Department of Economics
ISSN number 1441-5429

Understanding the potential adoption of agroforestry in Fiji using procurement auctions

Discussion Paper no. 2025-07

Paulo Santos, Benjamin Chipperfield and Shipra Shah

Abstract:

REDD+ is a promising mechanism for financing carbon sequestration, but limited research exists on the contract designs that maximise this outcome. We estimate the supply of carbon under different agroforestry contracts using primary data collected in Fiji through procurement auctions, artefactual experiments, and household surveys. Our findings indicate that the densest and longest-duration contract offers the most cost-effective opportunities for carbon sequestration. We contrast auctions with contracts defined on the basis of important drivers of bidding decisions (identified using regression trees), under different assumptions of variables that can be used to administratively target beneficiaries. Our analysis shows that for relatively high values of carbon sequestration, auctions outperform such targeted payments, supporting their use for implementing REDD+ in Fiji.

Keywords: agroforestry, auction, REDD+, Fiji

JEL Classification: Q23, D44

Paulo Santos: Economics, Monash University. (email: paulo.santos@monash.edu); Benjamin Chipperfield: Economics, Monash University. (email: benjamin.chipperfield1@monash.edu); Shipra Shah: Forestry, Fiji National University (email: shipra.shah@fnu.ac.fj).

Understanding the potential adoption of agroforestry in Fiji

using procurement auctions[1]

Paulo Santos[2], Benjamin Chipperfield[3], Shipra Shah[4]

Abstract

REDD+ is a promising mechanism for financing carbon sequestration, but limited research exists on the contract designs that maximise this outcome. We estimate the supply of carbon under different agroforestry contracts using primary data collected in Fiji through procurement auctions, artefactual experiments, and household surveys. Our findings indicate that the densest and longest-duration contract offers the most cost-effective opportunities for carbon sequestration. We contrast auctions with contracts defined on the basis of important drivers of bidding decisions (identified using regression trees), under different assumptions of variables that can be used to administratively target beneficiaries. Our analysis shows that for relatively high values of carbon sequestration, auctions outperform such targeted payments, supporting their use for implementing REDD+ in Fiji.

Keywords: agroforestry, auction, REDD+, Fiji

JEL codes: Q23, D44

[1] We thank officials from the Ministry of Agriculture of Fiji for their support throughout the preparation of this work. Funding from the Pacific Action for Climate Transitions (PACT), a collaboration between Monash University and the Fiji National University, is gratefully acknowledged.
[2] Economics, Monash University.
[3] Economics, Monash University. Email: benjamin.chipperfield1@monash.edu
[4] Forestry, Fiji National University.

1. INTRODUCTION

The world's climate is rapidly changing through rising temperatures, sea level rise, and increasingly frequent and severe extreme weather events (IPCC, 2023). These changes have caused significant economic damages (Newman & Noy, 2023) which are expected to escalate (Bilal & Känzig, 2024). Small island developing states (SIDS), including Fiji, the setting of our study, are among the most vulnerable to these shocks (Thomas et al., 2020).

One major driver of climate change is deforestation, which contributes to 13% of total net anthropogenic emissions of carbon dioxide (CO_2) (IPCC, 2019). Established by Parties to the United Nations Framework Convention on Climate Change (UNFCCC), the 'Reducing emissions from deforestation and forest degradation in developing countries' (REDD+) framework aims to reduce the impacts of climate change through supporting developing countries in protecting, sustainably managing and enhancing their forests, by paying land managers for keeping or increasing the carbon content of the forest they manage (UNFCCC, 2024; UNEP, 2024).

An important consideration in the design of contracts for enhancing carbon stocks through afforestation and reforestation activities under the REDD+ framework is the value of the payment to the party undertaking the activity. Landowners have private information on the costs and benefits associated with land use change, which creates the opportunity for opportunistic behaviour, via the submission of inflated statements about those costs. While these information rents can have the effect of reducing poverty (Jayachandran, 2022), maximising the quantity of CO_2 sequestration subject to a budget constraint requires their minimisation.

One approach that addresses the challenge of eliciting truthful valuations is the use of auctions. In a Vickrey (1961) auction, participants privately submit bids to receive a contract, whereby the winner is the participant who submits the lowest bid. Because the payment received by the winner is equal to the value of the bid submitted by the second-lowest bidder (and not the lower value submitted by the winner), truth-telling is the dominant strategy under this mechanism (Polasky et al. 2014; Southgate & Wunder, 2009).[5] Other design features act to reduce the potential for collusion: for example, sealed bids can be used to reinforce the incentive to undercut other bidders (Polasky et al. 2014). A generalised Vickery auction is a natural extension of this mechanism and allows for multiple winners, determined by an overall budget constraint, while preserving its incentive compatible properties (Jack & Cardona Santos, 2017).

Vickery auctions have been adopted in Payments for Environmental Services (PES) programs in developed countries, including the United States, Australia, and the United Kingdom (Claassen et al. 2008; Latacz-Lohmann & Schilizzi, 2005). Examples of its use in developing countries include the design of reforestation contracts in Vietnam, Kenya and Tanzania (The & Ngoc (2008), Khalumba et al. (2014) and Jindal et al. (2013) respectively), the promotion of technologies to reduce soil erosion or promote afforestation in Indonesia (Jack et al. (2009) and Skidmore et al. (2014), respectively) or protecting crop biodiversity (Narloch et al. (2011)).[6] In this paper we use auctions to inform the design of agroforestry contracts, a practice that involves integrating trees into agricultural landscapes, and a system that is associated with significant benefits at both local (e.g., provision of food and medicine, pest control, soil enrichment, and erosion control) and global (e.g., carbon sequestration and biodiversity conservation) scales (Jose, 2009).

Contrary to what the list of examples above might suggest, and despite the high proportion of PES projects proposed in developing countries, auctions remain relatively

[5] If participants increase their bids above their true valuation of the contract, they will reduce the probability of receiving the contract and, therefore, their expected payment. A bid below their true valuation is dominated by bidding truthfully, as it eliminates the scenarios whereby payments are less than the cost of the project without compromising their chance of winning a project equal to or greater than their valuation.

[6] See Wünscher & Wunder (2017), Lundberg et al. (2018) and Bingham et al. (2021) for recent reviews of the use of auctions in the context of payments for environmental services.

underused as a policy mechanism in developing countries (Bingham et al., 2021). This lack of translation of research into policy possibly reflects the uncertainty regarding the gains associated with their implementation, when contrasted with more traditional approaches to the design of land use policy.[7]

We address this gap by comparing the cost-effectiveness of uniform payments (based on the 2024 average global Emissions Trading Scheme price), targeted payments (based on bidders' characteristics) and auctions in sequestering carbon. Given institutional (information and administrative) constraints to targeting, we evaluate scenarios that differ in the extent to which information is assumed to be available and usable for payment design.

The remaining of this paper proceeds as follows. Section 2 presents the research context and the data collected. Participants in our survey were asked to submit bids to a hypothetical procurement auction for three different contracts, which differ in their tree density requirements and duration, and therefore the amount of CO_2 sequestered per acre. Section 3 presents the supply curves of CO_2 sequestration under the different contracts. We find that the densest (7m x 7m) and longest duration (50 years) contract provides the cheapest way of promoting CO_2 sequestration via agroforestry contracts. Contrasting this supply curve with average 2024 average global Emissions Trading Scheme price, our analysis shows the potential for agroforestry contracts to contribute to the implementation of REDD+ in this context. In Section 4 we use machine learning techniques (regression trees) to determine the most important predictors of bids across demographic, plot and behavioural characteristics, selected from information sets that differ in terms of what policymakers can plausibly use as targeting criteria. In the least restrictive set of variables, we find that the previous adoption of contour farming,

[7] In addition to evidence on their hypothetical cost-effectiveness, quantified in *ex-ante* lab-in-the-field analyses, projects implemented via auctions have been shown to outperform alternative ways of allocating these contracts: for example, in Malawi, compliance with tree planting contracts and tree survival are significantly higher for landowners receiving contracts through an auction design (Ajayi et al., 2012; Jack, 2013; Jack & Cardona Santos, 2017); see also Andeltová et al. (2019), in a different context).

plot area, age, whether the respondent is the child of the household head, and household size to be major determinants of respondents bid values. A comparison of the cost-effectiveness of auctions, targeted, and uniform payments shows that auctions outperform the alternatives: targeted payments approximate auctions only for lower sequestration levels, particularly so if policy makers have extensive information about bidders (i.e., not limited to a few easily observable characteristics). We conclude in Section 5 with a discussion of policy implications and directions for further research.

2. DATA

The data used for this research was collected in five villages from the Cuvu district, Southwest Viti Levu, the largest island of Fiji (Figure 1).[8] Cuvu is among the twenty Emission Reduction districts identified under Fiji's National REDD+ strategy specifically for implementing climate smart agriculture (Fiji Ministry of Forestry, 2020). In this district, the long decline of sugarcane farming and the recent end of several long-term leases (30-50 years), together, led to the supply of relatively large areas of marginal land, for which agroforestry is a potentially viable land use alternative.

Prior to data collection, the traditional *sevusevu* protocol, which involves gifting kava (*Piper methysticum*) to elders, was conducted in each village for the purpose of seeking permission of the village chief and introducing the research and research team. Although the Ministry of Forestry had previously conducted visits to Cuvu and the REDD+ scheme had been implemented in nearby districts (REDD+ Fiji, 2024), local residents initially had a limited understanding of REDD+ and its associated benefits. This was revealed during *talanoa* (dialogue) with the communities, which is considered a culturally appropriate research practice

[8] Site selection was done with the assistance of the Ministry of Forestry, Ministry of Agriculture, and Provincial Councils.

in the Pacific (Farrelly & Nabobo-Baba, 2014). Consequently, the research team conducted REDD+ awareness sessions in the villages prior to data collection. The intention of these discussions was to promote an understanding that, under REDD+, tree planting on farms is rewarded by payments for carbon sequestration, allowing landowners to make informed decisions about their bids in the context of hypothetical auctions (to be described in more detail in Section 2.3).

