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Comparing tools to predict REDD+ conservation costs to Amazon smallholders

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1. Introduction

Payments for environmental services (PES) are compensating landowners or resource stewards for safeguarding ecosystem externalities βnot accounted for in the marketplace (Ferraro and Kiss, 2002; Wunder, 2007; Engel et al., 2008). PES could become an important tool for forest-based climate change mitigation under REDD+ (Reducing Emissions from Deforestation and forest Degradation including conservation, sustainable forest management and enhancement of forest carbon stocks) (Wunder 2009), and be a quick way to reduce carbon emissions (Stern, 2007; Angelsen, 2008).

Proper design of such incentive instruments requires knowledge about the opportunity costs of forest conservation borne by affected agents, notably landowners and users. The main costs faced by landowners may be opportunity costs which may vary considerably, but landowners may also face protection costs (e.g. fencing off contracted conservation areas against third-party intruders) and transaction costs (e.g. legally documenting to-be-contracted landholdings). Moreover as information is typically asymmetric, information rents can be large (Ferraro, 2008). Insights into the level and variation of opportunity costs are pre-requisites for successful cost-effective conservation outcomes (Ferraro, 2008; Jack et al., 2009).

Opportunity costs of forest conservation have been estimated based on secondary census-based data (Börner et al., 2010), global simulation models (Kindermann et al., 2008), or household-level surveys (Grieg-Gran, 2008). Common to the first two approaches are assumptions on the homogeneity of productivity across households, input and output prices, time preferences, and risks. Yet, in low-income countries, the ill-functioning of many factor markets implies that these assumptions are often grossly violated (Parks, 1995; Dercon, 2002; Grieg-Gran, 2008). The third approach, i.e. survey-based cross-sectional assessments of opportunity costs, overcomes some of these issues, particularly the homogeneity assumptions, but due to complexity of farming systems, this approach is still challenging to implement at best (Jack et al., 2009). Furthermore, dynamic factors such as risk mitigation actions are hard to account for and consequently document (Sunderlin et al., 2005).

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This justifies the search for improved methods to assess opportunity cost among landholders, including for informing REDD+ implementation. One method to induce farmers to reveal their true costs can be through real auctions for finite conservation contracts with competitive bidding among landowners (Latacz-Lohmann and Schilizzi, 2005). Conservation procurement auctions have traditionally been applied in high-income countries (e.g. Stoneham et al., 2003; Latacz-Lohmann and Schilizzi, 2005), yet lately we have seen various field experiments and pilots in low-income countries, e.g. Jack et al. (2009), Jindal et al. (2013), Narloch et al. (2011a, 2015) Khalumba et al. (2014), and Pant (2015).

Contingent valuation (CV) methods, i.e. stated preference methods, have also been used to assess landowners' willingness to accept (WTA) compensations for entering environmental contracts that limit their land use options. Again, such studies are widespread in high-income countries (Horne, 2006; de Groot and Hermans, 2009; Gadaud and Rambonilaza, 2010; Broch and Vedel, 2012; Vedel et al., 2015a,b). While stated preference studies have been applied to low-income countries (Whittington, 2002, 2010), WTA assessments for environmental service provision remain incipient there (Southgate et al., 2010; Krishna et al., 2013; Kassahun and Jacobsen, 2015). Under suitable conditions WTA measures should reflect the opportunity costs incurred of entering a contract. Strategic bidding, yeah-saying and other potential response biases are inherent to stated preference approaches, in particular when incentives for truth telling are not clear to respondents (Bateman et al., 1995; Carson et al., 2001; Harrison, 2006). Careful framing of the payment question can enhance their validity and reliability (Bateman et al., 1995), but has proved challenging particularly in low-income countries (Whittington and Pagiola, 2012).

Yet, stated preferences hold some advantages over real conservation auctions. First, they are considerably cheaper, as no real contract needs management. Second, they can more easily test differential design options, since treating people differently in real-world auctions may raise ethical objections over fairness or deceit. Third, it is possible to control for some of the unobserved variation that occurs due to interaction between participants, or over time. Stated preference studies thus remain popular, and their application to forests in low-income countries could be a promising avenue.

In the following, we apply an auction-framing version of CV. We investigate the stated WTA and perceived opportunity costs amongst landholders in and around two sustainable development reserves in the Brazilian Amazon, when they are asked to consider a conditional REDD+ contract requiring them to halt all tree-felling and deforestation on their lands. Methodologically, we draw on key insights from Carson and Groves (2007), who discussed conditions for stated preference surveys to provide meaningful results. Notably, they argue that agents in their CV responses need to perceive the presented survey context as potentially consequential for the principal's actions, and thus their own resulting welfare. Moreover, the survey instrument needs to be incentive-compatible, i.e. it should pay off for the agents to reveal their true WTA (Dupraz et al., 2003). This will often require the principal to commit to a price-setting mechanism before the agent responds (Carson and Groves, 2007).

The landholders in our sample had experience with, or at least knowledge of a related policy instruments, namely the *Bolsa Floresta* program (Börner et al., 2013). REDD+ pilots have also been implemented in the area, namely the Juma Reserve (FAS et al., 2009). Respondents were thus already conceptually familiar with forest conservation contracts, and hence more likely to perceive their own responses as consequential for future conservation programs that potentially matter for their livelihoods.

Finally, we compare the performance of our auction-framed CV to that of standard CV framing. We scrutinize socio-demographic drivers of stated WTA under both framings. Further, we also gathered detailed household survey data on rents from local production systems that are used to determine the opportunity costs of forest conservation. We compare these measures of opportunity costs with the stated WTA measures.

Thus, our paper contributes to the literature on assessing opportunity costs by developing and evaluating a new, alternative auction framed CV. To our knowledge, this is the first study to attempt such a comparison. We further analyse the drivers of stated WTA. Finally, we compare measures of opportunity costs based on stated WTA with measures based on agricultural rent data.

In the following, we start out by discussing the case context itself (Section 2), and elaborate our hypotheses about WTA and framing effects (Section 3). We then present the results of the different framings and analysis of socioeconomic variables on WTA (Section 4). After discussing these in relation to policy and practice (Section 5), we conclude (Section 6).

