget balance is of less importance for the tax mechanism proposed in this paper, since we regulate water extraction from a river system in an area with limited resources for implementation. This means that water extraction by the individual farmer is expected to be small. Thereby, the total tax payment becomes small. For this reason, the possible "over correction" of the tax in monetary terms might be rather small, and therefore the aspect of budget balance might be minor in the case of the practical application of the proposed tax mechanism. Moreover, because in this case the focus is more towards regulation, a budget balance might be considered as being less important.

Finally, it is assumed that the communities are able to handle the problem of the resource constraint within the communities. That is, they are able to allocate the tax payments among themselves, depending on the amount of water extracted, or other criteria, such as geographic location in the river system. This may, however, require a well functioning community, which underlines the argument about the importance of supporting the functioning of the individual communities.

However, bearing in mind the listed potential problems, the suggested tax seems to have important applications as it takes care of two significant problems when farmers share a river, such as those in the Chiang Mai Province in Northern Thailand. First, it addresses the problem of asymmetric information, since only a minimum amount of information is required. Moreover, the information needed is aggregated, which is less expensive to collect than information on an individual level. Second, the tax regulates the negative externality, which upstream farmers impose on downstream farmers, allowing for internal regulation within the communities. Consequently, it is concluded that the tax mechanism proposed here has a practical application.

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