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Contributed Paper

Using Cost-Effective Targeting to Enhance the Efficiency of Conservation Investments in Payments for Ecosystem Services

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Abstract: *Ecosystem services are being protected and restored worldwide through payments for ecosystem services in which participants are paid to alter their land-management approaches to benefit the environment. The efficiency of such investments depends on the design of the payment scheme. Land features have been used to measure the environmental benefits of and amount of payment for land enrollment in payment for ecosystem services schemes. Household characteristics of program participants, however, may also be important in the targeting of land for enrollment. We used the characteristics of households participating in China's Grain-to-Green program, and features of enrolled land to examine the targeting of land enrollment in that program in Wolong Nature Reserve. We compared levels of environmental benefits that can be obtained through cost-effective targeting of land enrollment for different types of benefits under different payment schemes. The efficiency of investments in a discriminative payment scheme (payments differ according to opportunity costs, i.e., landholders' costs of forgoing alternative uses of land) was substantially higher than in a flat payment scheme (same price paid to all participants). Both optimal targeting and suboptimal targeting of land enrollment for environmental benefits achieved substantially more environmental benefits than random selection of land for enrollment. Our results suggest that cost-effective targeting of land through the use of discriminative conservation payments can substantially improve the efficiency of investments in the Grain-to-Green program and other payment for ecosystem services programs.*

Keywords: discriminative payment, environmental benefits, Grain-to-Green Program, household characteristics, opportunity cost, payments for ecosystem services, Wolong Nature Reserve

Utilización de Selección Rentable para Incrementar la Eficiencia de las Inversiones de Conservación el Pago por Servicios Ecosistémicos

Resumen: *Los servicios ecosistémicos están siendo protegidos y restaurados en todo el mundo mediante el pago por servicios ecosistémicos, en el cual los participantes reciben pagos por alterar sus hábitos de uso del suelo para beneficio del ambiente. La eficiencia de tales inversiones depende del diseño del esquema de pagos. Los atributos del suelo han sido utilizados para medir tanto los beneficios ambientales como la cantidad a pagar por la participación en el esquema de pagos por servicios ecosistémicos. Sin embargo, las características familiares de los participantes en el programa también pueden ser importantes en la selección de tierras a inscribir. Utilizamos las características familiares de los participantes en el programa Grano-por-Verde en China y las características de los suelos para examinar la selección de tierras inscritas en dicho programa en la Reserva Natural Wolong. Comparamos los niveles de beneficios ambientales que se pueden obtener mediante la selección rentable de tierras, bajo diferentes tipos de beneficios y bajo diferentes esquemas de pago. La eficiencia de las inversiones en un esquema de pago diferencial (los pagos difieren de acuerdo con los costos*

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de oportunidad, i.e. los costos por renunciar a usos alternativos del suelo) fue sustancialmente mayor que en un esquema de pago fijo (todos los participantes reciben el mismo pago). Tanto la selección óptima, como la subóptima, de tierras para beneficios ambientales obtuvieron sustancialmente más beneficios ambientales que la selección aleatoria. Nuestros resultados sugieren que la selección rentable de tierras mediante el uso de pagos de conservación diferenciales puede mejorar sustancialmente la eficiencia de las inversiones del programa Grano-por-Verde y de otros programas de pago por servicios ecosistémicos.

Palabras Clave: beneficios ambientales, características familias, costos de oportunidad, pago de servicios ecosistémicos, pago diferencial, programa Grano-por-Verde, Reserva Natural Wolong

Introduction

Conservation programs in which landholders are paid to alter their land-management approaches to achieve environmental benefits have been implemented in many countries (OECD 1997; Wunder 2008). These programs have reduced soil and wind erosion (Osborn et al. 1993), restored desirable attributes of ecosystems (Sierra & Russman 2006), and maintained habitat for native plants and animals (Johnson & Schwartz 1993; McMaster & Davis 2001). We refer to these desired changes or maintenance as environmental benefits. The efficiency of the investment in payment for such environmental benefits, often called payments for ecosystem services (PES), however, depends on the program's design.

To induce landholders to participate in PES programs, incentives should be greater than the cost of forgoing other uses of the land (i.e., opportunity costs). Landholder opportunity costs and the level of environmental benefits a parcel of land offers vary among landholders. In practice, flat payments (all participants paid the same price) and discriminative payments (participants paid different prices according to opportunity costs) have been used in PES programs (Claassen et al. 2008; Pagiola 2008). At first glance, flat payments appear equitable because every participant is paid the same price. Flat payments, however, are not equitable when landholders bear different opportunity costs and their lands supply different levels of environmental benefits (Ferraro 2008). In addition, discriminative payments through which participants are paid their opportunity costs will cost less than flat payments; thus, more environmental benefits are gained for a given investment (Jack et al. 2008).

