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Targeting REDD+: An Empirical Analysis of Carbon Sequestration in Indonesia

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Summary. — The implementation of REDD+ requires knowledge of the willingness to accept land use change contracts and its application over large areas. This paper uses primary data from Indonesia to contrast two approaches to the elicitation of the supply curve for carbon: an auction and an analysis of opportunity costs. The analysis shows that there are important differences between the two approaches for a wide range of prices. An analysis of bidding behavior shows that location and individual preferences (time and risk preferences), but not opportunity costs, play a significant role in this decision. The implications for targeting are discussed.
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1. INTRODUCTION

The economic consequences of climate change, and the possible mitigation and adaptation policies, are the focus of a wide debate, that was recently summarized in World Bank (2009). From this debate, there is a growing consensus to include Reducing Emissions from Deforestation and Degradation (REDD+) as a mitigation strategy, both due to the perceived low cost of using forests to sequester carbon (Stern, 2006; Eliasch, 2008) and the relative importance of deforestation as a major source of greenhouse gas emission, accounting for approximately 12% of global emissions (Corbera, Estrada, & Brown, 2010).

This emerging consensus fuels an increased interest in the definition of the actions that can be funded under this program, in particular the possibility of inclusion of afforestation and reforestation activities (the "+" in REDD+).[1] As evidence of the interest in these type of actions, it is worth mentioning that they are proposed as eligible for funding in most of the proposals put forward by both governments and NGOs regarding REDD+ (see, for example Parker, Mitchell, & Mardas, 2009).[2]

Because reforestation or afforestation projects are to be established on cleared land with some recognized property rights, their inclusion as part of REDD+ would address one difficulty with the practical implementation of this program: the fact that, in many forests throughout the developing world, there are conflicting local and governmental claims over the same forest with the consequent difficulty in clearly defining and enforcing carbon sequestration contracts (Wunder, Engel, & Pagiola, 2008).[3] The clarification of who should be paid for carbon sequestration (the landowner) under such actions comes at the cost of raising the potential importance of asymmetric information in determining how much should be paid. Landowners will have a private valuation of the reforestation project, known solely by him/her, and no incentive to reveal it to a potential buyer of such goods. Instead they will be interested in maximizing the amount of information rents that can be extracted from the uniformed buyer (Ferraro, 2008; Salanie, 1997). Problems of asymmetric information are not exclusive of REDD+ and generally plague any program that relies on the voluntary participation of beneficiaries, as shown by the extensive literature on targeting (see, for example Coady, Grosh, & Hoddinott, 2004; Ravallion, 2009).[4]

The targeting of REDD+, that is, the identification of how much should be paid to whom in order to encourage program participation while minimizing the costs of carbon sequestration, has been addressed in two ways. Most of the early work estimates the opportunity cost of land use change.[5] In essence, this approach assumes that reservation prices are highly correlated with observable behavior, which can then be used to target the program—or, in other words, that asymmetric information is not important. Estimates of opportunity costs rely on important conceptual assumptions (chiefly among them, the assumption of complete markets), that may not be easily met in developing countries where most of the deforestation occurs (see, for example, White & Minang, 2011; Gregersen *et al.*, 2010, for a discussion).

One alternative is to use mechanisms that create the incentive for individuals to reveal their private information (or reserve price), such as auctions. Vickrey (1961) showed that in a second price auction, truth-telling is a dominant strategy: in the context of a reverse (procurement) auction, the lowest bidder wins the contract but is paid the value submitted by the second-lowest bidder. Any bidder will then have to weigh the value of the payment requested (a positive function of the bid), against the probability of winning the contract (a decreasing function of the bid). Conversely, the auction also acts as an incentive to not underbid, as this would have negative implications on expected future profits. Additionally, a budget constraint combined with a sealed bid mechanism makes undercutting other bidders (while bidding at least the reserve price) the (weakly) dominant strategy, eliminating the possibility of strategic collusion. See Lusk and Shogren (2007) for a lengthier discussion.

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In developing countries, auctions have been used in the design and implementation of afforestation contracts in Vietnam (The & Ngoc, 2008) and Malawi (Jack, 2013) and of contracts for soil conservation in Sumatra, Indonesia (Jack, Leimona, & Ferraro, 2009). Ajayi, Jack, and Leimona (2012) provides a discussion of some of the lessons learned with these experiences. [6]

Despite their theoretical advantages and the growing experience with their use in the field, auctions are time consuming and expensive to implement, raising questions about the feasibility of basing the implementation of REDD+ on its generalized use. If the willingness to accept such contracts, as elicited through an auction, does not differ significantly from the values obtained through simpler approaches, such as those based on the estimation of opportunity costs (in particular if they can be approximated by easily available secondary data, as in the "minimum data" approach suggested by Antle & Valdivia (2006) and Antle, Diagana, Stoorvogel, & Valdivia (2010)), the use of the latter could be justified by their relatively lower cost.

We contribute to this discussion by comparing these two approaches using data from two locations in Central Sumatra. Through a detailed household survey, that paid special attention to the collection of information on the costs and returns associated with current land use (namely, rubber monoculture), we are able to estimate the opportunity costs of any change in land use, which can be compared with household decisions in an experimental auction that was designed to directly elicit willingness to accept land use change contracts. The remaining sections of this paper proceed as follows. The next section presents the data we use and is followed, in Section 3 by an analysis of the supply curve elicited through the different approaches. Although average values of bids and estimates opportunity costs are not statistically different, the supply curves associated with each approach differ for a wide range of prices.

