Forest Carbon is Not Cheap: Evidence from a Choice Experiment in Community Forests of Nepal

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Statement of Significance (120 Words: Max 120 Words)

Cost effective GHG mitigation requires knowledge of where in the world economy low-cost abatement opportunities exist. We analyze avoided deforestation and generate carbon abatement cost curves for the UN's Reduced Emissions from Deforestation and Forest Degradation (REDD+) program using a choice experiment conducted in Nepal. This is the first attempt to directly elicit carbon supply curves in community forestry settings and improves on previous methods by including all costs faced by respondents. We find that robust participation occurs at prices between $48 and $73 per ton rather than $1.00 to $5.00 as discussed in previous literature. At such low prices very little carbon will be supplied suggesting that optimism about low-cost carbon supply from avoided deforestation settings may be misplaced.

Abstract (250 Words: Max 250 words)

Cost effective GHG mitigation requires prioritizing mitigation options with the lowest abatement costs. Knowledge of where in the world economy low-cost abatement opportunities exist is therefore crucial. One particularly important GHG mitigation program is the UN's Reduced Emissions from Deforestation and Forest Degradation (REDD+) program. We generate household level carbon abatement cost curves for a REDD+ program using a choice experiment conducted in Nepal. This method improves on previous methods by eliciting all costs based on respondent's choices of REDD+ contracts and is the first attempt to directly elicit carbon supply curves for carbon sequestration in community forestry settings. We find that robust participation occurs at prices that are higher than those found in the literature on developing country carbon sequestration. Rather than prices of $1.00 to $5.00 per ton, we find that relatively little carbon would be supplied at such prices, and median/average prices to supply carbon are in the $48 to $73 range. We then analyze how abatement costs are affected by affiliation with formal community forestry, a key component of efforts to reduce GHG through avoided deforestation and find that abatement costs are greater in formal community forestry groups than in informal groups. Underprivileged formal group member households, such as landless, female-headed, or poor households, are found to be warier of fuelwood collection restrictions within the context of REDD+. They therefore require higher payments than average respondents. Overall, our results suggest that optimism about low-cost carbon supply from avoided deforestation in community forestry settings may be misplaced.

Keywords: GHG, Abatement Costs, Deforestation, REDD, Choice Experiment, Nepal

1. Introduction

Meeting the Paris Agreement goal to contain the increase in average surface temperature to 1.5 to 2.0 degrees Celsius will imply significant costs. Given that costs differ across the world economy, there is an opportunity to improve cost effectiveness by prioritizing reductions to methods and policies that can reduce net CO_2 emissions most cheaply. In the main cost estimate reported in the 5^{th} assessment, the IPCC indeed assumes that costs are divided up in such a way as to achieve a cost-effective allocation of CO_2e emissions abatement effort (IPCC, 2014). Knowledge of marginal abatement costs – and especially where low-cost abatement opportunities exist – is therefore critical for cost effectively allocating abatement effort and reducing total costs.

Information about CO_2 emissions abatement costs is particularly critical for designing payments ecosystem services (PES) programs, otherwise it is possible that compensation levels will be insufficient to spur abatement. One particularly important climate change-related PES program is Reduced Emissions from Deforestation and Forest Degradation (REDD+), which is a program by which The UN Framework Convention on Climate Change (UNFCCC) Annex 1 countries provide support to non-Annex 1 countries in exchange for measurable additional carbon sequestration (Angelsen, 2010; Bluffstone et al., 2013). What drives REDD+ is the notion that carbon sequestration in developing country forests is a class of particularly inexpensive climate investments; it therefore is cost-effective in a global sense for Annex 1 countries to "buy" forest carbon emission reductions from lower-income countries.

Low-income countries emit relatively little carbon pollution, but contribute to climate change through land use change and loss of forest biomass. Forest biomass loss from tropical land use change is an important part of total carbon emissions and an estimated net carbon source of 2.4 $\pm$ 0.4 Gt per year (Pan et al., 2011). Net deforestation and forest degradation make up 12% to 20% of total greenhouse gas emissions (GHG), which is greater than all transport sources combined (Saatchi et al., 2011; van der Werf, 2009). Preventing deforestation and degradation therefore have large potential to decrease GHG emissions. This paper focuses on a subset of all developing country forests, about 25% of total, that is increasingly controlled by people in village communities rather than central governments (World Bank, 2009, Agrawal 2008). These villagers use forests, among other things, to extract important products (e.g. firewood for cooking) that are essential for the daily lives of billions of people (Bluffstone et al., 2013). Programs to prevent deforestation and increase carbon sequestration is costly for them, because it can reduce the ease of accessing these essential products, increasing costs. Knowing these costs are necessary to both promote such programs and to evaluate their cost-effectiveness compared to other options for sequestering carbon.