To maximize environmental benefits, PES programs must be implemented on land that provides the desired environmental benefits with the least cost, which is referred to as cost-effective targeting or optimal targeting (Babcock et al. 1996). In a cost-effective targeting approach, a benefit-to-cost ratio (level of environmental benefits provided:cost) is used to rank plots of land from high to low. The lands with the highest benefit-to-cost ratio are enrolled in the PES program first so that a maximum amount of environmental benefit can be obtained with a fixed budget.

Lands enrolled in PES programs often supply multiple environmental benefits. Cost-effective targeting for one type of environmental benefit, however, usually does not maximize the provision of the other types of environmental benefits under a fixed budget unless the benefits are perfectly and positively correlated (Babcock et al. 1996). Therefore, the targeting approach that is optimal for a given environmental benefit is usually a suboptimal targeting approach for other types of environmental benefits (Babcock et al. 1996; Ferraro 2003). Nevertheless, where different types of environmental benefits are positively correlated, cost-effective targeting for achieving one environmental benefit will increase the level of other types of environmental benefits.

The environmental benefits provided by a particular parcel depend on the biological and physical features of the land and on the landholder's actions. In many cases, however, direct measurement of environmental benefits may be impossible or prohibitively expensive. Other researchers have used site-specific proxies of environmental benefits as measures of environmental benefits of land within PES programs. These proxies include a single biological or physical feature of land parcels (Babcock et al. 1997; Siikamaki & Layton 2007) or combinations of biological and physical features (e.g., Babcock et al. 1997; Ferraro 2004; Alix-Garcia et al. 2008).

Opportunity costs of landholders participating in PES programs are often difficult to measure because they are only known to landholders. Nevertheless, landholder's opportunity costs are often correlated with the location and features of the land and with household characteristics (Cooper & Osborn 1998). Researchers have estimated the value of a parcel on the basis of its biological and physical features (Ferraro 2003; Khanna et al. 2003; Alix-Garcia et al. 2008) as proxies for the opportunity costs of landholders. Even though households are often the basic unit on which land-use decisions are based (Liu et al. 2003), household characteristics of landholders usually have not been included in determination of opportunity costs (for exceptions see Naidoo et al. 2006; Siikamaki & Layton 2007). Despite these measurement difficulties, targeting in PES programs can substantially improve the efficiency of investments, especially when the level of environmental benefits and the costs to obtain the benefits are heterogeneous across the parcels within a landscape (Osborn et al. 1993; Babcock et al. 1996, 1997; Chan et al. 2006).

In actual implementation of PES programs, it may not be feasible to collect the information on households and land parcels needed to determine opportunity costs for cost-effectively targeting of lands to enroll. Another approach to enrolling lands in PES programs is to use competitive auctions in which potential enrollees submit bids (the payment they require) to provide environmental benefits. The cost-revelation mechanism in most competitive bidding processes makes auctions a powerful tool for inducing potential participants of PES programs to submit bids equal to their opportunity costs (Latacz-Lohmann & Van der Hamsvoort 1997).

China is implementing several large-scale conservation programs (Liu et al. 2008). Among these is the Grain-to-Green program (GTGP), which was implemented in 1999 and is the largest PES program in the developing world. Participating farmers receive payments in grain or cash for a maximum of 8 years to convert cropland to forest or grassland. Because the main objective of GTGP is to reduce soil erosion by increasing natural land cover (forest and grassland), the slope of enrolled land should be above 15° in northwestern China and above 25° elsewhere. Although croplands with slopes above the thresholds receive priority for enrollment, some croplands with slopes lower than the thresholds have been enrolled (Uchida et al. 2005). By the end of 2006, GTGP had converted about 9 million ha of cropland into forest and grassland (Liu et al. 2008). (In the United States, about 14.5 million ha of cropland are enrolled in a similar program, the Conservation Reserve Program [Claassen et al. 2008].) In addition to its main objective of restoring natural vegetation cover, GTGP aims to generate other environmental benefits, such as restoration of habitat for certain animals and plants (Zuo 2002).