In Section 4 we analyze the determinants of bidding behavior. This analysis further confirms the lack of relation between the estimates of opportunity costs and bids, and suggests that only spatial heterogeneity and behavioral preferences toward risk and time play a significant role in explaining these decisions. We conclude in Section 5 with a discussion of the implications of this work for the targeting of the REDD+ program. In particular, we suggest that, if the importance of unobservable preferences is confirmed in other settings, auctions may be cost-effective ways of implementing REDD+, given that they are a mechanism that accounts directly for such preferences (through bids), providing a way for low-cost bidders to self-select into the program.

2. CONTEXT AND DATA

The data used in this article were collected by the first author in Senamat Ulu and Tebing Tinggi, two villages in the Province of Jambi, Central Sumatra, Indonesia. The two villages were chosen due to their location in areas where local farmers have been encroaching into the native forest, with large and small tracts of forest replaced by palm oil, coffee and, particularly, monoculture rubber plantation. The reduction in carbon storage due to these changes in land use is important: native forest is estimated to store approximately 300 tonnes of carbon per hectare, more than six times the amount stored by rubber plantations (Swallow *et al.*, 2007). [7] However, there are differences between the two sites, with one of them (Tebing Tinggi) located 50 km closer to the regional center (Muara Bungo) than the other. We expected that difference, in a context of high transportation costs such as Central Sumatra, to have profound consequences for livelihood choices and, consequently, for the potential interest in a REDD+ scheme.

The data, collected with the objective of understanding the willingness to accept contracts that promote reforestation, fall into three categories: socioeconomic variables (collected through a survey of household heads), preferences toward risk and time (collected through artefactual field experiments, in the classification of Harrison & List (2004)), and willingness to accept for reforestation contracts (collected through an experimental auction).

Table 1 presents some descriptive statistics of the variables for which we collected information, both with respect to household and household heads (namely assets and economic activities, but also behavioral preferences) and the rubber plots that were brought to the auction (paying particular attention to costs and returns, but also including the bid submitted at the auction). Given the likely differences between the two sites, these data are presented first for the entire sample and then by village. As shown in the last two columns, there are not many statistically significant differences between the two villages—the exception being the higher prevalence of formal rights to land in Tebing Tinggi (p-value = 0.03). This is confirmed by a Hotelling T^2 tests of equality of joint distribution of the variables in each panel (Household variables: T^2=15.81, $p > F_{(11,49)} = 0.32$; Auctioned plots (excluding bids): T^2=22.61, $p > F_{(13,48)} = 0.20$). It seems then that, with the exception of distance from the closest regional center, there are not many important differences between these two locations.

It is possible, with the information collected through the household survey, to estimate the profits of rubber monoculture (as this is the use of the plots brought to the experimental auction). Profits were calculated by subtracting all intermediate input costs (seedlings, fertilizer, and pesticides) and labor costs (including costs with both hired and household labor, valued at the local wage rate of 30,000 IDR/day) from revenues. The distribution of the estimated profits of rubber monoculture (in US$/ha) is presented in Figure 1. [8] As shown in Table 1, there are differences between the two villages, with profits in Tebing Tinggi being 38% higher than in Senamat Ulu, but this difference is not statistically significant (p-value = 0.45).

Household heads were also asked to participate in an artefactual field experiment designed to elicit time and risk preferences. The risk preference experiment involved a choice between lotteries with different expected payoffs and different variances, as in the approach pioneered by Holt and Laury (2002). Varying numbers of red and blue tickets were combined in a lottery, and associated with different payoffs depending on which option the individual selected for that round, as shown in Table 2. These combinations were designed so that risk neutral individuals would switch between option A and option B at the fifth choice. In order to minimize the possibility that the choices would not correspond to their preferences, each participant was informed that one of the choices would be randomly selected *ex post* to determine the amount of winnings each individual would receive from the game. The expected payoff was IDR 20,000 (or 2/3 of the local daily rural wage).

The degree of risk aversion was then estimated by observing when (if ever) did the respondents change their selection from option A to option B and counting the associated number of safe choices, where a safe choice is defined as one in which the expected value of the option chosen was greater than the expected value of the alternative option. The distribution of