2. Case study area and survey method

The Amazon biome holds the world's largest expanse of tropical rainforest, of which two thirds lie in Brazil. Overall, the region has a history of aggressive deforestation, following infrastructure and agricultural expansion (Laurance et al., 2004).17% of the Brazilian Amazon's forest cover has been lost in the past 30 years (INPE, 2008). However, in 2004 annual deforestation peaked at 27,772 km^2, and dropped till 2015 by four fifths (INPE, 2015).

In the more remotely located Amazonas State, deforestation is lower, but clearing pressures have gradually been moving from the 'Arc of Deforestation' into its southern parts (May et al., 2011). The *Bolsa Floresta* (Forest Allowance) program, implemented since 2007 in 15 conservation units (FAS, 2009), pays resident households monthly 50 Brazilian Real (BRL) (at the time of data collection, US$30.07[1]) for committing to zero deforestation in primary forests, though allowing some deforestation and tree-felling in secondary forests. Coupled with initiatives aimed at improving community organization and

[1] 1 BRL = 0.6014 USD (http://www.oanda.com/ at 1 March 2011)

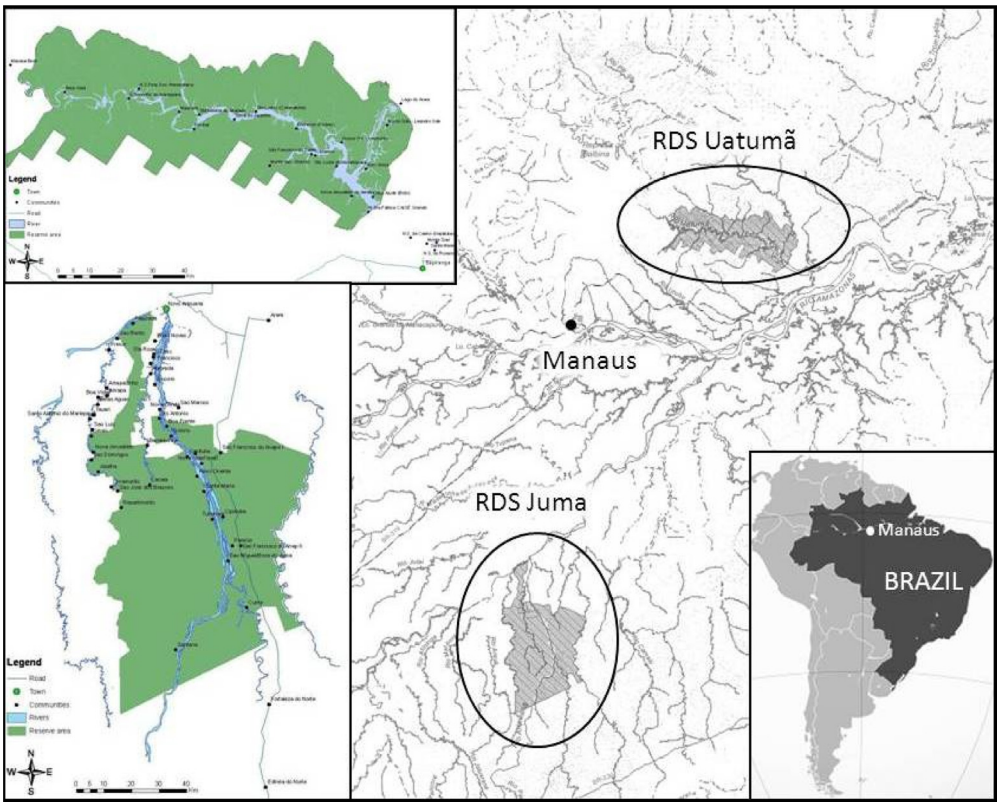

Fig. 1. The Juma and Uatumã Sustainable Development Reserves, Amazonas, Brazil.

livelihoods, the program aims to empower communities and strengthen conservation activities within reserve boundaries (Börner et al., 2013). Importantly, voluntarily leaving *Bolsa Floresta* is an option at all times.

We surveyed households in two sustainable development reserves (SDR) – a form of protected area that allows resident populations[2] – Juma (589,612 ha) and Uatumã (424,430 ha) (Fig. 1), as well as households living in buffer areas of these reserves. We selected the two reserves due to their currently modest, but high projected future deforestation up to 2050 (Soares-Filho et al., 2006; SDS et al., 2009). Plans to build two highways in Juma, which has been an SDR since 2006, were projected to accelerate forest loss in the reserve (FAS et al., 2009). The populations in the two reserves are rather homogeneous: they are ethnically of mixed (indigenous, white, and black) origin, and are largely subsistence-based smallholders engaged in farming, fishing, and forest extraction, with few options for commercially viable land-use expansion. Cassava is the main crop grown, supplemented by fruits (e.g. bananas, watermelon). Outside the reserves, however, some farms are distinctively larger focusing on market-oriented livestock production (Börner et al., 2013). The Bolsa Floresta Program in the Juma Reserve has been cast as the first REDD+ project in Brazil (Viana, 2008) and achieved gold certification under the Climate, Community and Biodiversity Alliance standards.

Local rules of forest use are multi-layered. First, under SDR rules households inside reserves are allowed to clear 3–4 ha/year of forestland for subsistence agriculture – preferably not primary forest, although this is not fully excluded. Land-use rights in the reserves are governed by the *concessão de direito real de uso* (CDRUs; "concessions of real right of use").[3] These are issued either to households or to community associations, whilst the state remains the d*e jure* landowner, and can be granted from 10 years to indefinitely (Carvalheiro et al., 2010). Secondly, households inside the reserve that have voluntarily enrolled in the *Bolsa Floresta* program face stricter rules: zero expansion into primary forest (only secondary forest can be cleared), but some timber extraction from primary forests is allowed. Thirdly, outside the reserves the Forest Code mandates land users to keep 80% of their land under forest cover, yet enforcement is relatively slacker. Our survey data (cf. Table 2 below) shows households on average self-declared to have cleared at least some forest, within as well as outside the reserves.

[2] SDR are created for nature and biodiversity conservation while ensuring sustainable resource use and socio-economic development of livelihoods of local communities (Medeiros, 2006; Servico Florestal Brasileiro, 2010).