The GTGP has only two payment levels nationwide that operate as flat payments within each region. On an annual basis payments are 2250 kg of grain or ¥3450 per ha of enrolled cropland in the upper reaches of the Yangtze River basin and 1500 kg of grain or ¥2400 per ha in the middle-upper reaches of the Yellow River basin. The different regional payment levels are used in part to account for the regional differences in opportunity costs of landholders because land in the upper reaches of the Yangtze River basin is usually more productive than in the middle-upper reaches of the Yellow River basin (Uchida et al. 2005). The payments for most participating farmers exceed cultivation income from the enrolled land (Uchida et al. 2009), which indicates similar environmental benefits may be obtained at lower cost. By the end of 2005, more than 90 billion yuan had been invested in GTGP (Liu et al. 2008). When contracts started expiring in 2008, they were extended for up to 8 years. In the future the program's budget is likely to be reduced (Liu et al. 2008). Given its large scale and heterogeneities in opportunity costs of landholders and environmental benefits, the cost-effectiveness of GTGP payments may be improved greatly if payments are made to landholders whose lands can provide environmental benefits at the lowest cost (i.e., cost-effective targeting of lands to be enrolled). We examined the GTGP in China's Wolong Nature Reserve to determine the efficiency of investments made through cost-effective targeting using flat and discriminative payments to landholders. We used features of specific parcels as proxies of environmental benefits and physical features of the parcels and household characteristics of landholders to estimate the opportunity costs of participating in GTGP. The results of our study can be used to maintain the environmental benefits from GTGP after the expiration of current contracts with a reduced budget.

Methods

Study Area

Wolong Nature Reserve (Fig. 1) is located in China's southwestern Sichuan province. It provides habitat for about 10% of Earth's wild giant pandas (*Ailuropoda melanoleuca*) and for 6000 other species of plants and animals (Liu et al. 2007). The reserve is also home to about 4550 human residents in about 1200 households distributed between 2 townships (Wolong and Gengda). People in the reserve engage in economic activities such as farming, fuelwood collection, road construction, and supporting tourism. Much of the original forest cover has been removed through these activities, which has resulted in decreases in habitat quality for many species in the reserve (An et al. 2005; Viña et al. 2007). In Wolong Nature Reserve, GTGP enrollment began in 2000, and additional contracts were signed in 2001 and 2003 (Chen et al. 2009*a*). The criterion for land in the reserve to be enrolled in GTGP is slope $>25°$, although some cropland with slopes $<25°$ was also enrolled (Chen et al. 2009*b*). Landholders who convert part or all of their cropland to forest and maintain forest cover (there were no conversions to grassland in Wolong Nature Reserve) receive an annual payment of ¥3450/ha for 8 years.

Modeling Strategy

To study cost-effectiveness of alternative GTGP targeting and payment schemes, we modeled enrollment in and environmental benefits from GTGP in Wolong Nature Reserve. We determined the locations, environmental benefits, and opportunity costs for all GTGP plots in the reserve. Because we did not know GTGP plot locations of all households, we distributed all GTGP plots across the landscape through stochastic simulations and then calculated environmental benefits provided by these plots. We then modeled the conversion to croplands of

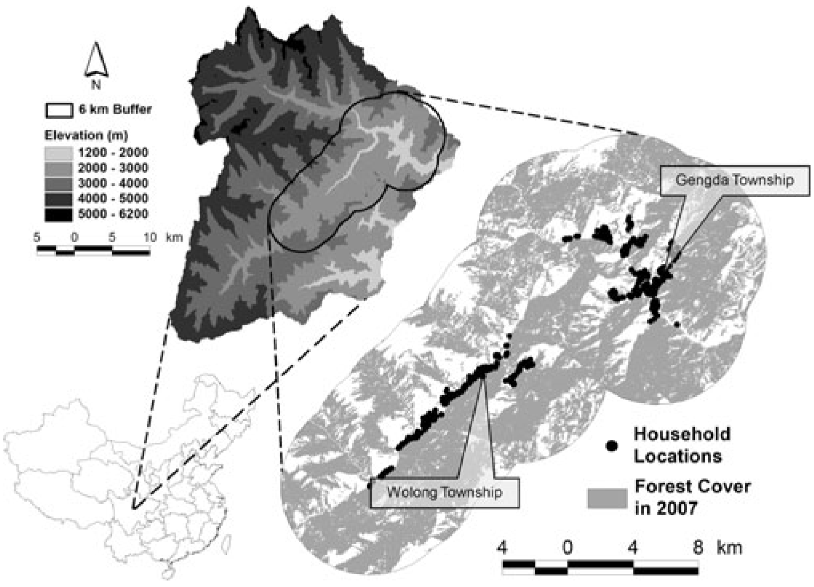

Figure 1. Locations and elevations of Wolong Nature Reserve, China, and households in the reserve.

GTGP plots that were not reenrolled in the program after cessation of payments and reenrollment of plots in the program. We used these models to identify the enrollment probabilities and opportunity costs for each GTGP plot. We modeled the environmental benefits provided by the enrolled GTGP plots under different conservation budgets and compared cost-effectiveness among the different targeting approaches and payment schemes.