Fig. 1. Locations of sample villages (n=5; yellow) and Sigatoka (main urban centre in the region; red) in Viti Levu. The inset shows the location within Fiji as indicated by the white square.

The data used in this study was collected through a household survey fielded to 101 households who manage land.[9] The questionnaire consisted of 6 modules that collected information on household characteristics, including non-incentivised measures of risk preferences and trust (Section 2.1), agricultural production, including plot characteristics and considerations about the impact of climate change (Section 2.2), and a hypothetical auction (Section 2.3).

2.1 HOUSEHOLD CHARACTERISTICS

As shown in Table 1 Panel A, most respondents were children of the household head (42%), followed by spouses of the household head and other household members (20%), and household heads themselves (16%).[10] This reflects the fact that, in this region, nonfarm work is becoming more important, leaving the management of agricultural land, including the land brought to auction, to members of the household other than its head (such as children and spouses). All respondents were iTaukei, relatively educated (95% had secondary or tertiary education), relatively well-off (more than 80% reporting having an income that allows them to save a little) and owned smartphones. Agriculture and forestry were the most important source of cash income for approximately 1/3rd of respondents, although its importance was much larger when respondents were asked to consider the value of own production (in which case, 90% of the households indicated it was the main livelihood activity in the household).

[9] At the beginning of the questionnaire respondents were asked a screening question: "Does the respondent, or any member of his/her household, manage any land for agriculture or forestry production?" All respondents confirmed that they or a household member manage land for agriculture or forestry. Although we interviewed 101 respondents, we present summary statistics and discuss the data for 97 respondents only, as four outliers (in terms of their bids) were removed from the analysis. See Section 2.3.

[10] Although this raises the possibility that respondents are submitting bids on land over which they may not have property rights at the time of the survey, we cannot reject the hypothesis that average bids submitted by non-owners differ from bids submitted by owners for any of the contracts described in section 2.3.

TABLE 1: DESCRIPTIVE STATISTICS: RESPONDENT AND HOUSEHOLD CHARACTERISTICS

Variable	N	Mean	SD
Panel A: Respondent characteristics			
Household head (0 no; 1 yes)	97	0.155	0.363
Child of household head (0 no; 1 yes)	97	0.423	0.497
Spouse of household head (0 no; 1 yes)	97	0.196	0.399
Parent of household head (0 no; 1 yes)	97	0.031	0.174
Relationship to the household head: other (0 no; 1 yes)	97	0.196	0.399
Sex (1 female; 0 male)	97	0.330	0.473
Age (years)	97	40.237	16.499
Highest level of education attained: primary (0 no; 1 yes)	96	0.052	0.223
Highest level of education attained: secondary (0 no; 1 yes)	96	0.740	0.441
Highest level of education attained: tertiary (0 no; 1 yes)	96	0.208	0.408
Mobile phone ownership (0 no; 1 yes)	96	0.875	0.332
Smart phone ownership (0 no; 1 yes)	97	0.856	0.353
Likelihood of wallet return with 25 FJD by villager: Likely (0 no; 1 yes)	97	0.464	0.501
Likelihood of wallet return with 25 FJD by villager: Unlikely (0 no; 1 yes)	97	0.423	0.497
Likelihood of wallet return with 25 FJD by villager: Don't know (0 no; 1 yes)	97	0.113	0.319
Likelihood of wallet return with 25 FJD by outsider: Likely (0 no; 1 yes)	97	0.103	0.306
Likelihood of wallet return with 25 FJD by outsider: Unlikely (0 no; 1 yes)	97	0.876	0.331
Likelihood of wallet return with 25 FJD by outsider: Don't know (0 no; 1 yes)	97	0.021	0.143
Amount gambled (0-100 FJD; 50% lose 50% win 2.5x)	97	53.454	24.784
Panel B: Household characteristics			
Household size	97	5.753	1.888
Income level: Allows you to build your savings (0 no; 1 yes)	97	0.711	0.455
Income level: Allows you to save just a little (0 no; 1 yes)	97	0.124	0.331
Income level: Only just covers expenses (0 no; 1 yes)	97	0.021	0.143
Income level: Not sufficient to meet expenses (0 no; 1 yes)	97	0.144	0.353
Agriculture/forestry main livelihood of household (0 no; 1 yes)	97	0.897	0.306
Agriculture/forestry main cash income source of household (0 no; 1 yes)	97	0.330	0.473

Notes: Four outliers in terms of their bids were removed from the analysis (see Section 2.3).

Non-incentivised artefactual experiments were used to elicit preferences regarding trust and risk (see Table 1 Panel A). Participants were asked to consider a scenario where they lose their wallet containing 25 Fijian Dollars (FJD), identity card and address, and how (un)likely that this cash would be returned to them if it were found by someone from or outside your village. While trust in neighbours slightly outweighs distrust (46% vs 42% respectively), trust in outsiders is low (only 10% of participants believing that their wallet would be returned with the 25 FJD if found by someone from outside their village).

To measure risk preferences, participants were asked to consider a scenario whereby they win a raffle for 100 FJD and have the opportunity to gamble some or all of this money, with a probability of 0.5 of losing the money gambled and a probability of 0.5 of receiving 2.5

times the money gambled. Although maximising the expected payoff in this experiment involves gambling all of the money, the average amount gambled in this experiment is 53.45 FJD.

2.2 CHARACTERISING AGRICULTURAL PLOTS AND THE IMPACT OF CLIMATE CHANGE

Table 2 Panel A shows that respondents operate an average of 3.46 plots, with a total area of 3.23 acres, and report that they may be willing to dedicate 90% of this land to agroforestry. Nearly all plots where agroforestry was considered are under native lease tenure (97%) and are located within an hour's travel from respondents' homes (92%). Households have managed their plots for a relatively long period (27.41 years, on average), suggesting that they would have a deep understanding of its production possibilities under a variety of conditions. Most plots had multiple uses, with the most common being permanent crops other than pasture (89%) and natural forests (61%), with smaller portions allocated to planted forests (26%), home gardens (12%), and floriculture (10%).

Respondents were also asked about the perceived impacts of changes in climate on their farm and livelihoods, and whether they had adapted to it (including by adopting agroforestry). As shown in Table 2 (Panel B), concerns regarding the impacts of climate change in the future (measured using a five-point Likert scale, from "not at all concerned" (=1) to "very concerned" (=5)) were relatively high, with 42% of participants very concerned and only 5% being not all concerned. The most common changes to farms in the last 10 years were increased weather uncertainty (68%), more frequent floods (50%), and declining crop yields (39%). Consistent with these changes, floods (69%), pest and disease outbreaks (36%), and bushfires (33%) were the most frequently reported occurrences. Adoption of agroforestry was high (71%), with medicinal (64%) and fruit (29%) trees being the most commonly planted. Other adaptation practices included contour farming (24%), using recommended agricultural inputs (21%), and waste product management (10%).

TABLE 2: DESCRIPTIVE STATISTICS OF THE PLOTS AND CLIMATE CHANGE IMPACTS, ADAPTIONS AND EXPECTATIONS

Variable	N	Mean	SD
Panel A: Plot characteristics			
Number of plots household operates for agricultural activities	97	3.464	1.860
Total area of plots household operates for agricultural activities (acres)	96	3.229	3.962
Land tenure of plot to adopt agroforestry: Native Lease (0 no; 1 yes)	97	0.969	0.174
Lease cost (USD/acre/year) estimated if traditional ownership or freehold)	91	368.551	1206.299
Plot ownership: household head (0 no; 1 yes)	96	0.021	0.144
Plot ownership: child of household head (0 no; 1 yes)	96	0.708	0.457
Plot ownership: spouse of household head (0 no; 1 yes)	96	0.094	0.293
Plot ownership: parent of household head (0 no; 1 yes)	96	0.156	0.365
Years operating plot for agricultural activity	97	27.412	17.213
Use for plot: Temporary Crops (0 no; 1 yes)	97	0.052	0.222
Use of plot: Permanent Crops (no pastures) (0 no; 1 yes)	97	0.887	0.319
Use for plot: Permanent Crops with pastures (0 no; 1 yes)	97	0.093	0.292
Use for plot: Natural Forest (0 no; 1 yes)	97	0.608	0.491
Use for plot: Planted Forest (0 no; 1 yes)	97	0.258	0.440
Use for plot: Home Gardens (0 no; 1 yes)	97	0.124	0.331
Use for plot: Floriculture (0 no; 1 yes)	97	0.103	0.306
Travel time from house to plot: 1 - 2hrs (0 no; 1 yes)	97	0.082	0.277
Travel time from house to plot: Less than 1hr (0 no; 1 yes)	97	0.918	0.277
Panel B: Climate change: Impacts & adaptation			
Impacts of climate change on livelihood: not at all concerned (0 no; 1 yes)	96	0.052	0.223
Impacts of climate change on livelihood: slightly concerned (0 no; 1 yes)	96	0.156	0.365
Impacts of climate change on livelihood: somewhat concerned (0 no; 1 yes)	96	0.104	0.307
Impacts of climate change on livelihood: moderately concerned (0 no; 1 yes)	96	0.271	0.447
Impacts of climate change on livelihood: very concerned (0 no; 1 yes)	96	0.417	0.496
Changes to farm in last 10 years: Loss of soil fertility (0 no; 1 yes)	97	0.227	0.421
Changes to farm in last 10 years: Decline in crop yield (0 no; 1 yes)	97	0.381	0.488
Changes to farm in last 10 years: New pest and disease (0 no; 1 yes)	97	0.278	0.451
Changes to farm in last 10 years: Increased soil erosion (0 no; 1 yes)	97	0.062	0.242
Changes to farm in last 10 years: Increased weather uncertainty (0 no; 1 yes	97	0.660	0.476
Changes to farm in last 10 years: Increased frequency of floods (0 no; 1 yes)	97	0.485	0.502
Any shock occurred in last 10 years (0 no; 1 yes)	97	0.825	0.382
Shock in last 10 years: waterlogging (0 no; 1 yes)	97	0.062	0.242
Shock in last 10 years: Saltwater intrusion (0 no; 1 yes)	97	0.041	0.200
Shock in last 10 years: Bushfire (0 no; 1 yes)	97	0.268	0.445
Shock in last 10 years: Pest and disease (0 no; 1 yes)	97	0.299	0.460
Shock in last 10 years: Drought (0 no; 1 yes)	97	0.041	0.200
Shock in last 10 years: Flood (0 no; 1 yes)	97	0.567	0.498
Adoption in last 10 years: Agroforestry (0 no; 1 yes)	97	0.660	0.476
Adoption in last 10 years: Planting climate resilient crops (0 no; 1 yes)	97	0.031	0.174
Adoption in last 10 years: Use of recommended agriculture inputs (0 no; 1 yes)	97	0.196	0.399
Adoption in last 10 years: Contour farming (0 no; 1 yes)	97	0.227	0.421
Adoption in last 10 years: Waste product management (0 no; 1 yes)	97	0.093	0.292
Species of tree planted for agroforestry: Fruit trees (0 no; 1 yes)	97	0.268	0.445
Species of tree planted for agroforestry: Medicinal trees (0 no; 1 yes)	97	0.598	0.493