Table 1. *Summary statistics.*

Variable	Description/Unit	All		SU		TT		H_0: SU = TT	
		Mean	SD	Mean	SD	Mean	SD	t	*p*-value
Household variables									
Tebing Tinggi	= 1 if Tebing Tinggi, 0 otherwise	0.53	0.5						
Time living in village	years	28.02	17.76	32.07	17.75	24.45	17.24	1.71	0.09
Household size	Number of people living in household	4.90	1.66	5.03	1.68	5.06	1.64	−0.06	0.95
Age	Age of household head (years)	44.99	14.65	46.9	13.39	43.58	16.34	0.88	0.38
Education	Education of household head (years)	7.38	4.16	7.31	4.49	7.61	3.99	−0.27	0.79
Assets	Value of assets owned (IDR 1000)	12406	19602	10809	12487	12650	23205	−0.40	0.69
Livestock	Livestock owned (in TLU)	0.44	0.89	0.27	0.37	0.64	1.18	−1.71	0.10
Non farm job	= 1 if individual has a non-farm job	0.07	0.26	0.03	0.19	0.09	0.29	−0.92	0.36
Non farm business	= 1 if individual has a non-farm business	0.12	0.32	0.07	0.26	0.12	0.33	−0.70	0.49
Plots	Number of plots	1.55	1.25	2.17	1.61	1.55	1.25	1.70	0.10
Risk	Number of safe choices	5.03	2.50	4.57	2.32	5.42	2.63	−1.33	0.19
Discount rate		0.77	0.33	0.79	0.32	0.75	0.34	0.48	0.63
Auctioned plot variables									
Bid	Bid (IDR 1,000/ha)	6384	8533	2199	2811	10061	10103	−4.05	0.00
Area of Plot	Area of auction plot (Ha)	3.19	4.17	4.55	5.72	2.39	2.09	1.92	0.06
No Document	= 1 household has no legal proof of ownership	0.78	0.42	0.90	0.31	0.67	0.48	2.27	0.03
Revenue	Total revenue (IDR 1000)	17661	21619	19229	20799	18528	23734	0.12	0.90
Household labor	Number of days of household labor	24.42	59.86	22.21	41.54	26.36	72.88	−0.28	0.78
Hired Labor	Number of days of paid labor	26.03	74.17	26.07	63.5	26	83.42	0.00	0.99
Seedlings	Value of seedlings (IDR 1000)	1227	7650	443	1406	1916	10430	−0.80	0.43
Fertilizer	Value of fertilizer (IDR 1000)	6.74	35.65	0	0	12.67	48.42	−1.50	0.14
Pesticides	Value of pesticides (IDR 1000)	1.81	8.13	0	0	3.39	10.97	−1.78	0.09
Profit	Plot profits (IDR 1,000/ha)	6995	11342	5823	6726	8024	14258	−0.75	0.45
Fertile	=1 if plot considered fertile	0.06	0.25	0.07	0.26	0.06	0.24	0.13	0.90
Average	=1 if plot considered average soil	0.69	0.46	0.69	0.47	0.70	0.47	-0.06	0.95
Flat	= 1 if plot is flat	0.31	0.46	0.34	0.48	0.27	0.45	0.60	0.55
Slight	= 1 if plot is low slope	0.47	0.50	0.34	0.48	0.58	0.50	−1.84	0.07
Moderate	= 1 if plot is of moderate slope	0.18	0.39	0.21	0.41	0.15	0.36	0.56	0.58
	N	62		29		33			

SU = Senamat Ulu, TT = Tebing Tinggi.

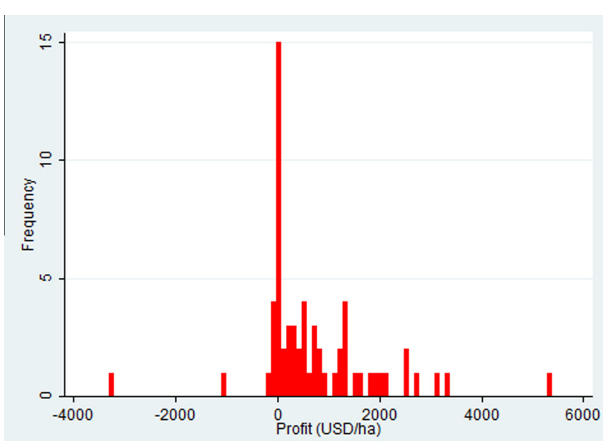

Figure 1. *Distribution of profits from rubber monoculture (all interviewees).*

risk preferences is presented in the last column of Table 2, while some summary statistics were already presented in Table 1. Our data show that the distribution of preferences is more or less evenly spread between risk averse and risk preferring individuals with, respectively, 30% and 25% of the respondents in each group.

The other behavioral parameter about which we collected information was the rate of discount. The elicitation of the time preference was done through a game that involved the participants choosing between the option of a specified amount of money now and a different amount of money in the future. There were six such options that allowed for the elicitation of a time preference rate for each individual depending on which time period they became indifferent between the two values of money. The results shown in Table 3 indicate that around 80% of respondents hold a discount rate at or above 0.50.

Finally, household heads were invited to an experimental auction for a reforestation contract. After identifying each household head through an individual number, there was a brief introduction of the research team and the objectives of the auction. Participants were told that they would be bidding on reforestation contracts, whereby they would alter their land from its current use (rubber monoculture, the only use of the plots brought to auction), to a fruit-based agroforest system with which the respondents were familiar. The fruit-based agroforest system, once established, requires little in terms of labor and capital inputs, containing a variety of local fruit trees, in combination of natural forest growth. See Swallow *et al.* (2007) for a more complete description of this system.

The contracts were specified to last 10 years and the payments per hectare were to occur in equal yearly installments, the first of which would accrue upon completion of the land conversion. A budget constraint of 30 million Indonesian rupiah per year was announced and participants told that the contracts would be awarded to the lowest bidders (in terms of bid per hectare) who fell within the budget. The auction