Household Survey

We interviewed heads of households in Wolong Nature Reserve in the summer of 2006. We used the government's household registration list of 2006 to randomly select 321 of the 1200 households for interviews. Of those 321, 304 (95%) completed an interview. For each plot enrolled in GTGP, we collected information on the landholder's land-use plans after expiration of their GTGP contact (Supporting Information). Surveyed landholders planned to convert 166 (22.6%) of their 735 GTGP plots to crop production after GTGP payments ceased (Chen et al. 2009*a*). Respondents who planned to convert at least some of their GTGP plots to crop production after their payments ceased were further questioned about the potential for reenrollment of their GTGP plots under alternative conservation programs with different payment levels. Varying payment prices across scenarios and respondents allowed us to statistically model reenrollment as a function of payments, thus to identify opportunity costs of reenrollment.

GTGP Land Identification

For all households in the reserve, we obtained information on characteristics such as household size and age and gender of the household head from the local government's 2006 household registration list. The geographic location of each household in the reserve was recorded in 2006 with global positioning system (GPS) receivers. Government data for the reserve showed that 2470 plots (total of 367.5 ha) belonging to 969 households were enrolled in GTGP in 2003.

Although information on the number of plots each household had enrolled in the program and the area of each plot was available, information on the geographic location of the plots was not available. We recorded the locations of 735 plots enrolled in GTGP by the 304 households we interviewed. On the basis of the locations of these 735 plots, Landsat Thematic Mapper imagery, and topographic data (elevation, slope, and aspect), we developed a map of the probability that each grid cell (i.e., pixel) was enrolled in GTGP (Fig. 2; Supporting Information). Because all 735 plots enrolled by the

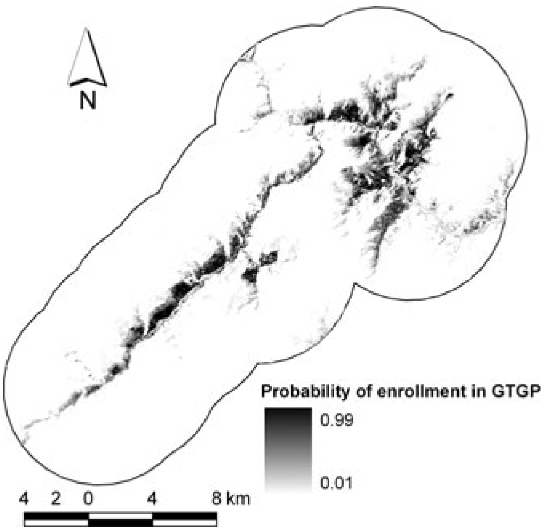

Figure 2. Probability of land being enrolled in the Grain-to-Green program.

304 households interviewed were within 6 km of their corresponding households, we assigned zero probability to having a plot outside the 6-km buffer around the household locations (Supporting Information). We then stochastically distributed all 2470 GTGP plots across the landscape on the basis of the GTGP probability map and the probability distribution of distances between the 735 GTGP plots and their corresponding households (Supporting Information).

Quantification of Environmental Benefits

To examine the different targeting approaches and payment schemes for GTGP, we constructed three possible indices of environmental benefits. Because slope was the only available measure of the reduction of soil erosion through GTGP (Uchida et al. 2005), we used plot-specific slope (measured by the mean slope of pixels in the plot) as a proxy for the environmental benefit of reduction in soil erosion. The soil-benefit index is the square of the standardized (Ferraro 2004) slope of the plots

$$\text{soil-benefit index}_i = \left(\frac{\text{slope}_i - \text{slope}_{\min}}{\text{slope}_{\max} - \text{slope}_{\min}}\right)^2, \qquad (1)$$

where slope_i is the slope of a GTGP plot and $\text{slope}_{\min}$ and $\text{slope}_{\max}$ are the minimum and maximum slopes among all GTGP plots, respectively. This index measures the steepness of a plot relative to the minimum and maximum slopes among all GTGP plots in the reserve. The higher the soil-benefit index of the *i*th plot (soil-benefit index_i), the greater the probability the *i*th plot will have less soil erosion if enrolled in the PES scheme than if used to grow crops. Because land with steeper slopes was given priority for enrollment in GTGP, we used the square of the standardized slope to place more weight on plots with steeper slopes.