[3] Under Decree-Law No. 271 of 28 February 1967, the CDRU grants use of public or private land for a specified or indeterminate period, and is resolvable as a real right for specific purposes of, inter alia, settlement in social interest, urbanization, industrialization, construction, cultivation of land, sustainable use of wetlands, and preservation of traditional communities and their livelihoods (Amended by Law No. 11,481, 2007).

Table 1
Sampling frame showing number of households across treatment and location.

Area	Standard payment card CV # of households	Auction CV # of households	Total number of households	Total number of villages
Inside Uatumã	69	53	122	11
Outside Uatumã	28	22	50	4
Inside Juma	58	64	122	24
Outside Juma	24	22	46	3
Total	**179**	**161**	**340**	**42**

2.1. Obtaining foregone income measures

Fieldwork was conducted between February and May 2011. 340 households in 43 villages located inside and just outside Uatumã and Juma reserves were randomly selected for interviews[4] (Table 1; Fig. 1; sampling intensity approximately 30%). The household survey (see online material) collects the information necessary to estimate opportunity costs of conserving forestland, and central to this are estimates of foregone agricultural rent from crops and small animal production across households,[5] as well as estimates of sustainable forest rents. Nonetheless, survey estimates may be affected by variations in productivity, respondent recall errors, and other measurement errors (Angelsen et al., 2011).

2.2. Contingent valuation instruments: auction and standard formats

We randomly allocated the auction and standard framing version of the CV across the sample. In both versions, the WTA question was preceded by a cheap talk script,[6] after which the interviewer guided the respondent through the WTA elicitation. The respondent was then shown a payment card from which they could evaluate possible payments and ultimately select their minimum required payment, or provide an open answer beyond the payment card range. A pilot survey suggested a suitable range up to 3000 BRL per month/hectare, in line with estimates of relevant agricultural rents. A payment card format was chosen, as it could easily be adapted to both formats. Payment cards have been criticized for anchoring and/or framing effects, although there is weak empirical evidence of these effects (Carson and Groves, 2007). On the other hand, they may also provide respondents with a realistic range of payments (Bateman et al., 2002; Carson and Groves, 2007). Other conditional cash transfer schemes in operation in Brazil could also provide the agents with an anchor. To reduce such influence and reduce hypothetical bias, we constructed the survey to ensure that the WTA section followed directly after the questions on agricultural, livestock and environmental income derived from their land, as well as questions on access to markets, salaried employment etc. This ensures awareness among respondents about their current income portfolio and options, and was deliberately intended as a firm bidding anchor (van Exel et al., 2006).

Both the standard and the auction framing CV interviews included the following information: *i*) Respondents were briefly introduced to forest carbon storage and landowner compensations for foregoing forest clearing, *ii*) They were asked to imagine that the government or an NGO would offer them a voluntary contractual guaranteed payment for foregoing all timber harvest and deforestation (i.e. significantly stricter than all pre-existing land-use rules, cf. above), accompanied by monitoring and enforcement policies; *iii*) Contracts would be for 50 years, but with monthly monitoring and payments, thus discouraging hit-and-run intentions.[7] Respondents were asked to consider the importance of their deforestation and timber harvest activity for their household and then asked only once to state their minimum WTA per hectare, assuming that *all* remaining forestland under control of the household is contracted, in order to avoid speculative on-farm leakage. This contrasts to other auctions (e.g. Stoneham et al., 2003) and conservation investments (e.g. Ferraro, 2004) where agents could freely set both bids and quantities, and potentially more than once.

Our standard CV framing respondents were then asked to state the minimum compensation per hectare and month needed to accept a contract on the described terms. Importantly, the standard framing had no explicit rule for setting contract price. Like for the auction framing, we explained that contracts were voluntary and subject to budgetary restrictions; both features likely to reduce strategic overbidding.

The auction-framing format developed for this study was designed to mimic the uniform price auction applied by Jack et al. (2009) in a real-world PES scheme. It lays out a 'first-rejected-bid-sets-the-price' mechanism, after a cut-off price

[4] Households were interviewed on their socio-economic characteristics, including incomes derived from forest, crops, livestock, salary work, businesses, or transfers and miscellaneous sources. We also asked about productive assets (livestock, business, land), recent changes in land use (e.g. forest cover) and their knowledge of the REDD+ issues. This part of the survey built on CIFOR's Poverty and Environment Network project (Angelsen et al., 2011; http://www.cifor.org/pen/), and is part of CIFOR's Global Comparative Study on REDD (http://www.forestsclimatechange.org).

[5] In order to make inter-household welfare comparisons, income figures were adjusted to adult-equivalent units (aeu), taking into account size and composition of households (Cavendish, 2002). This practice is common in the poverty-environment literature. Conversion factors for Brazil were provided by Claro et al. (2010). Income and asset measures were then divided by the aeu conversion factor for each household.

[6] Cheap talk script refers to a text preceding the hypothetical scenario, explicitly telling respondents that hypothetical bias exists, that people tend to report numbers that are often too high, and to be aware of this. It has been shown to effectively reduce WTP or WTA (Cummings and Taylor, 1999).

[7] This mimics existing monthly payments made in the current *Bolsa Floresta*, and the long-term land-use rights of households.

Table 2
Descriptive statistics for the two framing types.