Notes: Four outliers in terms of their bids were removed from the analysis (see Section 2.3).

2.3 ELICITING WILLINGNESS TO ACCEPT FOR AGROFORESTRY CONTRACTS

We quantify household's willingness to accept (WTA) for agroforestry practices using a hypothetical experimental auction fielded as part of the household questionnaire. Respondents were firstly provided with some background information, focusing on climate change and the potential for the REDD+ scheme to be used to mitigate this problem. This included reference to agroforestry, including the benefits at both the global (reducing the damage from climate change) and local level. This individual explanation complemented the presentation of REDD+ at community level, implemented before our data was collected, hence it seems reasonable to assume that respondents were well informed about the objectives of REDD+.

After providing this background information, the design of the hypothetical auction and the conditions of the contracts were explained to respondents.[11] They were encouraged to participate as if their decisions had real consequences, and to submit bids that should reflect the costs and benefits associated with this land use change. Participants were invited to submit a bid in FJD after this explanation.[12]

Mango (*Mangifera indica*) was selected as the tree species to be included in the design of agroforestry contracts as this tree was already planted, although in small scale and primarily for own consumption, in the district. Moreover, since farmers were supplying vegetable produce to nearby tourist resorts, it was potentially feasible to diversify into fruit trees for meeting demands from the tourism sector. We considered three different contracts that differed in terms of tree density and duration. The order the contracts were introduced was randomised

[11] The precise wording of the text read to the respondents in this module is presented in Appendix A2.
[12] At the time of this study 1 FJD was worth approximately 0.45 US dollar (USD). Subsequent analysis in USD.

to minimise the bias that may be caused by participants reflecting and learning from their bids in previous contracts (Choi & Pak, 2005).

Contract 1 involved participants changing their current land use to one that involves planting mango trees with a spacing of at most 7m x 7m, while being allowed other uses (including other food crops) in the space between the trees. They would need to pay for the initial investment in establishing the trees, including the plants and labour, and their first payment would be made immediately after verification that the trees were well planted, with the contracted minimum density, and could be expected to survive under normal weather conditions. Finally, it was explained that payments (with a value to be determined by the outcome of the auction) would continue every year for 50 years, provided after a yearly verification of the same conditions as above regarding density and overall vegetative status. Contract 2 was presented in the same way as contract 1, differing only in terms of the spacing of the trees, which was now to be at most 10m x 10m. Finally, contract 3 differed to contract 1 only in the duration of the contract, with yearly payments being made for a maximum period of 30 years.

Differences in tree density and contract duration across the contracts will result in differences in the amount of carbon sequestered per acre. We use estimates of carbon content in mango-based agroforestry systems (Clinton Development Initiative, 2011; Gaikwad et al., 2017) to account for these differences and obtain estimates of the carbon supply curve associated with each contract (see Appendix A1 for full details). Combining this information with participants bids allows us to calculate the average WTA per tonne of carbon dioxide per year (USD/tCO2/year) for each agroforestry contract.

As shown in Table 3 Panel A, the average WTA for contract 1 (high density and long duration) is lower than the WTA for both contract 2 (low density and long duration) and contract 3 (high density and shorter duration).[13] As shown in Table 3 Panel B, the lower carbon sequestration capacity of a shorter contract (contract 3) results in sequestration becoming more expensive relative to a longer contract (contracts 1 and 2). Moreover, the lower bids for denser contracts, with higher carbon sequestration capacity, results in a lower average WTA compared to the less dense option (contracts 1 vs contract 2).

These results are not obvious *ex ante*: for example, contract 2 requires both lower investment costs and provides greater flexibility in terms of other land uses than contract 1. Taken together, these choices may reflect the decreasing importance of agricultural production in local livelihood choices, both currently and in the future: longer contracts, that offer more certainty of revenue, while also producing an agricultural product that is potentially valued locally (mangoes), are then preferred to current alternatives (Mazhar et al., 2023). To the extent that these conditions are also applicable to other areas of Fiji, our results can potentially be extrapolated, although with local adaptations (e.g., with respect to the tree species).

TABLE 3: DESCRIPTIVE STATISTICS OF THE AUCTION BIDS

Variable	N	Mean	SD
Panel A: USD/acre/year			
Bid - Contract 1	97	280.344	193.310
Bid - Contract 2	97	299.157	225.691
Bid – Contract 3	97	305.549	223.844
Panel B: USD/tCO_2/year			
Bid - Contract 1	97	8.331	5.745
Bid - Contract 2	97	11.966	9.028
Bid - Contract 3	97	15.134	11.087

Notes: Four outliers in terms of their bids were removed from the analysis (see Section 2.3).

The differences in average bids across the three contracts are shown in Table 4. When bids are measured in USD/acre/year (Panel A), the only statistically significant difference

[13] Four outliers at the top and bottom of the bid distributions were excluded from the analysis. These included three bids on contract 1 at a USD/acre/year of 6750, 2250 and 0.6750 (200.59, 66.86 and 0.02 USD/tCO2/year respectively) and one bid on contract 2 at 0.6 USD/acre/year (0.024 USD/tCO2/year).

observed across the contracts is between contracts 1 and 3 (p-value = 0.039). In contrast, when bids are measured in terms of USD/CO2/year (Panel B), statistically significant differences emerge across all contracts due to differences in their capacity to sequester carbon, reflecting differences in tree density and the duration of contract.

TABLE 4: DIFFERENCES IN AVERAGE BIDS BY CONTRACT (H0: AVERAGE VALUES ARE EQUAL)

Comparison	Mean difference	Std. Dev.	t-statistic	p-value
Panel A: bid, per acre (USD/acre/year)				
Contract 1 vs 2	-18.813	150.41	-1.232	0.221
Contract 1 vs 3	-25.205	118.841	-2.089	0.039
Contract 2 vs 3	-6.392	119.17	-0.528	0.599
Panel B: bid, per ton of CO2 (USD/tCO_2/year)				
Contract 1 vs 2	-3.635	6.035	-5.932	<0.001
Contract 1 vs 3	-6.802	6.925	-9.675	<0.001
Contract 2 vs 3	-3.167	5.689	-5.483	<0.001

Notes: N=97. Four outliers in terms of their bids were removed from the analysis (see Section 2.3).

The cumulative distribution of bids for each contract in terms of USD/acre/year is shown in Figure 2. Across the 3 contracts, approximately 90% of land willing to be converted into agroforestry can be achieved at a price of 450 USD/acre/year. We can see that contract 2 is to the left of contract 1 and 3 in the lower bid range (and therefore is the most cost effective), however, in the middle and upper bid range, contract 1 mostly dominates. These differences are however overall insignificant (p-value of Kolmogorov-Smirnov test for difference in distributions: 0.619 (contract 1 vs contract 2), 0.974 (contract 1 vs contract 3) and 0.294 (contract 2 vs contract 3) respectively). In the remaining of this paper, we examine how these bids translate into carbon supply curves (Section 3) and possible explanations for the heterogeneity in bidding behaviour (Section 4).

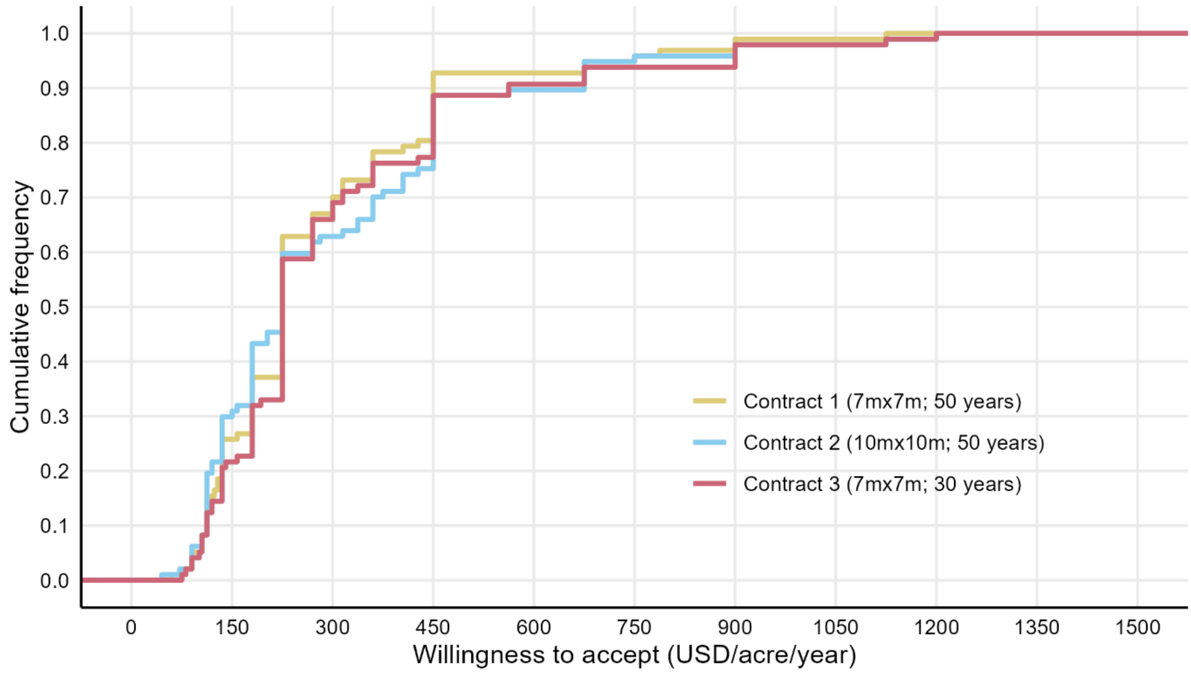


Fig. 2. Cumulative distribution of bids. Four outliers in terms of their bids were removed from the analysis (see Section 2.3).