Besides reducing soil erosion, GTGP also aims to restore habitat for many plant and animal species. Distance to patches of habitat that existed prior to PES programs has been used as a measure of habitat quality (Babcock et al. 1996; With et al. 1997). Nevertheless, distance-based proxies of habitat quality do not represent all the factors important in determining habitat quality. We used the distance between GTGP plots and the nearest patch of natural forest as a measure of the habitat quality of the GTGP plot. Using protocols described in Viña et al. (2007), we determined the distribution of natural forest (Fig. 1) in the reserve by classifying remotely sensed imagery acquired on 18 September 2007. The habitat-benefit index is

$$\text{habitat-benefit index}_i = \left(1 - \frac{\text{dist}_i - \text{dist}_{\min}}{\text{dist}_{\max} - \text{dist}_{\min}}\right)^2, \qquad (2)$$

where dist_i is the distance between a GTGP plot and the nearest natural forest patch, $\text{dist}_{\min}$ and $\text{dist}_{\max}$ are the minimum and maximum distances to the nearest natural forest patches among all GTGP plots, respectively. Here we used a subtraction from unity so that a higher index value would correspond to a smaller distance to the nearest forest patch. Therefore, the higher the habitat-benefit index of the *i*th plot (habitat-benefit index_i), the higher the habitat quality the *i*th plot is presumed to have for certain animals and plants. As with the soil-benefit index, we used the square of the standardized distance to place more weight on those plots that were closer to patches of natural forest.

We measured the amount of each type of environmental benefit of a plot by multiplying the benefit index by the area of the plot. For comparison purposes, we also measured the amount of land area enrolled in the PES program, defined as land benefit, when we examined the effectiveness of the different approaches to targeting environmental benefits and of the different payment schemes.

Opportunity–Cost Estimation

Given that GTGP plots were still under contract when our data were collected, we used landholders' plans for their GTGP plots after their contracts expired to model the probability of landholder reenrollment in GTGP. For those plots for which there were no plans to convert the land to crops after the contract expired, we assumed the plots would be reenrolled under any positive payment for participation. For GTGP plots landholders planned to convert, there was a probability that the plot would be reenrolled if any positive payments were offered. Thus, the probability of a GTGP plot being reenrolled is

$$\begin{aligned} P(\text{reenroll}_j) = 1 &- P(\text{convert}_j) \\ &+ P(\text{convert}_j) * P(\text{enroll}_j \\ &|\text{pay} > 0, \text{convert}), \end{aligned} \qquad (3)$$

where $P(\text{convert}_j)$ is the probability of the *j*th GTGP plot being converted to crop production after contract expiration, $1 - P(\text{convert}_j)$ is the probability the *j*th GTGP plot will not be converted to crop production after contract expiration (and thus the plot will be reenrolled at any positive payment), and $P(\text{reenroll}_j\,|\text{pay} > 0, \text{convert})$ is the probability of reenrolling the *j*th GTGP plot under a new payment program for plots that will be converted to crop production after contract expiration, which must then be weighted by the probability that the plot will be converted, $P(\text{convert}_j)$.

In logistic-regression models we used proposed conservation payments (Supporting Information), features of GTGP plots, and household characteristics to explain the probability of a GTGP plot being reenrolled (Eq. 3). We corrected for dependencies among plots of the same landholder and among responses to different proposed alternative payments for the same plot with Huber's variance correction (Wooldridge 2002). We applied these models to all GTGP plots in the reserve and calculated the probability of each GTGP plot being reenrolled ($P(\text{reenroll}_j)$ in Eq. 3). We determined the per hectare opportunity cost of each plot with a Bernoulli trial, which determined reenrollment of plots as a function of the payment. The rate parameter of the Bernoulli distribution was $P(\text{reenroll}_j)$, and we estimated it for different payment amounts (Cooper & Osborn 1998). The per hectare opportunity cost of a plot was the payment level at or above which the plot would be enrolled. The opportunity cost of a plot was the per hectare opportunity cost of the plot multiplied by its area.

Environmental Benefits Targeting Approaches

For each of the three types of environmental benefits, we examined the amount of that environmental benefit that could be obtained with cost-effective targeting of the lands to enroll in the PES program. We also illustrated how much of each type of environmental benefit would be obtained had one of the other two types of benefits been the target of the PES program (i.e., suboptimal targeting). In addition, we examined targeting of flat and discriminative payment schemes. We conducted the initial analysis only on those GTGP plots that would be converted to crop production after contract expiration. Under the discriminative payment scheme, we determined the cost-effective enrollment of plots for each type of environmental benefit by ranking all GTGP plots from high to low according to the benefit that could be obtained for each unit of cost (i.e., ratio of benefit-to-cost) and enrolling plots with the highest benefit-to-cost ratio first. For the land–benefit maximization approach, where the goal is to maximize the area of land enrolled, we based GTGP plot enrollment on per hectare cost; thus, less expensive GTGP plots had enrollment priority. In addition to determining cost-effective targeting for each type of environmental benefit, we also calculated the amount of each environmental benefit obtained and the amount of land enrolled in GTGP under suboptimal targeting (i.e., when plot benefit-to-cost ratios are ranked on the basis of the nontargeted environmental benefits). For instance, maximizing the amount of land enrolled is the optimal approach for land acquisition, but it is usually suboptimal for acquiring either of the other environmental benefits. Maximization of soil benefits, however, is the optimal approach to achieve soil benefits, but it is suboptimal for improving habitat quality for some species and for land acquisition.