	Auction framing sample					Standard framing sample					Test of equal mean
Variable (unit; fraction)	Mean	s.d.	Median	Min	Max	Mean	s.d.	Median	Min	Max	t-statistic[c]
Market distance (km)	70.3	39.9	64	15	160	73.7	42.6	65	15	160	0.77 (ns)
Age of HH head, (years)	45.9	15.6	43	22	89	46.3	15.4	45	18	84	0.29 (ns)
Years of Education of HH head	3.7	3.6	3	0	18	3.7	3.5	4	0	16	0.02 (ns)
Household (HH) size	4.8	2.6	5	1	12	4.8	3.0	5	1	16	0.10 (ns)
HH members above 15 years	2.7	1.4	2	1	8	3	1.8	2	1	10	1.76 *
Area of land controlled, rented or borrowed (ha)	98.5	194.2	50	0.01	1600	86.2	147.7	50	0	1088.0	−0.65 (ns)
Area of forest and old secondary forest, (ha)	87.2	189.7	41.25	0	1594	71.5	122.2	43	0	895.5	−0.90 (ns)
Inside reserves	83.5	218.2	38.5	0	1594	62.2	122.9	41.25	0	895.5	0.83 (ns)
Outside reserves	91.2	148.7	56.8	0	990.5	83.8	121.0	46.25	0	649.2	0.35 (ns)
Total land cleared in past 3yrs (ha)	3.4	17.8	1	0	225	3.2	15.2	3403.4	0	200	−0.14 (ns)
HH total income per aeu (BRL/year 95%;)[a]	4292.5	3310.3	3651.8	−608.9	14840.7	4298.1	3438.1	935.9	−896.4	15278.2	0.02 (ns)
Household assets per aeu (BRL/year; 95%)	1547.9	1537.1	1069.4	0	7580.56	1506.6	1572.8	117.6	0	7701.6	−0.24 (ns)
Net agricultural productivity (BRL/aeu, ha and year)[b] (95%)	281.3	346.7	140.5	−920.8	1530.7	367.4	545.8	0	−2400	2455.5	1.61 (ns)
Net livestock and animal product. (BRL/aeu, ha and year; 95%)	−9.5	190.6	0	−2320	361.9	14.8	59.2	0	−50.2	381.9	1.62 (ns)
Business income (BRL/aeu and year; 95%)	93.8	522.5	0	−358.4	4800	105.2	897.0	22.5	−2520	10526.32	0.14 (ns)
Salary income (BRL/aeu and year; 95%)	534.1	1041.0	0	0	5400	559.5	1034.8	628.6	0	5157.6	0.22 (ns)
Forest income (BRL/aeu and year; 95%)	976.8	1141.7	506.2	−849	4522.7	928.7	1034.8	370.7	−724.7	3851.1	−0.41 (ns)
Miscellaneous income (BRL/aeu and year; 95%)	790.8	1184.4	382.0	0	6800	812.2	1256.7		0	6800	0.16 (ns)

[a]For all measures followed by "(95%)", the top 5% observations have been omitted to eliminate the effect of outliers. All income measures have been standardized to adult equivalence units (aeu), to correct for differences in family size and available labour (Cavendish, 2002).
[b]Hectares (ha) refer to cropland, agroforestry and fallow hectares per household.
c = Significance levels are as follows: 5% = *, 1% = ** and 0.1% = ***.

determined by the principal's budget. This effectively decouples the individual agents from setting the final price. It follows the principles of the Becker-deGroot-Marschack mechanism (Becker et al., 1964) and the Vickrey auction (Vickrey, 1961), but is reversed here, with a single buyer and multiple competing sellers. Both auction types share the characteristic that bidding one's true cost is a weakly dominant strategy. Specifically, in the auction framing the interviewer carefully explained that the principal would rank all collected bids according to price and then accept only bids coming in below a cut-off price determined by an undisclosed budget. All eligible and selected households would receive that same price, irrespective of their stated bid. The interviewer then stressed the incentive implications: understating the costs would not affect the cut-off price nor the probability of getting a contract, but would imply that agents would not cover their true costs should agents win a contract – hence, a potential loss. Conversely, overstating the bid would only imply a risk of losing a possibly profitable contract. Thus, the interviewer essentially explained to the respondent that truth-telling is a weakly dominant strategy. When undertaking auctions, collusion between agents could thwart the pricing mechanism. In our case, the communities and households were scattered over a rather large area, with boating transport being costly. Hence, the cost of colluding across the several hundred participants would be prohibitive.

3. Hypotheses about WTA and framing effects

In the auction-framing CV, respondents face a clear price-setting and contract allocation mechanism: the probability of being offered contracts, and the price received, are both independent of respondent-stated WTA. Agents thus have incentives to bid their true opportunity costs. Conversely, standard framing CV offers no clear price and allocation scheme, so agents may think that a low stated WTA increases their probability of winning a contract, and probably decreases their price received. They may thus perceive incentives for strategic bidding, rather than truth-telling. They have no incentive to state WTA below their true opportunity cost: trading off a high probability of being offered a contract only makes sense if WTA is at least as high as true conservation costs. But they might have incentives to state a higher WTA, e.g. if they perceive that some overstatement would unlikely jeopardize their chances of winning a contract. Consequently, we expect that standard-framing CV respondents have no incentive to understate WTA, but that some would overstate their WTA.

Hence, we hypothesize different mean and variance of WTA-measures under auction framing (WTA^{Auc}) versus standard (WTA^{Std}):

Hypothesis 1. Compared to standard framing, the auction framing reduces mean WTA ($\text{WTA}^{\text{Std}} > \text{WTA}^{\text{Auc}}$) and its sample variance ($\hat{\sigma}^{Stdc} > \hat{\sigma}^{Auc}$).

Secondly, we scrutinize which socio-demographic variables determine stated WTA, using a logit model of the probability of a household accepting a given price. For the individual household, the expected opportunity costs of foregoing future deforestation and timber harvesting will depend on their future ability and plans for income-generating activities that are incompatible with scheme-imposed rules. Their stated WTA should reflect these expectations and plans. We have no direct measures of expectations and plans, but would expect them to correlate positively with current estimated agricultural rents, approximated by gross income from crops, livestock, and animals per hectare, minus all input costs except for household labour. Moreover forest income is expected to play a small role as it is mainly sustainable (non-timber) forest income. This is our second main hypothesis:

Hypothesis 2. The required minimum compensation (WTA) will increase proportionally with opportunity cost of land, as indicated by agricultural rents per hectare minus foregone forest rents

Some caveats may apply. First, in addition to production input costs, externally sold products will also carry transport and marketing costs, which tend to increase with distance to markets. Second, being paid for forest conservation would likely free family labour for other remunerative activities, but this would vary with household size, gender and salaried income options, as well as the distance to market. Finally, households may face diminishing returns to converted forestland e.g. due to larger distance from home, declining soil fertility, etc. Therefore the role of socioeconomic and contextual household attributes can be important. The probability that a household i would accept a given compensation payment p_n, as represented by different payment card levels could then be modelled – using a logit form, due to the discrete nature of the payment card:

$$Pr(WTA_i \leq p_n) = \frac{1}{1 + e^{-(\alpha + \gamma p_n + \beta^y y_i + \beta^z z_i + \beta^{xz} x_i)}} \tag{2}$$

Here the probability of a household's WTA being below a given payment level is set as a function of the size of the payment level (p_n), agricultural rent variables (vector y), socio-demographic variables incl. alternative income options (vector z,) and contextual household attributes (e.g. the treatment variable, land controlled, or distance to markets) (vector x). The β's and the γ are corresponding parameters to be estimated.

