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Smallholders' Adoption of Climate-Smart Technologies In Costa Rica

Anais Lamour

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THÈSE POUR OBTENIR LE GRADE DE DOCTEUR DE L'UNIVERSITÉ DE MONTPELLIER

En Sciences Economiques

École Doctorale d'Economie et de Gestion de Montpellier (EDEG)
Center for Environmental Economics – Montpellier (CEE-M)

Smallholders' Adoption of Climate-Smart Technologies In Costa Rica

L'Adoption de Technologies Climato-Intelligentes par les Petits Producteurs au Costa Rica

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Le 14 Novembre 2018

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"La faculté n'entend donner aucune approbation ni improbation aux opinions émises dans cette thèse ; ces opinions doivent être considérées comme propres à leur auteur."

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List of Acronyms and Abbreviations

AF	:	Agroforestry
CATIE	:	Tropical Agricultural Research and Higher Education Center
CE	:	Choice Experiment
CORFOGA	:	Ranchers' Corporation of Costa Rica
CSA	:	Climate-Smart Agriculture
CST	:	Time-constant pruning sequence
FAO	:	Food and Agriculture Organization of the United Nations
HIGH	:	High chemical input intensity
ICAFFE	:	The Costa Rican Coffee Institute
INEC	:	the National Institute of Statistics and Censuses of Costa Rica
IPCC	:	Intergovernmental Panel on Climate Change
LOW	:	Low chemical input intensity
MAG	:	Ministry of Agriculture and Livestock of Costa Rica
MWTP	:	Marginal Willingness-To-Pay
RBA	:	Recognition for Environmental Benefits program of Costa Rica
SUN	:	Full Sun system
USA	:	United States of America
VAR	:	Time-variant pruning sequence
WB	:	World Bank

General introduction

1 Climate-smart agriculture

1.1 Linking mitigation, adaptation and food security actions

Smallholding agriculture lies at the crossroads of mitigation and adaptation actions. First, agricultural systems largely contribute to climate change by emitting greenhouse gases (GHG). Tubiello et al. (2014) estimates that global agricultural GHG emissions even rose by 14% between 2001 and 2011, and that this increase occurred almost entirely in developing countries where small and medium holders predominate. Concomitantly, tropical ecosystems - including agricultural lands and pastures - offer considerable opportunities for low-cost mitigation actions to limit the atmospheric accumulation of GHG (Griscom et al., 2017). Second, climate change affects agricultural production worldwide as well as other vital ecosystem services and, combined with increasing population, threatens food security in low-latitude regions particularly (Smith, Schellnhuber, and Mirza, 2001; Morton, 2007). Adaptive technologies in order to reduce the risk of losses are available, but rapid response is unlikely in many countries because of socioeconomic constraints (Tompkins and Adger, 2005; Howden et al., 2007; Klein et al., 2014). Thus, both mitigation efforts and adaptation measures to at least maintain agricultural yields and incomes are instrumental in eradicating extreme poverty and hunger (Sanchez and Swaminathan, 2005).

Tradeoffs between mitigation efforts, adaptation measures and food security goal may occur however, when pursued separately in agricultural systems (Rosenzweig and Tubiello, 2007; Verchot et al., 2007; Smith and Olesen, 2010). The most glaring illustration is probably the conflict on land for food and land for biofuel (Searchinger et al., 2008). Besides, shifts in climate suitability zones for crops may increase cultivation in previously undisturbed lands as an adaptation measure. Magrath and Ghazoul (2015) estimated that

56% of the global area currently suitable for Arabica coffee farming will be brought out of the climate suitability range by 2050s, while meeting future demand for Arabica will very likely drive conversion of high-elevation forests up to 2.2 million hectares, causing major GHG emissions and biodiversity losses. Since neither adaptation strategies nor GHG emissions mitigation efforts can alone avoid further impacts of climate change (Klein et al., 2007), a challenge for public policy is thus to overcome the competition for land and resources (including funding) arising from treating climate change and food security issues separately.

Acknowledging potential tradeoffs and in search for synergies instead, the Food and Agriculture Organization (FAO) launched the concept of Climate-Smart Agriculture (CSA) in 2009. Defined by its intended outcomes rather than by a specific set of agricultural technologies, CSA refers to “agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievement of national food security and development goals” (FAO, 2010). CSA, conservation agriculture or ecological intensification largely overlap, however agricultural technologies are evaluated for their capacity to locally achieve the triple goal of adaptation, mitigation and productivity gain in the CSA framework. As an illustration of how CSA can coincide with ecological intensification, Havlík et al. (2014) found that livestock production systems will experience a transition toward an improved land-use efficiency based on a cattle diet shift from grazing pastures to greater shares of fodder and concentrate, as an autonomous response to the predicted demand increase. In addition to reducing reliance on pasture productivity, this transition will also decrease GHG emissions, mainly though avoided land conversion into pastures, according to the authors.

1.2 Focus on agroforestry and silvopastoralism

Significant attention is now being paid to agroforestry and silvopastoral systems as part of the CSA integrated approach (Verchot et al., 2007; FAO, 2010; Matocha et al., 2012). Agroforestry and silvopastoralism are management systems that combine trees with agricultural crops and livestock respectively, on the same piece of farm land. In such systems, trees are deliberately integrated into the agricultural ecosystem in order to derive ecological services supporting production (e.g. leguminous trees supply crops and pastures with nitrogen captured from the atmosphere) and direct economic benefits for the household (e.g. fruit trees provide food products for self-consumption or for sale). Agroforestry and silvopastoralism have been proven to enhance soil carbon stocks and above-ground biomass, also protect crops and cattle from heat stress through shade and from extreme weather events, while helping to

diversify farmer's income against production and market risks and providing food and fuelwood (Verchot et al., 2007; Matocha et al., 2012; Smith and Mbow, 2014; Lasco et al., 2014; Franzel et al., 2014). In addition, a wide array of ecosystem services can be derived from these systems, including enhancing water use, storage and efficiency, soil productivity, erosion control and nutrient cycling, as well as pest and disease control and biodiversity conservation (Verchot et al., 2007).

Agroforestry and silvopastoralism are ancient practices involved in the majority of subsistence farming across the world, prior to the Green Revolution. No longer popular in Europe, these systems have been pressured towards higher efficiency and converted into monocultures. Despite persistent attempts to introduce modern agricultural technologies in the developing world, many smallholders still practice agroforestry and silvopastoralism. It has been estimated that 46% of the world agricultural lands are covered by trees, concerning 30% of rural populations, mainly in Latin America, South-east Asia and Sub-Saharan Africa (Zomer et al., 2009). Regarding how tropical countries plan the future of their agricultural systems, agroforestry and silvopastoralism seem even instrumental to tackle climate change issues. In their pledges for climate action called Intended Nationally Determined Contributions (INDCs) submitted to the Conference of the Parties of the United Nations Framework Convention on Climate Change in Paris in 2015, twenty-three countries mention agroforestry as one of their mitigation priority and twenty-nine countries refer to it in its plan for adaptation (see Figure 1).

Most of the agricultural technologies constituting CSA, as agroforestry and silvopastoralism, are not new. Nonetheless, a part of the CSA challenge consists in overcoming the barriers weighting on the adoption of such technologies among farmers, especially when considering smallholders in developing countries. In the technology adoption literature, the incidence of market failures has been extensively involved in explaining why farmers can prefer technologies that poorly perform from the point of view of agronomists or that are costly from the economists' perspective. Inefficient market mechanisms can induce suboptimal levels of adoption, for either society or for the farmer. On top of that, the production decision context becomes more uncertain in many ways, with more erratic weather, more variable food prices and more intense and unpredictable pest and disease attacks (Morton, 2007).

2 Barriers to CSA adoption

2.1 Environmental externalities

Since CSA, if adopted, can enhance the provision of ecosystem services, the externalities consequent to the public-good nature of these benefits are not

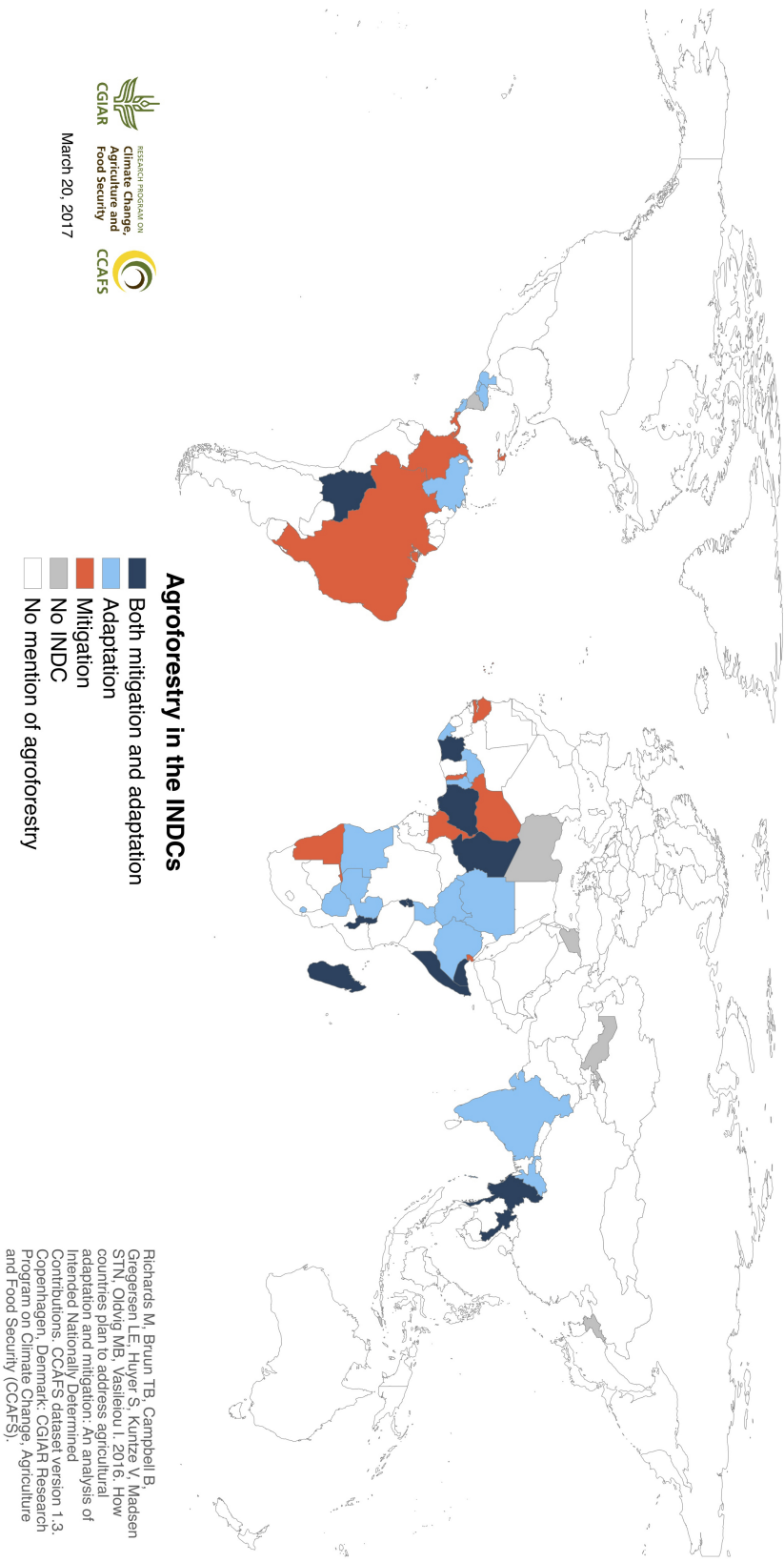


Figure 1: Agroforestry in the Intended Nationally Determined Contributions (INDCs)
 Source: Richards et al. (2016)

well accounted for in the farmer's decision-making. The inherent mitigation effort of adopting CSA provide benefits that go beyond the scope of the farm to beneficiaries at a global scale. A competitive market, where supply and demand could meet such that it would efficiently reflect the provision cost and social benefit, is clearly missing (Arrow et al., 2000).

CSA adoption can also generate local positive externalities within the farmer's community. Pest and disease control through resistant varieties is of great interest since agricultural systems face the threat of a dramatic disturbance in the spatial distribution of plant pests and diseases. However, if its private benefits are very limited but social benefits are large and even increasing due to this threat, the large incentive to free-ride on neighbors' control spillovers may provoke the underadoption of resistant varieties Kremer and Miguel (2007). Collective action does not fully address the issue of local externalities when it is weak or too costly (Dutilly-Diane, Sadoulet, and de Janvry, 2003), and the farmers' willingness to cooperate for this purpose may deteriorate with climate change (Cárdenas et al., 2017).

2.2 Temporal dynamics

The adoption of CSA, like conservation agriculture (Giller et al., 2009; Andersson and D'Souza, 2014), often requests substantial capital investment levels in the short term, especially if transaction costs in accessing input markets are high (Suri, 2011). Many smallholders rely on family labor and chronically lack of cash such that they cannot sustain the upfront requirements, even if in the long term the adoption would have been profitable. If market failures in labor and credit by themselves can explain these factor constraints, short planning horizon may also be involved as a result of attitudes towards the future of farmers who may prefer to live day-to-day (Macours, 2013). The role of time discounting is indeed crucial in the economics of climate change (Nordhaus, 2007).

In order to appropriately use the technology, adopters would have to experiment the new technology in addition to learn about the continuously changing climate. The process of experimentation is costly, time-consuming and again, borne in the short term whereas the benefits are delayed. In addition, it generates information for others about the correct use and benefits of the technology. Learning externalities play a major role in the technology diffusion, however farmers tend to free ride on the learning of the early adopters in the community (Foster and Rosenzweig, 1995).

Furthermore, insecure land tenure can also make investment with long payback periods least likely to be adopted since another farmer may have grabbed the land by the time that benefits are generated (Do and Iyer, 2008). In addition, some of the CSA technologies, such as fallowing and

agroforestry, can be associated with an increased risk of expropriation (Goldstein and Udry, 2008).

Overall, investing in CSA in the short term for longer-term gains runs counter to seeking to smooth income over time, which is a prevailing risk-coping strategy among farmers where financial markets are deeply limited (Fafchamps, 2003). In a future with more erratic weather, more variable food prices and more intense and unpredictable pest and disease attacks, the benefits of CSA that can be internalized by farmers are not only distant, they can be considered also uncertain whereas costs are foreseeable.

2.3 Risk and uncertainty

Future developments of climate, pests and diseases and prices are far from being perfectly predictable, while past experience of them does not necessarily provide a good prediction of the probabilities that the hazards will occur. Given the high economic losses that adverse events can engender for rural households, risk-coping strategies can involve production and labor decisions that are, on the one hand, costly for the household (Fafchamps, 1993), and on the other hand, detrimental to CSA adoption if they imply a high income variability (Andersson and D'Souza, 2014).

For the poorest, these multifaceted strategies can result in the introduction of other agricultural activities with low marginal returns into more diversified portfolios (Rosenzweig and Binswanger, 1993), increasing the share of land dedicated to subsistence farming (Fafchamps, 1992), the allocation of labor and capital to non-agricultural activities (Macours, 2013), a de-capitalization of productive assets (Rosenzweig and Wolpin, 1993), choosing flexible technologies to keep adjustment options open (Fafchamps, 1993) as well as cultivating resistant varieties and planting timber trees as precautionary saving for instance. Strategies consisting in sharing risks with a community of friends and relatives (Fafchamps, 2003) may be seriously challenged due to the covariant nature of negative shocks that are expected to be more frequent, such that the implementation of the aforementioned changes at the household level could become a much more attractive option.

Far from being limited to the externality issue, the challenge of CSA adoption raises many concerns and open questions, including about the capacity of smallholders to maintain agricultural yields while dealing with the uncertainty of their production context. Even in the United States of America, past adaptation actions have been found to be limited despite harmful effects of temperature rise (Schlenker and Roberts, 2009). In order to foster a technological change towards CSA, it has become critical to first identify and evaluate technologies that can be promoted within the CSA framework, not

only based on plot-scale experimental trials, standard household surveys and a partial vision of the adoption concept (Andersson and D'Souza, 2014; Glover, Sumberg, and Andersson, 2016). Second, given the agro-ecological heterogeneity of farms and socio-economic heterogeneity of rural households, the identified technologies are likely to only ever provide the expected benefits to a subset of farmers. A further challenge is thus to accurately target these farmers (ISPC, 2018). Finally, since rapid and broad-scale adoption of CSA technologies will require institutional arrangements and funding mechanisms, evidence on the effectiveness of such policies still has to be demonstrated. This dissertation proposes some evidence related to these three challenges, applied to Costa Rica.

3 Scaling-up CSA in Costa Rican smallholdings

3.1 The Costa Rican setting

Costa Rica is a small country of Central America. “Global climate change is already a reality throughout most of Central America” (WB, 2014). Past and projected climates analysis point out Central America as one of the most affected tropical regions in term of increased in temperatures and extreme climate events. Over the last decades, temperature mean and daily range have been increasing, as well as the frequency of heavy precipitation events (Aguilar et al., 2005). In the inner areas of the region and for the end of the century, climate is projected to be warmer of about 3 to 3.5°C compared to the 1980-2000 trend, and its warming could reach 6-7°C if GHG emissions are not stabilized at global scale (Lyra et al., 2017). By 2050 in Mexico, maximum daily temperatures could easily exceed 36°C during the hottest month (Baca et al., 2014). Mean annual precipitation slightly decreases, along with more extended drought events (Lyra et al., 2017).

Agriculture is a key sector in the country's economy, employing 13% of the active population, accounting for 7% of the gross domestic product and contributing to the export earnings. Jointly with pineapples and bananas, coffee is a major export crop, typically grown by smallholders (WB, 2014). As shown in Figure 2, pastures represent the principal productive land use (25% of the country), before coffee plantations, and once covered half of the country (WB, 2014). 41% of agricultural GHG emissions are derived from livestock and 25% come from coffee smallholdings, mostly due to their heavy use of nitrogen fertilizers (WB, 2014).

Costa Rica has a relatively long history of pioneering public interventions in environmental matters. In 2007 already, Costa Rica voluntarily engaged in a Carbon-Neutral development path as a pre-2020 national mitigation goal. It encompasses initiatives from the Ministry of Environment and Energy (MI-

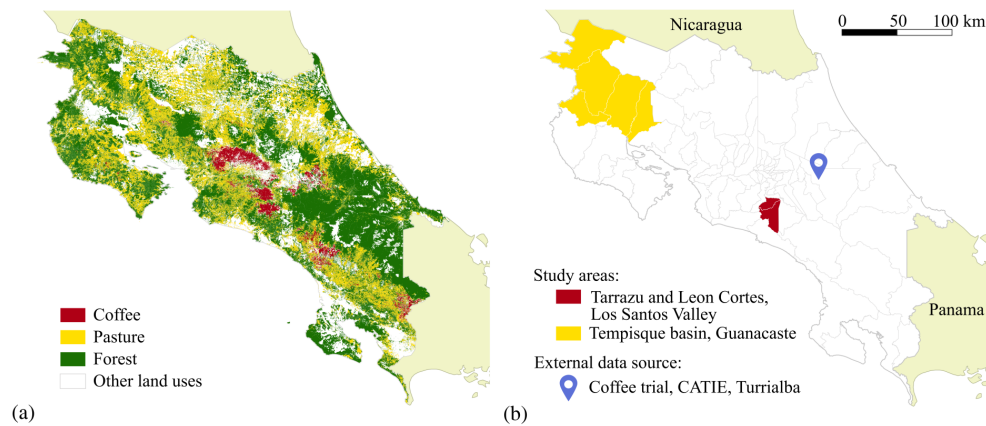


Figure 2: (a) Land use in Costa Rica and (b) study areas.

(a) Coffee cover in 2005, pasture and forest in 2012. Forest include primary, secondary and dry forests.

Source: CENIGA (2018)

NAE) and its well-known National Forestry Financing Fund (FONAFIFO) payment for environmental services (PES) program, as well as the Ministry of Agriculture (MAG) through a common agri-environmental agenda. In addition, coordinating institutions and specialized departments has been created, such as Nationally Appropriate Mitigation Actions (NAMAs) for both coffee and livestock sectors, the coffee NAMA being the first agricultural NAMA in the world to be implemented.

3.2 Coffee agroforestry and market risk

As emphasized above, coffee remains a leading agricultural commodity for the country, mainly produced by small-scale growers. The global coffee chain is tightly integrated and buyer-dominated, while two thirds of the world's coffee exports come from four countries. Arguing that the nexus between coffee farming and climate changes is clearly not limited to the local climate-induced crop damages, Chapter 1 evaluates the opportunity costs of adopting a potential CSA technology for coffee smallholders, who have to deal with an increasing price volatility at the same time. Such cost measures are required to inform climate politics (Alavalapati and Mercer, 2006) and build incentive-based mechanisms for CSA that are cost-effective (Jack, Kousky, and Sims, 2007).

A representative farm model of land allocation between production technologies is used to explore the tradeoff between adopting coffee agroforestry - a well-documented option for both mitigation and adaptation - and dealing with market risk. Based on original data collected in the Los Santos Val-

ley and on an experimental trial (see Figure 2), simulations results point out that adopting agroforestry is costly mainly due to a yield penalty. As a very concerning issue, agroforestry adoption also reduces the resilience against adverse price shocks. Results also suggest that coffee farmers' capacity to adjust to prices is very limited and their planning horizon is short. As it currently stands and as reflected by the simulation results, applying large amount of nitrogen fertilizers often appears as an efficient choice for the farmers especially in agroforestry systems, which needs more attention in the discussion about nitrous oxide emissions as well as about resilience against an increase in fertilizer prices.

3.3 Coffee agroforestry and farmers heterogeneity

Building on these conclusions, Chapter 2 studies the willingness of coffee farmers to adopt different agroforestry alternatives that pay more attention to the risks inherent to their activity. These agroforestry systems include resistant coffee varieties and/or timber trees, *a priori* attractive options as part of risk-coping strategies. In addition, Chapter 2 also aims at testing the hypothetical response of farmers to a set of incentives that could be used in a PES-like contract to promote CSA.

Applied on original data from a choice experiment conducted also in the Los Santos Valley (see Figure 2), the econometric models explicitly consider preference heterogeneity among respondents. The revealed preferences suggest that most of the respondents do value the introduction of resistant varieties such that they are willing to plant twice more trees in their plantations if combined with resistant varieties. Conversely, all agroforestry systems implying to plant timber trees were significantly less popular and on average, their adoption would require a compensation scheme. This compensation may be justified by the superior carbon sequestration associated with timber trees according to the literature. Regarding the respondents' preferences for the potential incentives, a large majority of respondents would be responsive to a contract offering a cash payment, a subsidized credit, a free trial of resistant coffee plants or technical assistance. Results also point out that respondents with a strong taste for the agroforestry system combining resistant varieties also tend to be very responsive to the credit offer. This suggests that the adoption of such systems may require an enhanced access to financing and in consequence, be slowed down in its absence.

3.4 Silvopastoralism and impact of a national program

Since in Chapter 2 coffee farmers appear to be responsive to economic incentives, Chapter 3 aims at evaluating a share-cost program promoting the

adoption of CSA-like technologies, namely the Recognition for Environmental Benefits (RBA) program. Such programs are rare in tropical regions, as is evidence of their effectiveness. Chapter 3 focuses on cattle-ranching systems in the Northwestern province of Guanacaste (see Figure 2). The study area is composed of extensive, undercapitalized and low-profitable cattle-ranching systems which also include substantial forested lands that are highly vulnerable to deforestation when the profitability of cattle ranching increases. The technologies promoted for cattle-ranching are technological packages consistent with silvopastoralism-based intensification.

Relying on a Difference-In-Difference approach applied to a random sample composed of ranchers who participated in the early RBA phase and future beneficiaries at the time of the data collection, Chapter 3 provides estimates of the additional impact of participating into the RBA program on both the technology adoption and the land use patterns. The results suggest that the program has been effective in increasing the adoption of the promoted technologies, in both quantities and diversity. In addition, it has fostered the ecological intensification of cattle-ranching systems, by inducing a reduction in the land used to feed cattle and probably by increasing stocking density too, while also sparing land from being grazed and trampled by cattle. The findings reported are relevant in the discussion about the potential of agricultural intensification to jointly achieve adaptation, mitigation and food security challenges. They are also important because they show that, in one of the poorest Costa Rican provinces, a state-funded intervention has been effective in stimulating CSA adoption in an activity representing a major source of greenhouse gas emissions.

In the General conclusion, results are discussed and conclusions are drawn for public interventions aiming at scaling-up CSA in developing countries, as well as for future research.

Exploring the tradeoff between dealing with market volatility and adapting to climate change in the adoption of coffee agroforestry

1

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Abstract

Coffee remains a leading agricultural commodity for many developing countries and is mainly produced by small-scale growers. Severe local impacts of climate change on coffee plantations are expected, however the nexus between coffee farming and climate change is clearly not limited to these direct impacts. Price volatility also happen to be a transmission channel of distant climate events to the livelihood of farmers in tropical regions. This Chapter evaluates the opportunity costs of adopting a potential CSA technology for coffee smallholders, who have to deal with an increasing price volatility at the same time. A representative farm model of land allocation between production technologies is used to explore the tradeoff between adopting coffee agroforestry - a well-documented option for both mitigation and adaptation - and dealing with market risk. Based on original data collected in the Los Santos Valley, Costa Rica, and on an experimental trial, simulations results point out that adopting agroforestry is costly (USD 800-1,200 per hectare and per year) mainly due to a yield penalty. As a very concerning issue, agroforestry adoption also reduces the resilience against adverse price shocks. Estimates of the price elasticity of supply attest that coffee farmers' capacity to adjust to prices in the short term is very limited. The results also suggest that their planning horizon is short. In addition, the findings reported provide insights for the discussion about the use of economic incentives such as a Payment for Environmental Services program in order to foster the adoption of agroforestry in Costa Rican coffee plantations.