Actual estimates of the opportunity costs – and therefore knowledge of the prices required to incentivize carbon sequestration in rural areas of low-income countries - are very limited. In contrast with our approach, which uses an experimental method that has the potential to fully account for all costs faced by participants, past studies have either used bottom-up estimates requiring assumptions about counterfactual behaviors or pure simulations of land-use changes. Strassburg et al. (2009), for example, use simulation methods to estimate the costs to reduce GHG emissions due to forest biomass loss in the 20 most forested developing countries. They find that a price per ton of CO_2e of $8.00 per ton would reduce global emissions by 90%. Similar simulation methods were used by Kindermann et al. (2008) and they find it would cost $10-$21 per ton of CO_2e emissions avoided to achieve a 50% reduction in deforestation. These findings suggest that carbon sequestration can effectively compete with other mitigation approaches like renewable energy, energy conservation and fuel switching. At the same time, there is some controversy regarding the degree to which all local opportunity costs of carbon sequestration were included in such approaches (Gregorsen *et al.* 2011). Further these studies do not look at community managed forests and the full costs in this setting.

Three studies have analyzed costs of carbon sequestration in Nepal, a country with a long and successful history of community managed forestry. and attempt to include opportunity costs, but to our knowledge ours is the first to directly elicit values from villagers rather than relying on assumptions about counterfactual behaviors and the values of non-marketed products like fuelwood; it is also the first to conduct a national Nepal study. Karky and Skutsch (2010) examine three REDD+ pilots and estimate the net benefits from three hypothetical forest management scenarios. They use likely market prices and non-market values elicited from focus groups and find breakeven prices of $0.55 to $3.70 per ton of CO_2 depending on the site and level of harvest reduction required. Marseni et al. (2014) analyze eight REDD+ pilot projects in two of Nepal's 75 districts. They catalogue costs as foregone forest product collections, plus meeting and forest management time costs. They find that the average payment of $1734 across the eight sites does not cover estimated opportunity costs and a price of $10/ton of CO_2 (at that time the EU Emissions Trading Scheme average price) would not even cover average meeting time opportunity costs. Pandit et al. (2017) use household survey data from 47 REDD+ pilot sites in two watershed in two of Nepal's 75 districts. They estimate a variety of opportunity costs using assumptions about market conditions similar to Marseni et al. (2014) and find that if unharvested fuelwood is taken into account, the average cost ranged from $50 to $74 per ton of CO_2, in the Terai (plains) and $20 to $30 per ton of CO_2 in the hills. All three of these studies are focused on relatively small REDD+ pilot regions and estimate costs using bottom-up assumptions about behavioral responses and market conditions.

In this paper we estimate a nationally representative, household-level carbon supply function based on reducing deforestation in rural Nepal. We model carbon supply as the marginal willingness to accept (WTA) payments for reducing fuelwood collections from village forests as part of a hypothetical REDD+ program. To estimate marginal willingness-to-accept, we use a choice experiment conducted with a nationally representative sample of 1300 households in 130 communities and forests (S2). Choice experiments allow us to decompose the effects of various aspects of the REDD+ program and elicit, at the household level, the payment necessary to incentivize participation and reduce fuelwood collections (Vincent 2014). This method offers a substantial improvement over previous methods used to estimate carbon supply, because it elicits the WTA directly from respondents who would participate in REDD+. It also in principle accounts for all the costs faced by respondents, but because respondents never directly state a price, it helps ensure that respondents do not overstate their WTA.

Using this approach, we find relatively high median WTA values per ton of CO_2e emissions avoided ($33 - $56). These values are substantially higher than global estimates and estimates from two of the three case studies from Nepal itself. We then examine factors that shift estimated carbon supply functions by estimating correlations between the marginal willingness to accept values and a variety of socioeconomic variables. We find that respondents who are poor, members of female-headed households and have bigger families have higher WTA values. Those who own land, use biogas and believe they will benefit from REDD+ require lower payments to reduce fuelwood collections. Our results suggest that the early optimism about low-cost carbon supply in community forestry settings – especially as applied to the underprivileged - may have been misplaced.

2 Methods

Carbon supply is the behavioral response in terms of emissions reduced expected from offering a particular monetary incentive. As is standard in the literature, we assume that carbon is supplied on the margin only if REDD+ contracts cover all opportunity costs; estimated WTA values therefore give insight into opportunity costs (Vincent et al., 2014). Our application is the supply of carbon from avoided forest degradation in rural Nepal, where most carbon emissions come from cutting and burning fuelwood. In our sample, 95% of households cook with fuelwood as their main fuel, sometimes in conjunction with other fuels. Half of all households in our sample are part of a formal, legal community forestry program called the Nepal Community Forestry Programme (CF) and half are outside the program (non-CF).

After estimating marginal WTA using our choice experiment, we simulate the quantity effects for a hypothetical nationwide program that reduces fuelwood collections by 25% compared with current levels. We chose this reduction after piloting with Nepalese forestry experts, because that value is viewed as significant by respondents, but is not considered an overwhelming reduction that could elicit protests against our experiment or an actual implementation of policy. At the mean, this reduction is 75 kg per month or about two basket loads per household (average household size ~ 6 persons). Reported responses, including fuel substitutions associated with such a reduction requirement, are discussed in S1.

