The Role of Deforestation Risk and Calibrated Compensation in Designing Payments for Environmental Services

Jennifer Alix-Garcia[1]
University of Montana
Department of Economics
32 Campus Dr # 5472
Missoula, MT 59812
jennifer.alix-garcia@mso.umt.edu

Alain de Janvry
Elisabeth Sadoulet
Department of Agricultural and Resource Economics
University of California at Berkeley
207 Giannini Hall
Berkeley, CA 94720

Abstract: This paper discusses the gain in efficiency from including deforestation risk as a targeting criterion in payments for environmental services (PES) programs. We contrast two payment schemes that we simulate using data from Mexican common property forests: a flat payment scheme with a cap on allowable hectares per enrollee, similar to the program implemented in many countries, and a payment that takes deforestation risk and heterogeneity in land productivity into account. We simulate the latter strategy both with and without a budget constraint. Using observed past deforestation, we find that while risk-targeted payments are far more efficient, capped flat payments are more egalitarian. We also consider the characteristics of communities receiving payments from both programs. We find that the risk-weighted scheme results in more payments to poor communities, and that these payments are more efficient than those made to non-poor ejidos. Finally, we show that the risk of deforestation can be predicted quite precisely with indicators that are easily observable and that cannot be manipulated by the community.

Keywords: Payments for environmental services, renewable resources and conservation, market-based mechanisms, environmental policy, simulation, rural development

[1] Corresponding author.

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Summary

Programs that pay for the environmental amenities provided by standing forests are becoming increasingly common. Most of the current programs, however, give the same payment for each hectare of forest enrolled, or for each hectare of different forest types enrolled up to a cap on allowable hectares per enrollee. This paper discusses the gain in efficiency from differentiated payments and the inclusion of deforestation risk as a targeting criterion in payments for environmental services (PES) programs. We contrast two payment schemes that we simulate using data from Mexican common property forests: (i) a flat payment scheme with a cap on allowable hectares and a budget constraint, similar to the program implemented in many countries, and (ii) a payment scheme without a cap that takes deforestation risk and variation in land value into account (risk-weighted flexible payments). We simulate the latter strategy both with and without a budget constraint. The program without a budget constraint is a payment of the potential income for all hectares of forest which are at risk of deforestation. We use the total amount of resources spent for this program as the constraint for the flat payments program, where it is assumed that recipients will not accept payments lower than the potential income generated by deforested land. In order to illustrate how to deal optimally with a budget constraint, we use 2/3 of the total budget of the other programs and allocate payments according to the forests' environmental benefits/cost ratio, paying the value of the potential income generated by hectares at risk of deforestation (benefit-maximizing payments). Our initial set of simulations assumes perfect foresight by using observed past deforestation, an assumption we later relax. We find that payments in our benefit-maximizing scheme provide more than 4 times the environmental benefits for each dollar spent than in the flat payments program. The intuition behind this result is that a large part of the money in the flat payments program is given to forests which would have been preserved even in absence of the incentive. The tradeoff, however, is that capped flat payments are more egalitarian – the Gini coefficient of payments is less than half that of the benefit-maximizing program. We also consider the characteristics of communities receiving payments from both programs. We find that the risk-weighted flexible payment scheme results in more, though smaller, payments to poor communities, and these payments are more efficient than those to non-poor ejidos. In the flat payment scheme, payments to poor and non-poor are equal, though the poor receive less of the budget than in the benefit-maximizing program. Finally, in order to address the problem of how to avoid strategic behavior, we simulate the benefit-maximizing program using deforestation risk predicted by easily observable variables. Even with errors in prediction, the benefit-maximizing program is at least twice as efficient as a program of flat payments.

Word count for text (not including abstract, summary, references or tables): 5,579

1. Introduction

Programs of payments for environmental services (PES) [2] are becoming an increasingly popular way of creating, conserving, and restoring natural resources throughout the world. Mayrand and Paquin (2004) inventoried more than 300 such schemes. In recent years, PES programs have increasingly been introduced in developing countries, with one of the earliest efforts occurring in Costa Rica in 1997, and pilot programs mushrooming throughout Latin America and Asia (World Bank, 2005). Payments for the conservation of standing forests are the most frequent of such programs in developing countries. The targeting strategy has been to pay a flat fee per hectare of standing forest, where the forest owners whose forests fall in specific, usually environmentally sensitive, geographical regions voluntarily enroll hectares but where there is a limit on the number of allowable hectares per enrollee. Examples of this type of targeting can be found in Mexico, Costa Rica (Zbinden and Lee, 2005), and Ecuador (Echavarría, 2002), among others (for a useful review, see Pagiola et al (2002)). China's "Grain for Green" program also offers flat payments, although farmers are paid for conservation activities such as reforestation rather than for preserving standing forests (Uchida et al, 2005). The appeal of this sort of non-differentiating strategy clearly lies in its transparency, ease of implementation, and impression of fairness. Unfortunately, since these schemes do not take into account the risk of losing the forest nor the productive capacity of the land enrolled, it is highly unlikely that one could find a situation in which such a program would maximize the environmental benefits accrued per dollar spent. Given limited budgets for conservation, the search for an efficient, readily implementable program design is imperative. In this paper we use the case of Mexico to illustrate the efficiency gain in including the risk of deforestation and calibrated payments in the design of payments for environmental amenities provided by standing forest.

[2] Such programs are also known as programs of payments for environmental amenities, conservation payments and environmental service payments.