Table 2. *Risk preference experiment*

Choice	Option A		Option B		N (%)
	Red	Blue	Red	Blue	
1	1/10 of IDR 25,000	9/10 of IDR 16,000	1/10 of IDR 40,000	9/10 of IDR 5,000	6 (9.8)
2	2/10 of IDR 25,000	8/10 of IDR 16,000	2/10 of IDR 40,000	8/10 of IDR 5,000	7 (11.5)
3	3/10 of IDR 25,000	7/10 of IDR 16,000	3/10 of IDR 40,000	7/10 of IDR 5,000	3 (4.9)
4	4/10 of IDR 25,000	6/10 of IDR 16,000	4/10 of IDR 40,000	6/10 of IDR 5,000	9 (14.8)
5	5/10 of IDR 25,000	5/10 of IDR 16,000	5/10 of IDR 40,000	5/10 of IDR 5,000	12 (19.7)
6	6/10 of IDR 25,000	4/10 of IDR 16,000	6/10 of IDR 40,000	4/10 of IDR 5,000	7 (11.5)
7	7/10 of IDR 25,000	3/10 of IDR 16,000	7/10 of IDR 40,000	3/10 of IDR 5,000	5 (8.2)
8	8/10 of IDR 25,000	2/10 of IDR 16,000	8/10 of IDR 40,000	2/10 of IDR 5,000	3 (4.9)
9	9/10 of IDR 25,000	1/10 of IDR 16,000	9/10 of IDR 40,000	1/10 of IDR 5,000	9 (14.8)

Note: Values in each choice (row) indicate the number of Red or Blue tickets and associated payoff. For example, in choice 1, Option A is a lottery formed by 1 Red ticket (that pays IDR 25,000) and 9 Blue tickets (that pay IDR 16,000) while Option B ia lottery formed by 1 Red ticket (that pays IDR 40,000) and 9 Blue tickets (each paying IDR 5,000). The last column presents the number of respondents that switched from Option A to Option B at each choice.

Table 3. *Distribution of time preferences*

Discount rate	N (%)
0.05	3 (4.9)
0.10	1 (1.6)
0.30	8 (13.1)
0.50	8 (13.1)
1.00	41 (67.2)
N	61 (100)

proceeded through several rounds of bidding (fixed a priori, but not revealed to the participants), with each round lasting 60 seconds. Participants were then encouraged to ask any questions, after which there would be no communication. After all questions were answered, they were encouraged to act as if in a real auction, in particular by keeping their own profits from rubber production in mind.

At the close of each round, all the bids were collected and recorded. The identification number of winners (those whose bids fell within the budget constraint) were then read aloud, allowing for participants to understand whether their bid fell within the finite budget constraint and, eventually, reassess their bid. [9] Each participant with bids that fell within the budget constraint was awarded a uniform price per hectare, determined as the price of the highest bid that fell within the finite budget. The distribution of the bids (in US$/ha) is presented in Figure 2. This figure hides important differences across villages, that are made clearer in Figure 3: the values requested to convert from rubber to the agroforest system are much lower in Senamat Ulu, the village further away from the regional center (mean bid = 232 US$/ha) than in Tebing Tinggi (mean bid = 1064 US$/ha).

At the end of the auction we had information that would allow us to estimate the supply of carbon through reforestation, using two different approaches: the opportunity costs of rubber (estimated through the information collected in the household survey) and land users' willingness to accept reforestation contracts (revealed through their bidding decisions in the experimental auction). The next section explores the relation between these two approaches.

3. THE SUPPLY OF CARBON SEQUESTRATION: AUCTIONS, OPPORTUNITY COSTS, AND SPACE

The supply of carbon sequestration, as a function of the land brought into reforestation contracts in the auction, is graphically presented in Figure 4. The additional carbon

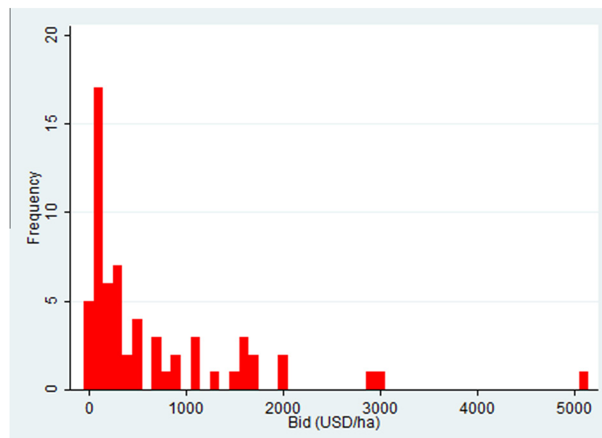

Figure 2. *Distribution of bids (all interviewees).*

sequestered from this transformation was approximated by the difference in carbon content between the rubber plantation and the carbon content of the agroforest system, taken from Swallow *et al.* (2007). [10] If we take US$25 per tCO_2 as the reference price for CO_2, the auction would have led to the sequestration of approximately 13,000 tCO_2. [11] Figure 4 also makes clear that most of this amount could be sequestered at much lower prices: for example, a price of US$10 per tCO_2 would be enough to guarantee the supply of roughly 85% of the above amount (almost 11,000 tCO_2).

Although the supply function represented in Figure 4 is an indication of the willingness to change land use, as promoted under the contracts being auctioned, it lacks the ability to explain what factors influence an individual's reserve price. Opportunity costs and spatial location are two obvious starting points for that discussion.