To estimate carbon supply functions, we use marginal effects derived from a choice experiment similar to Vincent (2014). Choice experiment surveys are used by environmental economists (as well as in transportation, health and marketing studies) to understand values and preferences for policies and non-marketed goods and services (Boxall et al. 1996, Louviere et al. 2000, Johnston et al. 2017). In a choice experiment, respondents are asked to make choices over combinations that are described using sets of key characteristics. The values of the characteristics that appear in each choice are varied according to experimental design methods and typically a price is included as one of the characteristics. In our study, households were repeatedly presented with choice cards, where each card had three possible REDD+ contract options from which the household was asked to choose one. One of the three options was the status-quo (no REDD+ contract), while the other two had different combinations of reductions in firewood collection, grazing, REDD+

payments to households, and REDD+ payment allocation (to households, to the community or shared).

The choices made by households reveal their willingness to trade-off firewood reductions for REDD+ payments. The moments of the price distribution are constant in choice experiments, which produces one marginal cost value for each respondent; this implies that the carbon supply price per ton does not increase when we evaluate a larger than marginal increase. For this reason, we only consider a program that requires a 25% reduction in fuelwood collections, which is likely to be at the upper end of "marginal," but significant enough to be measured and monitored. All details about the method, choice cards, data collection and derivation of marginal effects are provided in S2 and S3, as well as Dissanayake et al. (2015a) and Dissanayake et al. (2015b).

We use a nationally representative sample that is spatially distributed across Nepal, which distinguishes our work from previous attempts that only looked at specific REDD+ pilots, and allows us to generate a national carbon supply function. Fig. 1 shows the locations of our 1300-respondent sample, with forests delineated CFs and non-CFs. A detailed overview of the sample and evidence that leakage associated with such a REDD+ program may be limited are presented in S1.[2]

Using the estimated marginal effects from our choice experiment, we analyze the proportion of households willing to participate in a hypothetical REDD+ program requiring fuelwood collections to be reduced by 25% at various prices. We generate the carbon supply curve by estimating the additional CO_2e sequestered at various prices as follows; We utilize the average fuelwood collection estimate of 2.40 tons per household per year from Somanathan and Bluffstone (2015), which is derived from the nationally-representative 2010/2011 Nepal Living Standards Survey (NLSS).[3] Only

[2] The data used for this analysis is available from the corresponding author.
[3] This estimate is slightly lower than the 2.54 tons per household per year from Nepal et al. (2010), which used the 2003/2004 NLSS and is about 8% below the estimate of Baland et al. (2010), which uses the 1995/1996 survey. Our

preserving non-renewable biomass that would have otherwise been burned to generate heat for cooking and heating generates carbon savings. To estimate the percentage of biomass harvests that is unsustainable, we use the 52% estimate from Bailis et al. (2015), which implies that slightly more than half of reduced fuelwood harvests actually reduce total biomass loss. We then use the IPCC (2013) emissions factor (0.50) to convert fuelwood not burned to carbon not emitted and apply the standard factor of 3.67 tons of CO_2 per ton of carbon to convert carbon to CO_2, which is the metric of international carbon transactions.