There is a growing literature on cost effective designs for conservation programs, much of it inspired by the US Conservation Reserve Program (Babcock et al, 1996, 1997; Parks and Schorr, 1997). The main preoccupation of much of the current research is with the proper way of measuring environmental amenities. Several economists have proposed biodiversity metrics, including Weitzman's (1998) expected genetic diversity ranking, Ando et al's (1998) total species measure, and Ferraro's (2004) distance function approach. Ferraro (2003) compares the impacts of different index measurements for water quality benefits, and finds that all of them are highly correlated.

Our contribution to this discussion is to point out that, no matter the choice of amenity measure, it is a waste of money to pay for amenities which are not at risk of being lost. Mexico provides an excellent opportunity to study the efficiency of payments for services provided by forests, in part because it is in the early stages of implementing a nationwide PES program for standing forests. Presently, 80% of the country's forests are located in ejidos. These communities, which were created by the post-Revolution land reform, hold their forestry and grazing lands in common property. Their large share of national forest holdings makes them an essential place where to begin addressing the deforestation problem.

Using data obtained from a 2002 ejido survey, we compare three targeting strategies for payments.

1. *Flat Payment per Hectare, H*: A flat payment over all forested hectares with a cap on the number of hectares per enrollee. This scheme is used as a reference as it is similar to that currently observed in many existing PES programs.
2. *Risk-weighted Flexible Payments, R*: A payment for all hectares at risk of deforestation at the level of the income potentially generated by the deforested land, without a budget constraint or a cap.

3. *Benefit-Maximizing Payments, B*: A payment that maximizes the expected environmental benefits per dollar paid using an index of environmental value and is equal to the potential income generated by hectare at risk, for a given budget and without a cap.

The main result of these simulations is that while the benchmark scheme, *H,* is very egalitarian, it is highly inefficient in terms of environmental benefits per dollar spent. The risk-weighted flexible payments scheme, *R,* generates more than three times the environmental benefits at the same cost as the flat payments program, *H*. Simulation of the expected benefit maximizing program, *B*, increases efficiency over the flat payments program, *H*, by over four times. The intuition behind the result is simple: paying everyone to preserve their forest may achieve the goal of income redistribution, but at a high cost – much of the payments will go to forests which would remain standing even in the absence of incentive schemes. We also illustrate how to avoid strategic behavior on the part of recipients by conducting a final simulation which uses the predicted rather than actual risk to implement the benefit-maximizing program, *B*. We find that there are errors in targeting, but that efficiency is still much greater than in a flat payments program.

Since policymaking is both about efficiency and equity, we analyze the distributional implications of the first and last schemes that we consider. The results show that the budget from the flat payments program, *H*, is more equitably distributed amongst ejidos of different size and poverty classes, while the benefit-maximizing program, *B*, allocates more funds to larger and poorer communities. Program *B*, however, gives smaller payments to poor ejidos on a per capita basis, while flat payments per capita are equal for the poor and non-poor.

The paper proceeds as follows: we first describe the theoretical rationale behind the different targeting strategies considered, which leads us to the empirical strategy discussed in section 3. Section 4 describes the data to be used for the simulations and section 5 gives the results. Section 6 discusses some practical considerations for the implementation of our most efficient strategy and the last section concludes.

2. Alternative payment schemes – theoretical considerations

There are many possible ways of designing an environmental payment scheme. Any variation in design will change the kind of environmental services obtained and the people who receive payments. Conceptually, there is a lower and an upper bound on the "price" which one can pay per hectare in a PES program: the lower bound is the potential income of the land and the upper bound the value of the environmental services provided by the land. In this section we discuss general principles that apply regardless of the program design chosen.

Basic principles

Two essential components for the design of a PES program are targeting strategy and payment level. In theory, these should be jointly defined to maximize environmental benefits for a given budget. Because benefits can only be gained from voluntary enrollees, the optimal scheme depends upon the response function of the recipients, in this case, the ejidos. To formalize, let $U\left(F_e - \Delta F_e, c_e \Delta F_e; z_e\right)$ be the utility an ejido e derives from the remaining standing forest, $F_e - \Delta F_e$, and from the income generated by deforesting an area ΔF_e, where c_e is the income from deforesting a given hectare, and z_e are ejido characteristics. The optimal deforestation level $\Delta \tilde{F}_e$ is thus a function of the initial standing forest, the potential income per hectare of forest, and the ejido characteristics:

$$\Delta \tilde{F}_e = \Delta F\left(F_e, c_e, z_e\right).$$

The offer from the PES program is to not deforest at all against a payment P_e. The ejido will thus accept the contract if:

$$U\left(F_e, P_e; z_e\right) \geq U\left(F_e - \Delta \tilde{F}_e, c_e \Delta \tilde{F}_e; z_e\right).$$

Let $P_{e,\min}$ be the minimum value that satisfies this condition. Given the environmental benefit b_e provided per hectare in ejido *e*, the optimal transfer scheme under the budget constraint $\bar{P}$ is the solution to:

$$\max_{P_e} \sum_e 1\left[P_e \geq P_{e,\min}\right] \Delta F\left(F_e, c_e, z_e\right) b_e \qquad (1)$$

$$\text{s.t.} \qquad \sum_e 1\left[P_e \geq P_{e,\min}\right] P_e \leq \bar{P}.$$

Ideally, one would like to know the monetary value equivalent to the utility that ejidos derive from standing forest. In the absence of such valuation, one can use $P_{e,\min} = c_e \Delta\tilde{F}_e$ as a lower bound for the acceptability of the scheme to the ejido (this is equivalent to ignoring the loss in utility associated with the decrease in standing forest). Ejidos accept the payment and agree to not deforest if the payment P_e is at least as high as the income that would be generated by converting the land into pasture/crops, and do not accept the contract if the offered payment is below this magnitude:

$$\text{If } P_e \geq c_e \Delta F\left(F_e, c_e, z_e\right) \Rightarrow \Delta\tilde{F}_e = 0 \qquad (2)$$

$$\text{If } P_e < c_e \Delta F\left(F_e, c_e, z_e\right) \Rightarrow \Delta\tilde{F}_e = \Delta F\left(F_e, c_e, z_e\right).$$

