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Determinants and costs of strategic enrollment of landowners in a payments for ecosystem services program in a deforestation hotspot: The Argentine Chaco forest

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ABSTRACT

Understanding landowners' decisions about how much land to enroll in payments for ecosystem services (PES) programs is essential to strategically target lands for conservation, prevent forest fragmentation, and thus maintain ecosystem services. In this study, we targeted private lands surrounding and connecting public protected areas in a deforestation hotspot, the Argentine Chaco forest. We used alternatively configured PES contracts in choice experiments to understand landowners' decisions regarding how much land to enroll in PES. We found that factors influencing decisions on how much land to enroll differ from those influencing willingness to participate in PES. The percentage of their property that landowners were willing to enroll in the program increased with higher payments and permitted land use that closely aligned with traditional land use, specifically cattle ranching under tree canopy. Contract length was important in willingness to enroll but not in amount of land enrolled. Payments required to enroll all land in our study area, and thus conserve an unfragmented landscape, exceeded the financial resources of the Argentine PES program. Designing PES to enroll private lands on smaller strategic areas, in conjunction with other conservation initiatives, would be more effective than attempting to use PES alone to conserve large landscapes.

1. Introduction

Direct payments for ecosystem services (PES) aim to achieve conservation goals by rewarding landowners for sustainable stewardship of natural resources. However, funds to support incentive-based conservation programs like PES are limited and PES programs face many challenges in protecting lands at the spatial and temporal scales most relevant for long-term conservation (Blackman and Woodward, 2010). For example, PES programs are based on voluntary enrollment, which often results in discontinuous temporal and spatial coverage. Properties enrolled for short periods may lead to the allocation of PES funds for temporary conservation benefits (Núñez-Regueiro et al., 2019, 2020). Unlike more permanent mechanisms (e.g., fee-simple land acquisition and conservation easements), the ecological gains achieved on enrolled properties may reverse once the program ends (Etchart et al., 2020). In addition, voluntarily enrolled properties often translate into a patchwork of widely dispersed protected lands (Wood et al., 2020), and eventually fragmented landscapes. The ability of fragmented landscapes

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to support critical processes for ecosystem health is limited (e.g., climate controls, seed dispersal by wildlife; Haddad et al., 2015). Over time, these landscapes degrade, resulting in loss of the biodiversity and ecosystem services that PES aims to protect (Laurance et al., 2011).

One way to overcome these shortcomings is to target specific lands for conservation within the PES framework. In this case, policymakers must decide how and where to best allocate available resources to achieve program goals. For example, focusing PES on areas with low opportunity costs of enrollment could increase PES's spatial extent and temporal continuity even with limited funding (Wünscher et al., 2008). However, sites with low opportunity costs of enrollment often do not coincide with lands of high conservation value or lands under eminent deforestation threat (Zhang et al., 2021). In addition, habitat connectivity requires enrollment of adjacent lands (Drechsler, 2011). PES programs could address these challenges and contribute to landscape-level conservation by targeting lands identified as strategic for conservation (Wood et al., 2020). For example, PES programs could be linked to other conservation initiatives, particularly protected areas, and target buffer zones around protected areas and ecological corridors, thereby connecting them (Sims and Alix-Garcia, 2017; Wood et al., 2020). Protected areas represent a key mechanism to secure long-term biodiversity conservation, but many protected areas worldwide are small (less than100 ha; Vonelec and Dobson, 2019) and thus ineffective for conserving most biodiversity (McGuire et al., 2016). By conserving private lands in buffer zones around reserves and ecological corridors between reserves, PES programs potentially could help preserve large contiguous blocks of habitat, increase the effective size of protected areas, decrease threats to protected areas from outside (e.g., poaching, influx of agrochemicals), and increase habitat connectivity among reserves (Ramirez-Reyes et al., 2018). However, most studies on PES and protected areas have focused on evaluating and comparing their ecological and social impacts or assessing PES financing of public protected areas, rather than strategic targeting of payments to attain conservation outcomes (e.g., Clements and Milner-Gulland, 2015; Sims and Alix-Garcia, 2017; Zárrate Charry et al., 2022). A key question that remains unresolved is whether PES can be used to conserve large contiguous blocks of land required for long-term conservation of biodiversity and ecosystem services.

In order to answer this question, one must understand two key aspects of PES enrollment: the willingness of landowners to participate in PES and the number of hectares they will enroll in the areas designated as strategic for conservation. Factors influencing landowners' willingness to participate in PES may differ from those influencing the proportion of the property that landowners would enroll. For example, contract attributes were significant in Japanese farmers' decisions to participate in PES but not in determining the number of hectares enrolled (Tanaka et al., 2021). Likewise, U.S. farmers' willingness to consider PES depended on farm and farmer characteristics whereas their decisions about hectares enrolled depended on payment-driven benefit-cost factors (Ma et al., 2012). Often the amount of private land under PES and the conservation benefits of this land may not be commensurate with the number of enrolled landowners because landowners only enroll a fraction of their properties in PES schemes and contributions of enrolled lands to conservation differ with land use (Alix-Garcia et al., 2005). Factors that influence landowners' willingness to participate in PES have been studied extensively (Jones et al., 2020). However, factors that influence landowner decisions about how much land to enroll have received relatively less attention (see Authelet et al., 2021; Layton and Siikamaki, 2009; Ma et al., 2012; Massfeller et al., 2022; Tanaka et al., 2022), and insights from PES schemes in developing countries with high deforestation rates are limited (but see Authelet et al., 2021). Our paper addresses these gaps with a case study of PES in the Chaco region of NW Argentina.

The Gran Chaco, which is among the largest seasonally dry subtropical forests in the world, extends over more than one hundred million hectares in Argentina, Bolivia, Brazil, and Paraguay, with sixty percent of this forest in Argentina (Baumann et al., 2022; Thompson et al., 2022). The large-scale expansion of drought-resistant soybean production in the 2000 s and 2010 s into the subhumid areas of the Chaco and more recently, the expansion of cattle ranching in drier areas have turned the Chaco into a global deforestation hotspot (Baumann et al., 2022). This rapid conversion of Chaco forest has reduced ecosystem services such as carbon storage, rainfall retention, erosion control, and soil fertility (Barral et al., 2020). Also, this conversion has increased forest fragmentation (Piquer-Rodríguez et al., 2015), threatens wildlife (Núñez-Regueiro et al., 2015; de la Sancha et al., 2021), and has displaced local people (Matteucci et al., 2016).