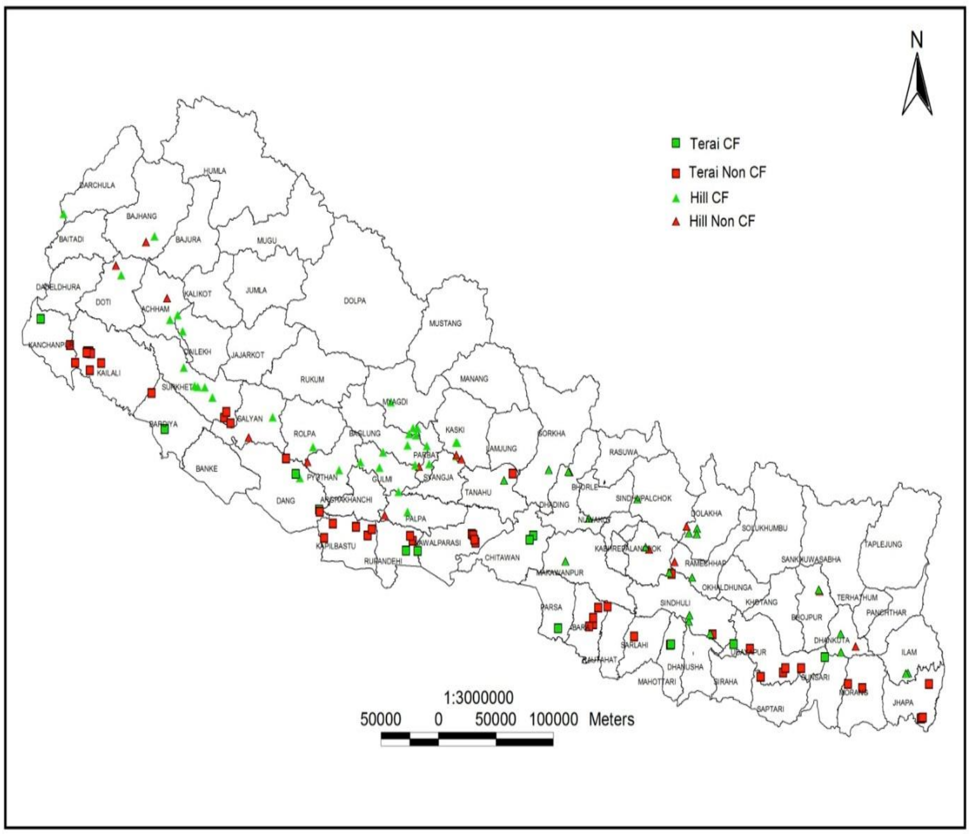


Fig. 1: Map of Research sites

In Nepal, only about 4% of households who cook with fuelwood use improved biomass cookstoves (Nepal et al., 2011). Much of the rest use traditional, inefficient stoves and typically vent

estimate is also 17% below those for Dolakha District by Kandel et al. (2016). We therefore see our estimate of a one-percent decrease in fuelwood collections (in tons) as reasonable, but erring on the conservative side, because each 1% reduction implies less wood reduced than in much of the literature.

waste gases within the home. Such traditional stoves not only emit CO_2, but also other gases, including aerosols that are estimated to have negative global warming potentials (GWP) and black carbon, which is a short-lived, but potent greenhouse gas. To calculate CO_2 reductions, we utilize calculations from Somanathan and Bluffstone (2015), based on emissions factors and estimated GWPs taken from IPCC (2013), Pandey et al. (2014) and Grieshop et al. (2011), to derive 1.6047 tons of CO_2e saved per ton of unsustainable fuelwood not harvested. These calculations are presented in Table 1. We then scale our experimental results using the 2011 estimated national rural population of 4.4 million rural households (CBS, 2012; 2016) and the 1.45 million rural households who are members of CFs (MoFSC, 2017) in order to estimate carbon sequestration at various prices.

Table 1: Emission Factors and 100-Year Global Warming Potentials in Tons of CO_2e.

Pollutant	Emission Factor (g of Pollutant/Kg of wood)	100-year Global Warming Potential (tCO_2e)	Tons of CO_2e saved per ton of wood
CO_2	1358	0.52	0.7062
BC	0.7	900	0.63
OC	1.9	-46	-0.0874
SO_2	0.1	-76	-0.0076
CO	76	1.8	0.1368
NMVOC	6.9	8.8	0.06072
CH_4	4.9	28	0.1372
N_2O	0.1	265	0.0265
TOTAL			**1.6047**

Sources: Emission factors: (Pandey et al. 2014), Table SI3. Global Warming Potentials: IPCC (2013), Appendix 8.A, except for SO_2 which is from Grieshop et al. (2011). The GWP for CO_2 is adjusted to account for an estimated 48% of all fuelwood that is sustainably harvested (Bailis et al., 2015).

Finally, we are interested in potential carbon supply shifters. We therefore run OLS regressions of marginal WTA values on key household and community variables. We emphasize that the cross-section nature of our data do not allow us to infer causality, because it is possible that omitted variables simultaneously affect choice experiment responses and key household and community variables. We in any case do not seek to infer causality. We merely would like to know which respondent characteristics, technologies previously adopted, assets and perceptions of REDD+ are associated with higher WTA. Correlations are therefore sufficient for our purposes.