3. CARBON SEQUESTRATION SUPPLY UNDER DIFFERENT CONTRACTS

Expressing these bids in USD/tCO_2/year allows us to estimate the supply of carbon under each agroforestry contract, and to easily quantify the differences between contracts beyond mean value of bids. As Figure 3 shows, the distribution for contract 1 dominates that of contracts 2 and 3 for all quantities of carbon supply, consistent with differences in means across the contracts (see Table 2) reflecting a preference for contracts that promote denser plantation of mango trees, and remunerate that change in land use for a longer period.

Although bids have a high variability, a fact we will further explore in the next section, almost all carbon can be sequestered by making relatively low payments for land use change: for example, the 2024 average global Emission Trading Scheme price of 35.61 USD/tCO2/year (World Bank, 2025) would be enough to reward all land use change promoted under contract 1 (and almost all that change under contracts 2 and 3: 97% and 95% of the total land use change, respectively). These results suggest that significant carbon sequestration opportunities are available in Fiji.

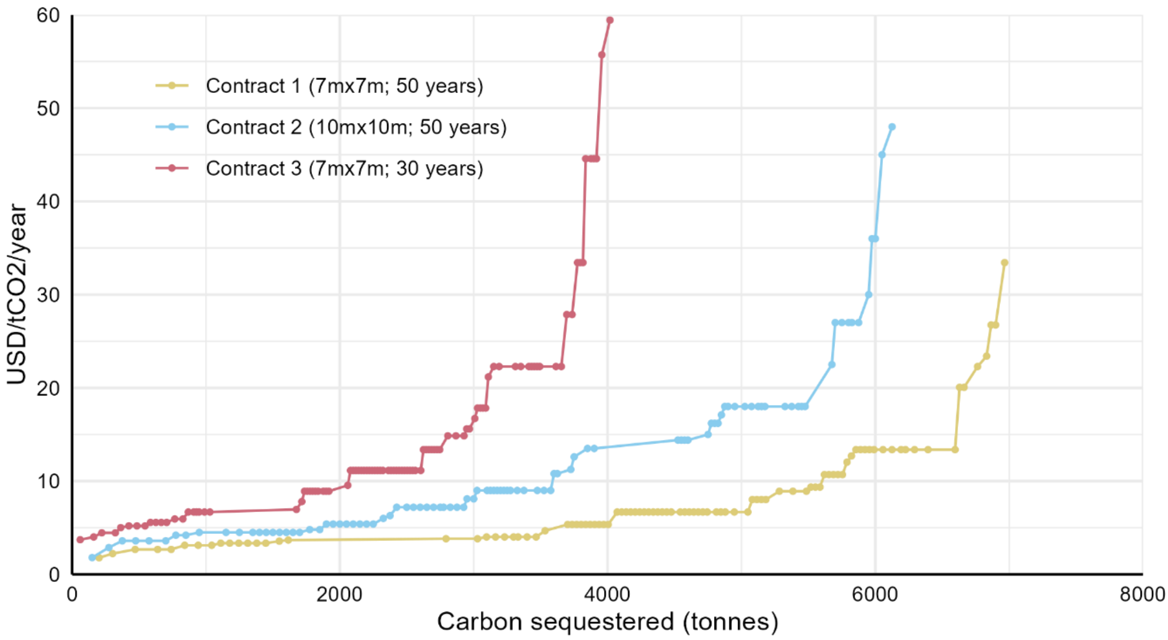


Fig. 3. Supply of carbon. Four outliers in terms of their bids were removed from the analysis (see Section 2.3).

4 HETEROGENEITY IN BIDDING DECISIONS

Bidding decisions reflect bidders' characteristics, including demographic, plot and behavioural characteristics such as those included in Tables 1 and 2. As shown in Figure 3, there is a wide heterogeneity in the value of these bids: even if we focus only on contract 1, which dominates other contracts, bids range from a minimum of 1.78USD/tCO2/year to a maximum of 33.43 USD/tCO2/year. Understanding what drives this heterogeneity is potentially useful for the design of REDD+ programs, as it allows us to determine how much should be paid to maximise participation and carbon sequestration while minimising program costs when large scale auctions are either politically or administratively unfeasible.

One approach to predict the effect of bidders' characteristics on their WTA for contracts designed to change land use and promote agroforestry would be to estimate a regression of bid characteristics on those variables. However, it is unclear a priori what is the specific functional form to be used, in particular, how to account for plausible interactions between variables that might limit the applicability of simple linear models (Shalizi, 2024). One alternative to determine the best predictors of bidding decisions is regression trees, a non-parametric approach that partitions the dataset into smaller, increasingly homogeneous groups (Breiman et al., 1984), allowing us to predict average bids for different subsamples (Shalizi, 2024).

This naturally raises the question of which variables to consider when characterising these bids, given both administrative constraints to targeting (e.g., it may not be feasible to exclude specific groups of beneficiaries (Pritchett, 2005)) and informational constraints (e.g., risk preferences and, in the case of many developing countries, income is private information). We consider three possibilities, which differ in what we assume is feasible. In the first case, information on all variables included in Tables 1 and 2 can be used to characterise bids and define contracts. In the opposite case, we exclude variables that are difficult to observe (e.g., risk preferences) and likely administratively impossible to consider in the definition of agroforestry contracts (e.g., sex of landowner). An intermediate case assumes that some information about bidders is private (e.g., risk preferences) but that policy makers have a wide latitude to choose who can be excluded from contracts.[14]

Figure 4 presents the results of this analysis when we fit a regression tree to predict the respondents bid (USD/CO2/year) for contract 1, controlling for all variables in Tables 1 and 2 (Panel A), and only those categorised as administratively observable and feasible (Panel B).[15,16] The distance from each village to the main urban centre in the region (Sigatoka) is included as an additional control in both models. Starting from the full dataset (the root node of the regression tree), observations are allocated to the left if they meet the condition specified in the split and to the right otherwise. This process continues until the observations reach the terminal nodes.

In the model that uses all available information (Panel A), the data is first split according to whether the respondent has adopted contour farming in the last 10 years. Possibly reflecting the higher costs associated with establishing and maintaining agroforestry plots in contoured plots relative to flat plots (e.g., accessibility, equipment required, etc.), respondents who adopted contour farming have a substantially higher expected bid (14 USD/tCO2/year) compared to those who did not adopt this practice (6.8 USD/tCO2/year). Conditional on not adopting contour farming, the next split reflects the total area of agricultural land. Respondents with larger plots (3.5 acres or more) submit the lowest bids predicted by the regression tree (averaging 3.7 USD/tCO2/year, a value that is less than half the bid submitted by those with smaller plots). In the subset of respondents with larger plots who have not adopted contour

[14] The classification of each variable as administratively observable and feasible as targeting criteria is somewhat subjective. See Tables A2 and A3 in Appendix for our own classification.

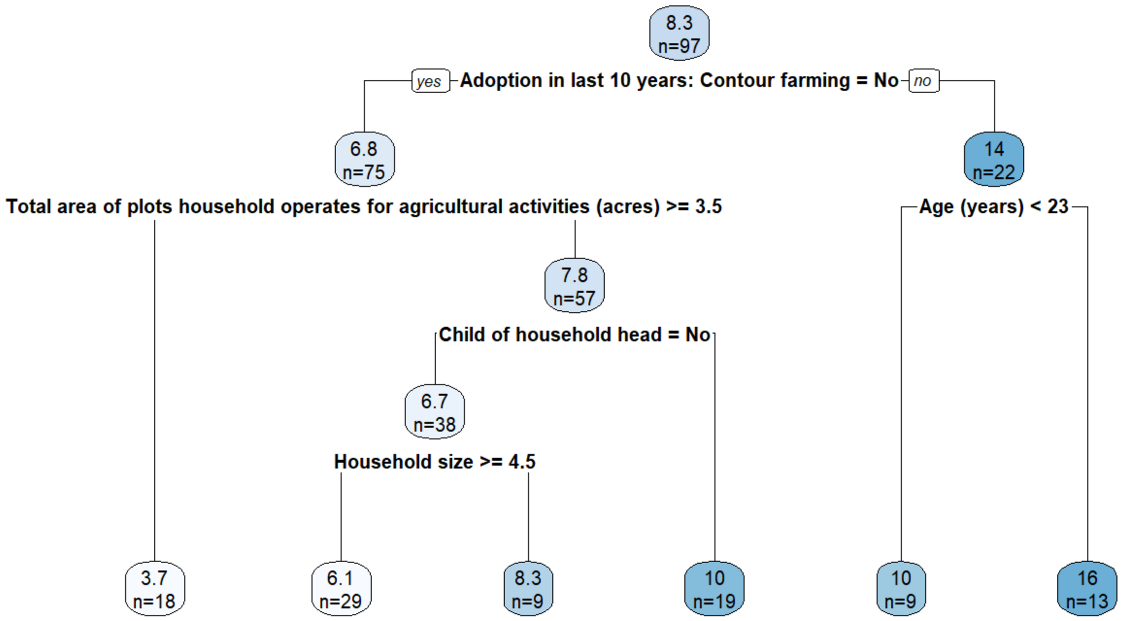
[15] We used the -rpart- package (Therneau & Atkinson, 2023) in R (R Core Team, 2023) to estimate the predictors of these bids using regression trees. The optimal tree minimises the sum of squared error plus the cost of complexity, where the cost of complexity is defined as the cost complexity parameter (determined by 10-fold cross validation) multiplied by the number of terminal nodes. To prevent overfitting, we use conventional values for the minimum number of observations in a node for a split to be attempted and in any terminal node are used (20 and 7, respectively).