The question that follows is: assuming full knowledge of all the variables, should one pay the minimum value necessary to preserve the environmental benefits, i.e., the potential income c_e of the land, or the entire value of the good being purchased, i.e., the environmental benefit b_e? In reality, this is a question of bargaining power. In both cases, payments will only be incentive compatible if the benefits offered by the land are greater than or equal to the value of the land in alternative activities, $b_e \geq c_e$. The difference is that in the first case, the surplus goes to society while in the second it accrues to the land owner.

If one looks at the formulae above, the optimal contract only pays for the hectares that would otherwise be deforested, $\Delta F\left(F_e, c_e, z_e\right)$, which varies with the deforestation rate. In actuality, one frequently observes a flat payment per hectare of currently standing forest F_e with a cap on hectares per enrollee set by the agency managing the program. In many places, this payment varies with quality of forest in terms of environmental benefits, but the point here is that it depends neither on the deforestation rate nor on the income-generating potential of the land (except as a floor value). Arguments in favor of this flat payment are the simplicity of implementation, as it does not take into account deforestation behavior, and the impression of fairness that it gives.

Regardless of the choice of payment scheme, the contract must be made over the entire forested area of the ejido. Neglecting this consideration could lead to "slippage" (a term coined by Wu (2000)), that is, if a contract is over a subset of the forest, then deforestation may simply be transferred from a contracted to an uncontracted area of forest. Hence, typically, the contract should specify a payment against no deforestation on all of the hectares that have a potential income below their environmental value. This arrangement, however, does not take into account the fact that preventing land from going into agricultural production may have an effect on prices of the corresponding agricultural goods, which may result in slippage between ejidos (Wu, Zilberman, and Babcock, 2001).

3. Proposed simulations

In this section, we specify the alternative payment schemes that will be simulated. Building from our theoretical considerations, we have selected 3 payment schemes: The capped flat payments program, *H,* provides the benchmark case for our simulations. We compare this design to two programs which incorporate deforestation risk and the potential income generated by deforested land. The first program, risk-weighted flexible payments, *R*, offers payments equal to the size of the potential income generated per deforested hectare only for those hectares that are at risk of deforestation. It is calculated without any limit on the budget, and the total money spent on this program is used to provide a point of comparison for the other two programs. First, the magnitude of the flat payments is established in order to give the same total expenditures as in the flexible payments program. Second, two-thirds of this budget (an arbitrary choice, but neutral on our argument) gives the constraint for the benefit-maximizing program, *B*, in which payments are distributed in order to maximize the expected environmental benefits per dollar spent.

Flat payments, H

We assume a flat payment *r* per hectare, up to a maximum of $\bar{F}$ hectares: $P_{e,H} = r \min\left[\sum_j F_{ej}, \bar{F}\right]$.

$P_{e,H}$ is the total payment to ejido *e*, which is the rate per hectare multiplied by either the sum of forest hectares of type *j* or by the maximum allowable hectares, which we set at 2000 hectares per forest owner, as is the case of Mexico's program. Assume that there is a constant annual deforestation rate τ_{ej} of forest of category *j* in the ejido, and that the potential income of a hectare of land in the ejido is c_e. All ejidos are offered a contract, but an ejido will only accept the contract and thus participate in the scheme if the potential income, $P_{e,R}$, of the area it would otherwise deforest is less than or equal to the offer: $P_{e,H} \geq \sum_j c_e \tau_{ej} F_{ej} \equiv P_{e,R}$.

In order to facilitate comparison of the schemes, the rate *r* is established at the level that equalizes the total budget to the budget of the scheme *R,* which pays the potential income generated by each hectare of land at risk of deforestation and will be detailed in the next section. It thus solves for:

$$\sum_e 1\left[P_{e,H} \geq P_{e,R}\right] P_{e,H} = \sum_e P_{e,R} .$$

Risk-weighted Flexible Payments, R

We allow for heterogeneity of environmental benefits within ejidos. Each hectare of forest of type *j* is characterized by an environmental benefit b_j. Ideally, one would prefer an actual monetary value for the environmental benefits offered by a given piece of land. In reality, however, this is quite difficult to establish, as markets are missing for these services. So, for the purpose of our simulations, we establish an index value b_j that allows the ranking of each hectare of forest by its relative environmental value. Note that this does not allow us to exclude lands whose true environmental value is less than the potential income generated by deforested land.

Let F_{ej} be the number of hectares with environmental benefits b_j in ejido *e*, with $\sum_j F_{ej} = F_e$ the total forest area in ejido *e*. The first year of the program, unchallenged deforestation would convert $\tau_{ej} F_{ej}$ of forest of quality *j* into pasture. The second year, an additional τ_{ej} of the remaining forest $\left(1-\tau_{ej}\right)F_{ej}$ would be converted, and similarly the following years. The deforested area after *t* years would thus be:

$$\Delta F_{ej}^t = \left(1-\left(1-\tau_{ej}\right)^t\right)F_{ej} .$$

If the program is to prevent deforestation over the years, it should thus "rent" an increasing share of the forest. Payments based on the income generated by deforested land, assuming that the environmental benefits of all hectares exceed this level, would be: $P_{e,\mathrm{R}}^t = \sum_j c_e \Delta F_{ej}^t$ These payments should be disbursed on a yearly basis for the services provided by the preserved forest. Because we are paying exactly the value of the alternative use for the hectares of land they wish to deforest, ejidos will always accept the contract. The participating ejidos are those that would otherwise deforest. Note that the contract is for no deforestation on the total initial ejido area with potential income below environmental benefits. Hence the area enrolled in the contract is $\sum_j F_{ej}$. Environmental benefits obtained by contracts in the participating ejidos are: $B_{e,\mathrm{R}}^t = \sum_j b_j \Delta F_{ej}^t$.