Having obtained both stated WTA and agricultural rent measures from households, we calculate and compare opportunity cost estimates based on both of these data sets, with the following hypothesis about their comparative size:

Hypothesis 3. Opportunity costs estimates based on WTA will be higher than opportunity cost estimates based on agricultural rent

Table 3
Parametric and non-parametric WTA estimates (mean and std. deviation) across treatments and censorings. In Brazilian Real (BRL)/hectare/month.

		Parametric WTA estimates			Non-parametric (Turnbull) WTA estimates		
Treatment	N	Mean	Std. dev.	Std. error of mean	Mean	Std. Dev.	Std. Error of Mean
WTA^{Auc}	158	161.74	499.39	39.73	94.18	6.98	0.55
WTA^{Std}	170	362.38	1740.81	133.51	182.06	53.42	4.10
WTA^{Auc}_95	147	69.08	105.84	8.73	53.61	2.98	0.25
WTA^{Std}_95	159	110.72	169.08	13.41	87.74	4.32	0.34
WTA^{Auc}_90	142	53.70	67.47	5.66	40	1.96	0.16
WTA^{Std}_90	149	77.55	111.87	9.16	60.07	3.07	0.25

Our hypothesis is founded in the empirical findings of past studies (e.g. Horowitz and McConnell, 2002; List, 2003; Blumenschein et al., 1997) that hypothetical measures tend to be higher than revealed, but also that WTA-measures may account for aspects not captured in the survey data on income, e.g. perceived risks about new contracts, and the reliability of payments are being incorporated, but also a loss of option values related to possible new developments. In addition, if contracts also trigger protection and transaction costs for landowners, their coverage calls for a further premium. We evaluate this hypothesis at the income quintiles across the distribution of households.

4. Results

4.1. Descriptive statistics

Table 2 shows summary statistics for various contextual, physical and socioeconomic variables applied, for both CV treatment samples. T-test statistics confirm that the two samples are very similar. Several features in Table 2 are noteworthy. First, most of the landholdings remain under primary forest cover (82% in Uatumã; 92% in Juma). Forest clearing is relatively low: on average around 3.3 ha amongst smallholders over the previous three years. Total land area is reported by households with great variation (probably in some cases including commons). The median is well below the mean, and we have a thin tail with outlier households reporting very large holdings. The median landholding may thus be a more reliable indicator than the mean for discussing results. Unsurprisingly, agricultural sources dominate household incomes, whereas livestock rearing is relatively less important than elsewhere in the Amazon. Forest income includes benign extractive activities that may co-exist with REDD+ contracts (fruits, fibers, hunting etc.), whereas a few others not (small-scale timber harvesting and charcoal making). Finally, salaries or business incomes that mostly do not depend on further deforestation are also reported.

4.2. Testing the framing effects on estimated WTA

Typical standard household descriptors did not differ significantly across the two samples (cf. Table 2). Among 16 variables, only "household members above 15 years" was slightly higher for the standard framing sample. Since the samples are thus comparable, we can report several tests based on uncorrected mean estimates.

In Table 3, we show the sample means, medians and standard errors for both CV elicitations: standard (WTA^{Std}) and auction framing (WTA^{Auc}). We use both a standard parametric and the non-parametric Turnbull estimator. Estimated mean and variance of the parametric estimator are known to be sensitive to even small subsamples of very high bids, be they strategic or just superficially stated bids. The Turnbull estimator is less sensitive here, as it truncates the distribution of bids at the highest observation (Haab and McConnell, 2003). We did not remove such high observations from our data, even if they looked like outliers. Rather, we supply estimates and tests for three differently filtered datasets: 1) the full sample (no suffix), 2) the top 5% of observations removed ('_95'), and 3) the top 10% removed ('_90'). Removing the top tails allows us both to evaluate hypotheses with less sensitivity to the assumptions of the parametric WTA measure, and to analyse whether differences between framing results are entirely due to changes in the top tail of the WTA distribution, or also changes to the core of the distribution.

First, we observe for the full sample that the mean of WTA^{Auc} is lower than the comparable mean of WTA^{Std} for both estimators. Also, the auction framing shows lower standard deviation (variance) than the standard framing scenario for both estimators. The differences between the estimators are substantial, with mean WTA being approximately double in the parametric case, and variance five to ten times higher for the parametric estimator. These observed differences are driven by the top end of the distribution: they vanish when we instead evaluate the lower 95% or 90% cores.

Welch's *t*-tests for differences in parametric estimates of the means between treatments, and for differences between the means of the Turnbull WTA estimates for the treatments are presented in Table 4, along with an F-test for equality of variance. Welch's *t*-test assumes unequal variance between two independent samples.

The means of WTA^{Auc} and WTA^{Std} in the parametric model were not significantly different in the full sample. They were, however, significantly different in the '_95' and the '_90' samples (at $p < 0.01$). The first finding was again influenced by a very large sample variance, and hence standard error, on the mean of WTA^{Std} compared to WTA^{Auc} (cf. Table 3), driven by the long, thinly populated tail. Results of Welch's *t*-test on the Turnbull estimations showed significant differences between

Table 4
Results of *t*-tests between method types and between outcome types.

Variables	Welch's *t*-test of equal means of parametric model	F-test for equality of variance; parametric model	z-test of equality of medians	Welch's-test on Turnbull mean estimates
WTA^{Auc} vs. WTA^{Std}	1.38[a]	1.92	−1.567	21.26***
WTA^{Auc}_95 vs. WTA^{Std}_95	2.58**	6.54**	−1.751†	80.96***
WTA^{Auc}_90 vs. WTA^{Std}_90	2.19**	4.79**	−1.366	66.70***

Significance levels: 10% = †, 5% = *, 1% = ** and 0.1% = ***.
[a] Normal *t*-test used here as no significant difference found between variances.

Table 5
Logit estimation of the probability of accepting a given payment option.