[16] See Figure A1 in Appendix for the regression tree modelled on only easily observable variables.

farming, further splits are made based on whether they are the child of the household head (higher bids if they are) and household size (higher bids for households with less than 5 people). For the respondents that practice contour farming, bid size depends on age: the highest bids (16 USD/tCO2/year) are submitted by those aged 23 or older, while those younger than 23 bid lower (10 USD/tCO2/year).

Restricting the variables to only those which are administratively observable and feasible (Panel B) only changes the splits for the subset of respondents who have not adopted contour farming with larger plots, as whether the respondent is the child of the household head and household size are not considered to be administratively feasible variables to define payments for agroforestry. Instead, this group is split based on whether they use their plot for permanent crops (higher bid if not) and age (higher bid if aged 59 or older).

Panel A: All variables



Panel B: Administratively observable & feasible variables

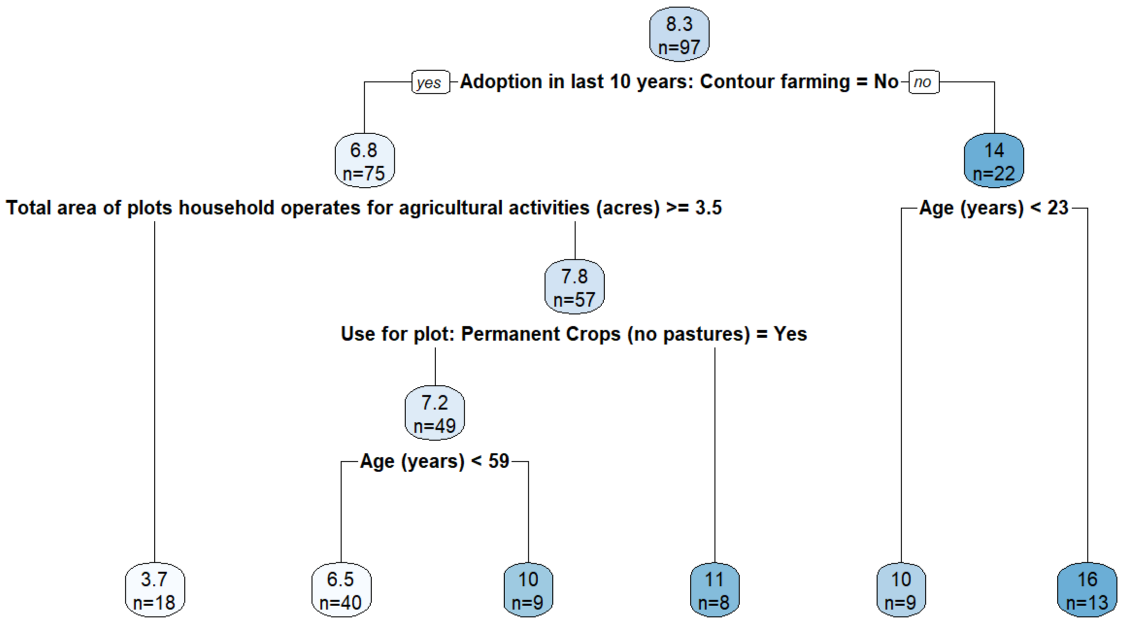


Fig. 4. Regression tree using all variables (Panel A) and only administratively observable and feasible variables (Panel B). See Tables A2 and A3 for variable classification. Outcome: Willingness to accept for agroforestry adoption (contract 1; USD/tCO2/year). Each node includes the predicted bid (top) and percentage of the sample (bottom). Four outliers in terms of their bids were removed from the analysis (see Section 2.3). Minimum number of observations in a node for a split to be attempted and in any terminal node set to 20 and 7 respectively.

The carbon sequestration supply curves associated with the set of contracts defined by each regression tree is contrasted with the those associated with the hypothetical auction and uniform payments in Figure 5. Several conclusions emerge.

Firstly, when aiming to sequester all available carbon under contract 1 (6,965.55 tCO_2), it is more cost effective to provide targeted or discriminatory payments compared to uniform payments, with discriminatory payments determined by the outcome of the auction achieving the same level of carbon sequestration at less than one fifth of the total cost (~USD 49K compared to ~USD 248K). Secondly for very low levels of carbon sequestration, associated with a payment of approximately 4USD/tCO_2/year, there is no clear advantage in running an auction over targeted payments. Third, given bid heterogeneity with each group (i.e., final node, as defined by the structure of the tree), the maximum amount of carbon sequestered in the absence of an auction is approximately 70% of what would be achieved were an auction available (~4,879 tCO_2). At this level of carbon sequestration, the total cost of using an auction to determine payments (~USD 21K) is only slightly above half the total cost required when using targeted contracts (~USD 35K). Finally, relying on administratively observable and feasible characteristics to define contracts further limits sequestration to approximately 45% of the amount achieved through auctions (~3,163 tCO2), with payments to achieve this level of sequestration costing more than twice as much as auction-based payments (~USD 25K compared to ~USD 11K). Although a final decision between these mechanisms depends on their specific transaction costs, this analysis suggests that auctions can in fact be a cost-effective way of implementing REDD+ in Fiji.

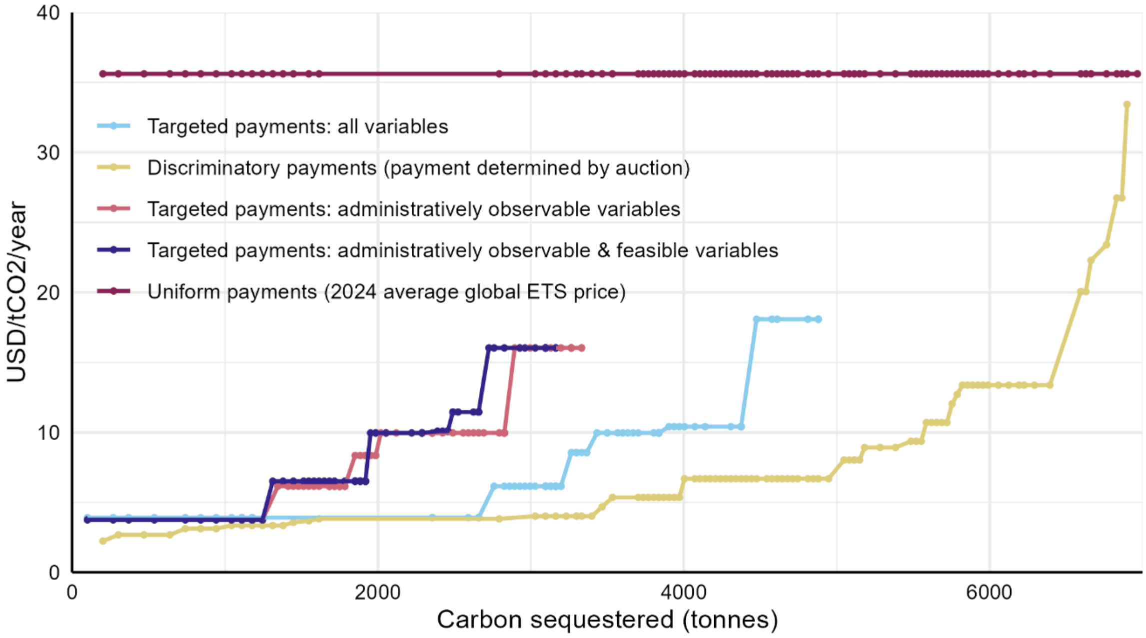


Fig. 5. Carbon sequestration supply curves under discriminatory, targeted and uniform payment mechanisms. See Appendix A4 and A5 for variable classification. Four outliers in terms of their bids were removed from the analysis (see Section 2.3).

5. Discussion

The REDD+ framework is an important mechanism for financing projects that aim at increasing sequestration of greenhouse gas emissions and mitigate the impacts of climate change. This paper uses primary data from Fiji to estimate the supply of carbon sequestration through the establishment of agroforestry contracts. Data on contract bids were collected through a detailed household questionnaire using an incentive compatible Vickery auction mechanism.

We find that the cheapest supply of carbon dioxide sequestration is delivered by a contract that requires denser plantation of trees for a longer period (mango trees with a spacing of 7m x 7m, maintained over a period of 50 years), dominating alternative contracts at all quantities of the carbon supply distribution. Future work may include a broader exploration of contract types, which could be useful in informing the implementation of this program. For instance, contracts could vary with respect the timing of payments, including the possibility of early reimbursement of investment costs, as well as exploring the potential of other tree species according to carbon sequestration potential and agroecological conditions.

The regression tree analysis of the determinants of bids submitted to the hypothetical auction highlighted that a relatively small number of characteristics is capable of predicting average bids by more homogeneous sets of producers. Although a decision of which variables to include in the definition of these contracts includes considerations of administrative feasibility and public acceptability (and, as such, is beyond the scope of our analysis), ultimately there seems to be little difference in the corresponding supply curves and in their relative cost-effectiveness vis-à-vis auctions: while targeted payments offer similar cost-effectiveness to auctions at low and moderate sequestration levels they become increasingly ineffective if one wants to sequester larger amounts of carbon. Future work on the transaction costs associated with the two different mechanisms (auctions vs targeted contracts) is needed before we can reach a firmer conclusion about the economic value of using auctions to allocate agroforestry contracts in the context of REDD+.