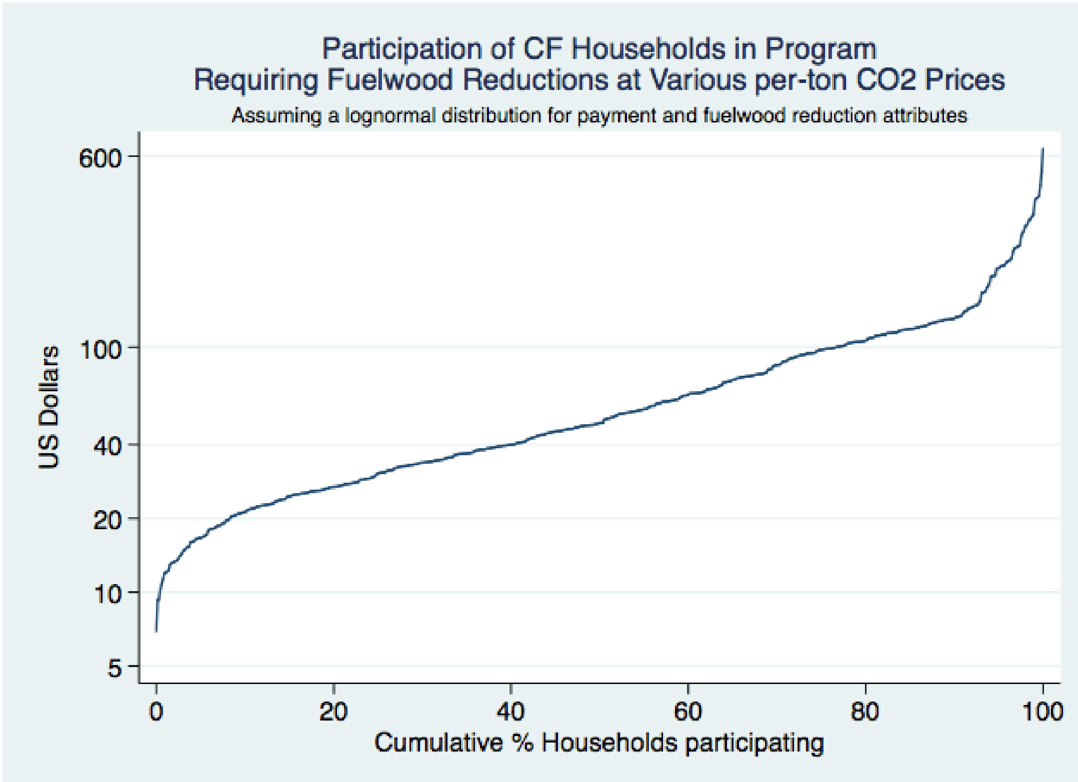
3. Results

We begin with estimates of household participation in the proposed REDD+ program and then present national level for CO_2 supply functions reductions from a program that requires all households to reduce fuelwood collections by 25%. We present separate analyses for CF and non-CF members as the choice experiments used were not identical as noted in the Methods. Finally, we present our OLS analysis of carbon supply shifters.

Carbon Supply by CF Member Households

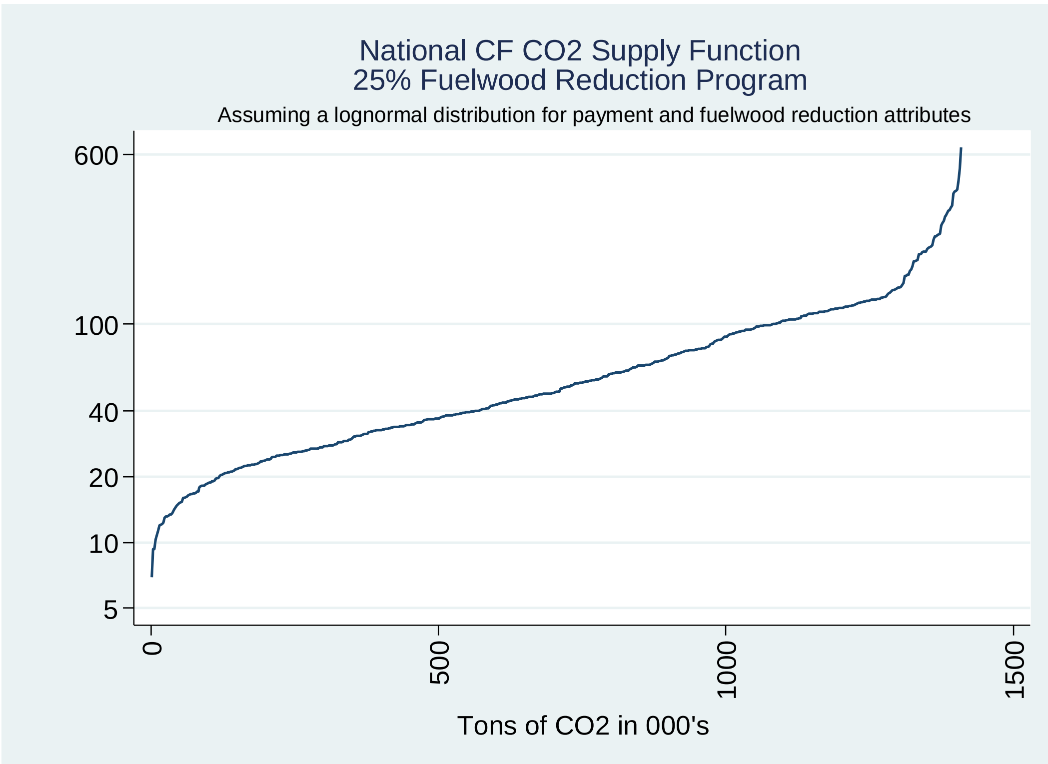
Figure 2 presents estimated participation of CF member households in a REDD+ program to reduce fuelwood collections at various CO_2 prices. Estimated prices to incentivize participation in the program range from $7.00 to $655 per ton of CO_2, with a median of $48 and an average of $73 (assuming normally distributed payment vehicle and fuelwood reduction attributes, the median WTA is $56 with an average of $63). Approximately 25% of households are estimated to participate at a price of $30 per ton and 75% participate at a price of $93 ($27 and $86 assuming normal distributions).