In the rest of the paper, since we are only concerned with comparing programs, we will only consider the first year of payment, and leave out the *t* superscript. Assuming that all communities have a fixed deforestation rate, or that any changes in the rate occur equally for all communities, calculating program outcomes for the first year will give us the same relative results for payment schemes that depend upon deforestation risk. Note that by restricting ourselves to the first year of payments we are showing the flat payment scheme in the best possible light. This is because the flat payments do not change over time, but ejidos with a constant rate of deforestation will have to be paid for increasingly large land areas as time goes on. Therefore, the first year gives the maximum number of communities that will accept the flat payments at any given time.

Benefit-maximizing payments, B

If the total payment $\sum_e P_{e,R}$ exceeds the available budget, the optimal scheme consists of ranking the ejidos by decreasing ratio of benefits over cost, *bc*: $bc_e = \frac{\sum_j b_j \tau_{ej} F_{ej}}{\sum_j c_e \tau_{ej} F_{ej}}$ and paying the potential income generated by the hectares at risk of deforestation $P_{e,B} = P_{e,R} = \sum_j c_e \tau_{ej} F_{ej}$ to those with the highest *bc* ratio until the budget is exhausted.

4. Data and Methodology

In the summer of 2002, Mexico's National Ecology Institute (INE), together with the Iberoamericana University, the Center for Economic Education and Research (CIDE), the University of California at Berkeley, and the World Bank, conducted a nationwide survey of Mexican ejidos. The purpose of the survey was to understand the deforestation process in these communities in order to inform the design of a PES program[3] that the Mexican government was interested in introducing. The survey randomly sampled 407 ejidos larger than 100 hectares located in the forested regions of the country. The total universe of ejidos with forest over 100 hectares is 7,679. The total amount of

[3] This program was effectively introduced in 2003.

forest covered by our sample is 2,106,592 hectares of primary and secondary forest. Table 1 shows the distribution of communities across regions.

The sample included ejidos in all states with the exception of Baja California, Coahuila, Guanajuato, Zacatecas, Morelos, and Aguascalientes. In order to measure forest cover and its change over time, we use the Forest Inventories for 1994 and 2000, which were constructed by visual interpretation from satellite images with pixels of 30 meters at a scale of 1:250,000 (Velázquez et al., 2002). In addition, we obtained slopes from digital elevation models with 100 meter pixels available from the Mexican government.

Overall, 86% of the ejidos in our sample currently have primary forest. The area of primary forests is largely related to ejido size, which varies considerably across ejidos. Total ejido area ranges from 180 to 170,143 hectares in our sample. The average percentage of a given ejido in primary forest is 34.7%. On a per capita basis, the distribution of the forest is quite skewed. Though the average number of hectares per capita is 37, the median is 6.5 and the Gini coefficient .83. This suggests that any payment program disbursed on a per hectare basis will be highly unequal in its distribution across communities and individual members.

The deforestation rate over the total forest in our sample is 1.2% per year from 1994 to 2000, which is comparable to what Torres and Flores (2001) term the "conservative estimate" of 1.3% per year calculated using all the forested area in Mexico. In our sample, the average ejido deforested about 1.3% per year over the period 1994-2000. 61% of the ejidos in the sample deforested over the study period, where deforestation is defined as the change from primary or secondary forest to agriculture or pasture. Amongst those who deforest, the average rate of forest loss is 2.1% per year, a very fast pace by international standards.

Calculation of the cost

In order to measure the potential income of forested land, we use the rainfed land rental rates reported in the 2002 ejido survey. Because ejido land cannot actually be rented, the numbers reported are the farmers' assessments of the land rental rate for a piece of land similar to the one that had been deforested. These rates were observed for those ejidos that experienced deforestation and refer to areas from which they had removed forest between 1994 and 2000. We consider this rate to be a fair estimate of the potential income of the land that is most likely to be deforested, although it is possibly not as accurate for the more remote areas of the ejido.

Because this rental rate was not reported for some ejidos, we use as a measure of the potential income of forested land the value of the rental rate predicted by the regression equation in Table 2. The variables in the equation include all the available physical variables which might affect soil quality, and hence land productivity (altitude and slope), and the yield of maize per hectare (which is only available at the state level). In addition, the distance from the village to the forest (calculated using GIS data) is included to account for the time cost associated with traveling to the land in order to cultivate it, the distance to town (given in the survey) to account for transactions costs in bringing products to market, and the total size of the ejido to give some proxy for land scarcity. The regression was fitted using OLS and values were predicted for those ejidos for which no rental rate was available in the survey. The R-squared value for the regression is .23. As one might have anticipated, both distance measures are negatively correlated with the rental rate, while land at higher altitude is associated with a lower rate. Land in states with higher average maize yield has higher rental rates. The one counterintuitive result is that larger ejidos are correlated with higher rental rates, though this might simply reflect unobserved variables, such as a higher propensity towards cattle-raising in larger ejidos, which would then raise the value of the land. The predicted average rental rate per hectare is $103[4] (sd $70) and the Gini coefficient of the per hectare rate is .37.