Largely in response to these challenges in the Chaco, the Argentine government established a PES program in 2007 as a central policy instrument of the National Forest Law. PES programs rely on voluntary agreements where individuals or communities receive payment in exchange for securing ecosystem services (Wunder, 2007). The Argentine program compensates landholders for forgoing deforestation with the stated aim of securing water regulation, biodiversity conservation, improved water and soil quality, greenhouse gas sequestration, landscape diversification and aesthetics, and maintenance of the cultural identity of smallholders and indigenous communities (Article 5, Forest Law). However, although Argentina has implemented the PES program in the Gran Chaco for over 12 years, no mechanisms exist to spatially orient payments for landscape conservation and, as a result, enrolled lands are highly fragmented (Núñez-Regueiro et al., 2020). Recent studies suggest that relying solely on the land-use regulations in the Forest Law may not be sufficient to maintain connected landscapes (de la Sancha et al., 2021; Piquer-Rodríguez et al., 2015), but little attention has been paid to the potential of targeting the PES program to preserve critical areas for forest connectivity. Here, we (1) examined factors that drive landowners' decisions regarding the number of hectares to enroll in Argentina's PES program based on the results of a stated preference choice experiment survey and (2) assessed whether PES is a viable option to target the large contiguous areas needed for conservation in this region. To achieve these goals, we:

1) defined a strategic conservation area comprised of private properties surrounding existing public protected areas and corridors that link these protected areas;
2) analyzed whether payment levels, contract length, and land uses explain the percentage of their properties landowners in this strategic area are willing to enroll under different PES contract configurations; and
3) estimated the funds required to incentivize landowners to enroll their properties in the strategic conservation area, which we compared with current PES payment levels for the region and the cost of fee-simple land acquisition.

We expected high payment levels, short contract lengths, and land uses with economic returns to be associated with enrollment of a larger percentage of land in PES, although short-term contracts are likely incompatible with long-term, landscape-scale conservation.

2. Methods

2.1. Study area and Argentine PES program

2.1.1. The Gran Chaco

The Gran Chaco comprises a mosaic of dry forests, woodlands, savannas, and grasslands (Prado, 1993) and constitutes a key conservation area because of high biodiversity, endemism, and habitat for many vulnerable species, such as the Chacoan peccary (*Catagonus wagneri*) and jaguar (*Panthera onca*) (Thompson et al., 2022). This forest originally was inhabited by indigenous people who relied on hunting and gathering of forest products. In the 16th century, a wealth of valuable timber brought logging to the Chaco of northwestern Argentina. During the

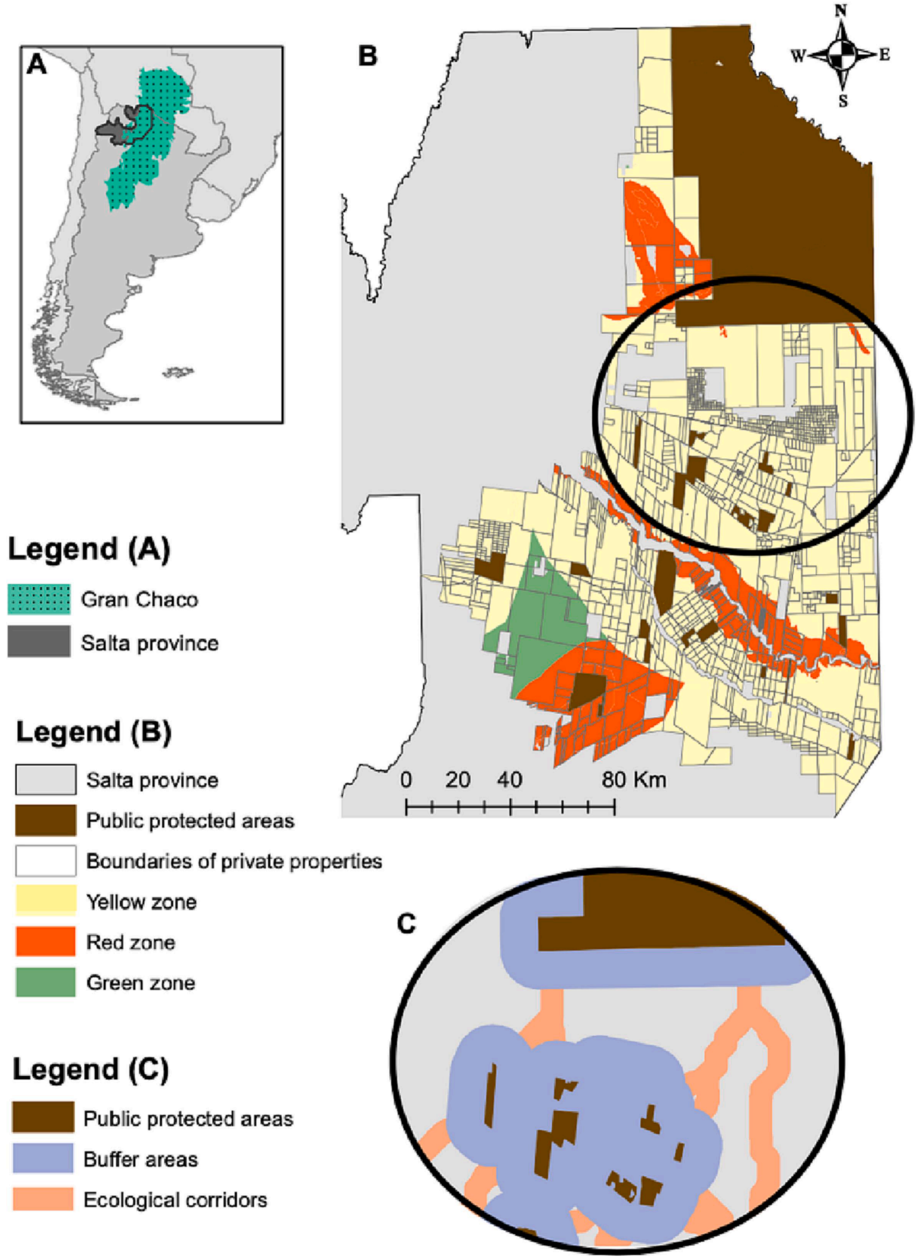

Fig. 1. Location of the study area comprising the semi-arid Chaco region of Salta province, Argentina.