To understand the relation between each environmental benefit and expenditure, we calculated the total level of an environmental benefit that can be obtained within a budget that varied from zero to the cost of obtaining all the environmental benefits possible. Because our spatial distribution of GTGP plots and enrollment decision were stochastic processes, we calculated the mean values of environmental benefits from 300 simulations for each targeting approach to facilitate relatively robust relations between environmental benefits and expenditure. We also drew a 45° line (Babcock et al. 1996) in each of the benefit-budget planes to show the amount of environmental benefit that could be obtained through random selection of plots constrained within a particular budget.

In addition to the discriminative payment scheme, we explored the environmental benefits obtained through a flat payment scheme. Under the flat payment scheme, all plots with per hectare opportunity costs less than or equal to the per hectare payment were enrolled. When all landholders are paid the same flat price for their plots, each increase in the number of plots enrolled requires that a higher per hectare payment be made to all plots, not just to the plots with higher opportunity costs. Thus, all plots that would have enrolled at a lower payment level (because their opportunity costs were lower) received a surplus equal to the difference between their opportunity costs and the amount of the flat payment. The magnitude of this surplus defined the difference in costs between discriminative and flat payment schemes.

Results

Effects of Household Characteristics and Plot Features

Household size had significant positive effects on the probability of conversion of a GTGP plot to cropland (Table 1). The more land the household had enrolled in GTGP, the less likely the household planned to convert any of the plots to agriculture. In addition, households in Gengda were less likely to have plans to convert plots than households in Wolong.

The higher the payment the more likely landholders were to participate in GTGP (Table 2). Households with more members were less likely to reenroll their plots. Probability of reenrolling increased as age of household head and area of cropland increased. The distance between plots and the household reduced the probability of reenrollment, perhaps because distance was correlated with some unmeasured variables such as the household's social status.

Cost-Effective Targeting of Land for Environmental Benefits

Our simulations showed that about 78% of GTGP land in the reserve would not be converted to agricultural uses even after the expiration of contracts. The approach that optimized soil benefits (i.e., cost-effective targeting for soil benefits) obtained 82% of the soil benefits when the budget for payments was ¥100,000 and 97% of the benefits when the budget was ¥200,000 (Fig. 3a). Cost-effective targeting for habitat benefits obtained 81% of the habitat benefits (Fig. 3b) when the budget for payments was ¥100,000, whereas cost-effective targeting for land

Table 1. Pooled logit estimation of conversion of Grain-to-Green program plots to agriculture after contract expiration.[a]

Independent variables	*Description*	*Parameters*[b] *(robust SE)*	*Marginal effects*
Household size	no. of people in the household	0.250* (0.103)	0.039
Cropland	cropland of the household (ha)	−0.963 (1.022)	−0.151
GTGP land	land enrolled in GTGP (ha)	−1.734** (0.633)	−0.273
Age of household head	years	−0.003 (0.012)	−0.001
Gender of household head	1, female; 0, male	0.400 (0.376)	0.069
Township	1, Gengda township; 0, Wolong township	−1.182* (0.515)	−0.199
Area	ha	0.015 (1.018)	0.002
Slope	degree	−0.004 (0.016)	−0.001
Elevation	100 m (asl)	−0.033 (0.104)	−0.005
Distance	100 m	−0.050 (0.030)	−0.008
Constant		0.396 (2.346)	
χ^2		44.41***	

[a] P*(convert$_j$) in Eq. 3; number of plots 735.*

[b] *Significance:* *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$.

benefits obtained 75% of the land benefits (Fig. 3c) when the budget was ¥100,000.

Even though cost-effective targeting achieved more of the targeted environmental benefit for any budget amount than when suboptimal targeting was used, suboptimal approaches were far superior to random selection of plots. In all cases, differences in the amount of environmental benefits obtained between optimal and suboptimal targeting approaches were much smaller than differences between any of the targeting approaches and random selection of plots. When the budget for payments was ¥100,000 (Fig. 3a), cost-effective targeting for soil benefits obtained 82% of the soil benefits compared with 76% and 69% of the soil benefit from the two suboptimal approaches, but only 29% of the soil benefit was obtained when plots were randomly selected for enrollment (45° line).