REFERENCES

Ajayi, O. C., Jack, B. K., & Leimona, B. (2012). Auction Design for the Private Provision of Public Goods in Developing Countries: Lessons from Payments for Environmental Services in Malawi and Indonesia. *World Development*, *40*(6), 1213-1223. https://doi.org/10.1016/j.worlddev.2011.12.007

Andeltová, L., Catacutan, D. C., Wünscher, T., & Holm-Müller, K. (2019). Gender aspects in action- and outcome-based payments for ecosystem services—A tree planting field trial in Kenya. *Ecosystem Services*, *35*, 13-22. https://doi.org/10.1016/j.ecoser.2018.10.004

Bilal, A., & Känzig, D. R. (2024). The Macroeconomic Impact of Climate Change: Global vs. Local Temperature. *National Bureau of Economic Research Working Paper Series*, *32450*. https://doi.org/10.3386/w32450

Bingham, L. R., Da Re, R., & Borges, J. G. (2021). Ecosystem Services Auctions: The Last Decade of Research. *Forests*, *12*(5). https://doi.org/10.3390/f12050578

Breiman, L., Friedman, J., Olshen, R. A., & Stone, C. J. (1984). *Classification and Regression Trees* (1st ed. ed.). Chapman and Hall/CRC. https://doi.org/10.1201/9781315139470

Choi, B. C., & Pak, A. W. (2005). A catalog of biases in questionnaires. *Preventing Chronic Disease*, *2*(1), A13.

Claassen, R., Cattaneo, A., & Johansson, R. (2008). Cost-effective design of agri-environmental payment programs: U.S. experience in theory and practice. *Ecological Economics*, *65*(4), 737-752. https://doi.org/10.1016/j.ecolecon.2007.07.032

Clinton Development Initiative. (2011). *Mango Orchard Technical Specification for Trees of Hope Project (A Plan Vivo Payment for Ecosystem Services (PES) Project)*. https://cotap.org/wp-content/uploads/_proj_add_doc/Malawi%20-%20TS%20-%20Mango%20Orchard%20-%202011.pdf

Farrelly, T., & Nabobo-Baba, U. (2014). Talanoa as empathic apprenticeship. *Asia Pacific Viewpoint*, *55*(3), 319-330. https://doi.org/10.1111/apv.12060

Fiji Ministry of Forestry. (2020). *Fiji's Forestry Carbon Emission Reduction Activities*. https://www.forestry.gov.fj/pressdetail.php?id=110#:~:text=The%20four%20activities%20proposed%20within,and%20plantations%20establishment%20by%20the

Gaikwad, S., Chalak, S., & Kamble, A. (2017). Effect of Spacing on Growth, Yield and Quality of Mango. *Journal of Krishi Vigyan*, *5*, 50. https://doi.org/10.5958/2349-4433.2017.00011.3

Intergovernmental Panel on Climate Change. (2019). Land–climate interactions. In C. Intergovernmental Panel on Climate (Ed.), *Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (pp. 131-248). Cambridge University Press. https://doi.org/DOI: 10.1017/9781009157988.004

Intergovernmental Panel on Climate Change. (2023). *Climate Change 2023: Synthesis Report*. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf

Jack, B. K. (2013). Private Information and the Allocation of Land Use Subsidies in Malawi. *American Economic Journal: Applied Economics*, *5*(3), 113-135. https://doi.org/10.1257/app.5.3.113

Jack, B. K., & Cardona Santos, E. (2017). The leakage and livelihood impacts of PES contracts: A targeting experiment in Malawi. *Land Use Policy*, *63*, 645-658. https://doi.org/10.1016/j.landusepol.2016.03.028

Jack, B. K., Leimona, B., & Ferraro, P. J. (2009). A Revealed Preference Approach to Estimating Supply Curves for Ecosystem Services: Use of Auctions to Set Payments for Soil Erosion Control in Indonesia. *Conservation Biology*, *23*(2), 359-367. https://doi.org/10.1111/j.1523-1739.2008.01086.x

Jayachandran, S. (2022). The Inherent Trade-Off Between the Environmental and Anti-Poverty Goals of Payments for Ecosystem Services. *National Bureau of Economic Research Working Paper Series, 29954*. https://doi.org/10.3386/w29954

Jindal, R., Kerr, J. M., Ferraro, P. J., & Swallow, B. M. (2013). Social dimensions of procurement auctions for environmental service contracts: Evaluating tradeoffs between cost-effectiveness and participation by the poor in rural Tanzania. *Land Use Policy, 31*, 71-80. https://doi.org/10.1016/j.landusepol.2011.11.008

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry Systems*, *76*(1), 1-10. https://doi.org/10.1007/s10457-009-9229-7

Khalumba, M., Wünscher, T., Wunder, S., Büdenbender, M., & Holm-Müller, K. (2014). Combining Auctions and Performance-Based Payments in a Forest Enrichment Field Trial in Western Kenya. *Conservation Biology*, *28*(3), 861-866. http://www.jstor.org/stable/24480348

Latacz-Lohmann, U., & Schilizzi, S. (2005). *Auctions for Conservation Contracts: A Review of the Theoretical and Empirical Literature*.

Lundberg, L., Persson, U. M., Alpizar, F., & Lindgren, K. (2018). Context Matters: Exploring the Cost-effectiveness of Fixed Payments and Procurement Auctions for PES. *Ecological Economics*, *146*, 347-358. https://doi.org/10.1016/j.ecolecon.2017.11.021

Mazhar, R.; Azadi, H.; Passel, S.V.; Värnik, R.; Pietrzykowski, M.; Skominas, R.; Wei, Z.; Xuehao, B. (2023) Does Contract Length Matter? The Impact of Various Contract-Farming Regimes on Land-Improvement Investment and the Efficiency of Contract Farmers in Pakistan. *Agriculture*, 13, 1651. https://doi.org/10.3390/agriculture13091651

Narloch, U., Drucker, A. G., & Pascual, U. (2011). Payments for agrobiodiversity conservation services for sustained on-farm utilization of plant and animal genetic resources. *Ecological Economics, 70*(11), 1837-1845. https://doi.org/10.1016/j.ecolecon.2011.05.018

Newman, R., & Noy, I. (2023). The global costs of extreme weather that are attributable to climate change. *Nature Communications, 14*(1), 6103. https://doi.org/10.1038/s41467-023-41888-1

Plan Vivo. (2023). *Agriculture and Forestry Carbon Benefit Assessment Methodology*. https://www.planvivo.org/Handlers/Download.ashx?IDMF=da84751a-fc9d-44dd-88ad-bdca8a248eb1

Polasky, S., Lewis, D. J., Plantinga, A. J., & Nelson, E. (2014). Implementing the optimal provision of ecosystem services. *Proceedings of the National Academy of Sciences, 111*(17), 6248-6253. https://doi.org/doi:10.1073/pnas.1404484111

Pritchett, L. (2005, January). *The political economy of targeted safety nets.* (Social Protection Discussion Papers and Notes No. 31498). https://ideas.repec.org/p/wbk/hdnspu/31498.html

Pudasaini, K., Rolfe, J., Bhattarai, T., & Walsh, K. (2024). Comparison of major carbon offset standards for soil carbon projects in Australian grazing lands. *Carbon Management, 15*(1), 2298725. https://doi.org/10.1080/17583004.2023.2298725

R Core Team. (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

REDD+ Fiji. (2024). *Who can participate in REDD+ and Why?* https://fijireddplus.org/%20what-is-redd/who-can-participate-in-redd-and-why/

Shalizi, C. R. (2024). *Advanced Data Analysis from an Elementary Point of View*. https://www.stat.cmu.edu/~cshalizi/ADAfaEPoV/

Skidmore, S., Santos, P., & Leimona, B. (2014). Targeting REDD+: An Empirical Analysis of Carbon Sequestration in Indonesia. *World Development*, *64*, 781-790. https://doi.org/10.1016/j.worlddev.2014.07.013

Southgate, D., & Wunder, S. (2009). Paying for Watershed Services in Latin America: A Review of Current Initiatives. *Journal of Sustainable Forestry*, *28*(3-5), 497-524. https://doi.org/10.1080/10549810902794493

The, B. D., & Ngoc, H. B. (2008). Payments for Environmental Services in Vietnam: An Empirical Experiment in Sustainable Forest Management. *ASEAN Economic Bulletin*, *25*(1), 48-59. http://www.jstor.org/stable/41231494

Therneau, T., & Atkinson, B. (2023). _rpart: Recursive Partitioning and Regression Trees_. R package version 4.1.23. https://CRAN.R-project.org/package=rpart

Thomas, A., Baptiste, A., Martyr-Koller, R., Pringle, P., & Rhiney, K. (2020). Climate Change and Small Island Developing States. *Annual Review of Environment and Resources*, *45*(Volume 45, 2020), 1-27. https://doi.org/10.1146/annurev-environ-012320-083355

United Nations Environment Programme. (2024). *Reducing emissions from deforestation and forest degradation (REDD+)*. https://www.unep.org/explore-topics/climate-action/what-we-do/redd

United Nations Framework Convention on Climate Change. (2024). *What is REDD+?* https://unfccc.int/topics/land-use/workstreams/redd/what-is-redd

Vickrey, W. (1961). COUNTERSPECULATION, AUCTIONS, AND COMPETITIVE SEALED TENDERS. *The Journal of Finance*, *16*(1), 8-37. https://doi.org/10.1111/j.1540-6261.1961.tb02789.x

Wambede, M. N., Akello, G., Mulabbi, A., Barasa, B., Lugumira, J. S., & Amonya, D. (2022). Carbon Sequestration of Fruit Trees under Contrasting Management Regimes. *Indonesian Journal of Geography*, *54*(3), 420-427. https://doi.org/10.22146/ijg.70203

World Bank. (2025). *State and Trends of Carbon Pricing Dashboard.* https://carbonpricingdashboard.worldbank.org/compliance/price

Wünscher, T., & Wunder, S. (2017). Conservation tenders in low-income countries: Opportunities and challenges. *Land Use Policy*, *63*, 672-678. https://doi.org/10.1016/j.landusepol.2016.12.026

Appendix

A1 CALCULATION OF CARBON DIOXIDE PER ACRE UNDER EACH CONTRACT

The Clinton Development Initiative (2011) find that mango trees, at a spacing of 7m by 7m planted over a duration of 50 years, sequester 83.16 tonnes of carbon dioxide per hectare (33.65 tonnes of carbon per acre). These estimates account for a 20% risk buffer to address potential uncertainties and ensure conservative reporting of net carbon benefits, in line with industry standards for carbon offset projects (Plan Vivo, 2023; Pudasaini et al., 2024). We can multiple this figure by 30/50 to estimate roughly the carbon dioxide sequestered for a 30-year-old acre at 20.19 (contract 3). Additionally, as there is 51% less trees in a 10x10 plot compared to a 7x7 plot, carbon dioxide per acre is expected to reduce from 33.65 in a 7x7 plot to 17.16 in a 10x10 plot (contract 2).