19th and early 20th centuries, the demand for timber grew exponentially, resulting in overexploitation of the most important timber species followed by a decline in the timber industry in this region. Non-indigenous workers who moved into the Chaco with the logging industry subsequently settled in the Chaco forest and have a subsistence economy based on open-access livestock grazing in the forest, selective logging, firewood extraction, and charcoal production (De Marzo et al., 2021). Currently, commercial exploitation of forests is primarily linked to charcoal production, but timber harvest also occurs. Landowners who rely on their property to generate income primarily engage in soy production and ranching.

2.1.2. *Application of the Argentine PES program in the Chaco forest*

Despite the ecological importance of Chaco forest and the high deforestation threat, less than 2% of the Argentine Chaco is in public protected areas (Izquierdo and Grau, 2009). Protection of Chaco forest in Argentina primarily comes from the National Native Forest Law 26,331/2007, which is comprised of two main parts. First, this law requires provinces to categorize their forests into three zones based on their assessment of conservation value and then implement land-use regulations (García Collazo et al., 2013). Land-use regulations forbid extractive activities (e.g., harvest of timber and non-timber forest products and silvopasture) in areas with high conservation value (red zone) but allow these practices in areas with medium (yellow zone) and low (green zone) conservation value. Most land uses are allowed in the green zone, including forest clearing for crop production (García Collazo et al., 2013). Second, the national law established a National Fund for Native Forests to compensate landowners through a PES program (70% of funds) for preserving or sustainably managing forests and to support technical assistance and monitoring of PES plans by provincial governments (30% of funds). Land use regulations are managed at the provincial level, but provincial allocations from the Forest Fund depend on federal approval. Regulations associated with land use zoning permit only the same activities as allowed under PES in yellow and red zones

	CONTRACT A	CONTRACT B	
Permitted activity Contract length Annual payment	Silvopasture 25 years US$ 2/ hectare	Ecotourism 15 years US$ 32 / hectare	NONE
I would choose:	○	○	○
How many hectares would you enroll?	…………	…………	

Fig. 2. Example of a scenario presented to respondents in the stated preference choice experiments.

and require sustainable management plans (e.g., for timber extraction, harvest of non-timber forest products, and silvopasture), but the approval process is much shorter and less expensive than enrolling in PES. The intent of PES is to provide additionality by making conservation and ecosystem services provision more acceptable and sustainable through financial compensation. This fund is a primary tool for federal intervention in the provincial application of the Forest Law and may help ensure conservation benefits beyond the impacts of provincial land use zoning, which often are considered inadequate to mitigate forest loss (Alcañiz and Gutierrez, 2020; Piquer-Rodríguez, 2015). For example, comparisons of deforestation and PES funding across provinces showed that a 1% increase in PES payments reduced deforestation by 5.8% between 2012 and 2018, but PES investments were less effective in areas with high land values associated with agricultural expansion (Alcañiz and Gutierrez, 2020).

Landowners who enter the PES program obtain annual compensation per hectare of property enrolled in approved conservation or sustainable management plans in yellow zones and conservation plans in red zones (Núñez-Regueiro et al., 2019). PES also supports sustainable management and conservation plans in green zones. However, land-use change plans that result in complete forest transformation, which are allowed in green zones, are not eligible for PES payments. Payments are conditional on compliance with PES plans and vary with land-use zone (higher payments per hectare in the red zone than in the green zone; Núñez-Regueiro et al., 2019). The program allows landowners to define the length of enrollment and re-enroll (Núñez-Regueiro et al., 2019). Landowners can enroll for short terms (e.g., 1–2 years), which may encourage enrollment (Del Rossi et al., 2021). However, high transaction costs as well as the requirement for a valid land title place some limits on participation, particularly for individuals who reside on land owned by other property holders. Unlike most PES programs, the Argentine PES program has legally mandated, long-term funding from the federal government. The federal government allocated over $45 million to 1,341 plans in the Argentine Chaco forest between 2010 and 2015. This investment resulted in almost 4,300,000 ha of land being enrolled in the program (equivalent to 17% of the Chaco forest).

2.1.3. Study area and population

We focused on the Chaco region of Salta province in northwest Argentina because this province has extraordinary biodiversity and rates of deforestation in areas of great conservation value (Vallejos et al., 2021). Also, private landowners in Salta are diverse (e.g., indigenous people, small-scale farmers, large-scale producers, and corporations; Vallejos et al., 2021) and have different motivations, perceptions, and financial goals regarding land use (Nuñez Godoy et al., 2022; Núñez-Regueiro et al., 2020). In addition, Salta is at the center of debates concerning implementation of the Forest Law and its effectiveness in reducing deforestation (Piquer-Rodríguez et al., 2015). Large areas of the Chaco forest were overexploited for timber prior to implementation of the Forest Law (Sarmiento et al., 2021). In general, industries for sustainable extraction of timber and non-timber products are not well developed in the Chaco forest and most extraction of timber occurs through informal, and often illegal, markets (Schmidt, 2014).

Traditionally, the Chaco forest of Salta province has been managed for livestock production, either livestock grazing on natural vegetation within the forest (semi-subsistence and low-production management system common with smallholders) or silvopasture (Fernández et al., 2020). Traditional silvopasture comprises mechanical removal of shrubs and small trees and planting of introduced grasses, often resulting in a park-like landscape of scattered trees in planted pasture with little or no tree regeneration (Kunst et al., 2012). Recently, an alternative to traditional silvopasture (Integrated Woodland and Livestock Management – MBGI in Spanish) has been proposed that allows timber harvest and introduction of nonnative pasture grasses for cattle ranching but preserves sections with more tree canopy and midstory of shrubs and small trees to promote regeneration (Fernández et al., 2020; Peri et al., 2022). MBGI also incorporates other land management approaches within each land holding, such as small forest reserves. MBGI is promoted by government agencies nationally and within Salta province as a silvopasture system more compatible with the Forest Law (Peri et al., 2022), but this system has not yet been adopted by landowners and its ecological consequences are unknown (Aprile et al., 2016).