Keywords: Payment for Environmental Services, Market risk, Climate Change, Farm Model, Coffee, Costa Rica.

1 Introduction

As signaled by historical price movements, the nexus between coffee farming and climate changes is clearly not limited to the direct and local impacts of local climate changes on the coffee plantation ecosystem. Price volatility also happens to be a transmission channel of distant climate events to the livelihood of farmers in tropical regions. These shocks are all the stronger as they also communicate the cumulative adjustments of buyers, producers and policy makers overseas, especially since the global coffee chain is tightly integrated and buyer-dominated (Eakin, Winkels, and Sendzimir, 2009). In this Chapter, we explore the trade-off faced by coffee smallholders who have to deal with both market price volatility and climate-induced damages.

In this context of smallholders being “double exposed” to global market shocks and climate changes with interacting risks and vulnerabilities, an improved understanding of the specific mechanisms linking risks and outcomes is required (O’Brien and Leichenko, 2000; Eakin, 2005; Mehta and Chavas, 2008; Eakin et al., 2011; Antle, 2015). Previous studies on the coffee sector in Central America and Mexico have considered the two issues together and conclude that prices were the dominant driver for changes in agronomic practices and livelihoods, over direct local climate change threats (Gay et al., 2006; Tucker, Eakin, and Castellanos, 2010; Eakin et al., 2011, 2014). In a previous article from the perspective of vulnerability in rural Mexico, Eakin (2005) pointed out that traditional mechanisms to cope with market risk such as diversification of agricultural activities and subsistence crops can lead to an increased vulnerability to climate-induced farm losses. This raises the concern that market risk may also counteract or render ineffective adaptive strategies that appear promising when climate change is considered in isolation from other stresses.

Covering coffee plantations with a layer of shade trees appears as the most documented strategy to adapt to warmer, dryer and more variable climate conditions (Lin, 2007, 2010; Siles, Harmand, and Vaast, 2010; Camargo, 2010; De Souza et al., 2012; de Carvalho Gomes et al., 2016; Rahn et al., 2018), while also providing multiple environmental externalities (Hergoualch et al., 2008; Philpott et al., 2008a; Hergoualch et al., 2012; Tully, Lawrence, and Scanlon, 2012; de Jesús Crespo et al., 2016). However, discussion on trade-offs in the adoption of coffee agroforestry is often limited to the comparison of yields, unless in the case studies on timber trees association analyzing the diversification of income sources from a financial point of view (Glover, 1981; Somarriba, 1992; Hernandez, Beer, and Von Platen, 1997; Vaast et al., 2015). Comparing net present values of a plot associating coffee plants and timber trees with an unshaded plot, Atallah, Gómez, and Jaramillo (2018) studied whether the benefits of timber production and pest control services from shade trees are offset by reduced coffee yields implied by limited sun-

light. They brought up another tradeoff which is likely to appear when the costs of planting and maintaining shade trees are immediate but their benefits come later: a relatively high time discount rate results in a strongly reduced outcome. Exploring financial risk in coffee agroforestry systems, Ramirez and Sosa (2000) found a risk-return tradeoff not caused by the timber sales: when coffee prices and yields are imposed to be positively (negatively) correlated, both expected net profits and risk representing by the profit variability are increased (decreased). This proves that depending on their risk aversion, coffee farmers could have an interest in timing their plantation so the highest possible production would be placed on the years of more favorable prices.

Facing the smallholders' strong concern about price risk and the researchers' pledge for coffee agroforestry, the potential tradeoff between dealing with market volatility and adapting to climate change in the decision of adopting agroforestry systems still requests to be assessed. In this Chapter, we develop a farm model of a coffee producer adjusting the management he/she operates on the coffee plantation in order to respond optimally to coffee prices. The model can be constrained such that we are able to value and compare outcomes from a farm under agroforestry and the same farm without shade trees, under different price scenarios. In the agroforestry case, shade trees are not considered for any commercial use. This allows us to exclude the portfolio diversification strategy, and thus to accurately represent technified shaded coffee productions which are characterized by their underdiversified tree species, mainly leguminous ones such as *Erythrina* and *Inga*, and which are also the closest alternative to unshaded plantations (Philpott et al., 2008a; Jha et al., 2014). We use parameters from coffee regions in Costa Rica where the debate between agroforestry and unshaded systems is well documented.

This study contributes to the literature in several ways. First, it makes explicit the short term adjustment mechanisms of coffee producers to prices. We identify the application of chemical input (Galloway and Beer, 1997; CEPAL, 2002) and the operation consisting in pruning a share of coffee plants (Ramirez and Sosa, 2000; Mehta and Chavas, 2008) as the annual operations used to adjust to prices in the short run. Taugourdeau et al. (2014) evidenced that shade intensity, nitrogenous fertilization and the pruning rate jointly account for 80% of the interannual variance of coffee yields in a Costa Rican coffee farm. While coffee supply has been often assumed to be perfectly inelastic to prices in the short run (Mehta and Chavas, 2008), our model then allows to estimate short-term price elasticities and the range of low values that we found is comparable to the few estimates reported in the literature (Akiyama and Duncan, 1982; Herrmann, 1986; Akiyama and Varangis, 1990).

A second contribution of this Chapter is to rely on original experimental data to account for the time and risk attitudes of a representative Costa Ri-

can coffee farmer. Thanks to the modeling of the intertemporal nature of the problem, our results underline that the tradeoff relative to the time allocation of net profits is salient despite the moderate time discount rate we obtained from the experimental data. It even supplants the risk tradeoff represented by the preference for smoothed consumption over time. This result highlights the crucial role of time discounting in the decision of adapting to climate change (Nordhaus, 2007).

Third, following De Cara et al. (2011) we also value the outcome differential between agroforestry and unshaded systems in term of a minimal annual payment required for agroforestry to be optimal. The payment measures the opportunity cost of agroforestry that a virtual Payment for Environmental Services (PES) program would have to offer in order to trigger a voluntary participation at the lowest cost. Hence the model produces measures of the cost of providing ecosystem services via coffee agroforestry. Such cost measures are required to inform climate politics (Alavalapati and Mercer, 2006) and build incentive-based mechanisms that are cost-effective (Jack, Kousky, and Sims, 2007). In addition, we provide insights into the viability and efficiency of such mechanisms in the case of coffee agroforestry, by testing the sensibility of this cost to the price forecasts available in the literature for 2020 and 2030 and by detecting a leakage effect of the virtual PES program through a consecutive increase in the input quantities applied.

Finally, thanks to the combination of a credit constraint, multiple adjustment decisions and simulations ran for various coffee price means, trends variability and fertilizer prices, we are able to explore the implications of adopting agroforestry for the resilience of the farm against price risk. Whereas the farmer in an unshaded farm performs short-term adjustments in order to time the plantation so that he/she seizes price opportunities and stands against adverse price changes, coffee agroforestry appears less adaptive and cases of land abandonment are observed for low prices. This results thus fuels the discussion about “adaptation gaps” in farming activities (Hsiang and Narita, 2012; Carleton and Hsiang, 2016). The adoption rate of a technology adaptive to climate change may appear suboptimal and bound by market failures, but it can also reflect an optimal strategy while facing the instability of the commodity markets. Even when crop yields are persistently sensitive to temperature, the business as usual strategy may avoid more revenue drops due to market risk than the climate-induced losses which would have been avoided by the adaptive strategy. The case of perennial cash crops is of special interest then, the unflexible or unreversible nature of an adaptive technology being a large disadvantage in the adoption decision.

The rest of the Chapter is organized as follows. Section 2 describes the various effects of climate change on both coffee markets and coffee yields, as well as how agroforestry can interact with these stresses. Section 3 presents

the economic model underlying the choice of system, input intensity and pruning rate by a coffee smallholder, as well as the data used for the calibration. In Section 4, we describe the results obtained from a baseline price scenario, using historical price series. In Section 5, we provide the results of optimization under simulated price changes, depending on the coffee systems (agroforestry versus full sun systems). As in Section 4, we estimate opportunity costs of agroforestry in Section 6, but this time under different price scenarios. Section 7 concludes.

2 Context

2.1 Direct local climate changes impacts

Native to the high altitude tropical forests of Ethiopia, Kenya and Sudan, Arabica coffee achieves its highest yields within a narrow range of mean annual air temperatures from 18 to 21°C, under annual rainfall of 1,200-1,800 mm (Alègre, 1959). Beyond the upper temperature threshold, and under changed rainfall patterns, damaging effects can be expected on flowering (Fournier and Di Stefano, 2004; Camargo, 2010), pollination (Peters and Carroll, 2012) and plant growth, with a net photosynthesis rate decreasing above 20°C and stopping at around 34°C (Cannell, 1975; Lin, 2007). In the Central Valley, Costa Rica, Fournier and Di Stefano (2004) evidenced a strong negative relation between air temperatures and coffee yields, which fall to zero when temperature during the dry season exceeds 31°C. Extrapolating 1969-1998 trends in temperature (+1.8°C on average in the dry season) and rainfall (-40% in mean rainfall in the dry season) in Veracruz, Mexico, Gay et al. (2006) got a simulated fall in coffee yields of 25% for 2020. A modeling of coffee yield under climate change scenarios in Central America shows a decrease in yield of between 7% in 2020 and 38% in 2100 (CEPAL, 2014). Accounting for the fertilization effect induced by rising atmospheric CO_2 concentration, Rahn et al. (2018)'s model predicts that elevated CO_2 would not be able to compensate for the negative effect of high temperature on yield unless in high-altitude areas and where there is no deficit in water availability for coffee plants. Furthermore, temperatures above 23°C hasten fruit ripening, leading to a lower quality of the output (Camargo, 1985). Extreme climate events can also damage coffee production, as heavy rains during Hurricane Stan caused fruit drop and landslides (Philpott et al., 2008b). Pests and diseases affecting coffee production, such as the coffee berry borer and the coffee rust, can also achieve greater prominence under a warmer climate as foreseen in East Africa (Jaramillo et al., 2011; Davis et al., 2012).

Because temperature and altitude are strongly related, global warming effects on Arabica coffee translate into a shift in altitude range for climate-

suitable land, from 400-2000 m.a.s.l. to 800-2500 m.a.s.l. by 2050s for Central America (Ovalle-Rivera et al., 2015). As a consequence, Arabica coffee farming will tend to migrate upwards by competing against current higher-elevation land uses, which are often forests, with severe topographical, ecological and legal issues (Gay et al., 2006; Schroth et al., 2009). Magrath and Ghazoul (2015) estimated that 56% of the global area currently suitable for Arabica coffee farming will be brought out of the suitability range by 2050s, while meeting future demand for Arabica will very likely drive conversion of high-elevation forests up to 2.2 million hectares, causing major carbon emissions and biodiversity losses especially in Costa Rica. In low-altitude coffee regions that are no longer suitable for Arabica, other land uses will compete against coffee farming. To a certain extent, hardier Robusta coffee could replace heat-stressed Arabica (Eakin et al., 2014; Bunn et al., 2015; Magrath and Ghazoul, 2015). In Costa Rica where Robusta coffee is not an option due to a ban on its cultivation (Reuters, 2016; Snider et al., 2017), major coffee conversion occurred in 2 different coffee regions after the 1997-2001 coffee crisis pointed to pasture, fallows, sugarcane and other annual crops replacing coffee farming, while fruit tree plantations (cocoa and banana) represented less than 15% of the converted coffee area (Bosselmann, 2012; Babin, 2015). Therefore, the loss of coffee agroforestry systems within the landscape mosaic threatens substantial ecosystem services, including biodiversity conservation due to their tremendous role in connecting forest fragments and surrounding protected areas (Perfecto et al., 1996; Jha et al., 2014).

2.2 Global coffee markets

Brazil, Vietnam, Indonesia and Colombia are responsible for two thirds of the world's coffee exports in 2017-2018 (ICO, 2018), and with that share historically increasing, climate-related events in these countries can drive sudden movements in global prices, affecting millions of smallholders who produce most of the coffee cherries across the world. Frost and drought provoking shortage of the Brazilian supply have far reaching implications for the entire global coffee market, as occurred in 1975-1976. At historically low levels in the early 1970s, prices for Central American coffees skyrocketed until 1977 (Akiyama and Varangis, 1990). In 1994, two consecutive frosts hitting Brazil resulted in coffee prices increase of almost 70% over a few days on the New York and London Stock exchanges (Marengo et al., 1997). Bastianin, Lanza, and Manera (2018) found evidence that this event explains almost entirely the tripling of the export price for Colombian coffee in the following months.

For the similar spikes observed in coffee prices in 1997-1998 and 2014-2015, extreme climate events in Brazil are again the main cause, with unusual hot and dry weather damaging Brazilian plantations. However, they have

been associated with extreme episodes of the El Niño Southern Oscillation (ENSO). Manifesting through climate anomalies in the tropical Eastern Pacific Ocean, this phenomenon radiates to more distant regions including East Asia where remote responses are observed (Wang, Wu, and Fu, 2000). Furthermore, ENSO can amplify weather conditions favorable to the outbreak and severity of some pests and diseases in coffee plantations, the coffee rust epidemics suffered in Colombia and Central America from 2008 to 2013 being an alarming instance (Avelino et al., 2015). Three studies examine the dynamics of ENSO and coffee prices and found a response of global prices to ENSO shocks (Ubilava, 2012, 2018; Bastianin, Lanza, and Manera, 2018). In particular, Bastianin, Lanza, and Manera (2018) shows that the ENSO impact on the supply side explains a small share of the variability of the price of Colombian coffee, but as for the demand-side of the global market to ENSO shocks, its reactions drive immediate and tremendous fluctuations in coffee prices. The authors point out expectations of international buyers regarding the availability of future supply which trigger large precautionary demand shocks and overshooting in the price response.

Whereas trading firms are hedging risks on the futures market, coffee smallholders in developing countries have poor mechanisms to manage their exposure and vulnerability to the increasing market instability (Ponte, 2002). Following Lewin, Giovannucci, and Varangis (2004), their response tends rather to magnify the cyclical behavior of prices. On the one hand, a price spike conducive to an incentive to produce more coffee is difficult to seize in the short run: unlike annual crops, new coffee plants are not productive until at least two years and the required investment is substantial. On the other hand, when the gestation period ends, worldwide oversupply occurs and drives prices down below marginal cost; then the reliance on safety net programs and informal insurance systems to address the adverse shock is precarious due to the covariate nature of the market risk and particularly in countries strongly dependent on coffee exports.

2.3 Coffee agroforestry

Increasing shade tree cover in a coffee agroforestry system appears as a promising practice to avoid production and quality loss from heat and water stress, due to the effect of shade level on the microclimate of the plantation. In the late nineteenth century yet in Lock (1888) about Sri Lanka, the need for shade in coffee plantation was described as an increasing function of climate. Many studies from Brazil, Costa Rica and Mexico corroborate this assertion, evidencing that shaded coffee plantations get fresher and more stable microclimate (de Carvalho Gomes et al., 2016). De Souza et al. (2012) measured a difference of 5.4°C in daily maximum temperatures between shaded and non-

shaded plantations. Similarly, Siles, Harmand, and Vaast (2010) found that the temperature of coffee leaves is from 1 to 7°C lower in a shaded plantation than in a non-shaded plantation.

Regarding its potential to limit drought stress, Lin (2010) highlights that the increase in shade cover can reduce water loss from both coffee plant transpiration and soil evaporation, and Camargo (2010) adds that the leaf litter provided by shade trees can also reduce soil temperature and improve soil water retention capacity. Rahn et al. (2018) identified that below 1500 m.a.s.l., a 50-75% shade cover coffee plantation will produce up to a 20% greater yield compared to less shaded plantations in 2050s, even when it was found to be outperformed by an unshaded plantation under current climate conditions. At higher altitudes, a 50-75% shade cover plantation is expected to be less productive than less-shaded plantations under both current and 2050s climates, yet changes in climate seem to close the yield gap gradually. In particular, in high-altitude areas that are currently drier, a 50% shade cover will likely lead to higher yield by 2050s compared to unshaded systems, whereas the opposite occurs under current climate.

In addition, shade trees can buffer wind (Camargo, 2010) and climate variability (Lin, 2007), including some climate extremes such as frost and heavy rains (Camargo, 2010) and even hurricanes (Philpott et al., 2008b). While limiting crop failures due to sub-optimal climate conditions, shade increase could also protect coffee production from a loss of quality (Muschler, 2001) and from the spread of some pests and diseases (Schroth et al., 2000; Avelino, ten Hoopen, and DeClerck, 2011). Finally, shaded coffee plants require lower levels of nitrogenous input to maximize yield (DaMatta, 2004) and simultaneously, traditional leguminous shade trees namely Erythras and Ingas have the ability to supply the plantation with an additional source of nitrogen captured from the atmosphere (Hergoualch et al., 2008; Tully and Lawrence, 2011). Accordingly, increasing the density of shade trees, especially leguminous ones, could decrease the demand for chemical fertilizers from coffee plantations (Beer et al., 1997; Rosenstock et al., 2014). Similar reduction in herbicide use can be expected thanks to lower weed densities (Beer et al., 1997). A resulting decrease in production costs and vulnerability to price shocks on input markets could be a substantial advantage of an adaptive strategy, especially because input reduction has been often used by Central American farmers as an adjustment mechanism against high input price or low coffee price (Galloway and Beer, 1997; CEPAL, 2002).

3 Coffee farm model

3.1 Farmer's decision

We consider a once-only decision made by a representative coffee farmer regarding i) how much land to allocate to agroforestry versus full-sun system (subscript k), ii) as well as on how much land to apply a sequence of pruning rates that can be varying versus constant over time (subscript j), and finally, iii) how much land to assign to low versus high input use intensities (subscript i). Farm capital endowments include a homogeneous coffee plantation area of LAND hectares that can be split by the farmer into each one of the two discrete levels composing the options the farmer has for the three subdecisions. For each production cycle $t \in \{1, 2, \dots, T\}$, eight alternatives (i, j, k) are defined as displayed in Table 1.1. x_{ijkt} denotes the resulting acreage allocated to the alternative (i, j, k) at period t , with $\sum_{ijk} x_{ijkt} \leq \text{LAND}$ for each t (equation 2) and x_{ijkt} non-negative (equation 3). The following exposes how the model considers timing, interactions and transmission channels to farm economics for each one of the three subdecisions.

Table 1.1: Alternatives among which the farmer decides to allocate land for period t

System	Pruning sequence	Input intensity at t	(i,j,k)
Agroforestry	Time-constant rate	Low	(LOW, CST, AF)
Agroforestry	Time-constant rate	High	(HIGH, CST, AF)
Agroforestry	Time-varying rate	Low	(LOW, VAR, AF)
Agroforestry	Time-varying rate	High	(HIGH, VAR, AF)
Full sun system	Time-constant rate	Low	(LOW, CST, SUN)
Full sun system	Time-constant rate	High	(HIGH, CST, SUN)
Full sun system	Time-varying rate	Low	(LOW, VAR, SUN)
Full sun system	Time-varying rate	High	(HIGH, VAR, SUN)

System subdecision

The system subdecision consists in allocating land between a traditional agroforestry system ($k = \text{AF}$) and a full-sun one ($k = \text{SUN}$) at the first period. In order to study the combined subdecisions that are operational and affect the farming system in a shorter run, a mature plantation is depicted independently from ecological dynamics of a transition from agroforestry to full-sun system or inversely. To this end, costs and labor demand as well as ecological dynamics due to planting shade trees or clearing them are assumed to be neglectable, and the farmer remains bound to maintain the

system acreages constant for the remaining periods. As such, for each k , $\sum_{ij} x_{ijk,1} = \sum_{ij} x_{ijk,2} = \dots = \sum_{ij} x_{ijk,T}$. The system subdecision defines the tree (Erythrinas) density in the plantation, being zero in a full-sun system. Longer run effects of the system subdecision is captured through the depreciation of the coffee plants over their life span, the latter being shorter in a full sun system compared to agroforestry because of a larger incidence of plant exhaustion.

Because a coffee plant is more frequently exhausted in a full sun system, it is also more frequently pruned such that the number of cycles of production until being pruned (YR_k) is lower in a full sun system compared to agroforestry. The model considers that each plant is pruned a fixed number of times denoted Q and replaced instead of being pruned the next time it is exhausted. Consequently, the life span of a coffee plant according to the system where it grows is $LIFE_k = Q \times YR_k$. Plantation depreciation is included in the model as a required annual cash flow per hectare DEP_k covering for the replacement cost of exhausted coffee plants that cannot be pruned anymore and $DEP_k = \frac{REP}{LIFE_k}$, with REP denoting replacement cost for one hectare of coffee plants. k impacts the annual labor demand through two operations, namely shade regulation and manual weed cutting. Further effects of the system subdecision are presented later jointly with the two operational subdecisions due to the existence of interactions.

Pruning subdecision

Simultaneously, the farmer chooses the acreages where he/she prunes for each period t a share of coffee plants $PRUN_{jkt}$. The intertemporal sequence can be time-constant ($j = CST$) or time-varying ($j = VAR$). The share of pruned coffee plants if the time-constant option is chosen corresponds to $PRUN_{CST,kt} = \frac{1}{YR_k}$ for each k and t . Conversely, the time-varying option makes the farmer postpone the pruning operation at period t and thus keep all his/her coffee plants productive for this period; then at $t+1$ the share of coffee plants to be pruned is assumed to have doubled. Because the postponement is likely to produce physiological feedbacks for which the model cannot control, the model does not allow the farmer to delay the pruning operation anymore for the two following years. This aims at constraining the time-varying option to internalize a reasonable recovery period of coffee plantation, such that the assumption of the absence of physiological responses can hold. Thus for each k , the intertemporal sequence of pruning rates under the time-varying option is defined as:

$$\begin{cases} \text{PRUN_VAR}, k, t & = 0 \\ \text{PRUN_VAR}, k, t + 1 & = 2 \times \text{PRUN_CST}, k, t \\ \text{PRUN_VAR}, k, t + 2 & = \text{PRUN_CST}, k, t \end{cases}$$

Constructing a model on a total number of production cycles $T > 3$ would imply to make the time-varying option complex with multiple time-varying sequences of pruning rates. Since operational decisions are supposed to be effective in the short run, T is rather fixed at 3. This period is supported by empirical findings from Ramirez and Sosa (2000) and Mehta and Chavas (2008). Hence the pruning subdecision comes down to whether the farmer postpones the pruning operation at the first period. It should be noted that $\sum_t \text{PRUN}_{\text{VAR},kt} = \sum_t \text{PRUN}_{\text{CST},kt}$ with $t \in \{1, 2, 3\}$ for each k . Furthermore, in order to simulate consistent time-varying pruning sequences, the equation ensuring that the farmer compels to maintain the system acreages constant over T is refined such that for each (j, k) , the farmers holds $\sum_i x_{ijkt}$ steady over T (equation (4)).

Chemical input subdecision

Finally the input intensity subdecision corresponds to land allocation among two intensity levels, applying low quantities of chemical input ($i = \text{LOW}$) or high ones ($i = \text{HIGH}$). The model assumes that the effects on coffee plants are immediate and limited to the production cycle during which input is applied, as such the farmer is allowed to switch between both levels over years. The input intensity level defines input purchase per hectare CI_i once combined with the system chosen, since demand in input required by coffee plants is higher in a full-sun system. Conversely, the pruning subdecision (and thus t) is assumed to have no effect on input purchase with pruned and unpruned plants requiring the same input amount. For a given k , i moreover determines the maximum feasible yield with 100% of the coffee plants being productive, denoted Y100_{ik} . Once taking into account the pruned coffee plants that are unproductive, the realized yield is $\text{Y}_{ijkt} = \text{Y100}_{ik}(1 - \text{PRUN}_{jkt})$.

Furthermore, annual labor (excluding harvest and coffee plant replacement) per hectare L_{ijkt} varies according to the option chosen for system, input intensity and also for pruning rate, as such it depends on period t . It is defined as the sum of labor for shade regulation and manual weed cutting ($\text{LSHADE}_k + \text{LWEED}_k$), pruning operation (LPRUN_{jkt}) and input application (LAPP_i). Annual labor for harvest per hectare is expressed as proportional to Y_{ijkt} .

3.2 Farmer optimization problem

Constraints

We consider a household which is representative of smallholder coffee farming in Costa Rica. Its socioeconomic characteristics and capital (excluding chemical input) are assumed to be constant in the short run. HHSIZE denotes the number of members in the household. Household members supply labor for coffee farming activities (excluding labor for harvest and coffee plant replacement) of up to LHH days per year and they harvest up to LHHHARV units of output in the harvest season. Because of the seasonality of the labor demand for harvest and the other productive operations, no interseasonal substitution is possible among unemployed labor. Whereas household members are not allowed to trade labour time if remaining for off farm income (equation 3) or to benefit from leisure time, labour market is assumed to perfectly fill farm demand for employed labour at daily wage W for operations excluding harvest, and at wage $WHARV$ per unit of output harvested. Therefore, for each t , $LD_t = LHH + LEMPL_t$ (equation 5), with total annual labor demand for operations excluding harvest being $LD_t = \sum_{ijk} x_{ijkt} L_{ijkt}$ and annual employed labor (excluding harvest) $LEMP_t$. Cost of total annual employed labor including harvest thus is $COSTL_t = W \times LEMPL_t + WHARV \times (PROD_t - LHHHARV)$, with total farm production denoted $PROD_t = \sum_{ijk} x_{ijkt} Y_{ijkt}$.