This however is likely an underestimate, as the wider spacing results in larger trees (and therefore more carbon) due to less competition for nutrients, water and light (Wambede et al., 2022; Gaikwad et al., 2017). Gaikwad et al. (2017) found that the average height and girth of mango trees in a 5x5 plot were 6.24 meters and 80.8 centimetres, while in a 10x10 plot, the averages were 7.02 meters and 98.5 centimetres, respectively. Approximating the average trees as cylinders, we can estimate the increase in the volume of an average tree in a 5x5 plot ($V = \pi * r^2 * h = \pi * \left(\frac{0.808}{2\pi}\right)^2 * 6.24 = 0.32m^3$) to a 10x10 plot ($V = \pi * r^2 * h = \pi * \left(\frac{0.985}{2\pi}\right)^2 * 7.02 = 0.54m^3$) as 67.19%.

As we are considering a reduction in density from 7x7 to 10x10 as opposed to from 5x5 to 10x10, this increase in volume is likely to be lower, as the reduction in trees from 7x7 to 10x10 (51%) is only 68% of the reduction in trees from 5x5 to 10x10 (75%). Therefore, assuming tree volume increases linearly with density, we would expect that the increase in the volume of an average tree in a 7x7 plot to a 10x10 to be 45.69%. Therefore, while we expect the carbon dioxide per acre in the 10x10 plot to be 17.16, the trees would be 45.69% bigger, increasing the expected carbon dioxide per acre to 25. These estimates are summarised in Table A1 below.

TABLE A1: CARBON DIOXIDE (TONNES) PER ACRE UNDER THE DIFFERENT CONTRACTS

Contract	Carbon dioxide (tonnes) per acre (tCO2/acre)
Contract 1 (7m x 7m; 50 years)	33.65
Contract 2 (10m x 10m; 50 years)	25
Contract 3 (7m x 7m; 30 years)	20.19

A2 AGROFORESTRY AUCTION QUESTIONNAIRE

Agroforestry auction (introduction)

I will now provide some background information relevant to the next series of questions. We have all heard that temperatures are rising and, with it, much of our environment is changing, including sea level rise, more severe storms, and more droughts. As trees can absorb pollution from the atmosphere and reduce the effects of global warming, governments and organisations are looking into ways to finance tree planting projects. That is one of the objectives of a program called Reducing Emissions from Deforestation and Degradation (REDD+), which is still under development but has received the interest of the Government of Fiji. One of the solutions that is under study is to plant trees in land that is currently used for agriculture. This will help reduce the damage from climate change at a global scale, but it can also have local benefits to your community, including cleaner water and more resilient coastlines.

We are here to understand your potential interest in changing the way you use your land, if these programs ever become available in reality. To be more concrete, we want to understand how much you would need these payments to be in order for it to be attractive to you to convert your land from agricultural land to a mix of agriculture and forestry. Although this program is not yet in place, we ask that you please participate as if your decisions had real consequences.

Do you have any questions about the background information?

- o yes
- o no

[if yes] What is your question? ____

____

Today we will be asking you to consider how much you would be willing to bid on agroforestry contracts offered by the Government of Fiji in a hypothetical auction scenario. An agroforestry contract is an agreement where you will be paid a regular pre-specified amount to convert your land from agricultural land to a mix of agriculture and forest. After describing each agroforestry contract, you will be invited to submit a bid for this contract, that is, how much you would ask these regular payments to be in order to adopt that system in your land in the conditions we would describe. We ask you to think of this bid as a serious commitment – the value you ask should reflect a valuation of your own costs and benefits associated with this change. When deciding your bid, you also need to keep in mind two other things. The first is that there is a chance that you may not get the contract. The reason for that is that there will be a fixed budget for this program. Once that amount is reached, no more contracts would be written. Hence, a lower bid makes it more likely for you to win the contract. Additionally, if you are among the winners, the amount of money you would receive would not be equal to your bid, but equal to the bid of the highest winner. [Use whiteboard or pen/paper to explain example] For example, imagine that person 1 had the lowest bid, person 2 had the second lowest bid, and person 3 had the highest bid. Also imagine that the bids of the first two people exhaust the budget. Then, those two people would receive a contract with the bid specified by person 2 and person 3 would not receive anything.

Do you have any questions about the bidding process and how we would determine the winners and payments?

- yes
- no

[if yes] What is your question? ____

[If they stated they have multiple plots in section 3] You told us previously you operate multiple plots for agricultural activities. I want you to think of the plot for which you would be more willing to consider changing its land use to agroforestry.

[If multiple plots] What is the total area of this plot? ____

Unit for previous question

- *acres*
- *hectares*
- *meters squared*
- *chains*
- *other*

[If other] Please specify ____

[If multiple plots] What made you choose that plot? [open question] ____

Pre-auction setup

I will now describe each of the agroforestry contracts and ask for your bid in the hypothetical auction.

[USE APP NOW TO DETERMINE THE RANDOM CONTRACT ORDER AND NOTE IT DOWN HERE] ____

Agroforestry auction (Contract 1)

[CONTRACT 1 - ORDER TO BE RANDOMISED AMONG CONTRACTS] This contract would involve you changing from your current land use to one that involves planting ###mango trees### with a spacing of at least ###7m X 7m###. In the space between trees, you can produce other food crops, like cassava. You would need to pay for the initial investment in establishing the trees, including the plants and labour. The first payment would be made immediately once we could verify that the trees were well planted, with this minimum density, and can be expected to survive under normal weather conditions. These payments would continue every year for ###50 years###, provided after a yearly verification that the trees are still well planted, with this minimum density, and can be expected to survive under normal weather conditions. The value of this payment will be determined by the outcome of the auction.

Do you have any questions about this contract?

- yes
- no

[if yes] What is your question?

Let's now proceed with this auction. Please take some time to consider the costs of establishing the trees, the value of the land given up for this contract, as well as your uses for the money you would receive.

What is the area of land from the previously identified plot that you would be willing to convert to agroforestry for the purpose of the contract?

Unit for previous question

- acres
- hectares
- meters squared
- chains
- other

[If other] Please specify

In Fijian dollars, how much would you be asking in order to change the use of this land to the practices that we just described?

[PROCEED TO NEXT CONTRACT]

Agroforestry auction (Contract 2)

[CONTRACT 2 - ORDER TO BE RANDOMISED AMONG CONTRACTS] This contract would involve you changing from your current land use to one that involves planting ###mango trees### with a spacing of at least ###10m X 10m###. In the space between trees, you can produce other food crops, like cassava. You would need to pay for the initial investment in establishing the trees, including the plants and labour. The first payment would be made immediately once we could verify that the trees were well planted, with this minimum density, and can be expected to survive under normal weather conditions. These payments would continue every year for ###50 years###, provided after a yearly verification that the trees are still well planted, with this minimum density, and can be expected to survive under normal weather conditions. The value of this payment will be determined by the outcome of the auction.

Do you have any questions about this contract?

- yes
- no

[if yes] What is your question?

Let's now proceed with this auction. Please take some time to consider the costs of establishing the trees, the value of the land given up for this contract, as well as your uses for the money you would receive.

What is the area of land from the previously identified plot that you would be willing to convert to agroforestry for the purpose of the contract?

Unit for previous question

- acres
- hectares
- meters squared
- chains
- other

[If other] Please specify

In Fijian dollars, how much would you be asking in order to change the use of this land to the practices that we just described?

[PROCEED TO NEXT CONTRACT]

Agroforestry auction (Contract 3)
[CONTRACT 3 - ORDER TO BE RANDOMISED AMONG CONTRACTS] This contract would involve you changing from your current land use to one that involves planting ###mango trees### with a spacing of at least ###7m X 7m###. In the space between trees, you can produce other food crops, like cassava. You would need to pay for the initial investment in establishing the trees, including the plants and labour. The first payment would be made immediately once we could verify that the trees were well planted, with this minimum density, and can be expected to survive under normal weather conditions. These payments would continue every year for ###30 years###, provided after a yearly verification that the trees are still well planted, with this minimum density, and can be expected to survive under normal weather conditions. The value of this payment will be determined by the outcome of the auction.

Do you have any questions about this contract?

- yes
- no

[if yes] What is your question?

Let's now proceed with this auction. Please take some time to consider the costs of establishing the trees, the value of the land given up for this contract, as well as your uses for the money you would receive.

What is the area of land from the previously identified plot that you would be willing to convert to agroforestry for the purpose of the contract?

Unit for previous question

- acres
- hectares
- meters squared
- chains
- other

[If other] Please specify

In Fijian dollars, how much would you be asking in order to change the use of this land to the practices that we just described?