Our study area comprised all private properties with greater than 50% forest cover that fell within buffer areas around key public protected areas in the Chaco forest and in corridors between them (2,051,674 ha total; Fig. 1). To identify these properties, we extracted forest cover for all properties from a forest GIS layer obtained from the Argentine Ministry of the Environment with ArcGIS (version 10.6.2; ESRI, CA). We identified key protected areas based on their potential to ensure spatial continuity of habitats, in this case, protected areas surrounded by properties with $\geq$ 50% forest cover. These protected areas included Provincial Reserve “Los Palmares” (6,000 ha), Provincial Reserve “Dragones” (3,935 ha), and one large reserve and several smaller areas (729,038 ha total) incorporated into the provincial system of protected areas by Decree 616/2018.[5] We delineated a 12-km wide buffer zone around each protected area and 12-km wide ecological corridors between them with ArcGIS (Fig. 1C). Buffers and corridors that are 12-km wide should facilitate movement and reduce threats to vulnerable species such as peccaries (*Catagonus wagneri*and *Tayassu pecari*) and large predators (jaguars and pumas, *Puma concolor*; Kautz et al., 2006; Rabinowitz and Zeller, 2010). We then excluded properties that (1) were not found in the government tax databases, (2) had missing landowner information (e.g., missing address), or (3) had owners living in other provinces as logistical constraints precluded interviews with absentee landowners. Most properties in Argentina have a formal title; thus, incomplete records and landowners’ unwillingness to release ownership information rather than the lack of land titles prevented us from locating some properties (518) in government tax databases. We obtained addresses for the remaining 260 properties owned by 154

[5] This decree currently lacks full implementation; however, it serves our purpose of analyzing spatial targeting of enrollment in PES.

landowners (839,186 ha; 41% of study area). We were able to contact 99 landowners (64% contact rate) and conduct 81 surveys from March-December 2019. Surveyed landowners included individual landowners, chiefs or elected presidents of indigenous communities, and owners or managers of private companies and non-profit organizations. The total area owned by respondents represented 34% of the study area (691,868 ha).

2.2. Data collection

We compiled the following information for all properties in our study area: size (ha), land-use zone (e.g., red, yellow, green), whether the property was ever enrolled in PES, and the amount paid to each landowner for enrolling their property in PES from 2010 to 2017. We obtained this information from the Argentine Ministry of the Environment. Then, we conducted in-person surveys with stated preference choice experiment (SPCE) scenarios to evaluate landowner preferences for alternatively configured PES contracts and the number of hectares they would enroll under these different scenarios (Nunez Godoy et al., 2022). Each choice scenario had two potential PES contracts and an opt-out option (Fig. 2). We obtained an efficient factorial design of 12 choice scenarios (%Choiceff macro, D-Efficiency = 93.6%, SAS 9.4) and created three survey versions, each with four SPCE scenarios, to prevent respondent fatigue related to survey length. The alternatively configured PES contracts included three attributes: contract length, an annual payment, and permitted activities (i.e., land uses allowed in return for PES compensation). Prior to presenting the choice scenarios to respondents, we described each of these land uses according to the objectives outlined in the Forest Law, specifically, (1) forest conservation with no commercial returns, involving activities such as excluding cattle and planting native trees to maintain or enhance the current condition of the forest; (2) ecotourism, comprising tourism activities that are consistent with forest conservation such as horse riding and bird watching; (3) sustainable timber harvest of native species, where timber harvesting is permissible as long as the number of native trees planted on the land exceeds the number of trees harvested annually; and (4) silvopasture comprising livestock grazing within the forest, sustainable extraction of timber, and low-intensity roller chopping to manage shrub layers and increase grasses within the forest.

Current program enrollment in Chaco forest ranges from 1 to 21 years (Núñez-Regueiro et al., 2019). We presented survey respondents with contract lengths of 5, 15, or 25 years. Shorter duration contracts were excluded to limit the number of choice sets and reduce respondent fatigue, and because contracts less than 5 years represent a small proportion (13%) of Salta province's conservation and management plans. In Salta province, landowners received an average US$5 per hectare annually for enrolling in PES between 2010 and 2015 (Núñez-Regueiro et al., 2019). We presented annual payments per hectare enrolled in PES of US$2, $12, $22, and $32. Our minimum payment was set low to reflect recent decreases in funding for the PES program (Núñez-Regueiro et al., 2019). The maximum payment was based on discussions with landowners during preliminary fieldwork about their expected returns from alternative land uses. Our surveys produced a total of 285 choice scenarios and a dataset of 855 observations (three alternatives in each choice scenario) after removal of incomplete choice scenarios. Data collection and the design of the stated preference choice experiments are described in more detail in Nuñez Godoy et al. (2022).

2.3. Data analysis

First, we summed the number of hectares enrolled in PES plans from 2010 to 2017 and used this as the observed amount (ha) of land enrolled in PES in the study area. To calculate the observed investment level, we divided the amount of money allocated for each plan by the number of hectares enrolled in the plan. Then, to identify the strongest predictors of the percentage of their property landowners would enroll in PES based on the choice experiment, we developed a generalized linear mixed-effect model in the program R assuming a Poisson error distribution (package lme4, R version 4.0.2). The model included a unique code for each respondent as a random effect to account for lack of independence in repeated measures from the same landowner (i.e., responses to multiple choice scenarios). We analyzed six potential predictor variables related to attributes of the PES contracts and properties and treated them as fixed effects in our models. These variables comprised permitted activities on the properties, annual payment in dollars per hectare of property enrolled, contract length, property size (ha), land-use zone of the property (red, yellow, and green), and a binary variable that denoted whether the property was ever enrolled in PES. For the response variable, we used the percentage of their property that landowners were willing to enroll in the different PES contract configurations instead of the number of hectares enrolled to account for differences in property sizes. We applied a model selection approach with AIC corrected for small sample sizes using the R package MuMin. We tested all variable combinations in groups of up to three variables per model but did not test combinations with more variables to avoid risks of overfitting our model. Finally, we used the parameter estimates obtained from the best fit generalized linear model to estimate the percentage of their properties that landowners would enroll under different permitted activities and payment scenarios [e.g., the minimum (US$2) and maximum (US$32) payments presented in the choice scenarios, and the average payment for currently enrolled lands]. Then, we projected these percentages to the study area and, for each permitted activity and payment level, obtained the total number of hectares that would be enrolled in the PES program and the annual cost of this enrollment.