Calculation of the environmental benefits index

Ideally, b_j should be expressed in monetary terms. This would require use of a valuation technique for services whose markets fail, or one of the techniques advocated by the authors mentioned in the introduction. For services where markets exist, such as hydrological benefits, values remain highly debated, with estimates ranging from $20/ha (Chomitz et al, 1998) to $188 (Hernández, et al., 2003). Still other studies suggest that a mixture of pasture and forest cover generates even higher hydrological benefits that contiguous forest (Aylward and Tognetti, 2002). Much of this variation is surely due to the fact that hydrological benefits are very site specific. Hesitant to enter into this valuation debate, we have instead established an environmental index based upon both the scale of payments for the existing PES scheme in Mexico and the country's environmental priorities. Mexico's current payment program, which gives higher payments for cloud forests as opposed to forests of other types, is intended to reflect the higher hydrological value of cloud forests. While changing the measure of benefits will alter the distribution of payments, the result that it is more efficient to pay for benefits which are at risk of being lost will remain unaffected.

Mexico's PES program is intended to preserve the hydrological benefits provided by standing forest. We therefore design a simple index which reflects this objective as follows. Forests that are closer to major rivers are given a higher value than forests that do not have this attribute. Because a detailed river map of the country is not available, we used digital elevation models to establish where the highest flow of water across the landscape would be. Around areas of high flow, we calculated a buffer distance of one kilometer as the area whose erosion would most affect water quality and

[4] All monetary values are given in US dollars.

infiltration, and gave higher value to forests in these areas. In addition, we give higher values to those communities located in watersheds which have been classified as over-exploited. Over-exploited watersheds have been identified and mapped by INE, and are those which have had long term withdrawal rates greater than their rates of aquifer recharge.

Finally, given that cloud forest is of particular concern because of its status as an endangered ecosystem in Mexico and is thought to produce a higher value of water services, we give them extra points as well. This scoring system reflects the price differential in the PES program currently implemented in Mexico – payments per hectare for cloud forests are 400 pesos, while for other types of forest they are 300. The current program was designed for payments to reflect the higher environmental value of cloud forest for water conservation. All forest types were defined according to the classification in the 2000 Forest Inventory. Clearly, many of these decisions could be called arbitrary. The index has been designed to demonstrate only one out of many possible configurations of environmental benefits indices, though we believe it to be the most likely. In addition, while the current program is focused on the domestic benefits of watershed preservation, one could certainly imagine a index that included global externalities.

Table 3 describes the values that we use for ranking the environmental benefits provided by different types of forest in different locations. The average benefits per hectare are 30.6 points (sd 5.3) and the Gini coefficient is .11. The simple correlation coefficient between average benefit per hectare and predicted rental rate is small and negative, equal to -.06 . This implies that the benefit to cost ratio falls with the rental value of the land, and hence that the program should enlist a maximum amount of inexpensive land.

5. Empirical results

Payments and participation

To compare the payment schemes, we begin by assuming perfect foresight in predicting deforestation by using the observed deforestation rate between 1993 and 2000. We will relax this assumption in section 6 by using a predictive equation for deforestation in discussing implementation of the optimal scheme. We simulate the three schemes as if they were put into place in 1994 and we are observing the results one year later. The results are reported in Tables 4 and 5. The flat payment ended up being $5 per hectare with the budget from the risk-weighted flexible payments program, *R,* as a constraint. In the program *R*, all of the deforesting ejidos (61% of the sample) are paid in 1994, though the payments are quite unequally distributed, with a Gini coefficient of .81. In the flat payment program, *H*, the participation rate is much higher, at 87 percent, due to the fact that many ejidos without deforestation participate, though we do lose some of the deforesters with potential income higher than the flat payment offer. The distribution of these payments is much more equitable than in the other two programs, with a Gini of .32. In the benefit-maximizing program, *B*, where we use 2/3 the budget of the first program, we have less than 2/3 participation (57%) and a Gini coefficient of 0.77, indicating the high inequality of payment distribution.

Table 5 shows what is gained by programs *R* and *B* in efficiency in exchange for the higher levels of inequality detailed in Table 4. The total number of hectares deforested in the sample between 1994 and 2000 is 22,667, which is the amount enrolled in program *R*. Despite its higher participation, program *H* enrolls less than a third of the total hectares at risk of deforestation, 6,732 hectares, and the amount of environmental benefits per dollar spent, at .08, is also less than a third that of the program *R*. This is due to the fact that it enrolls many ejidos that do not have positive deforestation. The benefit-maximizing program, shown in column three, results in the enrollment of 19,225 hectares, which is nearly all of those at risk, and an efficiency level of .35, four times higher than that of the flat payments scheme.

Table 6 illustrates another measure of efficiency – the dollar amount paid for each hectare at risk of deforestation. Note that this is extremely large for scheme *H* (despite the fact that those with zero deforestation cannot be included since the measure is undefined when there are zero hectares at risk) at $7,610 per hectare and smallest for strategy *B*, which pays $86 per hectare on average. This very high number from the flat payments results from the fact that a high price is paid for hectares that have a very low risk of deforestation. This is effectively a form of leakage of program funds to non-critical forests.

Who gets the payments?