An opportunity cost analysis of carbon supply would assume that the amount that landowners' would request to reforest their land would equate to the difference $\pi_r - \pi_{af}$, where π_i stands for the profit of activity i and the subscript r stands for rubber and *af* stands for agroforestry. If the supply curve elicited through this analysis largely coincides with the one elicited through the auction then problems of asymmetric information are not particularly important, and the opportunity cost approach may provide a simpler approach to the definition of these contracts. [12]

Because the agroforestry system is not adopted in the auctioned plots, we are not able to obtain precise estimates of

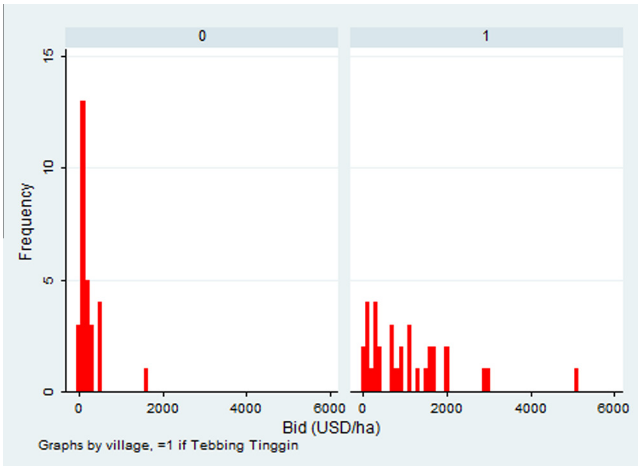

Figure 3. *Distribution of bids, per village.*

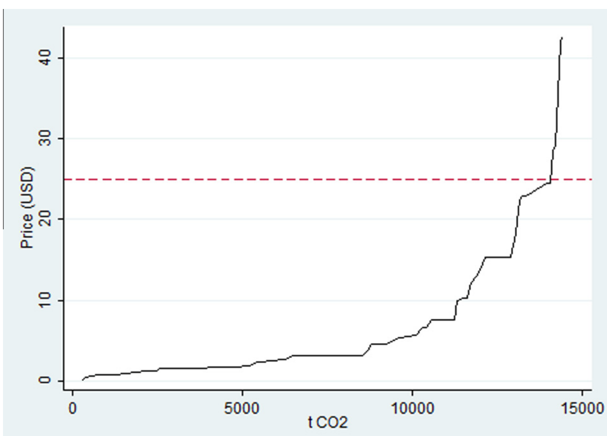

Figure 4. *The supply curve: auction.*

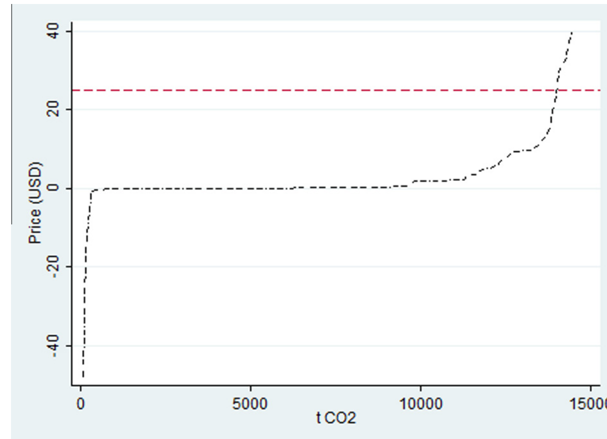

Figure 5. *The supply curve: opportunity costs.*

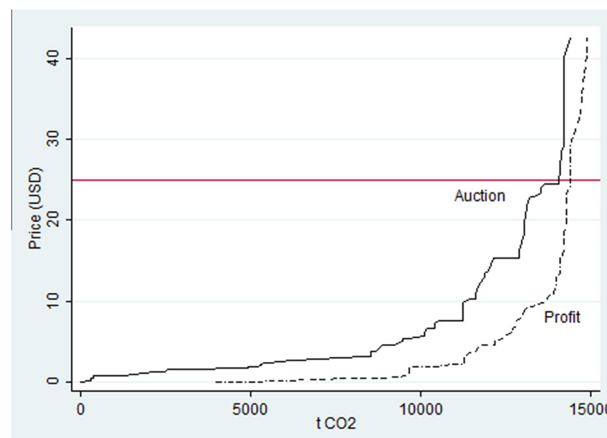

Figure 6. *The supply curve: contrasting auction and opportunity costs.*

the returns and costs associated with this activity. If we do not include them in the analysis but assume that $\pi_{af} \geqslant 0$ then π_r can be interpreted as an upper bound of the opportunity costs associated with these contracts and conversion to agroforestry would require, at most, a payment equivalent to π_r. [13]

The supply function estimated through this approach, which reflects the entire distribution of profits, is presented in Figure 5 and contrasted (for the subset of positive values of π_r) with the results of the auction in Figure 6. The first conclusion is that, irrespective of the approach used to estimate it, our results confirm the potential of using forest for low-cost sequestration of CO_2: substantial amounts of CO_2 can be sequestered at prices substantially below the reference price used in this discussion, even after accounting for the range of transaction costs presented in the literature. This conclusion mirrors the results of Cacho, Marshall, and Milne (2005) who, after accounting for an exhaustive list of different types of transaction costs (search, negotiation, verification and certification, implementation, monitoring, enforcement, and insurance), suggest that, taken together, and in the context of smallholder carbon forest, such costs would not threaten the feasibility of these programs. [14]

The second conclusion is that although the two curves are quite similar at the reference price of 25 US$/t$CO_2$, the supply curve estimated under the assumption that prices would need to equate profits from rubber is consistently to the right of the supply curve elicited through the auction: at 10 US$/t$CO_2$, for example, the opportunity cost approach suggests an amount of sequestered Carbon that is approximately 15% higher than the amount supplied through auctions. This difference increases for lower prices, reflecting the high frequency of very low values of profits (presented in Figure 1). Summarizing, there seems to be little relation between our estimates of profits and the bids for contracts elicited through the experimental auction. This visual result is confirmed by a Pearson correlation coefficient between bids and rubber profits of −0.103, which is low, negative, and imprecisely estimated (bootstrapped standard error of 0.137, with an associated *p*-value of 0.451).