Table 2. Pooled logit estimation of reenrollment of Grain-to-Green program plots after expiration of current contract.[a]

Independent variables	*Parameters*[b] *(robust SE)*	*Marginal effects*
Ln(payment in yuan)	1.816*** (0.300)	0.453
Household size	−0.372** (0.141)	−0.093
Cropland	3.668** (1.169)	0.914
GTGP land	0.340 (0.839)	0.085
Age of household head	0.034** (0.013)	0.008
Gender of household head	−0.330 (0.469)	−0.082
Township	0.102 (0.521)	0.025
Area	0.994 (1.203)	0.248
Slope	0.016 (0.020)	0.004
Elevation	−0.003 (0.134)	−0.001
Distance	−0.096* (0.041)	−0.024
Constant	−9.985*** (3.071)	
χ^2	59.83***	

[a] $P(\text{reenroll}_j \mid \text{pay} > 0, \text{reconvert})$ *in Eq. 3; observations 498; number of plots 166.*

[b] *Significance:* *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$.

The amount of environmental benefits obtained with discriminative payments and flat payments were quite different. It costs ¥92,000 with discriminative payments to obtain 80% of soil benefits (Fig. 3a). To obtain the same amount of soil benefit with flat payments (Fig. 3d), it costs ¥298,000. The difference between the cost of discriminative payments and the cost of flat payments increased as the percentage of environmental benefits increased. For instance, in terms of land acquisition, to obtain 30%, 60%, or 90% of the land with flat payments would cost ¥29,000, ¥128,000, and ¥585,000, which is about 1.7, 2.1, and 3.4 times the cost of discriminate payments, respectively.

These differences demonstrate how efficiency of investments can be improved by switching from the most cost-effective flat payment approach to the most cost-effective discriminative payment approach. Results presented in the graphs illustrate the effectiveness of targeting specific levels of benefit and assume that no payments would be made to landholders who did not plan to convert lands to crop production upon contract expiration. As such, even flat payments are to a small degree discriminative payments. When we included in the payment scheme the GTGP plots that would not be converted to crop production after contacts expired, the efficiency of the payments improved by more than 10 times when we switched from flat payments to discriminative payments.

Discussion

Substantially greater environmental benefits were obtained when lands were optimally or suboptimally targeted for enrollment than when enrollment of land was random. When suboptimal targeting approaches are used in PES schemes, the efficiency of the program depends on correlations among the types of environmental