In this section we examine the distribution of both the flat payments program, *H*, and the most efficient payment program, *B,* over different structural and social characteristics of participants. We do not include program *R* here due to the fact that its results are very close to those of *B*, given that they are essentially the same program with and without a constraint. Table 7 shows the distribution of programs *H* and *B* over size and poverty classes. For payments by poverty class, we consider per capita receipts rather than total payments. Poverty class was determined by the percentage of ejido member households predicted to receive Progresa, an educational and health subsidy program targeted at the poor. This prediction was done using household level data. This is calculated under the assumption that payments at the community level will be shared equally between members. Participation in *H* is higher than in *B* in all area classes and relatively constant across classes. For *B*, participation increases across area classes. This is due to the fact that deforestation in larger communities is higher. Efficiency is increasing with area in the flat payments program because as the properties get larger, the flat payments program is more likely to enroll hectares at risk of deforestation. We see an interesting result with regards to equity. Although participation in both programs is higher for the poor than it is for the non-poor, it is relatively greater in program *B* – 63 versus 50% - than it is in the flat payments program – 89 versus 85%.

In addition, the benefit-maximizing program allocates a greater share of the budget to the poor – 61% as opposed to 54 %. The larger share of the budget allocated to poor communities is likely due to the fact that the poor, in general, have larger forest areas (the simple correlation between poverty and forest area is .10). At an individual level, however, we find that payments per capita to the poor, $51, are much lower than to the non-poor, who receive $135 per capita. This is likely a combination of two factors. First, while forests held by poor communities have slightly higher average environmental value (the simple correlation between the two is .05), they have much lower predicted rental rates (the correlation between poverty and predicted rental rate is -.15). In addition, poorer ejidos are also more likely to have more members among which to divide the payments.

6. Implementation with predicted deforestation rate, *I*

In order to implement payment schemes which take deforestation risk into account, it is necessary to use the predicted rather than the actual deforestation rate. We label this scheme *I*. Using the actual deforestation to pay for hectares at risk would induce strategic behavior on the part of ejidos. This section focuses on the application of two predictions of the deforestation rate to the most efficient program. Whatever prediction is chosen, it must be based exclusively on determinants x_e that are truly exogenous to the behavior of the ejido (so that the scheme does not reward bad behavior), i.e., physical endowments of the ejido (area of different types of land, maybe on per capita basis), and structural characteristics such as distance, population, ethnicity, etc. We assume a uniform deforestation rate per ejido (i.e., all categories *j* of forest have the same deforestation rate τ_e), and perform the estimation on the observed sample of ejidos. Although this estimation gives prediction of the expected conditional deforestation rate $\hat{\tau}(x_e)$ in the population of ejidos of characteristic x_e, the actual optimal rate of deforestation of a specific ejido e remains unknown to outsiders: $\hat{\hat{\tau}}_e = \hat{\tau}(x_e) + u_e$, where u_e represents the idiosyncratic shock or behavior of the ejido, drawn from the estimated distribution $N\left(0, \hat{\sigma}^2\right)$.

Armed with this analysis, we simulate the most efficient scheme based on the predicted deforestation rate $\hat{\tau}_e$ as follows: We first rank ejidos by decreasing ratio of environmental benefits over potential income (which is independent of the deforestation rate), as we did above. We then pay the predicted conditional expected deforestation $\hat{\tau}_e F_{ej}$ proportionately to the expected potential income $P_{e,I} = \sum_j c_e (1+\mu) \hat{\tau}_e F_{ej}$ starting with those with the highest ratio until the budget $\overline{P}$ is exhausted.

A specific ejido will accept the scheme if the payment compares favorably to the opportunity cost of its optimal deforestation rate, i.e., if: $P_{e,I} \geq \sum_j c_e \left(\hat{\tau}_e + u_e\right) F_{ej}$ which can also be written: $\hat{\tau}_e + u_e \leq (1+\mu)\hat{\tau}_e$. This shows that if the payment is set at the expected potential income, i.e., $\mu = 0$, all the ejidos with higher deforestation rates than the predicted average will not accept the contract. Conversely, all ejidos with predicted rates lower than the predicted average are compensated for their "good" behavior. By proposing a higher payment, $\mu > 0$, the program faces a trade-off in paying more than necessary for many ejidos but attracting more of them into the scheme. It follows that the optimal value for the payment level μ is determined by the overall optimization program:

$$\begin{aligned} &\max_{P_e} \sum_e \Pr\left[u_e \leq \mu \hat{\tau}_e\right] \sum_j b_j \left(\hat{\tau}_e + E\left(u_e \middle| u_e \leq \mu \hat{\tau}_e\right)\right) F_{ej} \\ &\text{s.t.} \qquad \sum_e \Pr\left[u_e \leq \mu \hat{\tau}_e\right] P_{e,I} \leq \overline{P}. \end{aligned} \tag{3}$$

Two prediction equations

Much of the literature on deforestation uses the pixel, the smallest unit of a satellite image, in order to measure changes in forest cover. There have been a variety of analyses conducted using this approach, including Puri and Griffths (2001), Monroe, Southworth, and Tucker (2002), Godoy and

Contreras (2001), and Vance and Geoghegan (2002). Chomitz and Thomas (2003), Deininger and Minten (1999), and Pfaff (1999) are municipal level studies. Because the unit of decision-making in our case is the ejido, we use as a dependent variable the area deforested in a given ejido over the study period 1994 – 2000.

We present in Table 8 two different prediction equations for deforestation. The first is a parsimonious specification, containing only easily observable, mostly physical variables most of which have become standard in deforestation studies, while the second includes a range of variables associated with deforestation behavior in common property communities (see Alix-Garcia, de Janvry, and Sadoulet, 2005). The former represents a technique suitable for application in program settings. The intention of presenting both options is to see how much targeting precision is lost in omitting variables representing community behavior.