[PROCEED TO NEXT CONTRACT]

Agroforestry auction (Conclusion)

That was the final contract.

[Discussion question] Reflecting on your responses to these questions, what factors did you consider when formulating your bid?

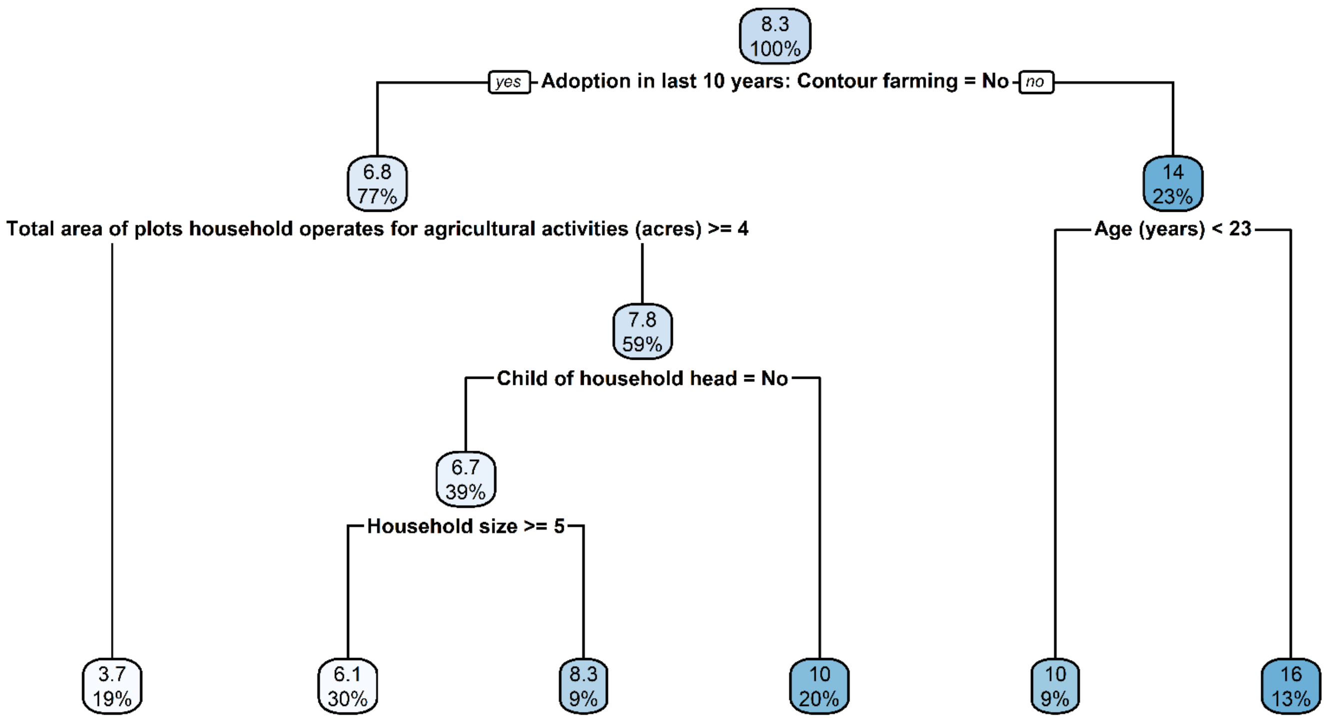


Fig. A1. Regression tree using subset of easily observable variables. See Table A2 and Table A3 for variable classification. Outcome: Willingness to accept for agroforestry adoption (contract 1; USD/tCO2/year). Each node includes the predicted bid (top) and percentage of the sample (bottom). Four outliers in terms of their bids were removed from the analysis (see Section 2.3). Minimum number of observations in a node for a split to be attempted and in any terminal node set to 20 and 7 respectively.

TABLE A2: VARIABLES FROM TABLE 1 CATEGORISED AS ADMINISTRATIVELY OBSERVABLE AND FEASIBLE

Variable	Administratively observable?	Administratively observable?
Panel A: Respondent characteristics		
Household head (0 no; 1 yes)	Yes	No
Child of household head (0 no; 1 yes)	Yes	No
Spouse of household head (0 no; 1 yes)	Yes	No
Parent of household head (0 no; 1 yes)	Yes	No
Relationship to the household head: other (0 no; 1 yes)	Yes	No
Sex (1 female; 0 male)	Yes	No
Age (years)	Yes	Yes
Highest level of education attained: primary (0 no; 1 yes)	Yes	Yes
Highest level of education attained: secondary (0 no; 1 yes)	Yes	Yes
Highest level of education attained: tertiary (0 no; 1 yes)	Yes	Yes
Mobile phone ownership (0 no; 1 yes)	Yes	Yes
Smart phone ownership (0 no; 1 yes)	Yes	Yes
Likelihood of wallet return with 25 FJD by villager: Likely (0 no; 1 yes)	No	-
Likelihood of wallet return with 25 FJD by villager: Unlikely (0 no; 1 yes)	No	-
Likelihood of wallet return with 25 FJD by villager: Don't know (0 no; 1 yes)	No	-
Likelihood of wallet return with 25 FJD by outsider: Likely (0 no; 1 yes)	No	-
Likelihood of wallet return with 25 FJD by outsider: Unlikely (0 no; 1 yes)	No	-
Likelihood of wallet return with 25 FJD by outsider: Don't know (0 no; 1 yes)	No	-
Amount gambled (0-100 FJD; 50% lose 50% win 2.5x)	No	-
Panel B: Household characteristics		
Household size	Yes	No
Income level: Allows you to build your savings (0 no; 1 yes)	No	-
Income level: Allows you to save just a little (0 no; 1 yes)	No	-
Income level: Only just covers expenses (0 no; 1 yes)	No	-
Income level: Not sufficient to meet expenses (0 no; 1 yes)	No	-
Agriculture/forestry main livelihood of household (0 no; 1 yes)	No	-
Agriculture/forestry main cash income source of household (0 no; 1 yes)	No	-

TABLE A3: VARIABLES FROM TABLE 2 CATEGORISED AS ADMINISTRATIVELY OBSERVABLE AND FEASIBLE

Variable	Administratively observable?	Administratively feasible?
Panel A: Plot characteristics		
Number of plots household operates for agricultural activities	Yes	Yes
Total area of plots household operates for agricultural activities (acres)	Yes	Yes
Land tenure of plot to adopt agroforestry: Native Lease (0 no; 1 yes)	Yes	Yes
Lease cost (USD/acre/year) estimated if traditional ownership or freehold)	No	-
Plot ownership: household head (0 no; 1 yes)	No	-
Plot ownership: child of household head (0 no; 1 yes)	No	-
Plot ownership: spouse of household head (0 no; 1 yes)	No	-
Plot ownership: parent of household head (0 no; 1 yes)	No	-
Years operating plot for agricultural activity	No	-
Use for plot: Temporary Crops (0 no; 1 yes)	Yes	Yes
Use for plot: Permanent Crops (no pastures) (0 no; 1 yes)	Yes	Yes
Use for plot: Permanent Crops with pastures (0 no; 1 yes)	Yes	Yes
Use for plot: Natural Forest (0 no; 1 yes)	Yes	Yes
Use for plot: Planted Forest (0 no; 1 yes)	Yes	Yes
Use for plot: Home Gardens (0 no; 1 yes)	Yes	Yes
Use for plot: Floriculture (0 no; 1 yes)	Yes	Yes
Travel time from house to plot: 1 - 2hrs (0 no; 1 yes)	Yes	Yes
Travel time from house to plot: Less than 1hr (0 no; 1 yes)	Yes	Yes
Panel B: Climate change: Impacts & adaptation		
Impacts of climate change on livelihood: not at all concerned (0 no; 1 yes)	No	-
Impacts of climate change on livelihood: slightly concerned (0 no; 1 yes)	No	-
Impacts of climate change on livelihood: somewhat concerned (0 no; 1 yes)	No	-
Impacts of climate change on livelihood: moderately concerned (0 no; 1 yes)	No	-
Impacts of climate change on livelihood: very concerned (0 no; 1 yes)	No	-
Changes to farm in last 10 years: Loss of soil fertility (0 no; 1 yes)	No	-
Changes to farm in last 10 years: Decline in crop yield (0 no; 1 yes)	No	-
Changes to farm in last 10 years: New pest and disease (0 no; 1 yes)	No	-
Changes to farm in last 10 years: Increased soil erosion (0 no; 1 yes)	No	-
Changes to farm in last 10 years: Increased weather uncertainty (0 no; 1 yes	No	-
Changes to farm in last 10 years: Increased frequency of floods (0 no; 1 yes)	No	-
Any shock occurred in last 10 years (0 no; 1 yes)	No	-
Shock in last 10 years: Waterlogging (0 no; 1 yes)	No	-
Shock in last 10 years: Saltwater intrusion (0 no; 1 yes)	No	-
Shock in last 10 years: Bushfire (0 no; 1 yes)	Yes	Yes
Shock in last 10 years: Pest and disease (0 no; 1 yes)	No	-
Shock in last 10 years: Drought (0 no; 1 yes)	Yes	Yes
Shock in last 10 years: Flood (0 no; 1 yes)	Yes	Yes
Adoption in last 10 years: Agroforestry (0 no; 1 yes)	Yes	Yes
Adoption in last 10 years: Planting climate resilient crops (0 no; 1 yes)	Yes	Yes
Adoption in last 10 years: Use of recommended agriculture inputs (0 no; 1 yes)	No	-
Adoption in last 10 years: Contour farming (0 no; 1 yes)	Yes	Yes
Adoption in last 10 years: Waste product management (0 no; 1 yes)	No	-
Species of tree planted for agroforestry: Fruit trees (0 no; 1 yes)	Yes	Yes
Species of tree planted for agroforestry: Medicinal trees (0 no; 1 yes)	Yes	Yes