Figure 2: CF Household REDD+ Program Participation at Various CO2 Prices



In Fig. 3, we present our estimate of the CO_2 supply function for a program that requires CF member households to reduce fuelwood collections by 25%, with CO_2 emissions reductions credited as in the Methods Section and S2. It is estimated that 1.45 million households are members of CFs and it is over this population that we estimate the supply of carbon. At the median willingness to accept value of $49 per ton of CO_2 reduced, we estimate an additional 0.70 million tons will be sequestered by the population of 1.45 million households, with a total revenue of $34.3 million or about $48 per household per participating household per year. The median is especially relevant, because it is the estimated minimum price at which a REDD+ program would pass a referendum. At a price of $40, which is consistent with contemporary estimates of the social cost of carbon (USIAWG, 2015), approximately 0.57 million additional tons are estimated to be sequestered with the participation of approximately 40% of CF households and total revenue of $22.8 million or about $39/participating household per year. At a price of $10 per ton, which the literature considers a low price, we estimate that very little carbon will be sequestered (less than 10,000 tons).

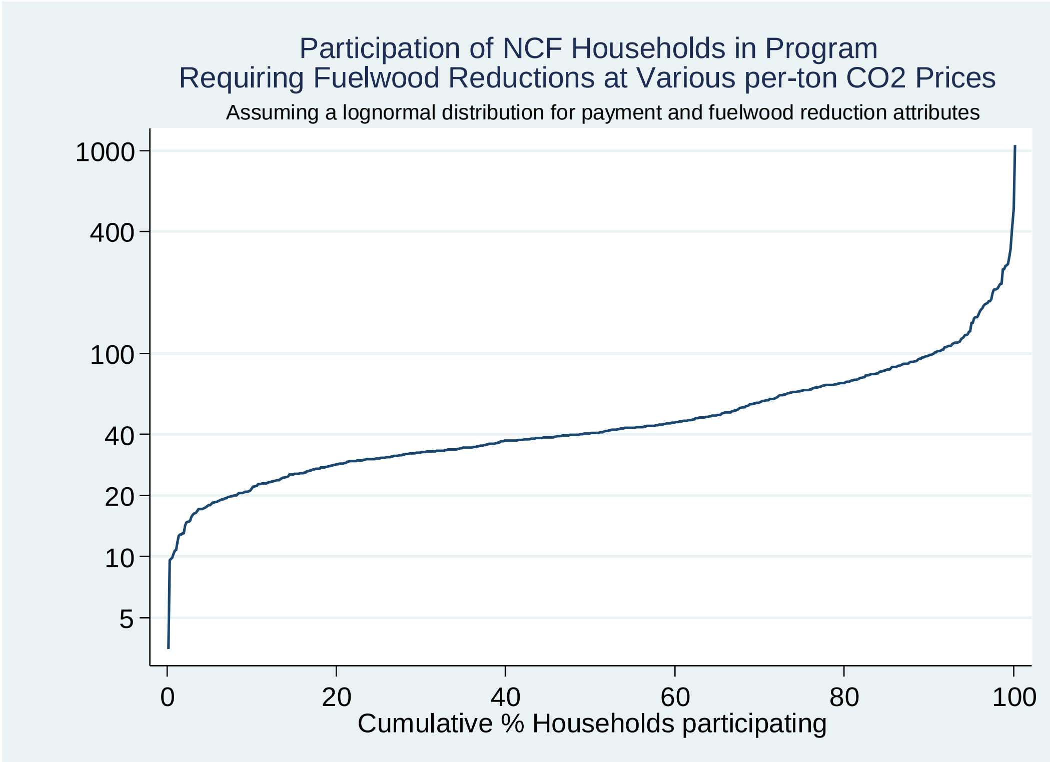
Fig. 3: CF CO_2 Sequestration Supply at Various CO_2 Prices