Once harvested, all the farm production is sold to a local cooperative at exogenous producer price P_t per unit. The farmer is assumed to have perfect knowledge of current and future coffee prices. Annual farm profit is $\Pi_t = P_t \times PROD_t - COSTI_t - COSTL_t - \sum_{ijk} x_{ijkt} DEP_k$, with $COSTI_t$ denoting total input expenses for cycle of production t . Prices for chemical input are assumed to be constant over time. The cooperative sales input on short-term credit to the farmer, such that the farmer's cash flow representing $COSTI_t$ occurs at the time of coffee sales. For simplification the farmer is also allowed to delay the cash flows for employed labor and plants replacement until the end of the current production cycle. Otherwise the model considers the farmer as credit constrained and compels him to secure the cash amount for repaying the production costs at each period, by constraining annual profits to be all positive (equation 3). No treasury flows between years are allowed¹, and neither cooperative credit nor cash potentially saved is subject to interest.

1. Resulting simulated profits are close to the poverty line calculated as $HHSIZE \times BFB$, BFB denoting the price of the basic food basket ensuring the minimum daily calorie requirement per individual. All profits are assumed to cover for the household expenses. There is no possibility of savings in this model.

Model

Simplifying assumptions on prices thus include that input and labor markets perfectly clear the farm demand, as well as output market clears its supply. No general equilibrium effects are taken into account. The farmer is perfectly informed about market prices, including sale prices for the three following periods. Price volatility is only considered on the output market. Since the farmer's decision problem corresponds to an intertemporal allocation of profit (through his choice of both pruning rates sequence and annual input intensities) and the credit market is assumed to be missing, the farm model accounts for his time preferences applied to the household's consumption streams. Farm activities are not diversified, hence the liquidity available for the purchase of consumption goods is limited to the coffee incomes that are received at the end of the production cycle. In addition, we conveniently choose to not apply any delay between the reception of coffee incomes and consumption. U is assumed to be a time-separable, stationary over time, intertemporal utility function defined as the discounted sum of the instantaneous utilities of annual profits. The farmer has a constant subjective rate of time preference $\delta \geq 0$ and we assume that the discounting is exponential, such that the discount factor at each t is $(\frac{1}{1+\delta})^t \leq 1$. Hence it allows for diminishing marginal utilities over time, meaning that the farmer would prefer early profits rather than late ones. The model uses a CRRA/CES specification of the instantaneous utility $u(\Pi_t) = \frac{\Pi_t^{1-r}}{1-r}$ for $r \neq 1$, where r is the constant relative risk aversion parameter and $IES_{t+1/t} = \frac{1}{r}$ the intertemporal elasticity of substitution measuring the willingness to substitute profit between two consecutive periods. When $r > 0$, u is concave and the farmer prefers profits that are smoothed over time. For $t \in \{1, 2, 3\}$, the farmer optimization problem can be expressed as follows:

$$\max_{\substack{x_{ijk,t} \\ i \in \{\text{LOW,HIGH}\} \\ j \in \{\text{CST,VAR}\} \\ k \in \{\text{AF,SUN}\} \\ t \in \{1,2,3\}}} U = \sum_t \left(\frac{1}{1+\delta} \right)^t \frac{\Pi_t^{1-r}}{1-r}, \quad (1.1)$$

s.t.

$$\sum_{ijk} x_{ijk,t} \leq \text{LAND}, \forall t \text{ (land constraint)} \quad (1.2)$$

$$x_{ijk,t} \geq 0, \quad \text{LEMP}_{L,t} \geq 0, \quad \Pi_t \geq 0 \text{ (non-negativity)} \quad (1.3)$$

$$\sum_i x_{ijk,t} = \sum_i x_{ijk,t+1}, \forall j, k, t \text{ (non-reversibility of decision on } (j, k)) \quad (1.4)$$

$$LD_t \leq LHH + LEMPL_t, \forall t \text{ (labor balance)} \quad (1.5)$$

A more detailed presentation of the program is provided in Appendix 1.1.

The solution x_{ijkt}^* of (1.1) is then the allocation of the farm land between all combinations (i,j,k) that achieves the maximum intertemporal utility of profits denoted U^* . It depends on coffee yields, sale prices and production costs induced by each alternative and determining the annual farm profits, as well as on the farm endowments (land and unemployed labor) and the farmer's risk and time preferences. For this last reason, the distribution of the profits over time may play a decisive role in the farmer decision. x_{ijkt}^* corresponds to a context in which no regulation instrument is applied, such that the farmer does not internalized the social cost or benefit of his/her farming practices.

Minimum payment as the opportunity cost

In order to value the opportunity cost of applying one specific combination $(\hat{i}, \hat{j}, \hat{k})$ with $x_{\hat{i}\hat{j}\hat{k}t} = \text{LAND} \forall t$, rather than to run the farm under x_{ijkt}^* , a conditional direct payment is introduced in a regulated version of the program as in De Cara et al. (2011). The PES-like payment is expressed per hectare and per year, and its minimum value $\underline{S}_{\hat{i}\hat{j}\hat{k}}$ required by $(\hat{i}, \hat{j}, \hat{k})$ to emerge in the optimum is determined such that:

$$\sum_t \left(\frac{1}{1 + \delta} \right)^t \frac{\left(\Pi_t \Big|_{x_{\hat{i}\hat{j}\hat{k}t} = \text{LAND}} + x_{\hat{i}\hat{j}\hat{k}t} \times \underline{S}_{\hat{i}\hat{j}\hat{k}} \right)^{1-r}}{1 - r} = U^*. \quad (1.6)$$

3.3 Parameters setting

The set of parameters (excluding sale prices) used to represent the conditions of a Costa Rican coffee smallholding is presented in Appendix 1.2. It originates from survey and experimental data, as well as from expert sources and technical reports of Icafé which is the Costa Rican Coffee Institute, and of INEC, the National Institute of Statistics and Censuses.

Yields

Operational characteristics and induced coffee yields defining input intensities in both agroforestry and full sun systems are defined according to field data from a long term trial established in 2000 at CATIE (Tropical Agricultural Research and Higher Education Center), Turrialba, Costa Rica. Turrialba region lies at a relatively low altitude (600 m.a.s.l.), with a climate defined as wet and without a marked dry season. The quasi-randomized block-design

applied in the experiment provides 15-years of observations for three plots of each combination of one system and one input intensity. Schnabel et al. (2017) and Merlo (2007) describe erythrin density, fertilizers quantities and numbers of application for herbicides, fungicides and foliar inputs, defining each treatment. Corresponding yields are computed from the output data from 2003 to 2014, by excluding the establishment period and ensuring a pair number of production cycles because of the bienniality of the fruit production. Mean yield $YMEAN_{ik}$ for each treatment thus is the average over the tree plots receiving the treatment and over the twelve years of observation. In order to ensure that yields Y_{ijkt} resulting from the farm model under the pruning rate $PRUN_{jkt} = \frac{1}{YR_k}$ correspond to the mean yields observed in the experiment, we define the maximum feasible yields as $Y100_{ik} = \frac{YMEAN_{ik}}{1 - \frac{1}{YR_k}}$. Yields are expressed in *fanega* which is the local unit for coffee production and corresponds to 258 kilograms of cherries.

Technical coefficients

Based on expert sources, we fixed the number of pruning operations applied on a coffee plant until replacing it at four times. Combined with the time span separating two pruning operations on the same plant defined as five years in an agroforestry system and as one year shorter time in a full sun system, this induces that the life spans of a coffee plant are considered to be twenty and sixteen years respectively. The shares of pruned coffee plants when $PRUN_{jkt} = \frac{1}{YR_k}$ is applied are also fixed accordingly, being 20% in an agroforestry system and 25% in a full sun system. Input doses per application are obtained from Icafé (2010a) and Icafé (2014a).

The farm model parameters for labor requirements result from predictions of the OLS models conditional on the operational characteristics of each alternative. Because annual labor time requirements per hectare are likely to vary across the farm model alternatives and in order to assess them, we use the survey data and plot measures collected in the Los Santos valley, Costa Rica, by Meylan et al. (2013). The sample is composed of 32 coffee farms (split into 59 plots) randomly selected from an exhaustive listing of the local coffee cooperative members. Farms stratification was previously performed, according to their size and their location on the East or West side of the valley. The authors mention the stratification criteria as the main factors of management practices diversity in the region. The data cover 2009-2010 production cycle and labor time dedicated per year to each one of the seven main farm operations is detailed at the plot level. The data exhibit high variability in labor times, plot areas and characteristics of the operations, such that the tree density, fertilizers quantities and numbers of application for herbicides, fungicides and foliar inputs describing the farm model alternatives are all encom-

passed within the range of observed data. We perform OLS regressions to estimate the relationship between observed labor data and available proxies accounting for the labor requirement per operation on each plot. The models results are displayed in Appendix 1.3. According to the adjusted R^2 across the seven models, between 39% and 80% of the labor time variation is explained by the set of independent variables used. In particular, all the models explaining the labor times required to apply chemical inputs are well-fitted with adjusted R^2 above 77%. All marginal effects of interest are significantly different from zero, confirming that the choice among the farm model alternatives is likely to affect annual labor time requirements. Their positive sign also indicate that the variables of interest stand in for the labor intensity of the operation.

The total land area is the average aggregated size of coffee plantation plots over a sample of 207 coffee farmers surveyed by the authors in 2016, in the Los Santos valley, Costa Rica. Farm endowments also include the average number of household members coming from the latter survey data, and family labor for both harvest and other operations which are derived from labor data of Meylan et al. (2013).

Prices

2009-2010 input prices are obtained from Icafé (2010a) and Icafé (2014a). Icafé (2010c) provides the total replacement cost of one hectare of coffee plants including labor and input costs, which is required to compute the depreciation expenses. Coffee farming being not mechanized, machinery costs are neglectable but labor requirements imply high employed labor costs, especially for harvest (Icafé, 2010a). Labor prices are fixed at the minimum legal wages published in the Official Gazette for 2009-2010 production cycle and included in Icafé (2010b). Unlike harvest workers who are paid for each 20-litre box they fill, employed labor for other operations is paid on a daily rate basis.

Finally, coffee prices corresponds to the historical prices received by the producers of one coffee cooperative in the Los Santos valley, Costa Rica. Available data from the Costa Rican Coffee Institute reports (Icafé, 2008, 2009, 2010d, 2011, 2012, 2013, 2014b, 2015, 2016b) cover 2008-2016 period and are expressed in constant 2010 CRC according to the national consumer price index found in IMF (2018). The resulting series of nine annual coffee prices is presented as the baseline prices in Appendix 1.5.

Risk and time preferences

The two parameters on the farmer's risk and time preferences result from two field experiments carried out by the authors in 2016, in the Los Santos

valley, Costa Rica, with the 207 coffee farmers aforementioned. The first one consisted in a multiple price list aiming at eliciting risk preferences and introduced by Holt and Laury (2002). Its design is presented in Appendix 1.4. Each participant was asked to choose between two lotteries structured so that the low payoff in the safer lottery S (8,000 CRC which is about the daily wage of a farm worker) is always worth more than the low payoff in the riskier lottery R (500 CRC, around the price of a bus ticket). Conversely, the high payoff in lottery R is higher than the one in lottery S. The probability to get the low payoff is common to both lotteries which is 0.90 at the first round, and it decreases by 0.10 at each round over the ten choice tasks, such that the expected payoff of B over A increases. Both lotteries were materialized by two bags of ten balls of different colors symbolizing their chances if chosen. Participants were incentivized to answer the choice tasks according to their underlying risk attitude by using their choices at the end of the experiment to realize one randomly selected round: after adjusting the bag to the lottery preferred by the participant and to the selected round, each participant blindly picked one ball out of the bag and received the corresponding amount in cash. A total number of 125 participants answered consistently over the choice tasks, meaning that they have not switched from preferring lottery S to preferring lottery R more than once, and they did choose lottery R at the last round when the high payoff was certain. We use the S-R switching point to directly elicit the relative risk aversion coefficients that shape the individual assumed CRRA instantaneous utility functions according to the expected utility theory². With a constant relative risk aversion parameter of 0.651, the mean Costa Rican coffee farmer surveyed is considered as risk averse according to the classification in Holt and Laury (2002).

The second field experiment aimed at revealing the 207 coffee farmers' time attitude. Appendix 1.4 shows its design organized in a multiple price list which was introduced in Collier and Williams (1999). Each participant made a series of choices between a constant payment of 2000 CRC to be received in

2. Because the S-R switching point variable is discrete, we first compute the minimum and maximum values of r for each possible S-R switching point according to the following equation defining the indifference between S and R under expected utility theory assuming zero background consumption:

$$S \sim R \iff p_l \cdot u(8000) + (1 - p_l) \cdot u(10000) = p_l \cdot u(500) + (1 - p_l) \cdot u(19250)$$

where $u(G) = \frac{G^{1-r}}{1-r}$ for payoff G . Minimum r value for each switching point is the constant relative risk aversion parameter that equalizes the expected utilities of both lotteries at round l such that they have equal certainty equivalent. These intervals are displayed in Appendix 1.4 and are in fact reported in Holt and Laury (2002). The value of r attributed to each participant is the midpoint of the interval of r corresponding to his/her S-R switching point. When his/her S-R switching point was Round 1 or Round 10, the value is the finite bound of the interval of r .

one month and a larger payment to be received in two months. The front-end delay of the early payment makes a possible present bias less likely to occur. Choosing one implies that the other one will not be received. At each round, the later payment increases by 200 CRC, such that the gross interest rate is increasing too. Answers of 159 participants do not exhibit multi-switching over the choice tasks. The round when the participant shifted from the sooner payment to the larger later one carries interval information on discounting.

We conditioned the elicitation of the discount rate by the concavity of the utility function measured by the previously elicited r . The mean value of r for the choice sequences that are consistent in the risk experiment is 0.651. We use this value to calculate the interval bounds for δ and directly compute the individual δ over the consistent answers in the time experiment³. We found a mean value for δ of 6.44% per year, which is close to market interest rates (see Appendix 1.4 for more details). Note that computing individual δ conditioned on individual r (rather the mean value) would have induced an erratic distribution of δ greatly affected by outliers. Averaging on the latter values would not have been appropriate, whereas we intend to describe the preferences of a representative farmer through the parameter δ .

4 Simulated opportunity costs of agroforestry using historical price series

In this Section, I provide the baseline results of the farm model simulations using the parameters displayed in Appendix 1.2 and the 2008-2016 series of annual coffee prices. This series is segmented according to the three-year time horizon of the farm model: 2008-2009-2010, 2009-2010-2011, ..., 2014-2015-2016. These seven series of three consecutive annual prices generate 7 maximum intertemporal utilities.

3. Similarly to the elicitation of r , we first compute the minimum and maximum values of δ for each possible A-B switching point according to the following equation defining the indifference between A and B assuming exponential discounting and zero background consumption:

$$A \sim B \iff \left(\frac{1}{1+\delta}\right)^{1/12} u(2000) = \left(\frac{1}{1+\delta}\right)^{2/12} u(G_l)$$

where G_l is the late payment amount at round l and $u(G) = \frac{G^{1-r}}{1-r}$ for payment G . Maximum δ value for each switching point is the discount rate that equalizes the present value of the utility of the early and late payments, according to the constant relative risk aversion parameter r . These interval for $r = 0.651$ are reported in Appendix 1.4. The value of δ attributed to each participant is the midpoint of the interval of δ corresponding to his/her S-R switching point.

4.1 Outcomes by alternative

First, we compute economic indicators for a representative farm run under each of the eight alternatives (i,j,k). For this purpose, we add an extra constraint in the farm model ($x_{ijk} = \text{LAND} \forall t$) forcing the farmer to allocate the entire farm land to a unique alternative. Results are presented in the unshaded rows of Table 1.2.

Production and costs

Columns 2 to 4 in Table 1.2 display mean annual indicators about the production technology. Compared to their low input counterparts, all alternatives operating with a high input level imply superior mean annual productions jointly with higher costs in both purchased input and employed labor. Conversely, these indicators confirm that the alternatives with a time-varying pruning sequence do not engender any differences in mean over the time horizon compared to their constant pruning rate counterparts. Considering the two farm systems, full sun simulations exhibit the largest productions and additional labor costs, for a fixed level of input.

Table 1.2: Mean annual farm production, cost of chemical input and labor, inter-temporal utility, mean and standard deviation of annual profits and interval of minimum payment (per hectare and per year) over alternatives, for 2008-2014 baseline

(1) $(\hat{i}, \hat{j}, \hat{k})$	(2) PROD (mean) in fan.	(3) COSTI (mean) in CRC	(4) COSTL (mean) in CRC	(5) U (mean)	(6) Π (mean) in CRC	(7) (St.Dev)	(8) Interval of S (min)	(9) (max)
(LOW,CST,AF)	59	653,050	1,220,819	71	2,059,402	664,156	1,101,443	1,929,136
(HIGH,CST,AF)	92	1,288,455	1,875,182	82	3,171,300	1,038,427	794,632	1,250,690
(LOW,VAR,AF)	59	653,050	1,220,819	78	2,057,343	1,080,404	847,941	1,550,888
(HIGH,VAR,AF)	92	1,288,455	1,875,182	91	3,168,080	1,640,672	429,084	695,736
(CST,AF)	92	1,288,455	1,875,182	82	3,171,300	1,038,427	817,919	1,250,690
(LOW,AF)	59	653,050	1,220,819	78	2,057,343	1,080,404	871,103	1,550,888
(AF)	92	1,288,455	1,875,182	91	3,168,080	1,640,672	452,022	695,736
(LOW,CST,SUN)	88	653,050	1,606,184	87	3,746,211	999,880	526,466	1,020,773
(HIGH,CST,SUN)	107	1,288,455	2,065,383	89	3,986,980	1,207,982	520,100	808,004
(LOW,VAR,SUN)	88	653,050	1,606,184	97	3,742,077	1,913,643	74,997	326,525
(HIGH,VAR,SUN)	107	1,288,455	2,065,383	100	3,981,985	2,287,523	-	-
(CST,SUN)	106	1,258,198	2,043,516	89	3,993,517	1,195,823	543,381	808,004
(LOW,SUN)	88	653,050	1,606,184	97	3,742,077	1,913,643	97,440	326,525
(HIGH,SUN)	107	1,288,455	2,065,383	100	3,981,985	2,287,523	0	43,043
(SUN)	103	1,106,911	1,953,581	100	4,030,504	2,229,240	-	-
Unconstrained farm model	103	1,106,911	1,953,581	100	4,030,504	2,229,240	-	-

Note: Indicators averaged over the seven 3-year sale price series, when all LAND is allocated to the alternative considered. All three sub-decisions are fixed in the 8 unshaded rows. Input level subdecision is not constrained in shaded alternatives (CST,AF) and (CST,SUN). Pruning subdecision is not constrained in shaded alternatives (LOW,AF), (LOW,SUN) and (HIGH,SUN). Neither pruning subdecision nor input subdecision is constrained in shaded alternatives (AF) and (SUN). The highest inter-temporal utilities for shaded and unshaded rows are indicated in bold and used for the calculation of minimum payments in both cases.

Profits and inter-temporal utility

Computed mean intertemporal utilities as well as means and standard deviations of annual profits are displayed in columns 5, 6 and 7. Mean farm profits lie between 2,059,402 CRC and 3,986,980 CRC (approx. USD 3,607 and USD 6,982) per year. Comparatively, total production costs appear large, representing almost half of the sales revenue. For a graphical representation of profits distributions over price series, see Appendix 1.6. Each full sun systems alternative not only achieves a higher mean profit than its agroforestry counterparts, it also outperforms the most profitable agroforestry alternative. The highest mean profits amongst agroforestry alternatives are clearly obtained when a high input intensity is applied. Amongst full sun systems, the same result emerges but by a narrower margin.

Moreover, annual profits exhibit more variability under full sun systems than their agroforestry counterparts. Moreover, highest standard deviations are observed in high input alternatives rather than in low input ones whatever the system. Considering only the mean utilities of constant pruning rate alternatives, this results in (HIGH,CST,SUN) being still preferred to (HIGH,CST,AF) due to profits that are higher in mean by 26% and despite the fact that they are slightly more variable. Regarding their time-varying pruning sequence counterparts, the mean and variability of profits exhibit differences apparently in favor of constant pruning rate alternatives. In particular, the standard deviations of profits are strongly increased under alternatives with a time-varying pruning sequence, especially in the full sun cases where the standard deviations are nearly being doubled. However it should be remembered that this higher variability also conveys superior profits at the first period and as such, higher instantaneous utilities that are time-discounted only once. As a result of the farmer's strong preference for early profits and despite his relatively moderate preference for smoothed profits over time, all the time-varying pruning sequence alternatives achieve higher mean intertemporal utilities compared to their constant pruning rate counterparts. Hence, the mean intertemporal utility is maximized under the (HIGH,VAR,SUN) alternative. The full sun system with the low input intensity and the time-varying pruning sequence still outperforms the full sun system with the high input intensity but with a constant pruning rate applied.

Opportunity costs of shifting to a suboptimal alternative

In order to value the opportunity cost of adopting alternatives yielding profits that differ in both mean and variability from the optimal alternative (HIGH,VAR,SUN), we compute the interval of minimum annual per-hectare payments \underline{S} solving equation (1.6) over the seven price series. Results are presented in column 9. The lower bound of the interval corresponds to the min-

imum payment ensuring the alternative achieves an intertemporal utility as high as the optimal alternative (HIGH,VAR,SUN) for at least one 3-year price series, whereas its upper bound is the minimum payment such that the alternative emerges in the optimum at each of the seven 3-year price series. Over all the seven suboptimal alternatives and price series, \underline{S} ranges from 74,997 CRC (approx. USD 131) to 1,929,136 (approx. USD 3,379) per hectare and per year.

The minimum \underline{S} is found for (LOW,VAR,SUN) and is positive, meaning that this alternative, and consequently the other suboptimal ones, do not perform better than (HIGH,VAR,SUN) at any of the price series. Still its lowest value of 74,997 CRC (approx. USD 131) signals that at least at one price series, (LOW,VAR,SUN) yields an intertemporal utility which is relatively close to the maximum achievable⁴. Conversely, \underline{S} for (LOW,VAR,SUN) reaches up to 326,525 CRC (USD 572) for the price series containing the highest prices of the period. This indicates that the farmer may gain in utility in a full sun system if he was relieved from the constraint of applying the same level of input intensity over the years. Therefore he may be willing to pay for more flexibility. At the other end of the preference relations, the agroforestry alternatives, especially when low input intensity is applied, require the highest payments, reflecting the absence of incentive to internalize environmental externalities. The \underline{S} value per hectare and per year ensuring that the least performing alternative (LOW,CST,AF) emerges in the optimum over all the price series represent almost the annual farm profit obtained under this alternative. Hence, joining two representative farms under (LOW,CST,AF) would not even match the utility achieved by one of them under the optimal (HIGH,VAR,SUN). Furthermore, the penalty due to applying a constant pruning rate rather than the time-varying sequence appears as substantial, whatever the system and input intensity. Compared to their time-varying counterparts, the upper bounds of \underline{S} intervals are sharply increased for the constant pruning rate alternatives. These differences signal that the farmer is willing to pay a surprisingly high price for not pruning his coffee plants and thus achieving the highest coffee yields at the first period, despite the fact that his production will be significantly lower at the second period. They also tend to approve the short time horizon applied in the model, relatively to the life span of a coffee plantation.

4.2 Outcomes when constraints are progressively relieved

Then, the farm model has been progressively relieved from selected constraints on land allocation over alternatives until simulating the unconstrained

4. Precisely, this occurs at two price series covering 2013-2016 prices characterized by being the lowest of the baseline period.

farm model as presented at equation (1.1) subject only to (1.2), (1.3), (1.4) and (1.5). Unshaded rows in Table 1.2 show these results. Intermediary simulations allow to assess the effect of the selected constraint on the farm performance by providing counterfactual indicators. In particular, we focus on cases where:

- the farmer cannot choose his system and applies a constant pruning rate, still he can choose the optimal input intensity; these cases are (CST,AF) and (CST,SUN);
- the farmer cannot choose his system and applies a low input intensity, still he can choose the optimal pruning sequence; these cases are (LOW,AF) and (LOW,SUN);
- the farmer cannot choose his system, still he can choose both the optimal pruning sequence and input intensity ; these cases are (AF) and (SUN);
- the farmer can choose the optimal system, pruning sequence and input intensity ; this case is the unconstrained model.