The other natural starting point for an analysis of what determines bidding decisions is spatial location. In Figures 7 and 8 we take a first step in the direction of analyzing the importance of location by disaggregating the supply curves by village. Several conclusions emerge. The first is that space does seem to make a difference: at 25 US$/t$CO_2$, we would be able to sequester approximately 9,000 tonnes of CO_2 in Senamat Ulu but only half of that amount in Tebing Tinggi, and these differences do not depend on how we estimate the

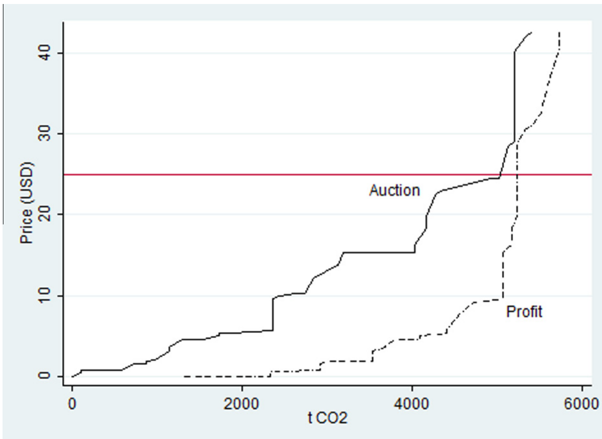

Figure 7. *The supply curve: contrasting auction and opportunity costs, Tebing Tinggi.*

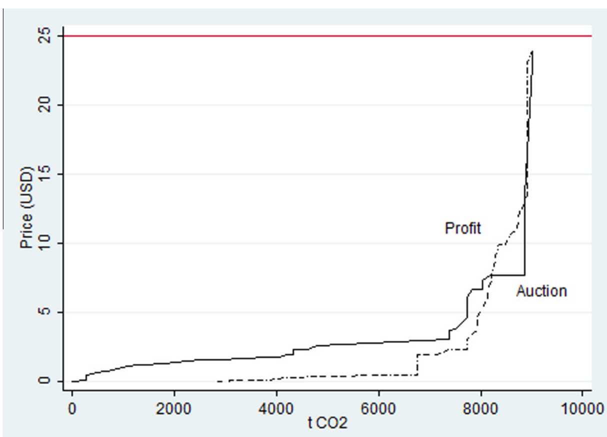

Figure 8. *The supply curve: contrasting auction and opportunity costs, Senamat Ulu.*

supply curve of Carbon. The second is that there is no clear evidence of a systematic relation between profits and bids even after conditioning on spatial location. As above, the differences between the supply curves are confirmed by the Pearson correlation coefficients between bids and rubber profits (Senamat Ulu: $\rho = 0.006$, bootstrapped standard error = 0.163, p-value = 0.969; Tebing Tinggi: $\rho = -0.191$, bootstrapped standard error = 0.177, p-value = 0.280).

This lack of relation matters for targeting of these type of programs, because profits (conditional on location) may be easy to approximate using secondary data (Antle & Valdivia, 2006; Antle *et al.*, 2010). However, if they do not provide a good approximation of the true willingness to accept for reforestation contracts, auctions such as the ones that we study may be the only feasible alternative to contract allocation. In the next section we explore the robustness of this conclusion using multivariate analysis.

4. EXPLAINING BIDDING DECISIONS

In order to explain the source of the differences between the two approaches, we estimated the relation between the value of the bid and several individual characteristics, including both the information usually collected through household surveys and the behavioral parameters elicited through the artefactual field experiments. The OLS estimates, with bootstrapped standard errors, are presented in Table 4.

The different specifications of the model explaining bidding decisions differ in the degree of observability of the explanatory variables, which can be used to target this program, from spatial location (easily observable and the only variable included in the first specification) to risk and time preferences (typically unobservable, and included in the last specification). Other variables (rubber profits, plot characteristics, and household characteristics) would be somewhat in between location and individual preferences in terms of how easily observable they are. The inclusion of profits from rubber monoculture among the explanatory variables is especially important, given our *a priori* hypothesis that opportunity costs would largely explain bids: if true, we would expect that this variable would be important (both in the economic and statistical sense) in explaining this decision.

Several conclusions emerge from these results. The first is that profits from rubber do not seem to be correlated with the values of the bids submitted in the experimental auction. This conclusion is robust to the inclusion of a variety of household and plot covariates for which we have information.[15]

The second conclusion is that spatial location matters, an effect that has been identified in the literature (see, for example Gaveau *et al.*, 2009; Wunscher, Engel, & Wunder, 2008): bids in Tibeng Tinggi (the village closer to the regional center) are substantially larger than in Senamat Ulu and its effect is remarkably stable across specifications. The third conclusion is that other easily observable covariates are not individually significant and, jointly, add very little to the explanation of bidding decisions: the adjusted R^2 is 0.235 for the model presented in column 4, and 0.202 for the simpler model that only includes location as an explanatory variable (column 1).