Carbon Supply by Households outside the Community Forestry Program

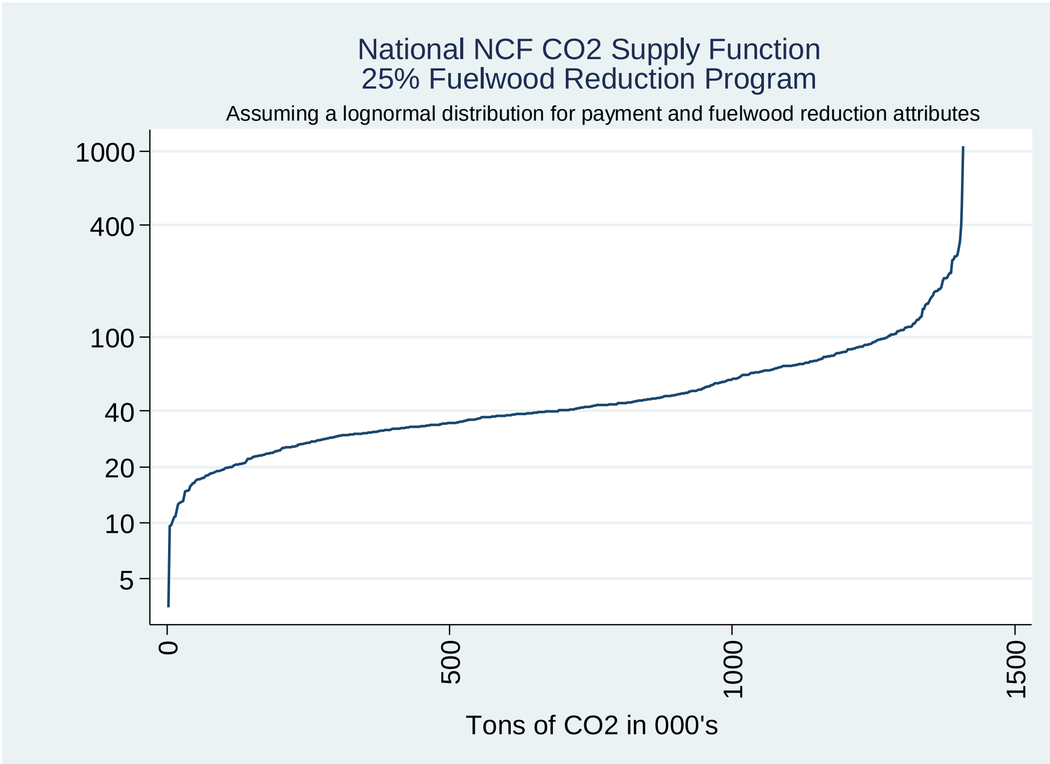
Next, we analyze households who are non-CFs and find they are willing to participate in the hypothetical REDD+ program at lower cost than CF households. For example, to incentivize three-quarters of the households to participate would require a carbon price of about $66 (for CF households this would be $97). At $10 per ton, roughly 8% of households are willing to participate, compared with 5% for CF households (Fig. 4). In terms of carbon supply, we estimate that the median cost per ton of CO_2e sequestered is $41/ton, which is 20% lower than for CF households.

Figure 4: Non-CF Household REDD+ Program Participation at Various CO_2 Prices



In addition to getting more reductions per monetary unit paid, there are many more households outside the CF program than inside it (2.95 million households versus 1.45 million). Implementing a program to reduce fuelwood collections by 25% therefore generates much more sequestration. As shown in Figure 5, at the median WTA of $41 per ton of CO_2, which is very consistent with the 2015 estimate of the global social cost of carbon, 0.7 million tons are estimated to be sequestered, raising revenues of $58 million. As this amount is spread over the 1.475 million (50% of 2.95 million) participating households, an average household receives just over $40 per year. At $10 per ton, only about 10,000 tons are sequestered, generating about $100,000 in revenues.

Figure 5 Non-CF Household CO_2 Sequestration Supply at Various CO_2 Prices



Carbon Supply Shifters

What shifts carbon supply functions? In Table 1 for CFs and S5 for non-CFs, we present results from an OLS regression of potential carbon supply shifters; this approach allows us to consider heterogeneous effects and explain the distribution of WTA values. As our goal is to explain the distribution of WTA estimates rather than estimate the cost of carbon sequestration measured as CO_2, we do not constrain WTA estimates to be positive. We therefore assume normal distributions. Estimates assuming lognormally distributed payment vehicle and fuelwood reduction attributes are presented in S5 and are similar to the results in Table 1.

Table 1: Relationship between Socioeconomic Variables and Marginal WTA from a REDD+ Program Requiring Reduction in Fuelwood Collections

Variable	Regression Coefficient	P Value
Respondent age (years)	-0.96	0.21

Respondent is female (1 = yes, 0 otherwise)	34.35*	0.10
Female-headed households (1 = yes, 0 otherwise)	63.71***	0.01
Household size (number of people)	8.61**	0.03
Household is classified as poor or ultra-poor (1 = yes, 0 otherwise)	35.83*	0.09
Dalit ethnic group (1 = yes, 0 otherwise)	-49.09	0.12
Indigenous or Newar ethnic group (1 = yes, 0 otherwise)	-3.46	0.87
Madheshi ethnic group (1 = yes, 0 otherwise)	-105.45***	0.03
Respondent migrated to site from another location (1 = yes, 0 otherwise)	-34.10	0.16
Uses biogas (1 = use, 0 otherwise)	-72.04***	0.01
Uses LPG (1 = use, 0 otherwise)	-21.21	0.32
Uses improved biomass cooking stove (1 = use, 0 otherwise)	68.95*	0.08
Uses firewood (1 = use, 0 otherwise)	-130.67	0.43
Household owns land (1 = yes, 0 otherwise)	-79.26**	0.02
Walking distance from respondent's house to road < 2 hours (1 = yes, 0 otherwise)	12.35	0.68
Respondent says they are very likely or extremely likely to benefit personally from REDD+ (1 = yes, 0 otherwise)	-41.28**	0.03
Reported firewood used per month (kilograms)	0.01	0.40
Number in formal CFUGs (number of groups)	-4.28	0.80
Constant	532.40***	0.01