The first estimation includes total ejido area, forest area, forest squared and forest cubed, the average distance to, slope and altitude of the forested area of the ejido, interactions of these terms, a dummy for if the ejido practices forestry or not, and the number of ejido members in 1990. None of these variables are easily altered by community members. Among these variables, the largest impacts on deforestation are through the size of the forest in 1994, the average slope of the forested area, and if the ejido practices forestry or not. Some of the variables which one might expect to be significant here, like the geographical ones, are likely not so due to their correlation with the percentage of total area in forest. The second specification includes, in addition to the physical variables, some characteristics that might influence group behavior, such as the number of people per household with secondary education, average size of individual parcels, the Gini coefficient of the distribution of private parcels, the ratio of member to total population in the ejido, and the predicted proportion of the population receiving Progresa – an educational subsidy program distributed to the poor. The largest impacts come from the Gini coefficient and the predicted proportion of the population receiving Progresa. It is important not to give causal value to these variables, as there are possible endogeneity problems with the proxy for poverty. However, since this regression is being used merely for predictive purposes, issues of endogeneity are of no importance. The second specification shows a small gain in the regression adjusted R-squared over the parsimonious specification – from .38 to .42. This suggests that the second specification has superior predictive power over the first. In general, however, an R-squared of .38 is quite respectable for such a cross-sectional estimation.

Since there is not much gain from expansion of the variable set in equation (2), Table 9 shows the payments in a *B* program calculated using only the parsimonious equation (1) specification. As in the program calculated using actual deforestation rates, the Gini coefficient of payments for the predicted program is considerably higher than that of the flat payments program, which has a value of .32. The efficiency level, 0.15, is considerably lower than that of the most efficient program using the actual deforestation rates, at 0.35, but is still twice as efficient as the flat payments' .08.

This leads us to the question of where the misallocation of payments causing the lower efficiency level occurs. Table 10 shows the characteristics of communities with payments in different error categories. The type II error comes entirely from deforestation rates that are estimated to be positive for ejidos that in reality had no observed deforestation during the period. These communities also have very high benefits and low potential income from deforested land, which means that they ranked quite high on our benefits to cost scale. Communities with type I error have very high deforestation rates (and were under-predicted). In addition, their potential incomes are large relative to the benefits that their land provides.

In sum, the more worrying type I error comes from ejidos with very high potential incomes and very high rates of deforestation. These are also communities with somewhat low environmental benefits per hectare. In avoiding the strategic behavior associated with using observed deforestation rates, we end up with a lower level of environmental benefits per dollar spent, though this is still nearly twice as high as the efficiency level generated by using a flat payments program.

7. Conclusion

The most important contribution of this paper is to empirically demonstrate that including risk into the targeting of environmental services programs can greatly increase their efficiency and to show that this is quite feasible to implement. We illustrate this point by comparing a flat payment scheme to a scheme which takes into account the risk of deforestation. We simulate three programs: a capped flat payment scheme, a payment of potential income for each hectare of forest at risk of deforestation, and, in order to illustrate the optimal manner of dealing with a budget constraint, a program which distributes payments according to the highest benefit/cost ratio and pays the potential income generated by each hectare of forest at risk of deforestation. Comparing these approaches, we find that the most egalitarian approach is to pay a flat rate per hectare per year with a cap on the number of allowable hectares per recipient. This is, however, the least efficient strategy in terms of environmental benefits per dollar spent. The highest efficiency comes from maximizing environmental benefits per dollar spent. The driving force behind these results is the leakage inherent in ignoring deforestation risk in the targeting process – in a program which gives the same payment for any hectare of forest, a high cost is incurred to conserve hectares of forest that were at no risk of being lost in the first place.

When we consider the distribution of payments of the flat payments and benefit-maximizing programs according to characteristics of recipient communities, we find that in the case of the benefit-maximizing program, larger ejidos receive the lion's share of the budget, although they are not always the most efficient in providing environmental services. We also find that poor ejidos have higher participation rates, get a larger proportion of the budget, and provide higher benefits per dollar spent than non-poor ejidos. In the optimal program, payments per member to the poor and indigenous are much lower than to their counterparts, reflecting the fact that environmentally valuable resources per capita are higher among the non-poor. In the flat scheme with a cap, the budget is distributed relatively equally across size and poverty classes, and payments to the poor and non-poor are equal.

Finally, we also address one of the important factors in implementing a scheme which accounts for deforestation risk. In order to avoid strategic behavior, one must use predicted deforestation using non-manipulable variables. We show that there is little advantage in venturing beyond easily observable variables in order to make this prediction. There is of course an efficiency loss in using the prediction as opposed to the actual rate of forest loss, but a program using the predicted deforestation rate is still twice as efficient as a flat payment program.

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10 Tables

Table 1. Distribution of forest ejido universe by region, Mexico

Region	Ejidos*	% of population	Sample	% of sample
Peninsula	745	9.7	39	10.0
Gulf	795	10.4	37	9.5
South	2,152	28.0	110	26.8
Central	2,488	32.4	122	29.6
North	1,499	19.5	99	24.2
Total	7,679	100	407	100

*Data provided by the Instituto Nacional de Ecología

Table 2. Prediction of Rainfed Land Rental Rate
Dependent Variable: Dollars per hectare of land per year

Variable	Coefficient	t-statistic
Average distance from village to forest in km	-48.9	1.7*
Average distance squared	2.1	1.5
Average altitude of forest in meters	-.13	1.3
Average slope of forest in degrees	10.8	1.1
Distance*slope	-.45	.53
Distance* altitude	.02	1.3
Total size in 1000 ha	1.2	3.7**
State level maize yield per ha	68.5	2.2**
Yield*slope	-4.3	1.5
Yield*altitude	-.02	1.3
Distance to nearest town in kilometers	-.17	.88
Constant	237.5	1.5
Observations	91	
R-Squared	.23	

* denotes significance at the 10% level and ** at the 5% level.