Table 1
Amount (ha) and percentage of land (%) in study area and enrolled in PES by land-use zone between 2010 and 2017.[a]

Land-use zone	Land in zone		Land enrolled in PES		
	Ha	% of total study area	Ha	% of zone enrolled	% of total enrolled ha in study area
Red	151,971	7.4	7,252	4.8	4.5
Red-yellow[b]	507,706	24.7	57,972	11.4	35.6
Red-yellow-green[b]	2,982	0.1	2,595	87.0	1.6
Yellow	1,241,290	60.5	95,066	7.7	58.4
Yellow-green[b]	129,454	6.3	0	0	0
Green	18,271	0.9	0	0	0
All zones	2,051,674	100	162,885	7.9	100

[a]Data obtained from the Argentine Ministry of Environment. [b]In these cases, landowners had land in more than one zone.

3. Results

3.1. Observed land enrollment and investment in PES

The PES program allocated over $18 million ARG pesos (~US$ 978,307 calculated using 2017 currency exchange) in the study area between 2010 and 2017. This investment resulted in approximately 8% (162,885 ha) of our study area being enrolled in PES by 2017 with an average payment per hectare of US$7 (Table 1). Approximately 60% of our study area was in the yellow zone (i.e., medium conservation value as designated by Salta province) and less than 8% of this land was enrolled in PES. Less than 8% of our study area was in the red zone (i.e., lands designated as high-conservation value by Salta province) and approximately 5% of this land was enrolled in PES. Land with low and medium–low conservation values (i.e., green and yellow-green zones) in our study area was not enrolled in PES.

Table 2
Comparison of AICc scores for the top four models for potential variables related to the percentage of property enrolled.

Model	DF	logLik	AICc	Delta	Weight
use + payment	8	−4050.15	8116.50	0.00	0.38
use + payment + pes	9	−4049.75	8117.70	1.24	0.21
use + payment + size	9	−4049.90	8118.00	1.55	0.18
use + payment + length	9	−4049.97	8118.20	1.68	0.17

Use = permitted activities on the properties; payment = annual payment per hectare; length = contract length; pes = whether the property was ever enrolled in PES; size = property size; DF = Degrees of freedom; logLik = Log-likelihood; AICc = Akaike Information Criterion corrected for finite sample sizes; Delta = Difference in AICc between best model and each individual model; Weight = Akaike weight of model.

3.2. Predictors of land enrollment in PES and costs of augmenting PES coverage

Respondents stated that they would enroll their properties in at least one of the two contracts in 60% (N = 170) of the choice scenarios (i.e., they opted out of PES 40% of the time). Respondents stated they would enroll 100% of their property in 73 choice scenarios, 50–99% of their property in 34 choice scenarios, and less than 50% of their property in 63 choice scenarios. The model containing PES payments and permitted activities was the model that best described the percentage of the property that respondents stated they would enroll in the potential PES programs (Table 2 and Table A.1). Three other models were competitive (i.e., $\Delta AIC_c < 2$, Table 2) suggesting that contract length, whether the property was ever enrolled in PES, and property size also may play a role in determining the percentage of their property respondents would enroll in PES. However, the explanatory power of these variables was low as indicated by confidence intervals that overlapped 0 (Table 2.A, Model 2–5).

On average, for each dollar increase in payment, respondents were willing to increase the total percentage of their property enrolled in PES by 7% (β = 7.35, 95% C.I. = 4.64, 10.05), albeit not equally with different permitted activities (Fig. 3; Table A.2, Model 1). For a given payment level, respondents were willing to enroll a higher percentage of their property in silvopasture (β = 26.10, 95% C.I. = 21.28, 30.93) than in all other permitted activities (Table A.2, Model 1). After silvopasture, respondents chose to enroll the highest percentage of the property in forest conservation (β = 18.81, 95% C.I. = 13.55, 24.07), followed by ecotourism (β = 12.44, 95% C.I. = 7.40, 17.48; Table A.2, Model 1). Timber production was the least preferred option (β = 5.24, 95% C.I. = 0.34, 10.15; Table A.2; Model 1).

The highest payment of $32/ha/year provided in the surveys was insufficient for landowners to enroll 100% of their properties (Table 3). Also, the funds needed to enroll properties varied by the permitted activities. Landowners would enroll the highest percentage of their property (59%) when lands could be used for silvopasture, and the payment was $32/ha/year. At this payment level, landowners would enroll approximately 28%–34% of their land when the permitted land use activities were conservation or ecotourism. Timber production was the permitted land use activity that would attract the least amount of land (14%) at a payment of $32/ha/year (Table 3). If we project these values to the study area of 2,051,674 ha, the estimated amount of land that

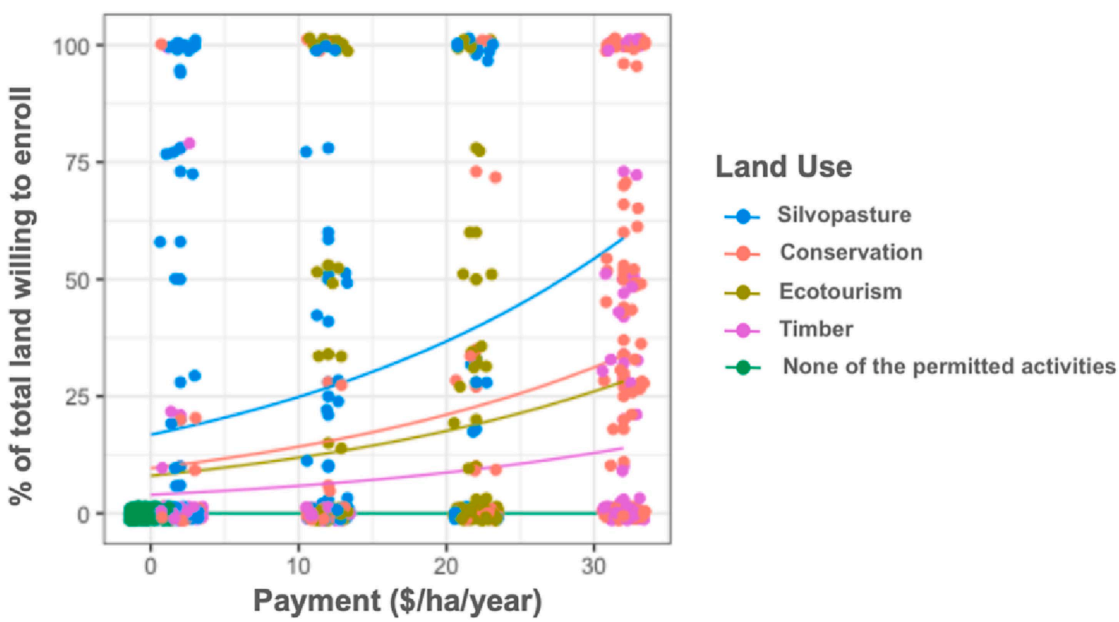

Fig. 3. Percentage of their property that respondents were willing to enroll for four payment levels and under different permitted activities on the properties. Points at a given payment level (x-axis) were offset slightly to show overlapping points.