Estimate using OLS. Units are Nepali Rupees. CF respondents only. ***, **, * indicate significant at 1%, 5% and 10% levels. n= 597, R^2=0.10, F=3.01, prob>F=0.0007
Assumes normally distributed payment vehicle and fuelwood reduction attributes

We find households that are poor, large, female-headed, use improved biomass cookstoves and are larger (likely indicating more children) require more compensation to be induced to participate in the REDD+ program. Compared with the mean, female-headed households require roughly 30% more than average households and the same is true for households that use an improved biomass cookstove. Female respondents require about 15% more than the average and the effect is approximately the same for poor households. Each additional household member above the average adds about 4% to the WTA compared with the mean. A household that is female-headed, poor, with 8 household members rather than the mean of 6 and the respondent is female, is expected to have a WTA about 69% above the mean. These findings suggest that women, the poor and households with many children would find REDD+ most costly.

Households who use biogas on average have estimated WTA values that are about 35% below the mean and the same is true for those who own land. Those who believe that REDD+ is very likely or extremely likely to benefit them personally on average have WTA values 19% below the mean and respondents of Madheshi ethnicity, which means they are of Indian origin and likely live in the Terai, have estimated WTA much lower than the mean.

The non-CF supply shifter model is only marginally jointly significant and while the signs of the estimated regression coefficients are similar to those for CFs, only household size and use of biogas are significantly different from zero, with same signs and magnitudes as for CFs. These findings suggest that with the exception of these two variables, the shifters of WTA may be fundamentally different in CFs and non-CFs (S5). Such differences are likely because non-CFs are largely open access and meeting REDD+ requirements will be substantially less difficult.

4. Discussion and Conclusions

We generate carbon supply curves for avoided deforestation using estimates of household-level willingness to participate in a REDD+ program that requires a 25% reduction in fuelwood collections within community-based forest management, which make up about 25% forests in developing countries. We conduct the study in Nepal and find that for households in both communities with an institutionalized community forestry program (CFs) and those that manage the community forests independently (non-CF), robust participation occurs at prices that are higher than much of the literature. Rather than prices of $1.00 to $5.00 incentivizing participation as has been found in much of the literature, we find that relatively little carbon would be supplied at such prices. This finding is in line with three recent published papers focusing on REDD+ pilots in Nepal. These findings in combination with our results, which use techniques that rely less on bottom-up assumptions, suggest that optimism regarding low-cost carbon supply in community forestry settings could be misplaced; our use of an experimental method to elicit WTA and the direct elicitation from households is novel in the recent literature, which has largely used bottom-up models and land-use simulations to estimate costs of avoided deforestation.

Formal community forest management will almost certainly be the core institution within which REDD+ is implemented in Nepal and likely in many other tropical countries. We find that average and median WTA values for CFs are substantially greater than for non-CFs, which is not surprising given that non-CFs are often open access, but CFs typically have existing fuelwood collection restrictions; REDD+ will just increase those restrictions to generate additional carbon sequestration. Our analysis of carbon supply shifters finds that, "underprivileged" CF member households, such as those who are landless, female-headed and poor, appear to be warier of fuelwood collection restrictions within the context of REDD+. They therefore require higher payments, all else equal than average respondents.

Less harvesting of fuelwood can potentially reduce carbon emissions if such actions result in increased efficiencies, replacing unsustainable harvest sources (e.g. open access forests) with sustainable ones, such as wood from trees planted on users' own farms or use of biogas from existing animals. Of course, if households comply with an agreement to reduce fuelwood harvests from their own forests by simply harvesting fuelwood from another forest, then carbon sequestration gains are reduced or eliminated due to leakage. Understanding the likely extent of leakage is therefore critical to the success of PES schemes, such as REDD+. In this paper, we are not able to conclusively address the possibility for leakage, but we do present descriptive results in S1 that suggest additional fuelwood collection limits would not cause households to primarily rely on alternative common forests.

Our choice experiment methodology has the important advantage in that WTA values come from household members themselves rather than being constructed based on assumed explicit costs. In this regard, our estimates may include a broader array of difficult-to-measure costs, such as inconvenience and transaction costs, that have been found in the literature to be significant and may be associated with - or suspected to be part of – REDD+. As we have noted, though, a downside of using the choice experiment methodology is that it can only provide us with one marginal (and average) WTA value for each household. We therefore can only construct our carbon supply functions across households and do not have the capacity to fully incorporate intra-household marginal carbon supply costs. Because the estimates are for 1% decreases in fuelwood collections, they are likely underestimates of true marginal WTA for larger reductions in fuelwood collections (e.g. 25% as we have simulated). Future research on carbon supply from households should attempt to incorporate both intra-household and inter-household marginal costs; both are valid elements of carbon supply functions. We have included the latter, which we see as a contribution to a literature that has generally estimated at most a few points rather than anything like a "function."

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