The unconstrained farm model induces the same results than the unconstrained full sun system (SUN), confirming that the optimal acreages between alternatives consists in allocating all the land to the full sun system, which outperforms agroforestry at each price series. The unconstrained full sun system (SUN) achieves a mean intertemporal utility that exceeds by a few decimals the one of the constrained (HIGH,VAR,SUN) through multiple shifts from a high input intensity level to a low one, at five of the seven 3-year price series, as reflected by the decrease in production costs and in mean coffee production compared to (HIGH,SUN). The shifts occurs when a low sale price appears at $T = 2$, making the intensification of the production not optimal anymore. The maximum opportunity cost of never shifting and thus maintaining a high input level for these years corresponds to 43,043 CRC (approx. USD 75) per hectare and per year which is the upper bound of \underline{S} associated with (HIGH,SUN). The minimum amount so that the farmer persistently compels with the low input level and does not benefit from the intensification of the production in case of high sale prices, is 326,525 CRC (approx. USD 572) according to the model. These two amounts represent measures of how much the farmer is willing to accept to restrain the flexibility he needs to adjust the input intensity, probably to seize price opportunities.

Unsurprisingly, the unconstrained agroforestry system (AF) is consistent with (HIGH,VAR,AF) which has been found as the optimal agroforestry alternative over each price series. The upper bound of its \underline{S} interval signals that a payment of 695,736 CRC (USD 1,218) per hectare and per year is required in order to offset the utility differential with (SUN) at every price series. This amount is equal to the previous payment required to make (HIGH,VAR,AF) outperform (HIGH,VAR,SUN), which reveals that the maximum differential

between (SUN) and (AF) occurs at the price series containing the highest prices such that the high input level is maintained over the time horizon. On the contrary, the lower bound of \underline{S} for (AF) is higher than the one for (HIGH,VAR,AF), due to the gain in utility the full sun system benefits thanks to the relief of the constraint on the input level, whereas the unconstrained agroforestry system does not benefit from this added flexibility. Again, the fact that in the agroforestry case, the farmer is unwilling to vary between low and high input levels points out the large profit differential between the two levels that results in a strong advantage for the intensified system in term of utility. As a consequence, a very high conditional amount of 1,550,888 CRC (USD 2,716) would make the farmer not only prefer (AF) to (SUN), but also it would ensure that the farmer adopts a low intensive agroforestry system over the baseline period.

At each price series, the time-varying pruning sequence is preferred, with a minimum incentive of 808,004 CRC (USD 1,415) required for (CST,SUN) in order to at least match the utilities reached by the unconstrained full sun system. In the agroforestry case, this incentive represents an additional 554,954 CRC (USD 972) to the agroforestry minimum payment for the adoption of (CST,AF). This results confirms the high opportunity cost of adopting the patient alternative consisting in allocating the production in the same proportion over time, rather than boosting early profits. Similarly to the conclusion about the large utility differential existing between the two input levels in the agroforestry system, the gap between the utilities of the constant pruning rate and the ones of the time-varying pruning sequence makes the farmer unwilling to switch from one to the other over the price series. Therefore, the pruning subdecision does not appear as an instrument to adapt to price variability either in the (SUN) case or in the (AF) case.

In this Section, we found an opportunity cost of agroforestry compared to a full sun system. According to the model, the minimum PES-like incentive reaches 695,736 CRC (USD 1,218) in order to make the farmer willing to produce coffee under agroforestry rather than in a full sun system, during all the baseline period. When high prices appear in the time horizon, the opportunity cost is the largest. Since under agroforestry, the low input level is too disadvantageous in term of profits leading to the high input level being consistently preferred, compelling the farmer with agroforestry induces a leakage effect of the chemical input use being intensive at all years. Conversely, the farmer managing a full sun system would have applied a low input level when the prices are low and the annual production is shorten by a deep pruning operation as at $T = 2$ in the time-varying pruning sequence. In addition to the environmental externality, this also reflects that agroforestry offers a reduced capacity to adjust the farm production to price signals. Thus the opportunity

cost to compensate in order to make the farmer voluntarily apply a low input intensity is significantly reduced under a full sun system than in agroforestry. Nevertheless, in case of low prices in a full sun system, the low level may arise as the optimal input intensity, making a potential PES-like instrument produce only a windfall effect as it would be an unconditional cash transfer for these years. Finally, no matter the system, the farmer attributes a great value to the utility differential of relying on a time-varying pruning rate that yields the highest early profits, rather than choosing the patient option consisting in applying a constant pruning rate over the years. This choice even induces that the farm supply is frequently varying in opposite direction with the price variations. The pruning subdecision hence is likely to only satisfy the time preference of the farmer rather to be an instrument to adapt to prices.

5 Comparing systems under price changes

In the following, we conduct a sensitivity analysis to explore how much changes in price can affect the optimal land allocation across farm systems⁵. We first look at the effect of changes in mean, trend and volatility of coffee prices. To do so, we decompose the time series of 14 sale prices that we use in the baseline representation, into a systematic pattern and a random compound. We estimate the coefficient for the slope of the trend assuming that it is linear, and the corresponding constant for the mean of the time series. Then we compute the deviation from the trend of each annual price. Hence we dispose of two parameters and a vector of individual deviations to simulate changes in price series.

We also run simulations under a range of fertilizer prices jointly with the sale price series used as baseline. All other parameters remain fixed at their baseline level. Each modified sale price series enters the model as 7 segments of 3 consecutive years over which we compute some summary statistics for the sale price series and compare them across farm systems.

5.1 Impact of changes in coffee price mean

A change in the constant of the price series is interpreted as a modification of the price level by making the mean vary without modifying either the trend or the deviation of individual prices. The mean price for the baseline is 70,827 CRC per output unit and the values for the constant range from 50,827 (with

5. The extra constraint that we apply in the farm model for the sensitivity analysis is $\sum_{ij} x_{ijk} = 0, k \neq \hat{k} \forall t$, forcing the farmer to not allocate any farm land share to the other system when considering a farm under \hat{k} at all price series, while allowing some land to be unproductive if optimal.

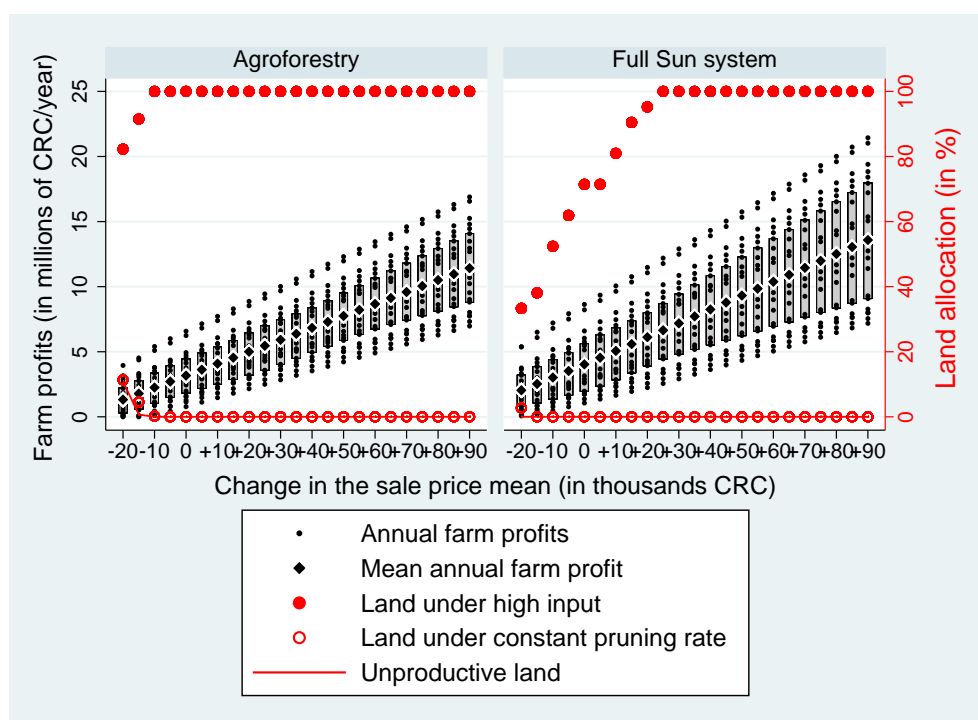


Figure 1.1: Summary of the distribution of farm profits and land allocation under changes in the sale price level

Source: CENIGA (2018)

a minimum price of 32,094 and a maximum of 69,337) to 160,827 (with a minimum price of 142,094 and a maximum of 179,337). Land allocation and profits after changes in the sale price level are described in Figure 1.1.

First, we notice that in both systems the profit averaged over the price series and the dispersion of annual profits per series increase linearly with the change in the sale price mean. The equation describing the relationship between mean agroforestry profits and changes in price mean has an intercept and a slope both inferior to the ones of the equation for the full sun system. Per 10,000 CRC increase in the output price, the mean agroforestry profit raises by 917,398 CRC, whereas the mean profit in the full sun farm is higher than before the increase by 1,055,454 CRC. With a steeper slope and a larger intercept, the mean full sun profits are consistently higher than the ones in agroforestry over the changes in mean price and the differential in mean profits between both systems is clearly increasing with the mean price increase. Although larger than in agroforestry, the dispersion of annual profits in the full sun farm does not exhibit inferior profits for the first quartile compared to the ones in agroforestry. Considering how the land allocation between alternatives is affected by the changes in mean price, the high input intensity clearly appears as the optimal input level under high mean prices. In the

full sun system, the transition toward a fully intensified farm is progressive, confirming that the higher the sale price level is, the larger the benefit of intensifying the production is. However, the arc elasticities of supply computed on the percentage changes of the farm production and sale price both averaged over each price series range only in $[0;0.35]$. These low values are in line with previous estimates found by Akiyama and Varangis (1990) (from 0.11 to 0.41 for Costa Rica) and Lewin, Giovannucci, and Varangis (2004) (0.15 for Latin America) and so with their conclusion that coffee supply is very price inelastic especially in the short run. For the farm in agroforestry, the alternative combining the time-variant pruning rate and the high input level is consistently applied on all the farm land, unless annual profits are drawing near zero. Apart from the severest negative changes in mean price, the production in agroforestry is perfectly price inelastic.

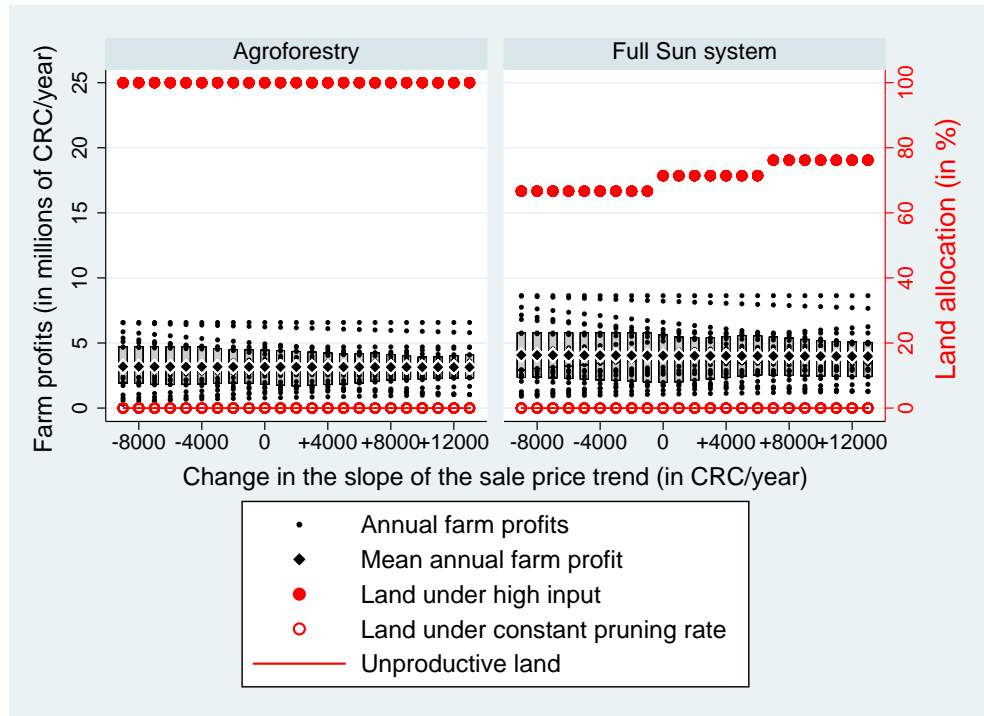
The land allocations corresponding to the maximum reductions in price mean are relevant in order to explain the effect of the credit constraint. Starting from a reduction of -15,000 CRC on the mean price, 3-year series including unit prices at period $T = 2$ under 50,000 CRC force the agroforestry farm to allocate some land to the constant pruning rate, in order to ensure coffee incomes large enough to cover for the production costs at $T = 2$ and despite the preference for early profits. In the full sun system, the constant pruning rate does not appear in the optimal land allocation until a $T = 2$ price under 40,000 CRC. Under agroforestry, the optimal land allocation dedicates a share to the low input level only when the annual price drops under 40,000 and jointly with land abandonment. No land abandonment in the full sun system is observed for any reduction in the price mean, hence the price threshold inducing it (if any) is lower. Therefore, the agroforestry farm appears less resilient to very low sale prices compared to the full sun system.

5.2 Impact of changes in coffee price trend

Although it will maintain the same mean price over the whole time series and the individual deviations from the long-term trend will not be modified, a change in the slope of the trend will generate short term differences in price expectation over each 3-year price series. If the change is positive, the first 3-year series will have prices that are all lower and the last one will jointly have prices that are all higher, and reversely if the change is negative. The more substantial the change is, the more likely some contrasted 3-year price series will emerge, some being very favorable and other being the opposite. The slope coefficient of the baseline price series is found to be -1,920, representing an estimated unit price reduction of 1,920 CRC per year over the baseline period. The changes applied to the trend make the slope vary from -11,920 (the resulting price series ranges in $[41,294;89,337]$) to 11,080 (the range of

prices is [52,469;89,337]. Figure 1.2 displays the land allocations and profits according to the changes.

Figure 1.2: Summary of the distribution of farm profits and land allocation under changes in the trend of the sale prices over years



Mean annual farm profits decreases linearly with the increasing trend slope coefficient. Compared to the case of a flat trend with the same mean price over the time series, the agroforestry profits diminish by 2,293 CRC (approx. USD 4) per year when the trend slope is increased such that the sale price gains 1,000 CRC annually. In the full sun system, the corresponding loss in profit is found to be 4,628 CRC (approx USD 8), still its mean profits are always superior to the agroforestry ones. In both system, the upper quartile informs that the highest profits tend to get closer to the mean profit, exceptional years becoming rarer. This observation is likely to be imputed to the time-varying pruning rate applied on 100% of the farm land. Because when the trend get a steeper positive slope, prices at $T = 2$ are more likely to be higher than the prices at $T = 1$, the allocation of a larger production to the first year while cutting the production of the second period is thus more likely to achieves a lower intertemporal profit. Moreover, since all the high prices are more likely to be consecutive, such a very favorable 3-year price series generates only two exceptional annual profits corresponding to $T = 1$

and $T = 3$. From the lowest negative change to the highest positive one, the losses in mean profit are 52,739 CRC (approx. USD 92) and 106,444 CRC (approx. USD 186) for agroforestry and full sun systems respectively. These amounts are far from matching the minimum payments found in the previous Section to make the constant pruning rate emerge in the optimum.

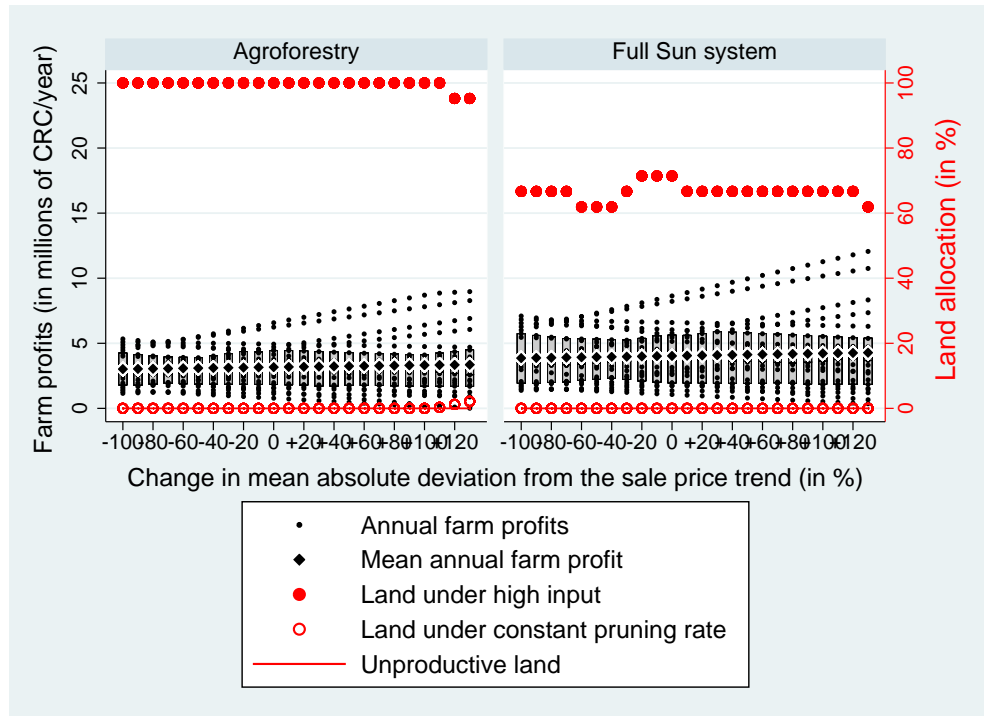
Nevertheless, if the land allocation of none of the systems shifts into the constant pruning rate, we identify a response in the full sun system signaled by the variations in the land share where the high input intensity is applied. At $T = 1$ and $T = 3$, the high input level is almost always applied, whereas at $T = 2$ the high level is preferred mainly during the most favorable 3-year series, being the beginning of the time-series with a strongly negative trend or the end of the time-series with a steep positive trend. Therefore, we can confirm that the flexibility of the full sun system to shift between input levels relates to its capacity to seize price opportunities.

5.3 Impact of changes in coffee price volatility

Considering a change in the vector of individual deviations from the trend, it will consistently affect the variation rate between two consecutive prices. When positive, the change will result in an increased variability of annual prices, whereas when it is negative, it will make the time series close to the trend. Although such changes do not affect either the trend or the mean over the time series, they can have a large impact on the price averaging over the 3-year price series. Due to the apparent positive autocorrelation of the annual prices, a change in the deviation from the trend can engender an effect which is similar to a change in the slope of the trend, in the sense that either of them is likely to exacerbate the differences in mean prices between the 3-year price series if it is large in the case of the trend and if it is positive in the case of the deviations. The mean absolute deviation of an annual price in the baseline series is found to be 8,475 CRC. The variation rates that we apply to the vector of individual deviations range in [-100%;+120%]. The lower bound corresponds to use the trend values as prices with resulting minimum price being 63,145 CRC and the maximum 78,508 CRC. For the most variable series, the minimum price is 37,727 CRC and the maximum is 113,401 CRC, with a mean absolute deviation of 19,492. Figure 1.3 presents the land allocations and profits after changes in the price variation.

Regarding the effect of an increased price variability on annual profits, the dispersion of profits seems to rise. The upper quartile includes production years that benefit widely from these changes, while the first quartile is also spreading but by a narrower margin. Pulled up by the exceptionally high profits, the resulting mean farm profits are incremented with the increased price variability, with an additional 14,923 CRC in agroforestry and 18,436

Figure 1.3: Summary of the distribution of farm profits and land allocation under changes in the variability of the sale prices



CRC in the full sun system per 10% increase in the deviations. Whereas extreme values are exacerbated with the added variability, we also observe that the second quartile steadily spreads around the median value in both systems, indicating that negative deviations are well compensated by the positive ones over all the time series. Despite the increase in mean annual profits, the intertemporal utilities are not improved with higher price variability likely due to the concavity of the utility function which implies that two consecutive profits are not perfect substitutes.

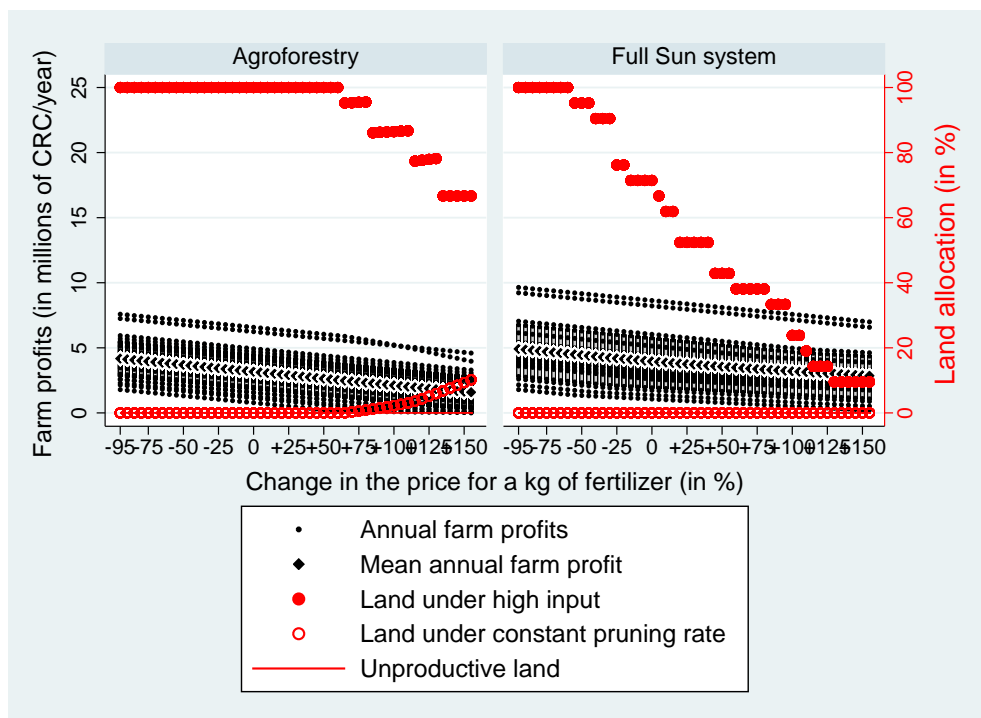
In the agroforestry farm, the high input intensity is optimal at every price variability, except when the baseline variability is more than doubled. Then some $T = 2$ prices drop under 50,000 CRC and the credit constraint forces the production costs to be tightened through applying low intensities of input, while simultaneously some land is allocated to a constant pruning rate. The shift between high and low levels is again used in the full sun system to adjust to the new price opportunities. At trend values, all farm land at $T = 1$ and $T = 3$ is under a high intensity while at $T = 2$ the level of input applied is the low one. While the price variability is increasing, the production becomes intensive at some $T = 2$ offering a high price and reversely, it becomes ex-

tensive at some $T = 3$ characterized by a low price.

5.4 Impact of changes in fertilizer prices

Finally, we simulate a change in the two parameters representing the prices of two nitrogenous fertilizers which are assumed to be constant over the sale price series. The sale price series used correspond to the baseline. In the previous Section, we found that one hectare under a low level of chemical input implies a production cost of 283,935 CRC per year for the input purchase, while it costs 560,198 CRC per year when a high level of input is applied. The variation rates used to simulate a change in the fertilizer prices range in $[-95\%, +155\%]$. The lower bound is associated with input costs per hectare and per year that drop to 57,315 CRC at low intensity and to 122,408 CRC at high intensity, while at the maximum increase simulated, the input costs are 653,655 and 1,274,438, respectively. Land allocations and profits resulting from the simulations are displayed in Figure 1.4.

Figure 1.4: Summary of the distribution of farm profits and land allocation under changes in the Nitrogen price



Unsurprisingly, the increase in fertilizer price is reducing the profits of both systems. A 5% increase induces a loss of 52,232 CRC in the mean

annual profit, when in the full sun system the corresponding loss is 40,929 CRC. Again, this differential in favour of the full sun system is imputed to the lack of adjustment of the input level applied in the agroforestry farm when the credit constraint is not restraining the production costs, meaning below the 65% increase (594 CRC per kilogram of NPK fertilizer) as signaled by the appearance of some land under a constant pruning rate. Starting from the 65% increase, the mean arc elasticity of demand to the price of the main fertilizer is found to be -0.40. Although the shift in the full sun system from a 100% intensive production to a less intensive one starts from lower fertilizer prices (-45% change corresponding to a price of 162 CRC per kilogram of NPK fertilizer) and is not related to an operating credit constraint, the price elasticity of demand in the full sun system is also -0.40 when averaged starting from the 45% reduction in fertilizer prices. Therefore, the demand for fertilizer in both systems is found to be perfectly or very price inelastic, with a full sun system able to adjust its consumption before the credit constraint forces it to cut the production costs.

In this Section, we found that the full sun system does not only achieves the highest intertemporal utility in our baseline analysis, it also outperforms the agroforestry farm in all simulations of change in mean, trend and variability of the sale prices and in fertilizer price. For all the simulations that we run, the unconstrained farm model never allocates any share of land to an agroforestry alternative. It appears as more adaptive to changes mainly by adjusting its input intensity to both seize price opportunities and stand against changes that negatively affects it. On the opposite, the agroforestry farm seems very low resilient to the changes, with profits approaching zero, even under changes of low magnitude, and with cases of land abandonment. However, the low price elasticities that we found highlights the fact that even under the more flexible system, coffee production is very inelastic to prices of both output and main input.

6 Simulated opportunity costs of agroforestry using price scenarios

Due to the result of the previous Section attesting that no matter the price changes, the full sun system appears as the optimal system according to the farm model, we measure the opportunity costs of agroforestry under various price scenarios.