Table 3
Estimated percentage of land that landowners would enroll under different payment scenarios and permitted land use activities, projected total land (ha) enrolled for the study area, and total annual cost (US$) for each of the payment levels.

Payment level[a]	Conservation			Ecotourism			Timber			Silvopasture		
	%[b]	Ha[c]	US$[d]	%[b]	Ha[c]	US$[d]	%[b]	Ha[c]	US$[d]	%[b]	Ha[c]	US$[d]
$ 2	10	205,167	410,335	9	184,651	369,301	4	82,067	164,134	18	369,301	738,603
$ 7	13	266,718	1,867,023	11	225,684	1,579,789	5	102,584	718,086	22	451,368	3,159,578
$ 32	34	697,569	22,322,213	28	574,469	18,382,999	14	287,234	9,191,500	59	1,210,488	38,735,605

[a]Annual payment per hectare in US dollars. [b]Estimated percentage of land enrolled for the study area. [c]Projected hectares enrolled for the study area. [d]Total projected annual cost for the study area in US dollars.

landowners would enroll under silvopasture at a payment level of $32/ha/year is 1,210,488 ha, resulting in a total annual cost of US$ 38,735,605 (Table 3). In contrast, the overall estimated amount of land that landowners would enroll under silvopasture at a $2/ha/year payment level is 369,301 ha (18% of study area), resulting in a total annual cost of US$ 738,603 (Table 3). The average price of forested land in the study area is about $250/ha.[6] If PES payments were reallocated to fee-simple land purchases, approximately 1,549,424 ha could be purchased with 10 years of PES payments at US$32/ha, assuming lands are available for purchase. Approximately 29,544 ha could be purchased with 10 years of PES payments at US$2/ha.

4. Discussion

Lands voluntarily enrolled in PES programs often result in isolated patches of forest surrounded by developed lands that do not support critical processes for ecosystem health (Wünscher et al., 2008). Even if the program attracts participants throughout a strategic conservation area, this may not translate into functional lands for conservation if landowners enroll only a portion of their properties. In this study, we examined the factors associated with the percentage of their property that landowners would allocate for Argentina's PES program in the Gran Chaco ecoregion and assessed the cost of strategically conserving large contiguous blocks of lands for biodiversity and ecosystem services with PES. Factors influencing the percentage of their property landowners were willing to allocate to PES exhibited both similarities and differences from the factors associated with willingness of landowners to participate in PES (Nuñez Godoy et al., 2022). For example, shorter contract lengths were significant in landowners' willingness to participate in PES in the Chaco (Nuñez Godoy et al., 2022), but not in determining the percentage of their property enrolled. This result differs from other studies that found that private landowners in Finland enrolled more hectares in PES when contract lengths were shorter (Layton and Siikamäki, 2009; Siikamäki and Layton, 2007). The short-term contracts available with the Argentine PES program (i.e., <5 years) may encourage enrollment (Del Rossi et al., 2021), but are unlikely to be as effective in securing ecosystem services as long-term contracts (Engel, 2016). Preferred contract lengths were highly variable for the same percentage of land enrolled. Some landowners may choose short contracts to retain flexibility in land management or to assess whether PES allows them to balance their financial objectives with mandated conservation actions before enrolling for longer durations. Changes in the amount of land enrolled and land management are possible when renewing a PES contract. Landowners who expect to maintain land in the same type of management may opt for longer contracts to reduce transaction costs. The Argentine program pays a fixed amount per hectare enrolled regardless of contract length. As expected, higher payment levels increased both landowner willingness to participate in PES and the percentage of land they would enroll in the Chaco, which is consistent with findings for PES programs that are implemented in temperate forests in Finland and USA (Layton and Siikamäki, 2009; Ma et al., 2012). Finally, both landowners' decisions to participate in the Argentine PES program and the percentage of their property that landowners were willing to enroll were influenced by land uses permitted within the PES program (Nuñez Godoy et al., 2022).

Silvopasture, which reflects historical land use in the Chaco (Viglizzo et al., 2011) and thus a well-known management system, was associated with the highest percentage of property landowners were willing to enroll in PES. The Forest Law permits silvopasture on up to 7 million hectares of native forest in Salta province (i.e., yellow and green zones, SayDS, 2021). The importance of this land use in landowners' decisions to participate in PES (Nuñez Godoy et al., 2022), and their willingness to enroll more hectares in silvopasture compared to other land uses, highlights the need for silvopasture management practices compatible with conserving native forest, biodiversity, and other ecosystem services. However, understanding of the ecological impacts of silvopasture is limited, and the ability of the newer Integrated Woodland and Livestock Management (MBGI) to address shortcomings of traditional silvopasture is unknown. Researchers have argued that silvopasture is either central to achieving multifunctional systems in the Chaco (Law et al., 2021) or is a concealed deforestation process (Blum et al., 2022). Although silvopasture provides more carbon storage and wildlife habitat than pasture systems, these benefits are greatly reduced compared to the amount provided by forests (Fernández et al., 2020; Mastrangelo and Gavin, 2012). Silvopasture practices aimed at reducing woody encroachment result in declining tree survival over time, potentially leading to complete deforestation (Fernández et al., 2020; Marquez et al., 2022). The introduction of fast-growing nonnative grasses, which is allowed with traditional silvopasture and MBGI, likely degrades wildlife habitat (Aprile et al., 2016). Development, evaluation, and adoption of carbon- and biodiversity-rich practices are imperative for silvopasture to be an effective PES strategy (Law et al., 2022).