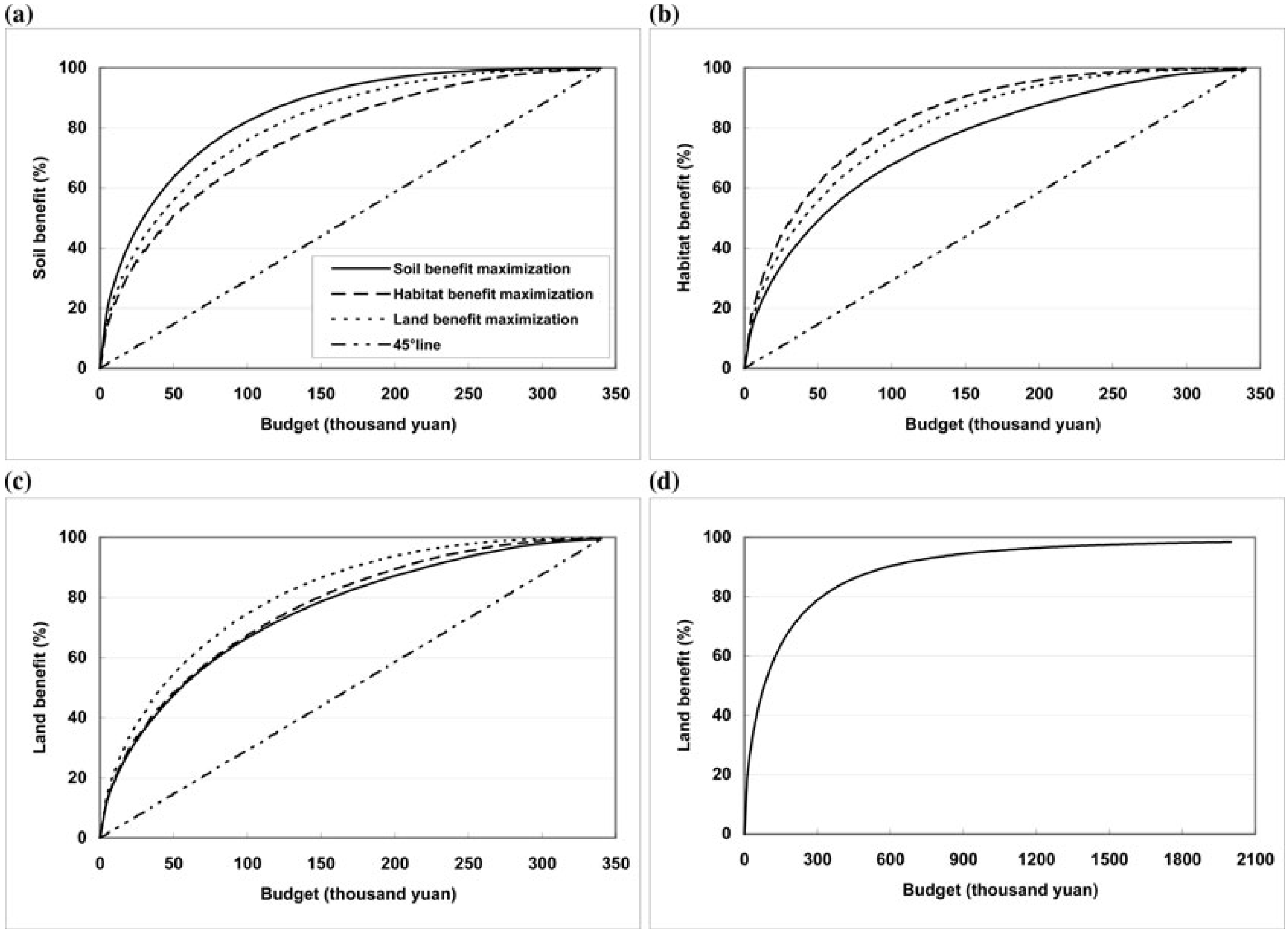

Figure 3. Percentage of environmental benefits obtained with different benefit targets and budgets through (a, b, c) a, discriminative payment scheme, and (d) a flat payment scheme. In the flat payment scheme, only the land-benefit (amount of land area enrolled in the payment for ecosystem services PES program) curve is shown because the curves for soil benefits and habitat benefits are almost identical to the land-benefit curve.

benefits (Babcock et al. 1997). When different environmental benefits of plots are highly and positively correlated, as in our case, similar amounts of environmental benefits can be obtained with suboptimal targeting as can be obtained with cost-effective targeting. More generally, however, targeting the desired environmental benefit can be critical to achieving conservation objectives if the environmental benefits of plots are not highly and positively correlated.

The differences in cost-effectiveness between the payment schemes was substantially larger than the differences among environmental benefit targets. In all cases, discriminative payments were more efficient (up to 10 times) than flat payments. The reason for the difference is that flat payments pay all enrollees the same price regardless of opportunity costs.

Household characteristics were also significant determinants of opportunity costs of landholders participating in GTGP. For instance, a plot that has little agricultural value for a household with a small labor supply can be much more valuable for a household with a larger labor supply. In addition, we found substantial regional differences in landholders' willingness to continue participating in GTGP. One of the main differences between the two townships in our study was that Gengda was closer to more urbanized regions outside the reserve. Thus, PES programs are more likely to achieve their objectives cost-effectively if household characteristics and regional differences, as well as biological and physical features, are incorporated in the planning of PES programs, especially in areas without robust land markets. Other household characteristics (e.g., off-farm income) were also significant determinants of opportunity costs (Chen et al. 2009*b*), but were not included in this study because such information was not available for all households in the reserve.

Opportunity costs of landholders are typically private information that is not available to the public, which results in an information gap between landholders and conservation practitioners (Ferraro 2008). Competitive auctions can reduce this information gap substantially (Latacz-Lohmann & Van der Hamsvoort 1997). Moreover, competitive auctions have been applied successfully in some PES programs and have improved the efficiency of conservation investments (Kirwan et al. 2005; Claassen et al. 2008; Jack et al. 2009). Cost-effective targeting for environmental benefits coupled with competitive auctions could greatly improve the efficiency of investments in PES programs, especially in programs, such as GTGP, that are relatively large and have substantial heterogeneities in opportunity costs and environmental benefits. Competitive auctions and cost-effective targeting may increase transaction costs of PES programs, but our results suggest that the improved efficiency from cost-effective targeting will far outweigh likely increases in transaction costs in GTGP. The growing demand for conservation resources globally (Ferraro 2008; Jack et al. 2008) makes it increasingly important to improve the efficiency of investments in PES and other conservation programs.

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Supporting Information

Additional methods on household survey and GTGP land identification (Appendix S1) are available as part of the online article. The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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