6.1 Sources of price scenarios

We combine changes in mean coffee price, coffee prices trend and fertilizer prices according to forecasts or predictions found in World Bank (2018) and in Bunn (2015). The first source provides historical coffee and urea price data as well as forecasts until 2030. The second source reports the simulation results of an integrated model based on the IPCC “business as usual” scenarios. The climate data used as input correspond to the historical climate (NoCC), the global wet (MRI), global dry (UKMO) and global medium (CNRM) General Circulation Models. The resulting coffee prices are weighted averages of the equilibrium prices on regional coffee markets, for 2000-2050. We define five coffee price scenarios for 2020 (WB20, NoCC20, MRI20 UKMO20 and CNRM20) and for 2030 (WB30, NoCC30, MRI30 UKMO30 and CNRM30), by extrapolating trends of nine consecutive prices based on the variation rates found in both sources. Due to the lack of variability in the data, we apply the vector of baseline deviations from the trend to all price series, so that all scenarios are comparable with the baseline. The two World Bank scenarios also combine the corresponding change in the fertilizer prices for WB20B and WB30B, unlike for WB20A and WB30A. All price scenarios used for simulations are displayed in Appendix 1.5 and resumed in Table 1.3.

6.2 Minimum payments to trigger agroforestry

Table 1.3 also shows the intervals of minimum payment obtained for the simulations and representing the minimum and maximum opportunity costs per hectare and per year of the agroforestry farm model compared to the unconstrained model. The unconstrained farm model never allocates any share of land to the agroforestry system, confirming that despite the changes in both sale price series and input price, the agroforestry farm is outperformed by the full sun system in all scenarios. Hence the intervals of \underline{S} amount to the opportunity costs of agroforestry compared to the full sun system.

The minimum \underline{S} values found across all scenarios correspond to the WB scenarios with a diminishing coffee price. Compared to the baseline interval, WB20A scenario has \underline{S} lower by 20% and 17% for its minimum and maximum respectively, whereas the changes in price are limited to a reduction of 15% of the mean price with a more moderate trend. Following the same trend, the WB30A does not imply a similar reduction in the \underline{S} interval, with a maximum \underline{S} that is higher at 2030 horizon than at 2020 horizon. This signals that with lower prices, the opportunity cost between agroforestry and the full sun system can still increase. In fact, the credit constraint carries a greater weight in the land allocation in WB30A than in WB20A, due to some very low prices that active the constraint in the agroforestry system and not in the

Table 1.3: Price scenarios and resulting intervals of minimum payment (per hectare and per year) for the agroforestry farm

(1) Scenarios	(2) Mean sale price in CRC	(3) Slope of the sale price trend in CRC/year	(4) Mean absolute deviation from the sale price trend in CRC	(5) Price for a kg of fertilizer in CRC	(6) Interval of \underline{S} (min)	(7) Interval of \underline{S} (max)
Baseline	70,827	-1,920	8,475	360	452,022	695,736
WB20A	59,691	-799	8,475	360	360,319	578,288
WB20B	59,691	-799	8,475	292	353,887	574,709
NoCC20	68,366	-246	8,475	360	446,447	657,085
MRI20	70,332	-50	8,475	360	458,028	675,802
UKMO20	72,912	208	8,475	360	472,498	700,478
CNRM20	71,455	63	8,475	360	464,302	686,549
WB30A	53,400	-799	8,475	360	341,117	588,618
WB30B	53,400	-799	8,475	314	314,578	565,576
NoCC30	66,289	-208	8,475	360	426,519	635,645
MRI20	68,918	-141	8,475	360	448,290	661,846
UKMO30	74,510	160	8,475	360	488,912	717,389
CNRM30	69,220	-224	8,475	360	454,041	665,630

Note: Shaded cells highlight the scenario changes relatively to the baseline. Intervals of minimum payment refer to the constrained (AF) farm model achieving inter-temporal utilities as high as the unconstrained model, under each price scenario. The bold numbers in columns (6) and (7) indicate the minimum and the maximum payments respectively, across all scenarios.

more resilient full sun system. Conversely to the reduction in sale prices, a reduction in the fertilizer price has a very limited effect on the \underline{S} interval. Still, it decreases both bounds. However if we compare the WB20A and the WB20B scenarios, the strong reduction of 18% in the input price only induces small differences of around USD 10 in the \underline{S} values. The reduction in input price appears more effective when its combined with very low sale prices as in WB30B. Between WB30A and WB30B, the \underline{S} values decrease by approximately USD 40, with a fertilizer price yet higher than in WB20B. Hence, the agroforestry system can become credit constrained when the sale prices are changed even in a moderate measure, but a lower fertilizer price is able to limit the negative effect of this constraint on the inter-temporal utility. This is likely to be the result of the high input intensity being clearly preferred to the low one in the agroforestry farm.

Regarding the maximum values found for \underline{S} across scenarios, they des-

ignite the UKMO30 scenario as the scenario where the differential in utility between agroforestry and the full sun system is the highest. With a slight positive trend for the sale price at 2020 and 2030 horizons, the resulting UKMO30 has bounds greater than the baseline ones, but the variations observed are less than proportional to the change in the mean sale price. Compared to the NoCC reference scenarios, all the scenarios taking into account climate changes are associated to higher \underline{S} intervals. Therefore, by only changing coffee prices as found in Bunn (2015), climate changes may impact the opportunity cost of agroforestry in a non negligible way. In the NoCC30 scenario, the payment ensuring that agroforestry emerges in the optimum at each 3-year price series at 2030 horizon is 635,645 CRC (approx. USD 1,113) which is less than the corresponding payment found for the baseline. An additional 81,744 CRC (USD 143) is required to the same purpose but when the impact on global prices of a dryer climate has to be compensated.

7 Conclusion

Given smallholders' strong concern about market price risk and the promising results of agronomic research on the performances of agroforestry systems in a context of climate change, this Chapter explores the incidence of market volatility in the decision of adopting agroforestry systems. We developed a farm model of a coffee producer adjusting the management he/she operates on the coffee plantation in order to respond optimally to coffee prices. The model has been constrained such that we were able to value and compare outcomes from a farm under agroforestry and the same farm without shade trees, under various price scenarios. To calibrate the model, we used parameters from coffee regions in Costa Rica, mostly based on survey and experimental data.

Simulation results point out that adopting agroforestry is costly mainly due to a yield penalty. Compared to a full sun system, exploiting a coffee farm under agroforestry is associated with opportunity costs ranging from USD 800-1,200 per hectare of plantation and per year. Since the model makes explicit the short term adjustment mechanisms of coffee producers to prices, it then allows to estimate arc elasticities of supply relative to sale price changes. Their values indicate that coffee supply is very price inelastic in a full sun system (from 0 to 0.35) and even perfectly inelastic in agroforestry. There is one notable exception of agroforestry supply responding to price shocks which is when coffee revenues are not high enough to cover for the costs of the high level of chemical input applications. This level was found to be always optimal in agroforestry, such that the farmer could even prefer abandoning some share of land rather than downgrading the input level applied. Overall, our results suggest that agroforestry is first outperformed by the full sun system

no matter the change in prices that we simulated. Second, it displays a very low resilience against adverse price shocks due to a lack of supply adjustment, whereas the full sun system tends to better adjust through input intensity.

In consequence, the opportunity costs of agroforestry that we measured include not only the maximum achievable yields gap, but also the cost of not adjusting to price signals as well as the full sun system does. The latter would translate into a risk premium in an expected utility framework. A PES-like program promoting agroforestry adoption would have to offer a compensation at least as high as the opportunity cost in order to trigger a voluntary participation. The prospect of lower sale prices and lower nitrogenous input prices could have the ability to lower the opportunity costs, mainly by reducing the differential in coffee incomes between both systems. If it proves to be accurate, as recent studies suggest, that agroforestry yields will be less negatively affected by climate change and pest attacks, therefore the opportunity cost of agroforestry would further decline and the system could attract more adopters.

However, this Chapter raises three main concerns. First, climate change impacts and global market equilibrium effects could instead translate into an increase in coffee prices and lead to higher opportunity costs of agroforestry. Second, as it currently stands and as reflected by the simulation results, applying large amount of nitrogen fertilizers often appears as an efficient choice for the farmers in agroforestry systems. This result deserves to be taken into account when discussing public interventions promoting agroforestry. Finally, the low resilience of agroforestry farms facing adverse price shocks is eminently problematic. Simulated profits under agroforestry are meager, below the national poverty line, and rapidly close to zero under price changes of relatively low magnitude. If adopted under a PES participation, agroforestry would still represent a risky choice for the households.

Appendices

1.1 Farm model equations

$$\text{LIFE}_k = Q \times \text{YR}_k$$

$$\text{DEP}_k = \frac{\text{REP}}{\text{LIFE}_k}$$

$$\text{Y100}_{ik} = \frac{\text{YMEAN}_{ik}}{1 - \frac{1}{\text{YR}_k}}$$

$$\text{PRUN}_{jkt} = \begin{cases} \frac{1}{\text{YR}_k} & \text{if } j = \text{CST} \\ 0 & \text{if } \begin{cases} j = \text{VAR} \\ t = 1 \end{cases} \\ \frac{2}{\text{YR}_k} & \text{if } \begin{cases} j = \text{VAR} \\ t = 2 \end{cases} \\ \frac{1}{\text{YR}_k} & \text{if } \begin{cases} j = \text{VAR} \\ t = 3 \end{cases} \end{cases}$$

$$\text{Y}_{ijkt} = \text{Y100}_{ik} \times (1 - \text{PRUN}_{jkt})$$

$$\text{LAPP}_i = \text{LNP}_k + \text{LNIT}_i + \text{L}\alpha_i + \text{L}\beta_i + \text{L}\gamma_i + \text{L}\rho_i + \text{L}\epsilon_i + \text{L}\zeta_i$$

$$\text{L}_{ijkt} = \text{LSHADE}_k + \text{LWEED}_k + \text{LAPP}_i + \text{LPRUN}_{jkt}$$

$$\text{CI}_i = \text{PNPK} \times \text{NPK}_i + \text{PNIT} \times \text{NIT}_i + \text{P}\alpha \times \alpha_i \times \text{Q}\alpha_i + \text{P}\beta \times \beta_i \times \text{Q}\beta_i + \text{P}\gamma \times \gamma_i \times \text{Q}\gamma_i \\ + \text{P}\rho \times \rho_i \times \text{Q}\rho_i + \text{P}\epsilon \times \epsilon_i \times \text{Q}\epsilon_i + \text{P}\zeta \times \zeta_i \times \text{Q}\zeta_i$$

$$\max_{\substack{x_{ijkt} \\ i \in \{\text{LOW}, \text{HIGH}\} \\ j \in \{\text{CST}, \text{VAR}\} \\ k \in \{\text{AF}, \text{SUN}\} \\ t \in \{1, 2, 3\}}} U = \sum_t \left(\frac{1}{1 + \delta} \right)^t \times \frac{1}{1 - r} \times \left(\text{P}_t \times \sum_{ijk} x_{ijkt} \times \text{Y}_{ijk} \right. \\ \left. - \sum_{ijk} x_{ijkt} \times \text{CI}_i - (\text{W} \times \text{LEMPL}_t + \text{WHARV} \times \sum_{ijk} x_{ijkt} \times \text{Y}_{ijk} - \text{LHHHARV}) - \sum_{ijk} x_{ijkt} \times \text{DEP}_k \right)^{1-r}$$

s.t.

$$\sum_{ijk} x_{ijkt} \leq \text{LAND}$$

$$x_{ijkt} \geq 0$$

$$\text{LEMPL}_t \geq 0$$

$$\text{P}_t \times \sum_{ijk} x_{ijkt} \times \text{Y}_{ijk} - \sum_{ijk} x_{ijkt} \times \text{CI}_i - (\text{W} \times \text{LEMPL}_t + \text{WHARV} \times \sum_{ijk} x_{ijkt} \times \text{Y}_{ijk} - \text{LHHHARV}) - \sum_{ijk} x_{ijkt} \times \text{DEP}_k \geq 0$$

$$\sum_i x_{ijk,t} = \sum_i x_{ijk,t+1}$$

$$\sum_{ijk} x_{ijkt} \times \text{L}_{ijkt} \leq \text{LHH} + \text{LEMPL}_t$$

1.2 Farm model parameters

Parameter	Symbol	Unit	Value	Source
<i>Farm endowments</i>				
Total land area	<i>LAND</i>	Ha	2.3	b
Number of household members	<i>HHSIZE</i>	number	4.2	b
Unemployed labour (excl. harvest)	<i>LHH</i>	days/year	57.4	a
Output harvested per unemployed labour	<i>LHHHARV</i>	fan./year	11.5	a
<i>Time preferences</i>				
Rate of time preference	δ	%/year	6.44	b
Relative risk aversion coefficient	r	CRC ⁻¹	0.651	b
<i>Prices</i>				
Individual basic food basket	<i>BFB</i>	CRC/year	779023	c
Daily wage (unqualified, excl. harvest)	<i>W</i>	CRC/day	6511	d
Wage for harvest	<i>WHARV</i>	CRC/fan.	13300	d
Price of NPK fertilizer	<i>PNPK</i>	CRC/kg	360	e
Price of amonium nitrate fertilizer	<i>PNIT</i>	CRC/kg	325	e
Price of herbicide glyphosate	$P\alpha$	CRC/L	2870	e
Price of fungicide triazol	$P\beta$	CRC/L	31926	e
Price of fungicide copper hydroxyde	$P\gamma$	CRC/kg	8837	f
Price of foliar multimineral	$P\rho$	CRC/L	4572	e
Price of foliar boro	$P\epsilon$	CRC/L	3599	e
Price of foliar zinc	$P\zeta$	CRC/L	3919	e
Total replacement cost of coffee plants	<i>REP</i>	CRC/Ha	2857017	g
<i>Technical operations</i>				
Herbicide glyphosate quantity per application	$Q\alpha$	L/app.	1	f
Fungicide Triazol quantity per application	$Q\beta$	L/app.	0.4	f
Fungicide Copper hydroxyde quantity per application	$Q\gamma$	kg/app.	1	f
Foliar multimineral quantity per application	$Q\rho$	L/app.	3.6	e
Foliar boro quantity per application	$Q\epsilon$	L/app.	1	e
Foliar zinc quantity per application	$Q\zeta$	L/app.	1.5	e
Number of pruning until being replaced	Q	app.	4	h

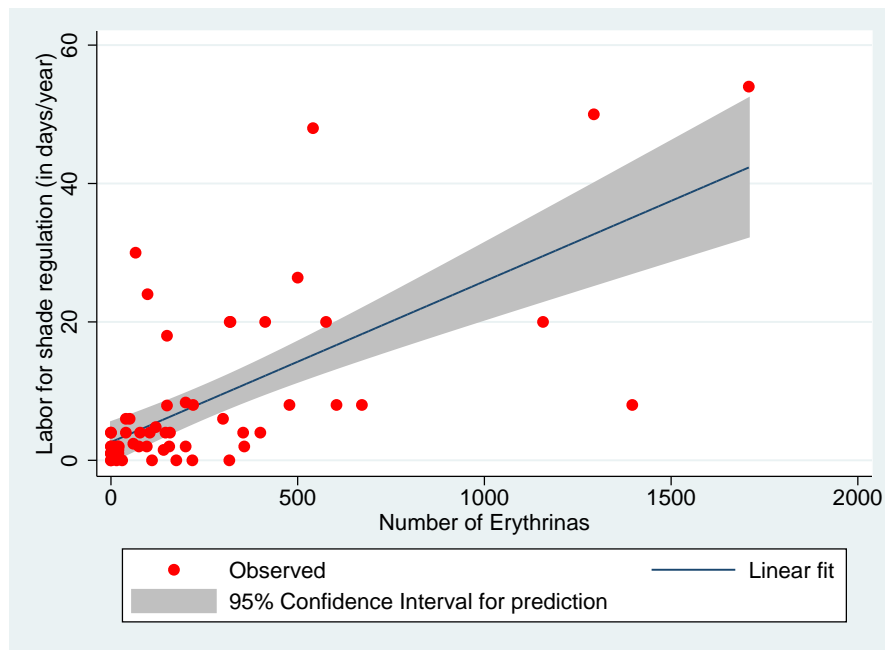
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a: Meylan (2012); b: Data collected by authors; c: INEC (2018); d: Icafé (2010b); e: Icafé (2010a); f: Icafé (2014a); g: Icafé (2010c); h: Expert source; l: Schnabel et al. (2017); m: Merlo (2007); *: Conditional marginal effects obtained from fitted models (see Appendix 1.3).

Parameter	Symbol	Unit	Value				Source
<i>Farm endowments</i>							
<i>System</i>							
	k		AF		SUN		
Erythras density	ERY_k	number/Ha	250		0		l
Time until being pruned	YR_k	years	5		4		h
Labor requirement for shade regulation	$LSHADE_k$	days/Ha/year	5.93		1.53		a*
Labor requirement for manually cutting weeds	$LWEED_k$	days/Ha/year	19.99		21.58		a*
<i>Input intensity at t</i>							
	i	<i>cat.</i>	LOW		$HIGH$		
Total N fertilization	N_i	kg/Ha/year	150		287		l
NPK fertilizer quantity	NPK_i	kg/Ha/year	500		1000		m
Amonium nitrate fertilizer quantity	NIT_i	kg/Ha/year	180		310		m
Number of herbicide applications	α_i	number/Ha/year	5		6		l
Number of fungicide Triazol applications	β_i	number/Ha/year	1		2		m
Number of fungicide Copper hydroxyde applications	γ_i	number/Ha/year	1		2		m
Number of foliar multiminerall applications	ρ_i	number/Ha/year	0		1		m
Number of foliar boro applications	ϵ_i	number/Ha/year	1		3		m
Number of foliar zinc applications	ζ_i	number/Ha/year	1		2		m
Labour for NPK fertilizer application	$LNPK_i$	days/Ha/year	5.55		7.21		a*
Labour for amonium nitrate fertilizer application	$LNIT_i$	days/Ha/year	4.65		5.00		a*
Labour for herbicide application	$L\alpha_i$	days/Ha/year	8.48		9.35		a*
Labour for fungicide Triazol application	$L\beta_i$	days/Ha/year	1.19		2.69		a*
Labour for fungicide Copper hydroxyde application	$L\gamma_i$	days/Ha/year	2.19		5.19		a*
Labour for foliar multiminerall application	$L\rho_i$	days/Ha/year	0.05		4.09		a*
Labour for foliar boro application	$L\epsilon_i$	days/Ha/year	1.17		3.41		a*
Labour for foliar zinc application	$L\zeta_i$	days/Ha/year	1.73		3.41		a*
<i>System X Input intensity at t</i>							
	(k,i)		(AF,LOW)	$(AF,HIGH)$	(SUN,LOW)	$(SUN,HIGH)$	
Coffee mean yield	$YMEAN_{ki}$	fan./Ha/year	25.50	39.87	38.39	46.38	l
<i>System X Pruning sequence X t</i>							
	(k,j)		(AF,CST)	(AF,VAR)	(SUN,CST)	(SUN,VAR)	
Labor requirement for pruning coffee plants at $t = 1$	$LPRUN_{jk,1}$	days/Ha/year	13.16	4.25	15.39	4.25	a*
Labor requirement for pruning coffee plants at $t = 2$	$LPRUN_{jk,2}$	days/Ha/year	13.16	22.07	15.39	26.53	a*
Labor requirement for pruning coffee plants at $t = 3$	$LPRUN_{jk,3}$	days/Ha/year	13.16	13.16	15.39	15.39	a*

1.3 Data analysis for parameters setting on labor demands

Labor for shade regulation vs. number of Erythrinas



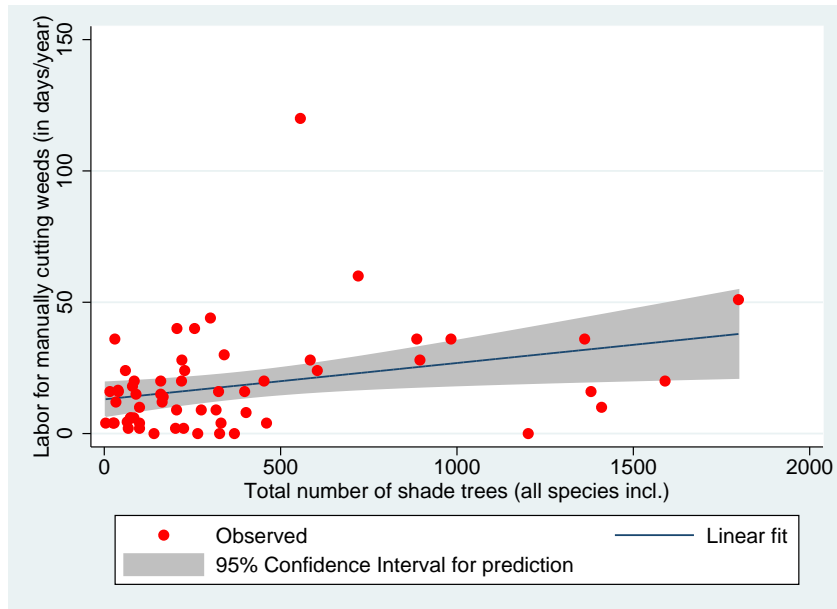
Marginal effect of the number of Erythrinas on the annual labor for shade regulation (in days for 2009-2010 cycle of production, plot observations, OLS estimates)

	(1)	(2)	(3)	(4)
	labor_tree	labor_tree	labor_tree	labor_tree
Erythrinas	0.0232*** (0.00578)	0.0213*** (0.00595)	0.0176** (0.00708)	0.0176** (0.00734)
Musas		0.0336** (0.0141)	0.0274** (0.0135)	0.0274* (0.0150)
Area			2.615** (1.268)	2.615* (1.359)
_cons	2.626** (1.233)	0.385 (1.112)	-1.085 (1.239)	-1.085 (1.521)
<i>N</i>	59	59	59	59
adj. R^2	0.452	0.570	0.587	0.587

Robust (models (1), (2) and (3)) or farm-clustered (model (4)) standard errors in parentheses

° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Labor for manually cutting weeds vs. number of shade trees



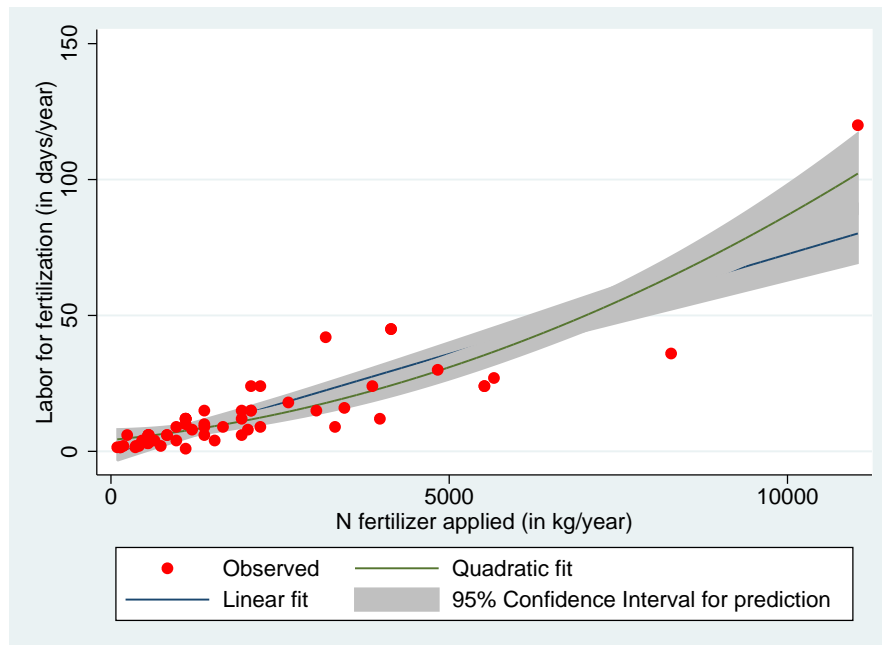
Marginal effect of the number of shade trees on the annual labor for manually cutting weeds (in days for 2009-2010 cycle of production, plot observations, OLS estimates)

	(1)	(2)	(3)	(4)
	labor_weed	labor_weed	labor_weed	labor_weed
Trees	0.0138*** (0.00502)	-0.00111 (0.0117)	-0.0280* (0.0142)	-0.0280* (0.0154)
Erythrinus		0.0202 (0.0156)	0.0217° (0.0131)	0.0217° (0.0138)
Area			17.66*** (4.545)	17.66*** (5.073)
_cons	13.03*** (2.299)	13.64*** (2.409)	3.920 (2.753)	3.920 (2.901)
<i>N</i>	59	59	59	59
adj. <i>R</i> ²	0.080	0.093	0.525	0.525

Robust (models (1), (2) and (3)) or farm-clustered (model (4)) standard errors in parentheses

° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Labor for fertilization vs. N fertilizer applied