Table 3. Constructing an environmental index

Characteristic	Points per hectare
Cloud forest	
Primary	40
Secondary	30
Other types of forest	
Primary	30
Secondary	20
Added to each hectare of above:	
Overexploited watershed	5
Within ½ mile of a river	
Primary	20
Secondary	10

Table 4. Participation and payments in different programs

Payment rule	Flat payments ***H***	Risk-weighted flexible payments ***R***	Benefit-maximizing payments ***B***
Percent of ejidos enrolled	87	61	57
Average payment per participating ejido	$7,341	$10,202	$7,418
Median payment per participating ejido	$7,234	$1,744	$1,586
Gini coefficient of payments over participants	.32	.81	.77

Table 5. Costs and benefits of different payment programs

Payment rule	Flat payments *H*	Risk-weighted flexible payments *R*	Benefit-maximizing payments *B*
Total hectares enrolled	1,022,133	1,836,535	1,534,405
Hectares at risk enrolled	6,732	22,667	19,225
Environmental benefits	216,378	682,643	606,729
Total budget	$2,598,870	$2,550,596	$1,713,509
Efficiency (environmental benefits/potential income)	.08	.27	.35

Table 6: Payments per hectare at risk of deforestation

	Flat payments *H*	Risk-weighted flexible payments *R*	Benefit-maximizing payments *B*
Mean payment per hectare at risk	$7,610	$96	$86
Minimum payment per hectare at risk	$34	$5	$5
Maximum payment per hectare at risk	$654,222	$331	$275

Table 7. Distribution of payments from schemes *H* and *B* over ejido size and poverty classes

Area and Distance classes	Participation rate (%)		Average payment per capita per community		Efficiency (b_j/payment)		Percentage of overall budget	
	H	***B***	***H***	***B***	***H***	***B***	***H***	***B***
Area:								
1st quartile	97	43	$3,216	$1,006	.04	.39	11	2
2nd quartile	91	50	$6,748	$3,371	.04	.29	23	10
3rd quartile	88	67	$9,698	$4,054	.08	.35	33	16
4th quartile	74	71	$11,300	$17,325	.14	.36	32	72
Poverty:								
Non-poor	85	50	$120	$135	.06	.30	46	39
Poor	89	63	$120	$51	.10	.39	54	61

The thresholds for the area quartiles are 1,240, 2,270, and 5,160 hectares. Ejidos are classified as poor if at least 53% of the population is predicted to receive Progresa.

Table 8. Prediction equations for deforestation
Dependent variable: Hectares of forest lost between 1994-2000

Variable	(1)Parsimonious specification	(2) Full specification
Total area of the ejido in hectares	0.01	0.01
	(0.91)	(1.22)
Hectares of forest in 1994	0.09	0.09
	(3.58)**	(3.58)**
Forest squared	-3×10^{-6}	-3×10^{-6}
	(2.95)*	(2.98)**
Forest cubed	3×10^{-11}	3×10^{-11}
	(2.41)*	(2.95)*
Percentage of total area in forest, 1994	-20.1	-18.5
	(2.50)*	(2.25)*
Average distance to forested area in km	-3.4	-9.9
	(0.29)	(0.83)
Average slope of forested area in degrees	-6.9	-8.6
	(0.75)	(0.93)
Average altitude of forested area in meters	-0.09	-0.12
	(1.45)	(1.89)
Average distance*average slope	-1.2	-1.1
	(1.36)	(1.20)
Average distance*average altitude	0.01	0.02
	(1.91)	(1.91)
Ejido practices forestry (dummy variable)	84.7	94.8
	(1.16)	(1.17)
Number of ejidatarios in 1990	-0.31	0.28
	(1.06)	(1.73)
Number of ejidatarios squared	9×10^{-5}	
	(0.81)	
Distance to nearest city in kilometers	-0.30	-0.32
	(0.77)	(0.72)
Average number of people per hh with secondary education		-198.26
		(2.38)*
Average parcel size of ejidatarios in hectares		-1.95
		(1.83)*
Number of ejidatarios*Gini coefficient of private parcels		-1.06
		(2.82)*
Membership ratio*forestry ejido		-39.70
		(0.44)
Ratio of members to total population in ejido		-4.75
		(3.04)**
Gini coefficient of private parcels		-206.9
		(1.53)
Predicted share of population receiving Progresa		-144.2
		(0.40)
Constant	145.34	704.84
	(1.21)	(2.70)**
Observations	395	395
Adjusted R-squared	0.38	0.42

Robust t-statistics in parentheses. * significant at 5% level; ** significant at 1% level

Table 9. Summary of payments and participants in a *B* program using predicted deforestation

Payment rule	**Specification (1)**
Percent of participating ejidos	50
Average payment per participating ejido	$8,744
Median payment per participating ejido	$2,058
Gini coefficient of payments over participants	.77
Total hectares enrolled	1,197,210
Hectares at risk enrolled	7,822
Environmental benefits	265,691
Total budget in dollars	1,757,652
Efficiency (environmental benefits/potential income)	.15
μ	.009

Table 10. Errors in payment distribution result from predictions

Characteristics	**Didn't receive payments but should have (Type I)**	**Received payments and should have**	**Received payments and shouldn't have (Type II)**
Number	121	109	92
Total size in hectares	5,106	10,872	2,647
Hectares of forest, 1993	4,029	9,567	1,678
Average deforestation rate	.031	.010	0
Predicted deforestation rate	.014	.014	.016
Predicted proportion of Progresa recipients	.52	.54	.53
Average environmental benefits per hectare	30.2	34	66
Average potential income per hectare	$105	$66	$72