Variable	Mean coefficient	Std. error	P-value	Partial effect	P-value
Constant	−0.24904	0.19955	0.2120	−0.03929	0.2121
Payment card bid	0.01854	0.00121	0.0000	0.00292	0.0000
Distance to market (km)	−0.00215	0.00144	0.1344	−0.00034	0.1344
Household size (numbers)	−0.01280	0.02306	0.5788	−0.00202	0.5788
Gender (=1 female) of household head	0.19934	0.18334	0.2772	0.03145	0.2772
Total area of forest and mature secondary (ha)	0.00199	0.00044	0.0000	0.00031	0.0000
Salary income per aeu (95%)	0.00009	0.00059	0.1336	0.00014	0.1336
Misc. income per aeu (95%)	−0.00002	0.00005	0.6937	−0.00000	0.6937
Net agricultural productivity per ha per aeu (95%, incl. family labour per output)	−0.00084	0.00017	0.0000	−0.00013	0.0000
Net livestock and animal productivity per ha per aeu (95%)	−0.00068	0.00032	0.0324	−0.00011	0.0324
Std_Payment card bid	−0.00277	0.00154	0.0720	−0.00044	0.0720
Std_Distance to market (km)	−0.00844	0.00309	0.0063	−0.00133	0.0063
Std_Household size (numbers)	0.00167	0.03855	0.9655	0.00026	0.9655
Std_Gender (=1 female) of household head	−1.68647	0.057323	0.0033	−0.26604	0.0033
Std_Total area of forest and mature secondary (ha)	0.00641	0.00151	0.0000	0.00101	0.0000
Std_ Misc. income per aeu (95%)	0.00023	0.00013	0.0692	0.00004	0.0691
Std_Net agricultural productivity per ha per aeu (95%)(incl. family labour per output)	0.00062	0.00032	0.0546	0.00010	0.0546
Std_Net livestock and animal productivity per ha per aeu (95%)	0.00457	0.00240	0.0568	0.00072	0.0568

N = 5840, Pseudo R^2 = 0.2313, Log-likelihood: −2,678.84
95% refers to the top 5% of observations being removed ('_95').

all treatment pairs, also in the full sample. Overall these results show that the auction framing reduces mean bids, perhaps suggesting that through the framing's focus on rooting the bid solidly in the agent's true costs, it reduces the occurrence of very high stated WTA. Thus, our Hypothesis 1 cannot be rejected; auction framing likely reduces mean and variance of WTA.

4.3. The effect of household determinants on stated WTA

The results of the logit estimations scrutinizing WTA variation are given in Table 5. We tested for scale differences (Holmes and Boyle, 2001) between the auction and standard framing samples, and found a larger unexplained variance in the latter answers (ratio of 0.3–1). To account for this in a joint model estimation both samples, we scaled the data of the standard framing correspondingly (Holmes and Boyle, 2001).

Thus, parameters for the main and partial effects are valid across the entire sample. In Table 5 'Std_' indicates an interaction variable capturing the add-on to the main effect for the standard framing sample. We note that the direct effect of the bid size on probability of acceptance is positive and significant, but even in this parametric model the direct effect is slightly lower for the standard framing; significant at the 10% level, reflecting the higher mean WTA.

Our Hypothesis 2 concerned the relationship between WTA and agricultural income variables, as proxies for land rents and prospective land opportunity costs. As expected, higher agricultural rent from crops significantly lowered the likelihood of accepting a given bid, as did higher livestock rent. Forest income was insignificant for both sub-samples, and was dropped from the model likely due to the fact that forest incomes are largely sustainable thereby not affecting WTAs. We note, however, that for the standard framing sub-sample, the effect of these rent variables is significantly lower (10% level), and the parameter is large enough to give a reduced (and likely insignificant) sensitivity of the WTA to these important variables.

We do find a positive sign for the salary income variable, but it is insignificant. Distance to market also means distance to outside markets for household labour as well as for crops, though with opposite effects. We find, in particular for the standard framing sample, that the higher the distance, the lower the probability of accepting a bid, likely reflecting reduced options for other sources of income generation from labour freed up from forest conservation, and hence lower value of labour outside the land-based activities.

Larger forestland holdings significantly increase the likelihood of accepting a given bid, reflecting decreasing returns to scale of this asset, i.e. if land remains abundant the benefits of some of the land will only be harvested in the distant

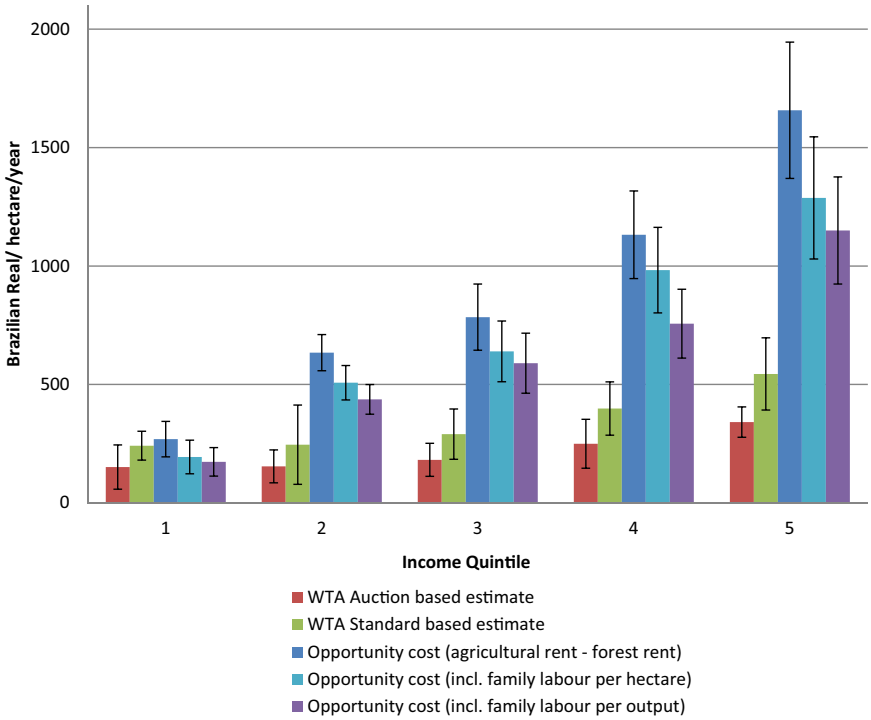

Fig. 2. Stated willingness-to-accept measures and agricultural rent per hectare foregone, across income quintiles. AEU-adjusted figures; top 5% WTA observations removed. WTA^{Auc_95} and WTA^{Std_95} measures are scaled up from monthly to annual payments. Bars show 2 * standard error on the mean estimates.

future. Hence, the larger the forest a household controls, the lower stated per-hectare WTA. Other assets had no effect on the probability of bid acceptance.