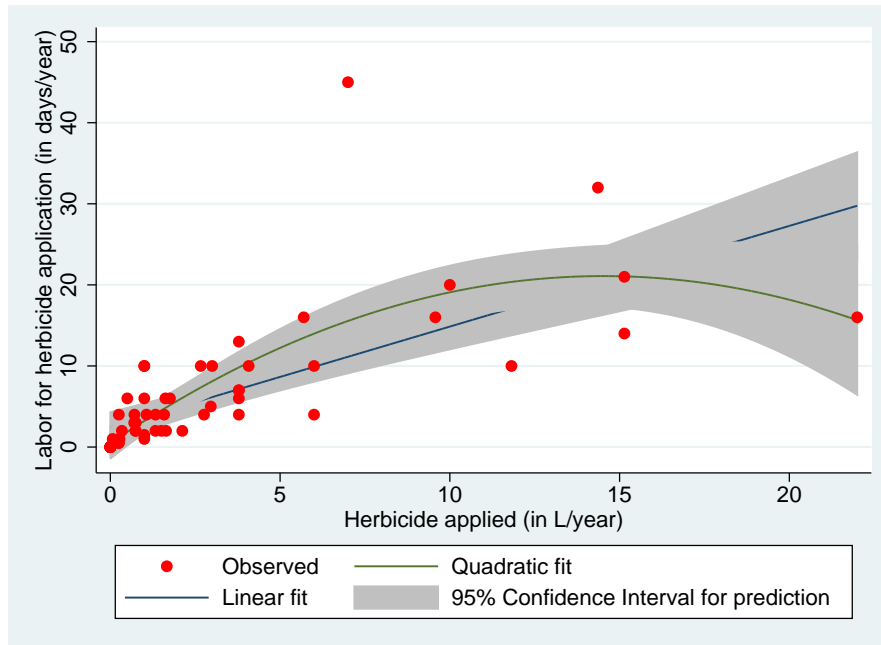


Marginal effect of the quantities of N fertilizer applied on the annual labor for fertilization (in days for 2009-2010 cycle of production, plot observations, OLS estimates)

	(1)	(2)	(3)	(4)
	labor_fert	labor_fert	labor_fert	labor_fert
Fertilizer	0.00734*** (0.00166)	0.00243 (0.00191)	0.00252 (0.00268)	0.00243* (0.00130)
Fertilizer_sq		0.000000584** (0.000000266)	0.000000583** (0.000000274)	0.000000584*** (0.000000136)
Area			-0.199 (2.173)	
_cons	-0.827 (2.484)	4.190** (1.575)	4.237*** (1.327)	4.190*** (1.314)
<i>N</i>	59	59	59	59
adj. <i>R</i> ²	0.726	0.781	0.778	0.781

Robust (models (1), (2) and (3)) or farm-clustered (model (4)) standard errors in parentheses
^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Labor for herbicide application vs. herbicide applied

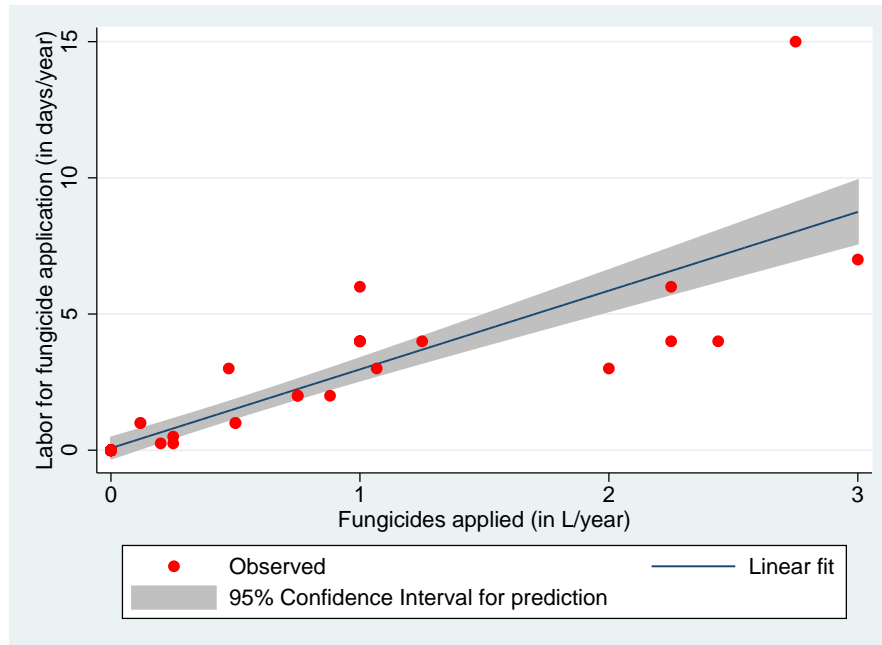


Marginal effect of the quantities of herbicide applied on the annual labor for herbicide application (in days for 2009-2010 cycle of production, plot observations, OLS estimates)

	(1)	(2)	(3)	(4)
	labor_herb	labor_herb	labor_herb	labor_herb
Herbicide	1.242*** (0.285)	2.836*** (0.672)	1.314*** (0.488)	1.314** (0.592)
Herbicide_sq		-0.0976*** (0.0329)	-0.0402* (0.0205)	-0.0402* (0.0233)
Area			4.948*** (1.688)	4.948** (1.883)
_cons	2.439*** (0.656)	0.484 (0.588)	-2.035* (1.049)	-2.035** (0.869)
<i>N</i>	59	59	59	59
adj. R^2	0.477	0.585	0.774	0.774

Robust (models (1), (2) and (3)) or farm-clustered (model (4)) standard errors in parentheses
 $^{\circ} p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Labor for fungicide application vs. fungicide applied

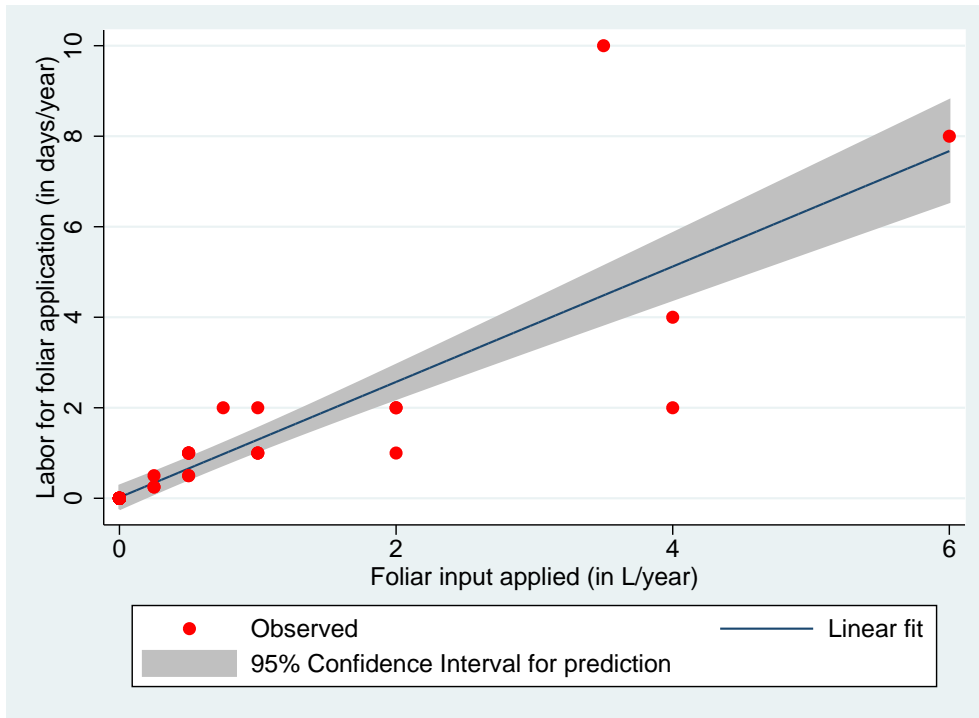


Marginal effect of the quantities of fungicide applied on the annual labor for fungicide application (in days for 2009-2010 cycle of production, plot observations, OLS estimates)

	(1)	(2)	(3)	(4)
	labor_fung	labor_fung	labor_fung	labor_fung
Fungicide	2.890*** (0.553)	3.131*** (0.859)	2.504*** (0.350)	2.504*** (0.362)
Fungicide_sq		-0.103 (0.528)		
Area			0.632° (0.401)	0.632° (0.396)
_cons	0.0771 (0.115)	0.0501 (0.0528)	-0.446 (0.388)	-0.446 (0.408)
<i>N</i>	59	59	59	59
adj. <i>R</i> ²	0.750	0.746	0.788	0.788

Robust (models (1), (2) and (3)) or farm-clustered (model (4)) standard errors in parentheses
 ° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Labor for foliar application vs. foliar input applied



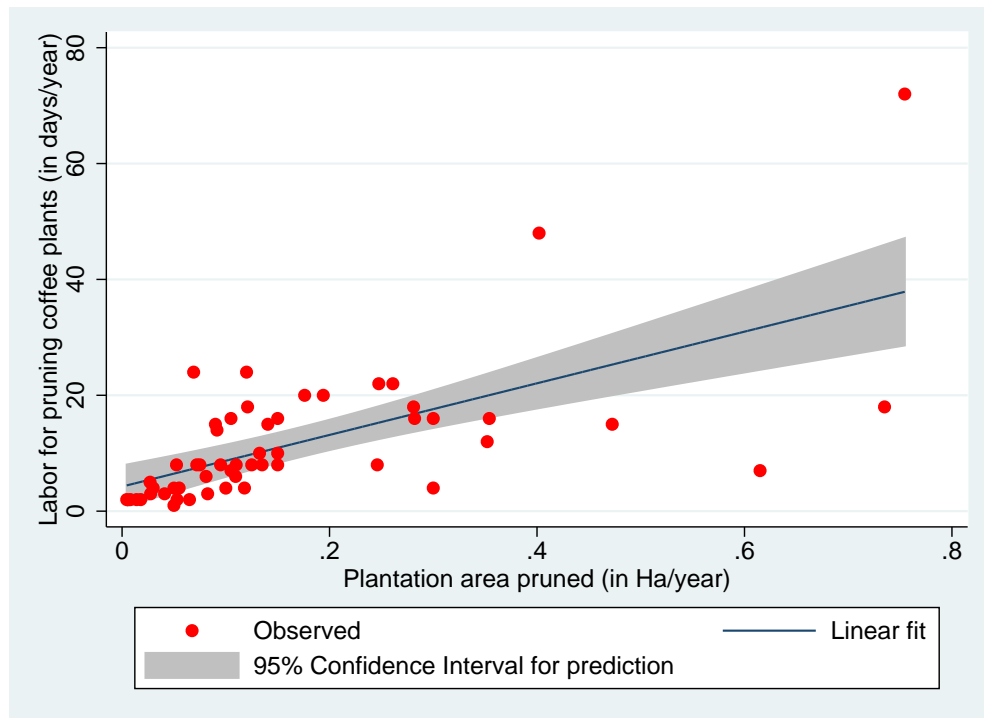
Marginal effect of the quantities of foliar input applied on the annual labor for foliar application (in days for 2009-2010 cycle of production, plot observations, OLS estimates)

	(1) labor_foliar	(2) labor_foliar	(3) labor_foliar
Foliar	1.275*** (0.253)	1.121*** (0.168)	1.121*** (0.174)
Area		0.506* (0.301)	0.506° (0.317)
_cons	0.0203 (0.0386)	-0.455° (0.283)	-0.455* (0.263)
<i>N</i>	59	59	59
adj. R^2	0.733	0.795	0.795

Robust (models (1) and (2)) or farm-clustered (model (3)) standard errors in parentheses

° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Labor for pruning coffee plants vs. plantation area pruned



Marginal effect of the plantation area pruned on the annual labor for pruning coffee plants (in days for 2009-2010 cycle of production, plot observations, OLS estimates)

	(1)	(2)
	labor_pruning	labor_pruning
Area_pruned	44.56** (17.82)	44.56** (18.63)
_cons	4.248* (2.227)	4.248* (2.263)
<i>N</i>	53	53
adj. <i>R</i> ²	0.393	0.393

Robust (model (1)) or farm-clustered (model (2)) standard errors in parentheses
^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

1.4 Data analysis for parameters setting on risk and time preferences

Risk aversion elicitation based on paired-lotteries choice

Round	Lottery Safe (S)				Lottery Risky (R)				Interval of r if switch to R	
	Low payoff	p	High payoff	$1-p$	Low payoff	p	High payoff	$1-p$		
1	8000	0.9	10000	0.1	500	0.9	19250	0.1	$-\infty$	-1.71
2	8000	0.8	10000	0.2	500	0.8	19250	0.2	-1.71	-0.95
3	8000	0.7	10000	0.3	500	0.7	19250	0.3	-0.95	-0.49
4	8000	0.6	10000	0.4	500	0.6	19250	0.4	-0.49	-0.14
5	8000	0.5	10000	0.5	500	0.5	19250	0.5	-0.14	0.15
6	8000	0.4	10000	0.6	500	0.4	19250	0.6	0.15	0.41
7	8000	0.3	10000	0.7	500	0.3	19250	0.7	0.41	0.68
8	8000	0.2	10000	0.8	500	0.2	19250	0.8	0.68	0.97
9	8000	0.1	10000	0.9	500	0.1	19250	0.9	0.97	1.37
10	8000	0	10000	1	500	0	19250	1	1.37	$+\infty$

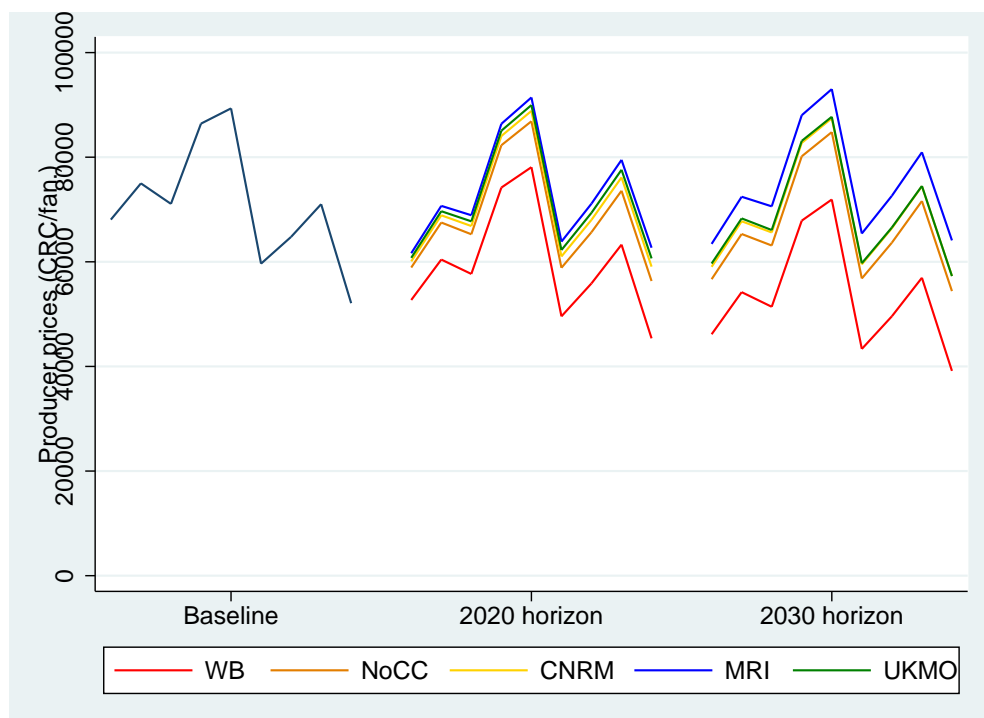
Rate of time preference elicitation based on paired-payoffs choice

Round	Payment A in 1 month	Payment B in 2 months	Interval of δ if switch to B		Interval of δ at $r = 0.651$	
			$1^{12-12r} - 1$	$1.1^{12-12r} - 1$		
1	2000	2200	$1^{12-12r} - 1$	$1.1^{12-12r} - 1$	0	0.490
2	2000	2400	$1.1^{12-12r} - 1$	$1.2^{12-12r} - 1$	0.490	1.145
3	2000	2600	$1.2^{12-12r} - 1$	$1.3^{12-12r} - 1$	1.145	1.999
4	2000	2800	$1.3^{12-12r} - 1$	$1.4^{12-12r} - 1$	1.999	3.090
5	2000	3000	$1.4^{12-12r} - 1$	$1.5^{12-12r} - 1$	3.090	4.459
6	2000	3200	$1.5^{12-12r} - 1$	$1.6^{12-12r} - 1$	4.459	6.153
7	2000	3400	$1.6^{12-12r} - 1$	$1.7^{12-12r} - 1$	6.153	8.219
8	2000	3600	$1.7^{12-12r} - 1$	$1.8^{12-12r} - 1$	8.219	10.711
9	2000	3800	$1.8^{12-12r} - 1$	$1.9^{12-12r} - 1$	10.711	13.685
10	2000	4000	$1.9^{12-12r} - 1$	$2^{12-12r} - 1$	13.685	17.203

Descriptive statistics on risk attitude and time preference experiments results

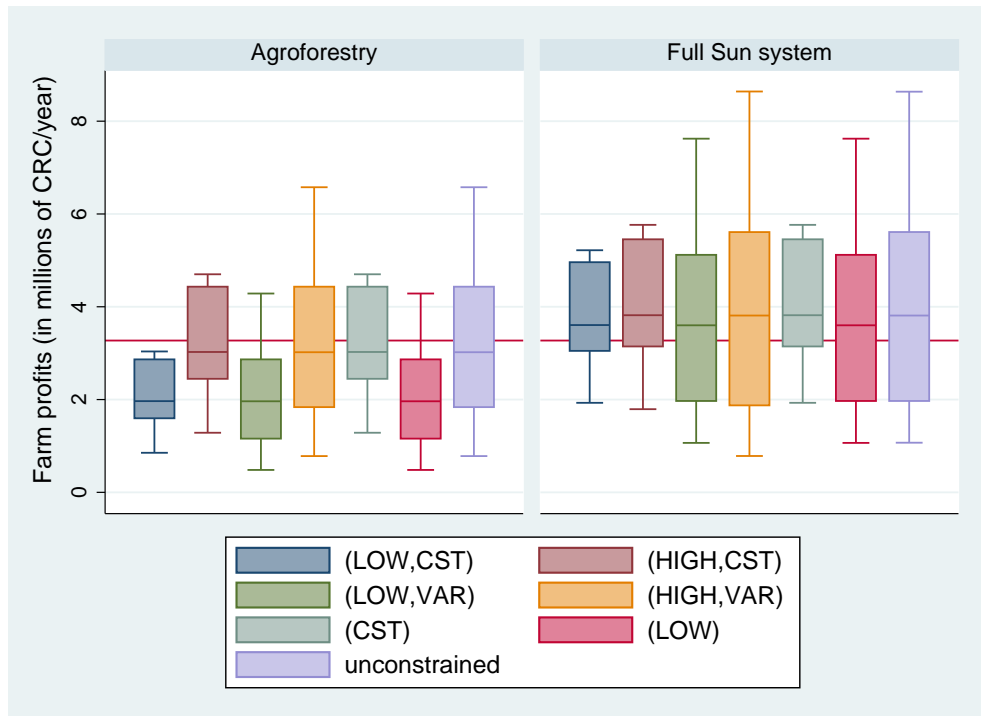
Variable	N	Mean	St. Dev.	Median
<i>Consistent risk attitude observations</i>				
Round with shift to R	125	7.52	2.01	7
r	125	0.651	0.587	0.545
<i>Consistent time preference observations</i>				
Round with shift to B	159	5.57	3.56	5
δ at $r = 0.651$	159	6.44	6.35	3.77
<i>Consistent risk and time observations</i>				
Round with shift to R	114	7.58	2.19	7
r	114	0.641	0.599	0.545
Round with shift to B	114	5.83	3.42	5
δ at $r = 0.651$	114	6.79	6.39	3.77
δ at $r = 0.641$	114	7.36	7.00	4.00
δ at individual r	114	709.78	5308.10	1.12

1.5 Producer price scenarios used for simulations at baseline, 2020 and 2030 horizons (in 2010 CRC/fan.)



1.6 Simulated farm annual profits distributions over price series from baseline

Farm annual profits distributions for 2008-2014 baseline over alternatives and poverty incidence



Note: Annual farm profits when all LAND is allocated to the alternative considered, over the seven 3-year sale price series composing the baseline period. Red horizontal line represents the cash amount covering for the annual basic food basket of all household members ($POVERTYLINE = HHSIZE \times BFB$).

Achieving Mitigation and Adaptation to Climate Change through Coffee Agroforestry: A Choice Experiment Study in Costa Rica

2

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Abstract

We use primary data from a choice experiment carried out with 207 coffee farmers in Costa Rica, in order to study their willingness to adopt various agroforestry systems under various types of support. We test four adaptation strategies that are based on resistant coffee varieties introduction, timber tree species production and/or shade tree density increase. Revealed preferences suggest that most of the respondents do value the introduction of resistant varieties. They are willing to plant twice the number of trees in their plantations when these are combined with resistant varieties. Conversely, all agroforestry systems requiring timber trees to be planted are chosen significantly less often and on average, their adoption would require a compensation scheme. We moreover find that a large majority of respondents is very responsive to non-monetary rewards, namely a subsidized credit, a free trial of resistant coffee seedlings or technical assistance. We conclude that each of these incentives could be used as an incentive to induce land use changes.

Keywords: Payment for Environmental Services, Non-monetary Incentives, Climate change, Choice Experiment, Coffee, Costa Rica.

1 Introduction

Coffee agroforestry appears as the most documented strategy to adapt to warmer, dryer and more variable climate conditions (Lin, 2007, 2010; Siles, Harmand, and Vaast, 2010; Camargo, 2010; De Souza et al., 2012; de Carvalho Gomes et al., 2016; Rahn et al., 2018), while also providing multiple environmental externalities (Hergoualch et al., 2008; Philpott et al., 2008a; Hergoualch et al., 2012; Tully, Lawrence, and Scanlon, 2012; de Jesús Crespo et al., 2016). However, there is a wide variety of agroforestry-based adaptation strategies and little is known about their acceptability by small producers in the real world. Moreover, it remains unclear what types of measures or schemes should be implemented to encourage the adoption of these diverse strategies. This Chapter uses original data collected from a large sample of coffee farmers to evaluate their willingness to adopt various agroforestry systems under various types of support.

Based on the assumption that improving risk management within agroforestry systems could reduce the opportunity cost of adopting the technology, the agroforestry systems studied include resistant coffee varieties and/or timber trees - *a priori* attractive options as part of risk-coping strategies that may better fit within local farming contexts - in addition to a shade tree cover of various densities. Since these adaptive strategies also have the potential to provide environmental externalities, this study assesses coffee farmers' preferences in the framework of an external reward scheme such as a Payment for Environmental Services (PES).

Direct performance-based payments have been initially described as the most cost-effective form of incentive to induce the provision of environmental services such as biodiversity conservation (Ferraro and Kiss, 2002). Nonetheless, in cases where market frictions prevail, indirect interventions which relax constraints may be preferred by both the farmer and the program planner (Groom and Palmer, 2010) and the key innovation would be to make such indirect interventions conditional on the provision of environmental externalities (Cranford and Mourato, 2014). This study investigates the potential of three incentives to trigger a decision to adapt to climate change through agroforestry: the use of a subsidized credit¹, a free trial of resistant coffee seedlings and technical assistance.

Given the agro-ecological heterogeneity of farms and socio-economic heterogeneity of rural households, the net benefits of agroforestry adoption are likely to vary between coffee farms. Both opportunity costs and adoption barriers are often related to specific circumstances. Knowler and Bradshaw (2007) showed that empirical evidence about the specific circumstances for the adoption of conservation agriculture is sparse and therefore it is difficult to highlight the universal conditions of adoption. Building on this literature, Andersson and D'Souza (2014) argued that most of current studies on technological adoption, by relying on standard households survey data, fail at providing useful insights due to the rival interpretations constituting the so named "adoption puzzle". In this context, using contingent valuation

1. In Ecuador, Cranford and Mourato (2014) proposed a credit contract that incorporates an environmental condition - which was the adoption of agroforestry - and found a very large demand for it.

methods to explore individual preferences can be an interesting approach as highlighted in recent studies on adaptation-related technologies for agriculture (Tesfaye and Brouwer, 2012; Ward et al., 2013; Ahmed et al., 2015; Ward et al., 2016; Kassie et al., 2017).

Originally developed to predict demand in traditional markets (Train, 2009), discrete choice methods are now a popular tool for eliciting individual's preferences for environmental attributes. In the context of developing countries, several studies have highlighted the dependence of rural poor households on the services provided by the ecosystems (Vedeld et al., 2004; Atkinson, Bateman, and Mourato, 2012). Following studies conducted in developed countries (Ruto and Garrod, 2009; Espinosa-Goded, Barreiro-Hurlé, and Ruto, 2010; Christensen et al., 2011) and in China (Grosjean and Kontoleon, 2009), a growing body of literature uses these methods to understand preferences of landowners from the developing world not as consumers but as suppliers of environmental externalities, regarding potential designs of PES contracts (Kaczan, Swallow, and Adamowicz, 2013; Cranford and Mourato, 2014; Costedoat et al., 2016). These studies are based on Choice Experiments (CE) during which respondents are asked to select the PES contracts they prefer between various hypothetical alternatives. Recent development of mixed logit models has allowed CE data analysis to incorporate random taste variation, unrestricted substitution patterns and correlation in unobserved factors over time (Train, 2009).