For a given payment level, we expected that other income-generating activities like ecotourism and timber production would encourage landowners to enroll higher percentages of land than conservation activities. However, contrary to our expectations, these activities did not attract large amounts of enrolled land, possibly because ecotourism and timber harvesting may not be perceived as financially viable due to poor infrastructure, high initial investments, competition from timber illegally harvested in the Chaco, long rotation times for timber harvest, and previous overexploitation of timber (Gobbi et al., 2022; Sarmiento et al., 2021). In addition, the harsh conditions of the Chaco, particularly water scarcity and increasing drought with climate change, limit both human habitation and production activities (Matteucci et al., 2016). Despite these challenges, ecotourism is developing in the Chaco and could generate alternative economic benefits, especially for individuals who live in or near possible ecotourism locations (e.g., protected areas and Bermejo River).

Forest conservation was the second most attractive land use for enrolled land. Enrolling more land under forest conservation would allow landowners to obtain more PES funds to cover fixed costs (e.g., taxes) while sustaining low recurring costs Also, forest conservation does not require major upfront costs or changes in land use (Duke et al., 2014). In Chaco, activities such as planting native trees or developing fire breaks are allowed under forest conservation, but maintenance of forest with no management also qualifies as conservation. Respondents may have opted for conservation in the PES program in Chaco because it does not require active land stewardship and the PES payment would generate income without investment in production activities.

The Argentine PES program has enrolled approximately 8% of the study landscape with an average payment level of US$7/ha/year. Our models indicated that landowners might enroll, at most, 59% of the total study landscape if the program were to elevate that sum to $32/ha/year, the highest payment that we offered. This area, with over 1,200,000 ha, would be larger than the largest national parks in Chaco of Argentina (Copo National Park, 118,119 ha) and Paraguay (Defensores National Park, 719,722 ha), but much smaller than Kaa Iya del Gran Chaco National Park in Bolivia (3,441,115 ha). If these enrolled lands were contiguous and situated around existing protected areas, they could help decrease forest fragmentation and maintain habitat for wide-ranging species (Núñez-Regueiro et al., 2015). However, with a maximum of 59% of the study area enrolled in PES, many properties in PES likely would not be contiguous and the landscape would remain fragmented.

Our models predict that enrollment of 100% of the study area would require current investment levels in PES to increase eight times (i.e., $54/ha/year). This value could be an overestimate if respondents requested higher payments than they would accept in a non-hypothetical situation (Bateman et al., 2018), and future studies

[6] Information from ProGrano, the agricultural producers' association of northern Argentina (https://prograno.org/).

should incorporate higher payment levels to corroborate or adjust our estimates. If our estimates are correct, enrollment of 100% of the study area might fall outside the financial abilities of the Argentine program given current financial hardships, but a payment of $54/ha/year is well within payment levels observed in many other PES programs around the world (Ezzine-de-Blas et al., 2016). Many national PES programs, however, face restricted long-term financing (Blackman and Woodward, 2010).

Given these financial constraints, potential alternatives for achieving landscape-level conservation might include altering PES programs to reduce costs, combining PES with other income-generating strategies, or land purchase. For example, PES payments could be scaled so that higher payments are provided for the most strategic lands and less money is spent on low-priority areas (Wünscher et al., 2008). The Argentine PES program already incorporates this mechanism as payments differ across the land use zones that were established based on conservation value (i.e., red, yellow, and green). Further differentiation of payments within these zones would support more effective conservation but requires development of allocation criteria at a much finer geographic scale, a process that could be costly as well as politically charged, with equity impacts (Aguilar-Gómez et al., 2020; Ferraro, 2008).

Second, regular PES payments could be combined with asset-building payments (Wunder, 2007), where landowners are paid to adopt profitable and sustainable land use practices (e.g., sustainable livestock production). Unlike regular PES, these asset-building payments are temporary and only cover costs of transitioning to new land uses. However, because of the extreme environmental conditions and prior degradation of the Chaco, transitions to practices that are profitable and do not cause further environmental degradation in this region may be slow and require sustained financial support over a long period of time.

Third, complementary schemes such as forest certifications or carbon credits could contribute to landscape-level conservation while reducing the financial burden on PES programs. To date, economic and technical challenges have prevented widespread adoption of forest certifications in the Chaco. Carbon-market initiatives have gained interest among medium and large-sized landowners, but carbon initiatives are incipient and their success in the Argentine Chaco as well as the legal regulatory framework are still unclear.

Fourth, given climate limitations and land use restrictions on production activities in the Chaco, land purchase could be an attractive cost-effective alternative compared to PES payments (Curran et al., 2016; Nuñez Godoy et al., 2022). The primary economic activity of many Chaco landowners (e.g., large companies, investors, and other absentee landowners) is not agriculture (Núñez-Regueiro et al., 2020), and these landowners may choose to sell land and invest returns in other economic sectors. However, purchasing land from landowners who rely on income from their properties could result in displacement of agricultural activities to other regions (i.e., leakage). This needs to be evaluated and addressed. For example, where leakage occurs and environmental conditions permit simultaneous achievement of income and conservation goals, asset-building payments could be targeted to landowners to ensure that they are able to meet their income needs while also conserving ecosystem services. With a land purchase strategy, other issues such as post-purchase management costs also need to be considered. Nonetheless, assuming that increasing demand will not raise land prices, investing 3–4 years of funds at $54/ha/year from PES to purchase available land is arguably an investment worth considering for securing long-term conservation of lands with an average selling price in the study region of approximately $250/ha. In contrast, because PES funding would have to be paid annually, conserving large landscapes with PES would be extremely costly, not only initially, but in perpetuity.

5. Conclusion

Meeting targets for landscape-level forest conservation with PES, and avoiding forest fragmentation, requires enrollment of large amounts of contiguous private land. Our study demonstrates the importance of program configuration as a determinant of PES coverage, with payment levels and permitted land uses driving the percentage of the property that landowners would enroll in PES. The most attractive land uses aligned closely with traditional land uses, and thus provided known economic returns in addition to PES payments, or aligned with land uses that required low investment in land stewardship. The design and implementation of PES programs should consider the long-term impact of permitted land uses because these land uses affect the structure and function of forests and the capacity of landscapes to conserve biodiversity and provide ecosystem services. For example, a revised design might include more strict criteria for approved land use practices and higher payments for land uses that offer greater benefits regarding biodiversity and ecosystem services. Nonetheless in our study area, PES alone cannot achieve landscape-level conservation (e.g., sufficient unfragmented habitat for wide-ranging wildlife) under current contractual conditions and funding. Even the highest payment level offered to participants in this study, which was 4.6 times higher than the current observed payment, would be insufficient to motivate landowners to enroll all their property in PES. Protecting 100% of the study landscape under the PES program would require funds to increase approximately eight times from current levels and long-term financing might be unsustainable. Fee-simple land acquisition may be a more feasible alternative in some regions where landowners are interested in selling their land (e.g., where potential for commercial activities is limited by access; Nuñez Godoy et al., 2022). Given the financial constraints of PES programs and the need to achieve spatial continuity of forested land for long-term conservation, PES would be most effective coupled with priority setting for spatial coverage within the constraints of PES funding, and thus often focused on a limited target area (e.g., a single corridor between two protected areas) as a complement to other conservation policy instruments.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Cristina Nunez Godoy reports financial support was provided by Rufford Foundation. Cristina Nunez Godoy reports financial support was provided by Neotropical Grassland Conservancy.