For socio-demographic variables, larger household size was presumed to lower WTA through freed-up labour available to pursue other opportunities, yet had no significant effects. Gender had no significant effect in the auction framing, however, females in the standard framing were less likely to accept a given bid, suggesting they were more sensitive to the difference in framing. Years of education (human capital and labour value proxy), and years lived in the community (indicating access to social networks), both presumed also to lower WTA were insignificant. The differences in forest land regulation inside and outside reserves could have an effect on WTA, but dummies accounting for a direct reserve effect proved insignificant, suggesting that such effects are either absent or picked up by the remaining sociodemographic variables. In conclusion, we cannot reject Hypothesis 2 that WTA increases proportionally to opportunity costs, and we find additional interesting patterns of policy interest.

4.4. Comparing stated WTA with opportunity costs measures

From our household survey, we have proxies for agricultural rent foregone by halting deforestation, cf. Table 2. From this, we calculate a survey-based estimate of conservation opportunity costs, using household survey data in our case study area. We additionally drew on the literature about shifting cultivation in *varzea* (seasonally flooded) Amazon scenarios, typically involving length of rotations between itinerant crops (specifically cassava), pastures and fallows (Vosti et al., 2002). For labour costs, we applied different scenarios about labour intensity and remuneration outside of the land-based sectors. We present estimates with and without labour cost corrections.[8] Fig. 2 compares mean estimated per-hectare opportunity costs to mean per-hectare WTA. We compare across income quintiles, all scaled up to annual amounts and expressed in adult equivalent units (aeu) (Cavendish, 2002). Thus, these WTA measures are not directly comparable to Tables 3 and 4.

All three opportunity cost measures increase substantially over income quintiles, due to the underlying increase in average productivity of agriculture, and hence agricultural rent, correlating with total income. We stress that these survey-based

[8] Prices and quantities of outputs per hectare were obtained from the survey to account for income from deforested lands using tested reliable survey methods (Angelsen et al., 2011).Costs of factor input were deducted to obtain agricultural rent foregone. To that end, household labour was included in the agricultural productivity calculation in two ways: labour per-hectare and per output unit. The main agricultural products were cassava (and its derivatives) and banana. These productivities were combined with village-level estimates of the typical labour cost. All resulting foregone income measures are in annual per-hectare BRL, in aeu (Cavendish, 2002). $WTA^{Auc\_t}\_95$ and $WTA^{Std\_t}\_95$ measures were also adjusted using the AEU scalar vector, and scaled up from monthly to annual payment.

estimates of foregone income from avoiding deforestation are similar in size to those of other Amazon studies (e.g. Börner and Wunder, 2008). We note that while estimated WTA and foregone income appear fairly similar for the lowest quintile, the difference becomes larger in high-income groups. Also, WTA-based measures of opportunity costs do not exceed agricultural rent-based measures for any income group.

5. Discussion

5.1. Evaluating the auction framing effect

In this paper, we have compared two CV methods, an auction and standard framing, for obtaining information about the foregone incomes in forest conservation contracts offered to rural households in the Central Amazon region of Brazil. The hypothetical contracts we offered simulate existing and potential REDD+ initiatives. The results of the split-sample test suggested that auction framing effectively reduced both mean and sample variance of WTA. This lends some support to the idea that auction framing was likely to be incentive-compatible, and to the recommendation to build a credible context around the agent's answer that encourages truth-telling (Carson and Groves, 2007). Hence, some of the challenges identified in applied stated preference studies in low-income countries (Whittington and Pagiola, 2012) can perhaps be overcome by careful choices of payment vehicle context and framing.

5.2. Factors driving the WTA

Our second hypothesis alleged that *WTA* is driven by agricultural rents determining opportunity costs, which was confirmed: both higher crop and livestock rents significantly reduced the probability of accepting a given WTA level in the auction framing sample. The partial effects of these measures in the standard framing sample, however, appeared to be either smaller or absent. Among other tested socio-demographic variables, distance to markets tended to increase WTA acceptance, which could reflect reduced options for households to redirect labour to other income generating activities, if forest conservation was enforced. Total land area controlled by households increased acceptance, especially under standard framing, possibly implying decreasing returns to deforestation scale, at least under the predominating itinerant cultivation system.

5.3. Survey-based opportunity costs exceed stated WTA

We found that our stated WTA against theoretical expectations fell short of the survey-based opportunity cost estimates, in particular for higher household income strata (Fig. 2). We thus need to discuss why the WTA-based estimates were lower, and why the survey-based estimates came out higher than we had expected.

Firstly, stated WTA may be downward biased across framings due to moral hazard among respondents. If respondents believe contract enforcement would be slack, e.g. as they have experienced in ongoing environmental programs, they might factor in an option to receive payments without complying, and thus strategically state lower WTA hereby hoping to get a contract.

Secondly, respondents may perceive contractually stable REDD+ cash transfers as less risky and more attractive than future fluctuating crop yields and prices – a non-trivial factor in disease-prone tropical agriculture (e.g. Arnold et al., 2011; Hanlon et al., 2010). This would generally reduce stated WTA, although it would not explain the growing gap when moving from lower income to higher income groups, as it is not obvious why higher income groups should be more risk averse than low-income groups.

Third, our survey-based corrections for standard labour costs may be underestimating the shadow value of labour to higher-income households, relative to lower-income ones. Income- and asset-rich households may have better options for redirecting labour resources and other inputs from deforestation-based activities to alternative income-generating options, and engage more readily in higher-return non-farm activities (Barrett et al., 2001; Reardon et al., 2001). Being unable to directly assess this impact, we may come to underestimate their labour value, implying an overestimation of their opportunity costs of land for higher income households.