For this case study, a CE approach is uniquely useful to reveal coffee farmers' heterogeneity in making differential profits from both agroforestry systems and rewards. This can help to design technological and institutional innovations tailored to the needs of coffee farmers. We investigate Costa Rican coffee farmers' acceptability for a policy portfolio mixing adaptation technology adoption with the provision of environmental service including mitigation efforts. We carried out a choice experiment with 207 coffee producers in two neighboring cantons in the Los Santos Valley. This relatively homogeneous agro-ecological zone is the main region for coffee farming in term of area, number of producers, production and quality in Costa Rica. In our experiment, the hypothetical PES contracts include a "requirement" (one of four agroforestry systems) as well as four types of "rewards" (a cash payment, a subsidized credit, a free trial of resistant coffee plants and technical assistance) conditional on the compliance with the requirement.

Revealed preferences suggest that most of the respondents do value the introduction of resistant varieties such that they are willing to plant twice the number of trees in their plantations when these are combined with resistant varieties. Conversely, all agroforestry systems requiring timber trees to be planted are significantly less popular and on average, their adoption would require a compensation scheme. This compensation may be explained by the high level of carbon sequestration associated with timber trees. Regarding the respondents' preferences for the various proposed incentives, a large majority of respondents is responsive to a contract offering a cash payment, a subsidized credit, a free trial of resistant coffee seedlings or technical assistance. By showing that farmers were willing to pay for agroforestry systems combining resistant varieties, this study suggests the existence of an unfilled demand for more tolerant plants and highlights the incidence of market frictions in constrain-

ing autonomous adaptation to climate change. It also points out the role of such attractive technological packages as PES requirement, in fostering voluntary participation at a possibly lower cost for the program planner. By estimating demand for the subsidized credit, free trial of resistant coffee seedlings and technical assistance, this study also adds to the few studies that empirically investigate interventions to induce land use changes through reducing market constraints.

Following this introduction, Section 2 reviews previous studies on the attributes used in the experiment. Section 3, Section 4 and Section 5 describe the study area, the data collection and the design of the choice experiment, respectively. Then Section 6 presents the econometric models used. Results are explained in Section 7. Section 7 concludes.

2 Toward Climate-Smart Coffee Farming

2.1 Adaptive practices

As explained in Chapter 2, covering coffee plantations with a layer of shade trees appears as the most documented strategy to adapt to warmer, dryer and more variable climate conditions (Lin, 2007, 2010; Siles, Harmand, and Vaast, 2010; Camargo, 2010; De Souza et al., 2012; de Carvalho Gomes et al., 2016; Rahn et al., 2018). In this Section, we present two other adaptive practices for which evidence have been found about their effectiveness to address some of the needs of coffee farming for incremental adaptation to global changes in Central America: the association of the timber tree *Cordia* with coffee plants and coffee hybrid varieties introduction. In the last part of this Section, we detail the ability of these practices to provide ecosystem services.

Cordia timber tree

The association of the timber tree *Cordia* with coffee plants is in fact a common agroforestry system in traditional coffee farming in Costa Rica (Beer, 1979), Colombia (Venegas Tovar, 1978) and Venezuela (Lamprecht, 1955). *Cordia* is a widespread specie in tropical America where it can naturally regenerate and grow very rapidly (Pérez Figueroa, 1954). Beer (1979) asserts that coffee farmers can value it as a suitable shade tree also due to its tall straight trunk and compact crown which does not require any pruning operation but provides the leaf litter with a large amount of organic material. Furthermore, *Cordia* is one of the most popular timber tree in the countries where it occurs naturally, supplying high-quality wood suitable for construction, cabinet work and furniture-making (Greaves and McCarter, 1990), unlike *Erythrina*s which can provide only firewood. From 1985 to 2005, sale price for *Cordia* wood increased by 570%, as a result of higher demand in the region (Vaast et al., 2015).

Timber production as an important source of income has been reported in low-altitude coffee farms and attributed to a portfolio diversification strategy (Galloway

and Beer, 1997; Rice, 2008; Vaast et al., 2015). Explaining coffee land losses occurred after the 1997-2001 sale price crisis in Turrialba, a low-elevation region in Costa Rica, Bosselmann (2012) evidenced that the sale or consumption of products from shade trees (72% of the sample) had decreased the probability of converting coffee plantation to other uses. Some evidence suggests that in the same region, coffee plantations with both *Cordias* and *Erythrinas* can be more profitable than plantations shaded with *Erythrinas* only (Glover, 1981), even when damages from timber harvest to coffee plants are discounted while coffee yields and coffee prices are high (Somarriba, 1992). Observed *Cordia* densities in this region and at higher elevations in Colombia cover a range from 50 to 350 trees per hectare of plantation (Beer et al., 1997). For a density of 100 *Cordias* per hectare, the additional annual revenue from timber sale has been estimated at USD 150-250 per hectare (Vaast et al., 2015). No obvious environmental constraint would prevent the introduction of *Cordia* in the coffee plantations in Los Santos region, given that the specie is yet found from 0 to 2,000 meters above sea level, reaches its best growth at about a mean annual temperature of 24 °C and mean annual rainfall above 2,000 mm, without being impacted by the pattern of annual rainfall distribution and tolerating very low rainfall levels (Greaves and McCarter, 1990). Moreover, Greaves and McCarter (1990) mentions that *Cordia* has proven a better resistance to hurricanes and cyclones compared to other timber species.

Hybrid varieties

Coffee hybrid varieties introduction has good prospect for improving farm resilience to climate-related threats, especially pest and disease issues. Due to their reproductive biology and evolution, Arabica varieties bear low genetic diversity (Lashermes et al., 1993) leading to be vulnerable to most pests and diseases affecting coffee production worldwide (Bertrand et al., 1999). In response to production risk, selective breeding for innovative varieties has led to put on the market several varieties which are high-yield and disease resistant (Silva et al., 2006; Camargo, 2010) and can technically be propagated on an industrial scale (Etienne et al., 2012). Nevertheless, the failed experience of the hybrid variety Catimor in Central America highlighted that such hybrid varieties again face up to the quality imperative of reaching the taste standards of buyers and maintaining local reputation (Bertrand et al., 2003, 2006).

Considering both productivity and quality aspects, Arabica hybrids named F1 from traditional Central American varieties or Catimors, crossed with wild Sudanese-Ethiopian origins have shown promising results. First, they bear some genes of resistance to pests and diseases that are highly prevalent, including the coffee berry disease found only in Africa for the moment (Bertrand et al., 1999). Planted from 750 to 1580 m.a.s.l in current climate conditions, F1 hybrids display yield from 30 to 35% more than traditional Central American varieties in unshaded conditions, and even up to 60% under shade (Bertrand et al., 2011). F1 yield could be also more stable facing environmental stresses (Bertrand et al., 2011). Finally, with regard to the biochemical composition of their beans and taste quality of the processed bever-

age, Bertrand et al. (2006) found them at least as good as the best traditional varieties from Costa Rica.

Environmental Services provision

Implementing those farming practices may improve environmental services provision compared to current practices, including carbon capture and storage. Shade trees in coffee plantations can be significant sinks of atmospheric carbon mainly by sequestering carbon in their aboveground biomass, that has been quantified in the literature as around 5.4 and 19.9 tonnes of carbon per hectare for given densities of Erythrinas and timber trees respectively, according to Hergoualch et al. (2012). Consequently, increasing shade tree density has the potential to enhance carbon stocks in coffee plantations, even to a greater extent if timber trees such as Cordia are associated. Accounting for non- CO_2 greenhouse gases, the net GHG balance would be improved under large densities of shade trees (Hergoualch et al., 2012), even if leguminous trees such as Erythrinas and Ingas would likely underperform Cordias again, at a given amount of chemical fertilizers and due to their effect on nutrient cycles (Hergoualch et al., 2008). Furthermore, nitrogen losses from fertilizer use through leaching decline with increasing shade tree densities in coffee plantations (Tully, Lawrence, and Scanlon, 2012), hence shade trees could limit contamination of local drinking water supplies and ecosystems (de Jesús Crespo et al., 2016). Again, the assessment of nitrate transfer into local water supplies would likely favour Cordias over Erythrinas (Rosenstock et al., 2014).

As a decrease in the density and in the complexity of the shade cover has been related to a loss of birds and ants richness (Philpott et al., 2008a), shade trees in coffee plantations can contribute to biodiversity conservation, and because of the severe pruning traditionally operated on Erythrinas, an additional shade strata of Cordias would likely preserve more habitats. In addition, the provision of wood products by shaded coffee plantations could reduce the pressure on neighboring forested lands (Vaast et al., 2015) and thus limit anthropogenic disturbances on forests, considering that even in Costa Rica, 13% of the dwellings have walls made of wood and that in the Los Santos coffee region, around 25% of the households still rely on firewood for cooking (INEC, 2011) as well as thousands of seasonal migrants during the harvest season (Bolaños et al., 2008). Lastly, no evidence in the literature refers to improved provision of environmental services by growing hybrid coffee varieties rather than current varieties, except the aforementioned provision of higher coffee yields and potential role in pest and disease control.

2.2 Overcoming market failures to support adaptation

Standard economic theory assumes that the decision of whether or not to adopt such adaptive practices depends on the comparison between the utility a farmer expects from the adoption and the expected utilities of the alternative practices. However, market mechanisms may not lead to an optimal decision for either society or for the farmer. On the one hand, since the studied practices if adopted can enhance

the available knowledge about their use as well as the provision of aforementioned ecosystem services, the externalities consequent to the public-good nature of these benefits are not well accounted for in the farmer's decision-making, as explained in Chapter 1. As a result, social welfare is not likely to be maximized.

On the second hand, the farmer's decision may reflect the constraints created by local markets imperfections rather than whether or not a farming practice is worthwhile from his/her point of view. In order to meet the conditions of an optimal collective welfare, public intervention may then be required. Economic literature provide relevant findings regarding the public interventions that can adequately address these market inefficiencies issues in developing countries. In this Section, we focus on four instruments likely to support the adoption of the studied adaptive practices: a cash payment (PES-like), in-kind payment (free trial of improved seeds), technical assistance and a subsidized credit facility.

Cash payment

PES schemes have recently emerged as a Coasean-type solution to align farmers' incentives to provide positive externalities with the demand for the services. They offer a payment to convey private benefits for adopting or maintaining land uses or practices that generate the positive externalities (Engel, Pagiola, and Wunder, 2008; Jack, Kousky, and Sims, 2008). Regarding avoided deforestation, several impact evaluations suggest that PES can induce lower deforestation rates (Honey-Rosés, Baylis, and Ramírez, 2011; Alix-Garcia, Shapiro, and Sims, 2012; Arriagada et al., 2012; Robalino and Pfaff, 2013; Alix-Garcia, Sims, and Yañez-Pagans, 2015; Costedoat et al., 2015; Jayachandran et al., 2017).

Little similar work has been carried out in developing countries on the impact of PES schemes that are conditional on environmental practices in farms. Assessing the impact of such an intervention incentivizing a new tree specie planting, Jack et al. (2015) evidenced that more farmers actually implement the practice in their farm when they are rewarded conditionally on its use.

In-kind payment

Regarding the provision of local positive externalities similar to pest and disease control, Kremer and Miguel (2007) suggested that a shift from underadoption to a high-adoption equilibrium requires large ongoing subsidies in order to cover for the opportunity cost of adopting rather than free riding on neighbors' control spillovers. Dupas (2014) found that temporary subsidies increase adoption rates among both recipients and their neighbors with a demand highly price-elastic around a zero price, giving credit to free trial periods.

Results in Suri (2011) suggest that addressing constraints on input market access would alleviate large costs that put a strain on the adoption profitability in remoted areas. By making improved seeds available through door-to-door delivery, Emerick et al. (2016) found that farmers with access to the seeds cultivate more land and displace traditional varieties, they use more fertilizer and improved practices, resulting

in increased yields. Studying the impact of a one-time subsidy for fertilizers and improved seeds, Carter, Laajaj, and Yang (2014) found that the voucher receipt induce an increase in short-term adoption and that demand persists over time and generates learning by others.

Technical assistance

Much public intervention related to input markets consists of agricultural extension services, providing agricultural and farm management knowledge as an input for farmers' activity (Anderson and Feder, 2007). Benefits from agricultural advisory are the greatest in the early stages of a new technology dissemination, when information related to the correct use of the technology is not available such that experimentation costs are the highest and all borne by early adopters. These costs for acquiring information could thus be limited by adequately meeting the demand for learning. Studying the impact of different interventions on the adoption of an improved seed, Emerick and Dar (2017) suggest that simple learning activities can increase the adoption of new but profitable technology. Duflo, Keniston, and Suri (Forthcoming) also evidenced that attending trainings is sufficient to make coffee farmers more likely to implement the practices that are encouraged if the practices are not too labor-intensive. Moreover, strategic delays of adoption would have lower benefits in communities where agricultural extension is not missing so the farmers do not rely on learning from their peers as underlined by Bandiera and Rasul (2006).

Credit facility

Especially when technology adoption requires large upfront costs, imperfect rural credit markets can prevent farmers from borrowing to invest in a profitable technology. Credit constraints have been found to reduce the adoption of both improved seeds Simtowe, Zeller, and Diagne (2009) and agroforestry systems (Pattanayak et al., 2003; Blackman et al., 2005; Pagiola et al., 2007). Recent studies focused on innovative credit products that are tailored to farmers' needs. Jack (2013a) supported that customizing collateral requirement can reveal a large demand for credit, and Matsumoto, Yamano, and Sserunkuuma (2013); Beaman et al. (2014) found that the availability of a credit product with a repayment schedule adapted to the seasonality of farmers' cash flows can enhance their investments. Moreover, Emerick et al. (2016) evidenced that the adoption of resistant varieties triggers the credit uptake by farmers from existing sources, while increasing production costs through the use of modern input and labor-intensive practices. This result suggests that securing the access to adapted credit products in agriculture could induce that farmers would be able to switch to a high-yield system based on improved input, while the credit supply from existing sources could increase in response to the reduction in production risk.

Combining interventions

Since technological change involves various market frictions, combining interventions appears as an attractive options for an increased program cost-efficiency by

an interplay of effects. Matsumoto, Yamano, and Sserunkuuma (2013) showed that an intervention offering credit sales was more effective on farmers who had received free trials of modern inputs previously. In line with these results, results in Emerick et al. (2016) also signal that once farmers are given access to an improved technology, they tend to take out more loans. Glennerster and Suri (Forthcoming) found that an increase in yields ensues from training coupled to a new variety receipt, whereas farmers who receive the seeds but no the training experienced a small decline in yields.

3 The coffee sector in the Los Santos Valley

3.1 Agro-climatic characteristics

The study takes place in the Western half of the Los Santos Valley, in Leon Cortes and Tarrazu cantons, Costa Rica. Alongside with Dota canton, the two selected cantons lie on the Pacific side of the Cordillera de Talamanca and share very similar agroclimatic conditions characterized by the influence of the Pacific ocean (relatively low rainfall and a marked dry season) (Coen, 1983), steep slopes and eroded ultisols (Meylan et al., 2013). Arabica coffee is the main crop cultivated, the remaining land uses being extensive pastures or high-altitude forests (de Jesús Crespo et al., 2016), except in Dota canton where around 80% of the area are inside protected areas (SINAC, 2017). Leon Cortes and Tarrazu cantons jointly account for 20% of the national coffee production (Icafé, 2016a). 1,400 small-scale farms has coffee growing on a total of 8,000 hectares of coffee plantations, distributed nearly equally between these two cantons (INEC, 2007).

Farms usually exhibit a shaded monoculture pattern characterized by the association of underdiversified tree species, mainly leguminous trees, with highly productive coffee plants that are sustained by an intensive use of chemical inputs (Castro Tanzi et al., 2012; de Jesús Crespo et al., 2016). As displayed in Table 3.1, a very large majority of local farmers grows Caturra and/or Catuai as coffee variety, under the shade of Erythrinas associated with Musaceae (banana trees). This agroforestry system has been identified as the most intensive system of shaded coffee plantations in Latin America (Philpott et al., 2008a) and is distributed very homogeneously among the study site compared to other coffee regions in Costa Rica. For instance while *Cordia* is not used at all as shade tree in the study site, this tree can be found frequently in some coffee farms across the country (see Table 3.1).

3.2 Institutional features

The entire local coffee production from the study site is classified as Strictly Hard Beans and one processed, obtains high-quality sensory characteristics so similar and renowned that a common geographical indication certification is upcoming (Avelino et al., 2005; La Nación, 2017). In fact, coffee farmers in the study area are strongly organized in cooperatives, namely CoopeTarrazu as the main one and CoopeLlanoBonito, for the processing of harvested coffee cherries and marketing

stages. The cooperatives have been successful in accessing specialty market niches for export, still price risk management (Hazell, 2000) and decisions on farming practices (Snider et al., 2017) belong to the farmers who own their land for almost all of them (see Table 3.1). Farmers often choose to deliver their coffee cherries not exclusively to one cooperative, in a context of competition prevailing between local buyers which include also private firms (Wollni and Fischer, 2015). Besides processing and marketing, the cooperatives provide technical assistance by their agronomists, market and price information and input supplies on credit amongst other services (Wollni and Zeller, 2007), to a lesser extent in CoopeLlanoBonito which is limited by its smaller size (Snider et al., 2017).

In spite of the cooperatives services, the lack of access to knowledge and to some goods and services still concerns 11% of the population in this rural area (INEC, 2011). The closest main Costa Rican cities are about two or three hours away by car. About sources of financing, the study area presents the specificity of a low prevalence of formal credit use (see Table 3.1). Since local farmers rely on seasonal loans from strong and competitive coffee buyers, they may have limited access to larger and longer term credit from financial institutions on the other hand (Carranza, Díaz Porrás, and Salazar Rivera, 2010). Formal credit market inefficiencies have been salient during coffee crisis, when coffee farmers underwent a wholesale rejection of their loan applications by banks and 3 farms on 4 had to cope by reducing input use, stopping the renovation of their plantations, selling land and/or limiting household expenditures for consumption (Carranza, Díaz Porrás, and Salazar Rivera, 2010; Valenciano Salazar, 2010). Based on this knowledge about local institutions, we hypothesize that some of the coffee farmers from the study site are likely to be constrained in their decision relative to technology adoption by imperfect information and inefficiencies on the markets of credit and inputs that are non traditionally used.

3.3 Socioeconomic vulnerability

Because farmers from the study site own small but specialized and intensive farms, their profits are risky and burdened with high production costs. Off-farm work opportunities are limited for the coffee farmers, given that most of them have elementary or no academic education (see Table 3.1) and local employment outside of coffee production is dominated by the service sector (INEC, 2011). The very steep and eroded slopes are likely to generate high production costs and low productivity for annual crops (Pfaff et al., 2009; Ferraro and Hanauer, 2011), leading to the current absence of such crops in local coffee farms (INEC, 2007) and to a considerable barrier to climate change adaptation through diversification of farm activities and/or crop switching. Expanding coffee plantations to higher-altitude land is a very limited alternative as well, insofar as remaining on-farm area is dedicated either to livestock production which is one of the rare suitable diversification strategies, or to forest falling under the 1996 Forest Law that forbids landholders to clear it and restricts timber extraction. Using focus groups in October 2014, incremental adaptation of existing coffee plantations appeared as a consensual response to climate change according to the group of stakeholders from the local coffee sector, whereas in another

Costa Rican coffee region with higher pressure from competing land uses, adaptation strategies that were discussed involved more drastic changes in the agroforestry system including crop switching. Therefore, coffee farmers' preferences for farming practices in the study site are likely to be driven by their expectations in coffee incomes in isolation from their beliefs regarding the returns of competing land uses.

3.4 Heterogeneity in mesoclimates and socioeconomic backgrounds

Besides this relative homogeneity in farming context, the study site includes major variability in altitude (from 1,300 to 2,000 meters above sea level), slope and slope exposure that ensures covering a broad range of mesoclimates and therefore, differences in coffee farming practices, as found in previous studies (Castro Tanzi et al., 2012; Meylan et al., 2013; de Jesús Crespo et al., 2016; Bhattarai et al., 2017). In their typology of coffee farming systems in a part of Leon Cortes canton included in our study site, Meylan et al. (2013) characterize four groups different in their practices, using a small sample of 32 farmers and in spite of the apparent homogeneity of the agroecological system.

Furthermore, communities across Leon Cortes and Tarrazu cantons comprise a diversity of socioeconomic backgrounds. In Leon Cortes canton, 60% of the population live in rural areas, poverty incidence is relatively high (27.5% of its population living below the national poverty line) and some communities severely lack access to public infrastructure (INEC, 2011). Tarrazu population is mainly urban, with the service sector employing half of the workforce (INEC, 2011) and offering several financial institutions in the main town. Comparing to Leon Cortes, the average coffee farmer from Tarrazu owns two hectares more land, resulting in one additional hectare dedicated to coffee production. Farms of less than one hectare are twice less frequent than in Leon Cortes; still they represent nearly 10% of coffee farms (INEC, 2007). Hence we expect that the preferences of a sample of local coffee farmers will reflect the heterogeneity in individual and/or local characteristics that are difficult to observe and affect the farmers' choices in farming practices.

4 Survey and sample

4.1 Data collection

The data collection was carried out by the authors from end of February to mid-May 2016. With guidance and active support from four local organizations - including CoopeLlanoBonito and CoopeTarrazu - we visited 14 different communities across both cantons. We set up one group session of interviews by location to which most of identified coffee farmers from the community have been invited by way of a personal visit to their homestead and communication material, through the week before the session. Each session gathered an average of 15 coffee producers, resulting in a sample of 207 respondents (117 from Leon Cortes and 90 from Tarrazu).

We introduced each session with a presentation of the main scientific results about future trends in temperature and rainfall in the Los Santos Valley. In addition, participants have been told about the agronomic rationale behind the three farming practices we defined previously as adaptive practices, as well as some common knowledge informing of their implementation costs. Each respondent filled an individual questionnaire with reading and writing assistance from an enumerator if he/she requested it. The first section of the questionnaire consisted in a survey collecting information about the household's social characteristics, sources of income, credit access and participation in producers' organizations, land ownership and use, as well as the respondent's past experience and current practices in coffee farming.

4.2 Respondents characteristics

Column (3) in Table 3.1 displays some descriptive statistics in order to compare the populations of coffee farmers from the study site with the sampled coffee farmers. It shows that the respondents own farms that are very similar in means to the farms in the study site. In addition, we know that half of the sampled farmers had yet experienced to grow some hybrid coffee plants, mostly from Catimor variety. Nevertheless, most of them have dropped it or to still grow it but not as their main variety. The sampled farmers also declared a proxy of their density of Erythrinas in the coffee plantations, providing a mean of 300 and a median of 180 Erythrinas per hectare. We notice that the sample is composed of a smaller proportion of farmers over 60 years old and relatively large farm owners than in the population of the study site. These main differences likely result from selection due to the sampling process: volunteer respondents may have more time available for social events compared to the mean local farmer. Besides, the sampled farmers seem representative of the local population of coffee farmers.

Our questionnaire also included debriefing questions where the respondents were asked to give their opinion on the studied adaptive practices using Likert scales, as well as to rank their 3 main preoccupations regarding the future of coffee production. Figure 2.1 displays the scores aiming at measuring the importance of the seven main preoccupations cited in the literature regarding the future of local coffee farming and ranked by the sampled farmers. Lower rainfall heads the list under the first-past-the-post method, with 25% of the respondents who declared it as their main preoccupation. The subsequent one is the evolution of coffee sale price, followed by temperature increase, gathering 21% and 18% of the votes respectively. All in all half of the sample declared as their main preoccupation one of the three items directly related to climate change, knowing that higher frequency of extreme climate events represents only 7% of the votes. Taking into account the second and third choices of each respondent through a weighted score, a Borda count establishes that pests and diseases are the predominant preoccupation in the overall sample. This item were declared as one of the 3 main preoccupations by 84% of the respondents. Almost the same share of respondents declared at least one item directly related to climate change within their three main preoccupations. As a result, we assume that a majority of coffee farmers grants importance to direct impacts of climate change

Table 2.1: Description of the coffee farmers from Costa Rica, from the study site and from the sample (means)

	(1) Costa Rica	(2) Leon Cortés and Tarrazú cantons	(3) Sample
Age	<24 years	2%	3%
	25-59 years	69%	75%
	>60 years	29%	22%
Female head of household		32%	28%
Academic education	None	8%	6%
	Primary	76%	82%
	Secondary	10%	9%
	Higher	6%	3%
Household size (members)	3,7	4,1	4,3
Owned area	96%	99%	98%
Farm area	<1 Ha	19%	14%
	1-5 Ha	50%	47%
	5-10 Ha	15%	18%
	>10 Ha	16%	21%
Farms without credit	51%	84%	81%
Forest area in the farm (Ha)	1	1,5	0,9
Caturra/catuai coffee variety	95%	100%	99%
Erythrina specie as shade trees	77%	91%	88%
Musaceae species as shade trees	58%	78%	85%
Cordia specie as shade trees	8%	0%	0%

Notes: Data in columns (1) and (2) have been compiled from INEC (2007), except for the share of female heads of household found in Alpizar, Carlsson, and Naranjo (2011). Shaded percentages indicate noticeably large differences compared to the previous column.

on coffee production in the long run, with the exception of a higher occurrence of climate extreme events. We also expect that the risk of pests and diseases is likely to represent an underlying trade-off upon technology adoption.

Figure 2.2 tends to confirm that coffee farmers' beliefs about climate changes match the predictions. Respondents also declared that they need to adapt coffee farming to climate change. Hence, respondents are assumed to be well-informed about climate trends and to consider their current practices sub-optimal under future climate conditions. Regarding the three adaptive practices we study, all of them met with the approval of most of the respondents, even if the acceptance of associating Cordia trees was not as unanimous as the ones of increasing shade-tree density and introducing hybrid coffee variety. They all appear as options the respondents would be willing to consider as alternatives to their current practices.