Data availability

Data will be made available on request.

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Appendix A

Table A1

Comparison of all model AICc scores for variables related to the percentage of property enrolled. Null model is an intercept only model. Models with more than one variable show additive effects.

Model	DF	logLik	AICc	Delta	Weight
use + payment	8	−4050.15	8116.50	0.00	0.38
use + payment + pes	9	−4049.75	8117.70	1.24	0.21
use + payment + size	9	−4049.90	8118.00	1.55	0.18
use + payment + length	9	−4049.97	8118.20	1.68	0.17
use + payment + zone	11	−4048.83	8120.00	3.50	0.07
use	7	−4064.11	8142.40	25.89	0
use + length	8	−4063.71	8143.60	27.12	0
use + pes	8	−4063.83	8143.80	27.36	0
use + size	8	−4063.86	8143.90	27.42	0
use + length + pes	9	−4063.42	8145.10	28.59	0
use + length + size	9	−4063.45	8145.10	28.65	0
use + pes + size	9	−4063.46	8145.10	28.68	0
use + zone	10	−4062.89	8146.00	29.58	0
use + zone + size	11	−4062.18	8146.70	30.20	0
use + zone + length	11	−4062.48	8147.30	30.80	0
use + zone + pes	11	−4062.53	8147.40	30.92	0
length + payment	5	−4070.44	8151.00	34.48	0
payment	4	−4080.62	8169.30	52.82	0
payment + pes	5	−4080.19	8170.50	53.98	0
payment + size	5	−4080.37	8170.80	54.35	0
payment + zone	7	−4079.22	8172.60	56.10	0
length	4	−4094.76	8197.60	81.11	0
length + pes	5	−4094.47	8199.00	82.54	0
length + size	5	−4094.59	8199.30	82.79	0
length + zone	7	−4093.51	8201.10	84.68	0
null	3	−4121.15	8248.30	131.85	0
pes	4	−4120.80	8249.70	133.18	0
size	4	−4120.93	8249.90	133.45	0
size + pes	5	−4120.47	8251.00	134.55	0
zone	6	−4119.81	8251.70	135.26	0
zone + size	7	−4119.13	8252.40	135.93	0
zone + pes	7	−4119.38	8252.90	136.42	0

Use = permitted activities on the properties; payment = annual payment per hectare; length = contract length; pes = whether the property was ever enrolled in PES; size = property size; zone = land-use zone of property; DF = Degrees of freedom; logLik = Log-likelihood; AICc = Akaike Information Criterion corrected for finite sample sizes; Delta = Difference in AICc between best model and each individual model; Weight = Akaike weight of model.

Table A2

Mixed-effect models estimates for the influence of activities permitted on the properties (use), annual payment per hectare (payment), whether the property was ever enrolled in PES (pes), property size (size), contract length (length), and land-use zone of property (zone).

				Confidence Intervals	
	Estimate	Std. Error	t-Value	2.50%	97.50%
Model 1:					
use + payment					
(Intercept)	18.81	2.68	7.02	13.55	24.07
use ecotourism	12.44	2.57	4.85	7.40	17.48
use none	6.85	2.19	3.12	2.54	11.16
use silvopasture	26.10	2.46	10.62	21.28	30.93
use timber	5.24	2.50	2.10	0.34	10.15
payment	7.35	1.38	5.33	4.64	10.05
Model 2:					
use + payment + pes					
(Intercept)	18.05	2.80	6.44	12.55	23.56
use ecotourism	−6.30	3.25	−1.94	−12.67	0.08
use none	−11.86	3.73	−3.18	−19.18	−4.53
use silvopasture	7.40	3.58	2.07	0.38	14.42
use timber	−13.51	3.21	−4.21	−19.79	−7.22
payment	7.38	1.38	5.35	4.68	10.09
pes	2.42	2.70	0.90	−2.95	7.76
Model 3:					
use + payment + size					
(Intercept)	18.83	2.68	7.03	13.58	24.09
use ecotourism	−6.36	3.25	−1.96	−12.73	0.01
use none	−11.98	3.73	−3.21	−19.30	−4.66
use silvopasture	7.26	3.57	2.03	0.25	14.28
use timber	−13.59	3.20	−4.24	−19.88	−7.31
payment	7.34	1.38	5.33	4.64	10.05

(continued on next page)

Table A2 (*continued*)

	Estimate	Std. Error	t-Value	Confidence Intervals 2.50%	97.50%
size	−0.82	1.17	−0.70	−3.14	1.49
Model 4:					
use + payment + length					
(Intercept)	19.30	2.80	6.89	13.81	24.79
use ecotourism	−6.63	3.27	−2.02	−13.05	−0.20
use none	−13.45	4.48	−3.00	−22.24	−4.66
use silvopasture	7.90	3.72	2.13	0.61	15.20
use timber	−13.87	3.24	−4.28	−20.23	−7.50
payment	7.30	1.38	5.29	4.59	10.01
length	−0.93	1.54	−0.60	−3.95	2.10
Model 5:					
use + payment + zone					
(Intercept)	26.77	7.61	3.52	11.71	41.85
use ecotourism	−6.20	3.25	−1.91	−12.58	0.17
use none	−11.83	3.73	−3.17	−19.15	−4.50
use silvopasture	7.43	3.58	2.08	0.41	14.45
use timber	−13.47	3.20	−4.21	−19.76	−7.18
payment	7.37	1.38	5.35	4.67	10.08
zone red	−7.45	8.24	−0.91	−23.73	8.93
zone red-yellow	−5.56	7.74	−0.72	−20.94	9.82
zone yellow	−9.18	7.38	−1.24	−23.84	5.48

Number of observations was 855.

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