Finally, preferences toward risk and time (included in the final specification) matter both in the economic and statistical sense: increases in risk aversion or impatience lead to lower bids. This effect is important: a two standard deviation in risk preferences leads to a reduction in bid that is equivalent to 70% of the increase in bid that is due to being located in Tebing Tinggi. In other words: if there is evidence that REDD should be implemented in this village, it seems important to identify who would be the lowest cost providers of reforestation contracts, but easily observable variables (such as land ownership) seem to provide little guidance regarding who such providers would be. Given that, conditional on location, only hard to observe variables seem to matter in determining how much to pay, only mechanisms that allow for their revelation in an incentive compatible way (such as the auctions studied here) would be able to provide such guidance.[16]

There are two potential explanations for this effect. The first is that this simply reflects omitted variables (such as poverty status). This explanation seems hard to accept given that we already control for a wide range of socioeconomic characteristics, including wealth and education. The alternative explanation is that such preferences do matter independently and that they can be rationally linked with lower bids. For example, given the structure of the contracts, and the schedule of the first payment immediately after the conversion, it makes sense that bidders would prefer the land use contract to other investments with a longer time horizon such as rubber. Similarly, a certain payment (such as the one offered by the proposed contracts) is more attractive than a risky one (such as the current land use) for risk-averse bidders, driving the observed result

Table 4. *Explaining auction bids*

Variables	(1)	(2)	(3)	(4)	(5)
Tibeng Tinggi	7,863***	8,111***	7,710***	7,211***	8,201***
	(1,838)	(1,984)	(2,216)	(2,519)	(3,069)
Profit (1,000 IDR/ha)		−0.113	−0.127	−0.130	−0.040
		(0.129)	(0.133)	(0.131)	(0.114)
No document			−550	−1,547	−1,031
			(2,638)	(2,803)	(2,785)
Fertile			4,741	5,085	8,694
			(5,990)	(6,826)	(7,292)
Average soil			−3,265	−3,710	−1,809
			(3,228)	(4,636)	(3,990)
Flat			2,094	2,852	6,306
			(2,921)	(4,790)	(5,212)
Slight			2,785	3,101	4,824
			(3,552)	(5,309)	(5,699)
Moderate			2,202	3,604	7,819
			(3,239)	(4,887)	(5,600)
Years living in village				109	167**
				(74)	(83)
Education				60	106
				(324)	(294)
Non farm Job				−4,561	−4,301
				(6,915)	(6,602)
Non farm business				1,409	3,196
				(6,649)	(5,877)
Number of plots				47	−653
				(1,351)	(993)
Livestock, in TLUs				2,238	1,902
				(2,152)	(1,973)
Land				−113	12
				(253)	(186)
Discount rate					−7,671*
					(4,185)
Risk aversion					−1,137*
					(600)
Observations	62	62	62	62	61
Adjusted R^2	0.202	0.227	0.241	0.235	0.348
$H_{0:\ X} = 0$					
χ^2 (d.f.)	–	–	4.45 (7)	7.73 (14)	13.63 (16)
p-value	–	–	0.720	0.903	0.626

Dependent variable: bid (US$/ha). Bootstrapped standard errors in parentheses. The vector X includes all variables with the exception of Tebing Tinggi. A constant is included but not reported.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.10$.

that the higher the levels of risk-aversion the lower the value of the bids.

These results, if generalized, carry important implications for the definition of contracts that underly REDD+. Taken together, they reinforce the importance of geographical targeting but also suggest that other variables do not provide much information that may guide the targeting of this program at a lower level of aggregation.

5. CONCLUSION: OPPORTUNITIES, AND CHALLENGES TO THE IMPLEMENTATION OF REDD+

Reducing Emissions from Deforestation and Degradation (REDD+) continues to be one of the few internationally agreed alternatives for reducing global greenhouse gas emissions. This paper uses primary data collected in two villages in Sumatra, Indonesia, to compare two approaches to estimate the supply of carbon sequestration through reforestation contracts: a reverse, second-price experimental auction and estimates of opportunity costs obtained from a detailed household survey. The two sites are statistically identical in terms of household and plot characteristics that may determine their willingness to accept carbon sequestration contracts (including estimates of profits from rubber, the only use of the plots brought to auction), but one of them is much closer to the main urban center in the region.

The analysis identified three aspects that seem important when considering the implementation of REDD+. Firstly, and as revealed by the supply curve of carbon, reforestation contracts seem clearly feasible given what is usually assumed about market prices for carbon and what is known about transaction costs associated with these types of contracts. However, we must also notice one important limitation of the analysis presented here. When estimating the supply curve, we disregarded the time lag in the supply of carbon sequestration. The consideration of that aspect of supply necessarily matters for the definition of contracts underlying REDD+, even if it does not have a direct bearing on our comparison of the two approaches to the estimation of how much to pay for carbon.

Secondly, the analysis of the determinants of the bids submitted highlighted that spatial location and individual preferences (namely time preferences and risk aversion) were major determinants of such values while measures of opportunity costs were not. This result, if confirmed more widely, suggests that it may be difficult to target this program at household level, given that there does not seem to exist any easily observable covariate that identifies low-cost providers of land for reforestation (other than location). In addition, and because only typically unobservable variables (such as individual preferences toward risk and time) matter when explaining bids, our results suggest that ways of generalizing the use of auctions to allocate such contracts may be an important way to reduce the costs of implementing this type of program.