Fourth, opportunity costs are calculated as average estimates across cleared land in use. As the best lands (in terms of soil fertility, drainage, slope, transport access) are typically cleared first, the marginal value of clearing further land may be well below these average costs. The lack of a well-functioning labour market and hence possible labour constraints at household level may also reduce the value of marginal lands below the average of already cleared lands. Moreover, if constrained from further land expansion, households will reduce efforts on low-return activities, e.g. cassava production, and focus on higher-return activities, e.g. processing of agricultural goods or production of higher-value crops, thus systematically putting opportunity costs on marginal lands well below the average. The significant positive effect we found of total land controlled on the probability of accepting a bid seems to support such an interpretation, which is typically not accounted for in standard opportunity cost calculations (see e.g. Börner and Wunder, 2008).

Table 6
USD per t CO_2 at different discount rates.

	Opportunity cost estimated based on		
Discount rate	WTA Auction	WTA Standard	Agricultural rent
5%	3.65	6.02	16.98
10%	1.98	3.27	9.22
15%	1.33	2.20	6.19

5.4. Caveats

The experiment was conducted in and around reserves with an existing forest conservation PES program (*Bolsa Floresta*), as well as imperfectly enforced protected-area restrictions on land clearing imposed by the SDR (see Section 3). The current Bolsa Floresta, as well as other only lightly conditional state cash transfers, could have created an anchor in respondents' choice of bid due to moral hazard inclinations. Interviews with households in both reserves suggested that the issuing of sanctions was rare, and cases of expulsion of households from the program appeared unknown (Börner et al., 2013). Hence, respondents might not have truly believed that contract compliance would be effectively monitored and sanctioned, despite this being explained and stressed in both framings. If so, underbidding would become a rational strategy.

Conversely, our survey-based data may come with measurement and reporting errors. As mentioned, a small subset of households reported holding use rights over huge land areas, possibly counting in 'commons'. Yet, the median land area remains plausible. Since we asked for per-hectare WTA, our auction treatment effects should not be affected either. The means may be influenced though: WTA amounts tend to decrease in both treatments for larger landholdings, which could reflect decreasing returns to scale of the asset, thus also lowering the perceived opportunity costs of putting them under conservation.

5.5. Perspectives

Our paper points to several observations of relevance for both policy design and further research. In spite of potential caveats and difficulties common to low-income country contexts, we find that respondents reacted fairly predictably to clear, theoretically well-informed CV framing formats (Carson and Groves, 2007). The auction framing developed may thus have good application potential, e.g. in screening WTA ranges prior to implementing full-scale REDD+ or PES-type schemes. Prospective gains can include to pre-check economic and political feasibility of incentives, to test compensation levels, to target most cost-effective areas, and to ensure adequate incentives for service providers (Whittington and Pagiola, 2012).

The auction framing results were also more meaningfully correlated with socio-demographic drivers, e.g. distance to markets and land area held, which could help identifying differentiated payment tiers (Pagiola, 2008; Wunder et al., 2008), rather than the common but typically less efficient fixed per-hectare payments (Engel et al., 2008). For example our results indicate that implementing a PES scheme of this sort could be designed to account for decreasing returns to scale of landholdings, e.g. discriminating between small and large land owners in different auctions, effectively tapping into the latter's lower WTA. Uniform price schemes and auctions like the one simulated here do not aim at only covering opportunity costs for landowner, except at the price setting margin, offering some rent to low-cost agents.

Indeed, in current practice, uniform prices per hectare as well as per household are often used, where the latter is currently practiced under Bolsa Floresta. Moreover some PES programs have sliding scales, e.g. the larger the plot enrolled, the lower the per-hectare payment (e.g. Ecuador's Socio Bosque), or stratify payments to reflect expected opportunity cost, e.g. closeness to roads or rivers.

It is worthwhile to evaluate our empirical results on opportunity costs also in terms of costs per tonne of carbon. Current estimates of carbon emissions from projected deforestation stand at 189,767,028 t CO_2 for the Juma reserve (FAS et al., 2009), which translates to 575.95 t CO_2 per ha. Table 6 shows how much this corresponds to in terms of USD per tCO_2, under different discount rates.[9] These NPV figures show that to meet survey-based opportunity costs of land conversion to subsistence agriculture and livestock minus foregone sustainable forest income, payments would have to be in the range of USD6.19 to USD16.98 per tCO2. Estimated payments are lowest for the WTA auction (USD1.33–3.65), with the WTA standard framing falling in between (USD 2.20–6.02). These estimates are reasonably comparable in range to existing estimates in the literature (e.g Stern, 2007 at $6.52USD per t$CO_2$). CV based methods might thus also meaningfully predict the opportunity costs related to REDD+ schemes.

6. Concluding remarks

Reduction of emissions from deforestation and forest degradation (REDD+) has been singled out as a potentially cost-efficient large-scale option for rapid climate change mitigation. Hence, approaches to assess the opportunity cost of REDD+

[9] The upper values of discount rates (10%, 15%) reflect the very high real interest rates in Brazil in general, and in settings of poverty and risk in particular.

have also attracted increasing attention. They typically rely on measures of foregone agricultural rents to landowners. In this study, we triangulated REDD+ opportunity cost estimates among rural households in the Northern Brazilian Amazon, using a standard survey-based measure for foregone agricultural rents, alongside two variants of CV based measures of willingness to accept (WTA), the novel of these involving a 'first-rejected-bid-sets-the-price' auction framing.

The results showed that the auction-framing format reduced means and variances of stated WTA vis-à-vis the standard framing. Furthermore, WTA measures of the auction framing were positively correlated to measures of households' current agricultural rents, and negatively correlated to the size of landholdings. The robustness of results is promising for replicating the method, including in low-income country contexts, where implementation can be challenging (Pattanayak et al., 2010). The details of what drives WTA can help to inform policy design and targeting efforts.

We further compared WTA-based opportunity cost estimates with standard agricultural rent estimates. We find that the latter exceed the WTA based estimates for the higher income households and discuss possible reasons for this. Across our three methods for opportunity cost results suggest that reduced CO_2 emissions from forest conservation in the area could be secured at mean prices in the range of USD1.33–16.98 tCO_2.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.reseneeco.2017.02.002.

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