Finally, these results may matter for REDD+ even if afforestation and reforestation activities are not included in the program, given the equivalence between opportunity costs of avoided deforestation and of afforestation/reforestation. However, determining the existence of a similar lack of relation between auction bids and opportunity costs in the case of forest conservation contracts is potentially much more complicated, given the lack of private property rights in much of the forest area in developing countries. Such absence (and the potential importance of local communities) not only complicates the definition of the potential bidder but also brings to the forefront the possibility that criteria such as fairness or distributional concerns may matter when deciding the value of the willingness to accept.[17] Given the potential impacts on both forest conservation, climate change mitigation, and poverty alleviation, this seems a particularly important area of future research.

NOTES

1. Afforestation refers to the conversion of land that has not recently or ever been classified as a forest into a forested area. Reforestation refers to the conversion of a previously cleared forest back to forest use.

2. This interest reflects the recognition of the *potential* of afforestation and reforestation to contribute to carbon sequestration (Zomer, Trabucco, Bossio, & Verchot, 2008; Richards & Stokes, 2004). Simultaneously, there has been little demand for carbon credits generated through these type of projects in the initiative that already allows for them, the Clean Development Mechanism. This lack of uptake likely reflects both the transaction costs of CDM projects and the lack of demand for temporary carbon sequestration in existing carbon markets.

3. For a discussion of the potential impact of REDD+ on forest governance under ill-defined property rights see Phelps, Webb, and Agrawal (2010).

4. This is not to argue that asymmetric information and incomplete markets are the only problems in implementing REDD+. See Agrawal, Nepstad, and Chhatre (2011), Jack, Kousky, and Sims (2008) and Bulte, Lipper, Stringer, and Zilberman (2008) for a discussion of other problems with the implementation of Payments for Environmental Services and/or REDD+.

5. The opportunity costs of avoided deforestation that have received much attention (including Stern, 2006; Eliasch, 2008, mentioned above), and the opportunity costs of afforestation and reforestation (for example, those presented in Swallow *et al.*, 2007) should coincide if we disregard forest clearing costs (not present in a afforestation/reforestation project) and the time that it takes for the forest to grow and carbon to be sequestered.

6. See, in particular, section 4, pages 1220–1222. There is also a large body of work that discusses the use of auctions in the implementation of payments for environmental services in developed countries (see, for example, Stoneham, Chaudhri, Ha, & Strappazzon, 2003; Claasen, Cattaneo, & Johansson, 2008).

7. One figure easily illustrates the scale and the importance of this process of land change. In the neighboring Riau Province, the estimated mean annual CO_2 release between the years of 1990–2007, due to deforestation, was estimated at 0.22 Gt CO_2, the equivalent to 58% of Australia's estimated annual CO_2 emissions (Uryu *et al.*, 2008)

8. The exchange rate at the time of fieldwork was US$1 = IDR 9450.

9. See Jack (2009) on the importance of learning in this type of experiments

10. It is important to notice that, when representing the supply curve in terms of tCO_2 (as in Figure 4 and following ones) we are assuming the carbon content of a mature forest and a mature rubber plantation. Hence, the values represented here neglect the time lag between conversion to agroforestry and forest maturity, during which the supply of carbon sequestration services would necessarily be smaller. However, it is important to notice that this assumption does not have any implications for the question we address in this paper, that is, whether the two approaches to the estimation of how much to pay for reforestation contracts lead to equivalent supply curves.

11. The values of US$25 per tCO_2 adopted as the reference value in this discussion corresponds to the recent estimates of the net present value of expected global benefits per reduced tCO_2 presented in Interagency Working Group on Social Costs of Carbon (2009).

12. There may be other considerations besides implementation costs when deciding between ways of allocating payments for environmental services, including carbon sequestration. Jindal, Kerr, Ferraro, and Swallow (2011) suggests that auctions are socially more easily accepted of allocating reforestation contracts under a budget constraint because they are perceived to be fairer, while Jack (2013) presents evidence of higher compliance rate when contracts are allocated through an auction compared with a fixed "take-it-or-leave-it" offer. For a discussion of the effect of different designs, in terms of reduction of emissions and program budget, see Busch *et al.* (2012).

13. Although a comparison with the opportunity costs of land use change in other settings is beyond the scope of this paper, we note that the values that we present are similar to the ones presented in Swallow *et al.* (2007) for the entire province of Jambi.

14. Several studies estimate such costs to be in the range US$4–5/$tCO_2$, although there is still substantial variability around this value. Kindermann *et al.* (2008) estimated around \$6/tCO_2, Antinori and Sathaye (2007) estimated around \$5/tCO_2 and Grieg-Gran, Noel, and Porras (2005) uses \$4–\$15/ha/year based on PES programs in place in Costa Rica, Mexico, and Ecuador.

15. In the bottom panel of Table 4, we present the results of the test of joint significance of profits and other covariates, with the exception of location. We can never reject the null hypothesis that the effect of these variables is jointly equal to 0 at the usual levels of statistical significance. This result confirms that the lack of importance of profits in models (3)–(5) can not be due to possible multicollinearity between profits and the additional covariates included in models.

16. It is important to notice that the estimates of the effect of other covariates do not change, either in statistical significance or in magnitude, suggesting that artefactual field experiments add information that goes beyond what can be accounted through correlates of such preferences (such as wealth, as measured by ownership of land or livestock, for example) that are usually collected in household surveys.

17. See, for example, the related discussion in Noordwijk (2010).

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