Figure 2.1: Sampled farmers' preoccupations regarding the future of coffee farming

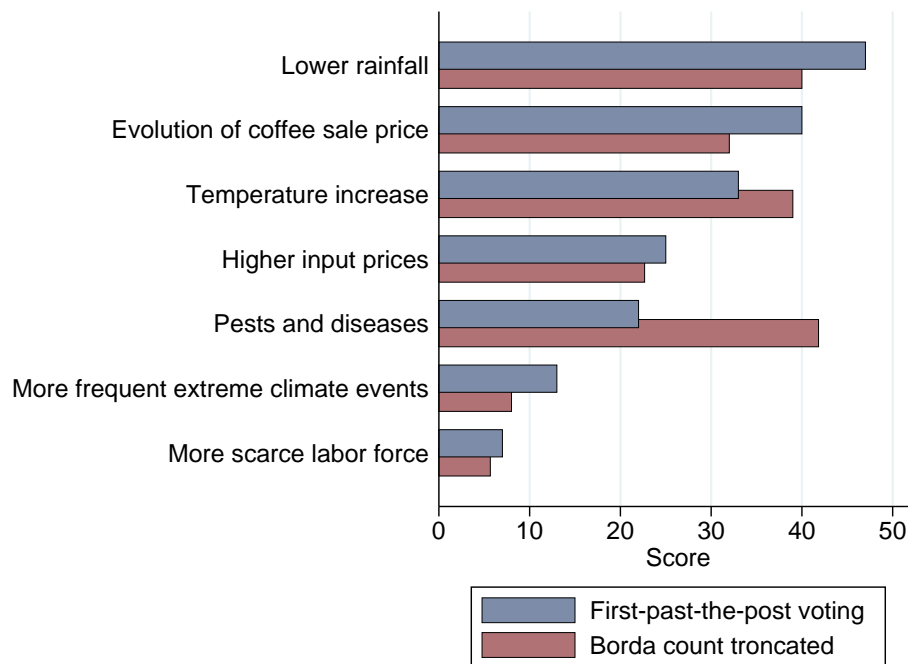
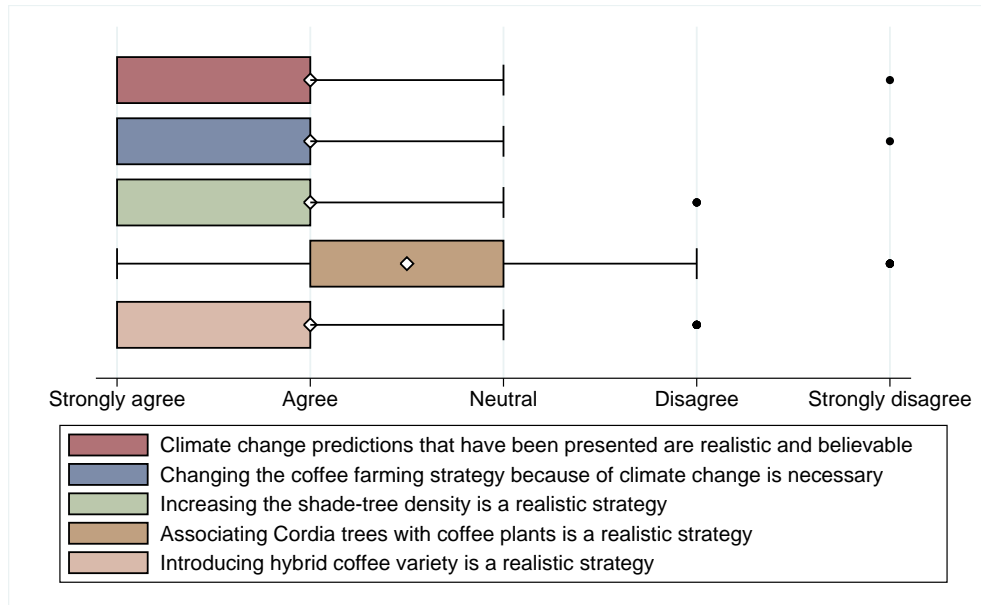


Figure 2.2: Sampled farmers' opinions regarding climate change and the adaptation of coffee farming



5 Choice experiment design

A discrete choice experiment was conducted in the second section of the questionnaire. It aims at eliciting respondents' preferences for the adaptive practices we describe in the Section 2, under various hypothetical incentive scheme. Its explanatory statement outlined that a national institution could offer various contracts in which a participant would implement a specific technical requirement in exchange of some rewards; the participant and institution would commit for five years, while the institution would carry out inspections to ensure the enforcement of the contract. The hypothetical contracts offered to the respondents in our CE combine five varying attributes: one attribute settles the technical requirement and four attributes compose the types and levels of the rewards a participant would get. The attributes and levels are displayed in Table 2.2. Table 2.3 gives an example of the choice tasks the respondents performed.

5.1 Adaptive strategies attributes

The four strategies from table 2.2 were defined to design an attribute for the technical requirement that is plausible and gradual *a priori*, as well as to limit cognitive burden for the respondents. Thus, we excluded the most unlikely combinations of adaptive practices and forced the hybrid coffee variety to be introduced jointly with at least one another practice in order to provide enhanced carbon capture and storage.

Table 2.2: Hypothetical contract attributes definition

Attribute variables	Definition
One technical requirement amongst:	
	This attribute mentions one exclusive strategy that a participant would have to implement on his/her coffee plantation (a part or the totality), of four possible required strategies. Each strategy is a combination of 1, 2 or 3 adaptive practices as follow: 1) shade tree density, 2) shade tree specie 3) and coffee variety.
<i>Strategy#1</i>	Double Current Current
<i>Strategy#2</i>	Current Cordia Current
<i>Strategy#3</i>	Double Current F1 hybrid
<i>Strategy#4</i>	Double Cordia F1 hybrid
From one to four rewards amongst:	
<i>Credit facility</i>	This attribute mentions if a participant would have access to a subsidized credit of 3,000,000 CRC maximum (approx. USD 5,650), per hectare enrolled in the contract (0/1).
<i>In-kind payment</i>	This attribute mentions if a participant would receive 200 F1 hybrid seedlings in the first year of the contract, per hectare enrolled in the contract (0/1).
<i>Technical assistance</i>	This attribute mentions if an agricultural engineer would visit the participants' farms twice during the contract length (0/1).
<i>Cash payment</i>	This attribute sets the amount to be received by a participant, per year and per hectare enrolled in the contract (8 amounts approx. from USD 0 to USD 163).

Note: Shaded texts highlight the adaptive practices we study; current practices were defined as Caturra and/or Catuai for coffee variety, grown under Erythrinas at 200 trees per hectare (see table 3.1).

Current practices were defined as Caturra and/or Catuai for coffee variety, grown under Erythrinas at 200 trees per hectare (see table 3.1).

Doubling shade tree density require a density of 400 trees per hectare if the tree specie is Erythrina (*Strategy#1* and *Strategy#3*), and 100 trees per hectare if it is Cordia (*Strategy#4*). In *Strategy#2* where the density of Cordias is at a current level, only 50 trees are required to meet the shade conditions of a current plantation with 200 Erythrinas, due to the larger foliage of a Cordia. These densities were referred to as the minimum levels a participant would have to implement, without any restriction on other tree species the participant would like to associate in the coffee plantations. F1 hybrids introduction (*Strategy#3* and *Strategy#4*) would require the most drastic change because a participant would have to rehabilitate all coffee plants at once at the beginning of the contract, whereas coffee farmers are used to replace each year only a share of their plants that the farmers select on the grounds of the plants' poor condition. Our concern was to ensure the feasibility of an inspection as the credibility of the enforcement would depend on. In response to the *a priori* high cost of imple-

mentation, a participant would be free to engage its coffee plantations either in whole or in part, so the experiment included a question asking the land area the respondent would engage in the preferred contract (see Table 2.3).

5.2 Rewards attributes

Regarding the rewards attributes, we chose to study a subsidized credit facility, an in-kind payment, technical assistance and a cash payment, following the hypothesis supported above in this Section according which the coffee farmers from the study site are likely to be constrained in their decision relative to technology adoption by imperfect information and inefficiencies on the markets of credit and inputs that are non traditionally used. We adapted the levels of each reward attribute to the adaptive practices we study.

The *Credit facility* attribute mentions if a participant would have access to a subsidized credit facility of USD 6,000 maximum, per hectare enrolled in the contract. The credit limit corresponds to an estimate of the costs a farmer would handle to renovate one hectare with hybrid seedlings. Respondents have been also informed about its fixed interest rate of 6% which were the Tasa Básica Pasiva² during the time of the survey. In addition, the credit facility would not require the subscriber to pledge any collateral or to repay the borrowed amount during the three first years, which correspond to the unproductive period of young coffee plants.

The *In-kind payment* attribute mentions if a participant would receive 200 F1 hybrid seedlings in the first year of the contract, per hectare enrolled in the contract. The hybrid seedlings would be delivered locally and would cover for a mean annual demand for seedlings to progressively replace old and unproductive coffee plants on one hectare.

The *Technical assistance* attribute mentions if an agricultural engineer would visit the participants' farms twice during the contract length, providing personalized support in matters of agricultural issues and contracts paperwork.

Regarding the *Cash payment* attribute, its sets one of 8 amounts which would be received by a participant, per year and per hectare enrolled in the contract (from 0 CRC to 87,500 CRC, approx. from USD 0 to USD 163). The range we used encompasses the cash payments offered to participate in the existing PES scheme covering the coffee sector³.

2. The Tasa Básica Pasiva of the Central Bank of Costa Rica is a weighted average of the rates applied by financial institutions for saving accounts in CRC. It is used as the base rate for calculating long term loans interest rates in Costa Rica (BCCR, 2008).

3. The FONAFIFO-MINAE *Programa de Pago por Servicios Ambientales* includes a category, namely Coffee Agroforestry Systems, to which coffee farmers with shaded plantations could apply. Each tree would yield around USD 1.7 per tree divided along the 5-year length of the contract, with a upper limit of 250 Cordias and 277 Erythrinas per hectare.

5.3 Design

A full factorial design of the attributes generates 288 ($4 \times 3^2 \times 8$) combinations, each being an alternative contract. We reduced the number of choice tasks submitted to the respondents following an efficient design using Bayesian priors. Based on orthogonality, level balance and minimum overlap, the design also balance the utilities of alternative contracts (Huber and Zwerina, 1996). Because no *a priori* values of the utility-parameters were available, the utility balance relied on priors that correspond to the assumptions that 1) the technical requirement attribute is related to a loss in utility compared to business as usual while getting any reward increases utility, 2) *Strategy#4* induces the greatest loss, following by *Strategy#3*, then *Strategy#2* and lastly *Strategy#1*, the utility loss being linear between them, 3) getting the *Credit facility*, the *Technical assistance* or the *In-kind payment* increases utility to the same extent that the maximum level of the *Cash payment* and 4) the sum of gains in utility induced by the midpoints of the 4 rewards attributes compensates for the loss in utility induced by the midpoint of the technical requirement attribute, such that the overall variation in utility is centered at zero. The uncertainty exhibited by the assumed priors were incorporated through the assumption that all priors have random (uniform) distributions rather than fixed values (Sándor and Wedel, 2001). The Bayesian D-error was approximated using quasi random Monte Carlo draws (Halton). Compared to an orthogonal design, this design improves the reliability of the estimates even using distorted estimates as priors, on the grounds of richer information generated when a choice task brings together 2 similar-utility alternatives in competition (Huber and Zwerina, 1996).

Each choice task included also an opt-out alternative, namely a *status quo* option, to ensure consistency with standard utility theory and thus avoid forced choices (Hanley, Mourato, and Wright, 2008). 2 blocks of 8 choice cards were generated, so that each respondent was asked to choose amongst two hypothetical contracts and a *status quo* option 8 times. Table 2.3 provides a selected choice card we used during the experiment. Illustrative logos were used. Each respondent was randomly assigned to one of the 2 blocks and the order of the choice cards within each block was also randomized between individual questionnaires.

From the 207 CE respondents, 11 skipped one of the eight choice cards they were assigned, or one of their choice cards were not filled in legibly. In addition, 2 respondents only answered to 1 of their choice cards. A total of 4893 observations were collected, being the 3 alternatives of 1631 choice cards.

6 Econometric framework and model specification

6.1 Mixed logit model

Mixed logit models (MXL), also known as random-parameter logit models, were used for the econometric analysis of the choice experiment. Using a logit specification, they model the probability that a decision-maker chooses one of several given alternatives, which depends on parameters that enter the decision-maker's utility func-

Table 2.3: Example of a choice card

	Option A	Option B	Option C
<i>Requirement</i>	Strategy#2	Strategy#1	
<i>Credit facility</i>	Yes	Yes	
<i>In-kind payment</i>	Yes	Yes	Neither option A, neither option B
<i>Technical assistance</i>	Yes	No	
<i>Cash payment</i>	37,500 CRC	37,500 CRC	
1. Which option would you prefer? (tick your choice)	[...]	[...]	[...]
2. If you prefer A or B, how much area would you sign up?			

tion. The utility-parameters hence captures marginal utilities of alternatives' modalities. Specifically, MXL estimate the extent to which decision-makers are heterogeneous in their preferences for alternatives' modalities, by specifying the "mixing" distribution of the utility-parameters over the population (Revelt and Train, 1998). If specified as randomly distributed, a utility-parameter on an alternative-specific explanatory variable gets two estimates: 1) a population mean and 2) a standard deviation of the population around that mean resulting from individual stochastic deviations.

Following Train (1998), the utility that a decision-maker n ($n \in \{1, \dots, N\}$) obtains from an alternative j ($j \in \{A, B, C\}$) in a choice situation T is:

$$U_{nj} = \beta'_n x_{nj} + \epsilon_{nj} = b' x_{nj} + \eta'_n x_{nj} + \epsilon_{nj} \quad (2.1)$$

where x_{nj} is a vector of observable explanatory variables that includes alternative-specific variables and individual characteristics, β'_n is the corresponding vector of utility-parameters for the decision-maker n , and ϵ_{nj} is a random term that represents the unobserved component of utility. β'_n can be decomposed as the sum of the vector of population means b' and the vector of his/her individual stochastic deviations η'_n ; it represents that decision-maker's taste.

A continuous density function of unobserved β_n which varies over the population of decision-makers can be denoted $f(\beta_n|\theta)$ where θ refers to the parameters of the distribution of β_n (such as its mean and covariance). Under the assumption that ϵ_{nj} is IID extreme value Type 1, the MXL probability that the decision-maker n chooses the alternative i in choice situation t is given by the integral of the logistic probability $L_{ni}(\beta_n)$ over all possible values of β_n , which is:

$$P_{ni}(\theta) = \int L_{ni}(\beta_n) f(\beta_n|\theta) d\beta_n = \int \frac{\exp^{\beta'_n x_{ni}}}{\sum_{j,j \neq i} \exp^{\beta'_n x_{nj}}} f(\beta_n|\theta) d\beta_n \quad (2.2)$$

Because our CE data has a panel structure with eight choice tasks for each sampled decision-maker, we need the probability of each decision-maker's sequence of choices. i becomes $\mathbf{i} = \{i_1, \dots, i_8\}$, a sequence of alternatives, one for each choice

situation t ($t \in \{1, \dots, 8\}$). Since we assume that the utility-parameters vary over decision-makers but are stable over the CE duration, resulting in $\epsilon_{n,jt}$ being independent over choice situations, the choice probability of sequence \mathbf{i} , $L_{nit}(\beta_n)$, is therefore a product of logistic probabilities, one for each choice task t . Once the functional form of $f(\cdot)$ is specified, the probabilities are approximated through simulation for any given value of θ , the maximum simulated likelihood estimator being the value of θ that maximizes the simulated log-likelihood.

6.2 Unobserved heterogeneity and correlation issues

When unobserved heterogeneity is a major threat to the assumption of IID random term of utility in multinomial logit models and thus can occasion spurious test results (Louviere, Hensher, and Swait, 2000; Train, 2009), MXL explicitly captures variance and correlations in unobservable factors through η_n entering the stochastic portion of utility which is $\eta_n'x_{n,jt} + \epsilon_{n,jt}$ (Revelt and Train, 1998).

First, we expect that there are some individual-specific or context-related factors that are unmeasurable and affect the utility obtained by a given alternative from our CE. In their typology of coffee farming systems in a part of Leon Cortes canton included in our study site, Meylan et al. (2013) characterize four groups different in their practices, using a small sample of 32 farmers and in spite of the apparent homogeneity of the agroecological system. According to other studies conducted in the study site, soil chemical properties of the plantations (Castro Tanzi et al., 2012; Bhattarai et al., 2017), as well as the degree of risk aversion and perceptions of income losses due to unpredictable climate extreme events differ strongly amongst the coffee farmers (Alpizar, Carlsson, and Naranjo, 2011). Their findings mean that some individual and/or local variations that are difficult to observe can be related to the decision-makers' past choices in farming practices (Meylan et al., 2013), as well as to their future choices of adaptation to climate change (Alpizar, Carlsson, and Naranjo, 2011). Hence the expected profitability corresponding to the adaptive strategies in our CE would likely depend on these random variations. As a consequence, there would be correlations in utility over alternatives when modeling the take-up of our CE alternatives with farming practices entering $x_{n,jt}$, violating the IID assumption in a multinomial logit model.

Because of the panel structure of our data, we also expect that these unobserved factors induce correlated errors across each of the decision-makers' repeated choices as mentioned by Hensher and Green (2003). A multinomial logit model could not again handle these correlations, whereas the modeling of individual heterogeneity η_n is present in all alternatives across all choice situations in a MXL. Considering decision-makers' intrinsic motivations regarding an environment valuation, Daniels and Hensher (2000) give some empirical evidence suggesting that in a MXL specification, serial correlation over the choice sequence made by each decision-maker may be negligible or absent.

Another correlation issue is expected in our empirical analysis because our CE alternatives include a set of several payments. Revelt and Train (1998) find that the sampled decision-makers who have large utility-parameters for rebates tend also to

have large utility-parameters for attractive financing. Such unobserved effects that are correlated amongst alternatives in a given choice situation can be handled in a MXL, because it allows for full correlation between the utility-parameters of each decision-maker (Hensher and Green, 2003). Scale heterogeneity, which is one source of correlation by which the utility-parameters of all variables are larger in magnitude for certain decision-makers than others, is also accounted for in a MXL with full correlation (Hess and Train, 2017).

In fact, MXL is found to approximate any choice model with any distribution of preferences, to any degree of accuracy depending on the choice of variables and mixing distribution (McFadden and Train, 2000). The following discusses the latter issue, presenting the final variables entering the MXL models we estimate along with the distributional specifications of their utility-parameters.

6.3 Empirical specification

The choice situation heterogeneity due to the inclusion of a *Status Quo* alternative is controlled in a nested logit approach, through an additional dummy variable coded 1 when the alternative is a contract and labeled *ASC*, namely alternative-specific constant (Train, 2009). The inclusion of the *ASC* intercept nevertheless gives rise to an identification problem because it simultaneously causes 1) the intercept being the mean effect of all unobserved factors on the utility of any contract, and 2) each of the dummy alternative-specific variables contrasting its utility-parameter with the intercept. Following Adamowicz, Louviere, and Williams (1994), we use effects-coding rather than dummy-coding to let the alternative-specific variables contrasting their utility-parameter with one of its level and thus avoid confounding their effects with *ASC*, with the exception of the continuous variable *Cash payment*. For each effects-coded variable, the reference level is assigned a value of -1, and the pivot value is zero. For instance, a hypothetical contract with no credit, no in-kind payment and no technical assistance offered has all rewards variables set at a -1 value and a *ASC* at 1, unlike a *Status Quo* alternative which has a zero value for each of these variables and thus its utility is normalized to zero. Regarding how the 4 mutually exclusive adaptive strategies enter the model, we let their effect to be non-linear in spite of our *a priori* order, using 3 effects-coded variables whose effects are interpreted relatively to the reference level being *Strategy#1*.

Therefore the MXL we estimate are specified such that the utility U_{njt} that the decision-maker n derived from alternative i in choice situation t takes the linear form:

$$U_{njt} = \beta_0 ASC_{njt} + \beta_2 Strategy\#2_{njt} + \beta_3 Strategy\#3_{njt} + \beta_4 Strategy\#4_{njt} \\ + \beta_5 Credit_{njt} + \beta_6 Inkind_{njt} + \beta_7 Assistance_{njt} + \beta_8 Cash_{njt} + \epsilon_{njt}$$

where all the β s are random and allowed to be correlated with each other over choice situations. β_0 to β_8 are free to take either sign, so they are given a normal distributions with mean and standard deviation that are estimated. The mean for the underlying β_1 associated to *Strategy#1* equals to $-(\beta_2 + \beta_3 + \beta_4)$ according to the effects-coding we apply.

7 Model results

Table 2.4: Mixel logit model estimates of discrete choice regarding each alternative

Attributes	MXL 1	
	Mean (S.E.)	St.Dev. (S.E.)
<i>Strategy#1</i> = Double shade	0.325 ^a	-
<i>Strategy#2</i> = Cordia	-0.306 (0.180)	1.040 (0.249)
<i>Strategy#3</i> = Double shade + Hybrid	0.396 (0.209)	1.457 (0.290)
<i>Strategy#4</i> = Double shade + Hybrid + Cordia	-0.515 (0.193)	1.171 (0.319)
<i>Credit facility</i>	0.555 (0.107)	0.816 (0.147)
<i>In-kind payment</i>	0.220 (0.080)	0.362 (0.189)
<i>Technical assistance</i>	0.302 (0.115)	0.397 (0.140)
<i>Cash payment</i> (scaled by 1/1,000 CRC)	0.013 (0.004)	0.022 (0.004)
<i>ASC (intercept)</i>	0.994 (0.384)	4.216 (0.453)
N observations	4893	
Simulated log likelihood	-1264	
Wald χ^2	63.27	***
BIC	2901	
AIC	2615	

Note: All variables but Cash payment are effects coded. 2000 Halton draws. Correlated random parameters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

^a: *Strategy#1* coefficient has been obtained by identification as $\beta_1 = -(\beta_2 + \beta_3 + \beta_4)$.

Results from a mixed logit model are presented in Table 2.4. The model includes the CE attribute variables and estimates their effects on the probability of an alternative to be chosen. It is specified as justified in Section 5. Similar results are obtained from other mixed logit models with marginal modifications in the specification and displayed for comparison in Appendix 2.1 and in Appendix 2.2.

7.1 Preference regarding adaptive strategies

Regarding the mean effects of the adaptive strategies we study, the results presented in Table 2.4 indicate that *Strategy#2* and *Strategy#4* significantly decrease the probability of a take-up, whereas *Strategy#3* significantly increases it, compared to *Strategy#1*. The mean utility-parameter of *Strategy#1* is positive, revealing that its effect is not associated with a lower take-up in the CE. When the reference level is switched as in the models in Appendix 2.2, results show that *Strategy#1* does not significantly change the mean choice probability. Furthermore, *Strategy#4* discourages an alternative choice significantly more than *Strategy#2* (see Appendix 2.2). The revealed differences in the expected utilities thus define the preference relations of the mean respondent for the adaptive strategies as $Strategy\#3 \succ Strategy\#1 \succ Strategy\#2 \succ Strategy\#4$.

Nevertheless, this preference relations correspond to the mean respondent, whereas the standard deviations are all significant and large, revealing very high heterogeneity in the estimated utility-parameters amongst respondents. From the model in Table 2.4, we observe that a large number of respondents have an opposite sign on their utility-parameters compared to the ones of the mean respondent, with 38% of the sample who associate a loss in expected utility from *Strategy#3* compared to *Strategy#1*, while 29% prefer *Strategy#2* rather than *Strategy#1*, and 27% prefer *Strategy#4* rather than *Strategy#1*.

Besides, the covariance matrices of the models in Appendix 2.2 include some relevant coefficients demonstrating that individual preferences for different attributes are correlated, and explaining the differences in estimates between the model in Table 2.4 and the restricted model with zero correlations in Appendix 2.1 (MXL 1.2). The correlation between the utility-parameters of *Strategy#1* and the ASC intercept is significant and large while being the only coefficient between adaptive strategies and ASC that is negative. It reflects that the more a respondent is inclined to choose the *Status Quo* option over any contract alternative, the more likely he/she expects a large gain in utility from *Strategy#1*. The opposite occurs on the preferences for *Strategy#3* and the ASC intercept, with a significant but positive correlation of their utility-parameters. This result indicates that a respondent who has a propensity to choose any contract alternative over the *Status Quo* option, expects a large gain in utility from *Strategy#3*. Furthermore, the covariance coefficients are significant and negative between the utility-parameters of *Strategy#1* and *Strategy#3* as well as between the ones of *Strategy#1* and *Strategy#4*. Accordingly, the respondents who have a strong taste for *Strategy#1* not only prefer the *Status Quo* option over any contract alternative, they also tend to associate a large loss in expected utility to both *Strategy#3* and *Strategy#4*. Knowing that all adaptive strategies are combining the same 3 practices, an underlying individual taste (or distaste) for hybrid introduction, which is the common requirement of *Strategy#3* and *Strategy#4* that is not shared with *Strategy#1*, may then drive both preferences for *Strategy#3* and *Strategy#4*, with *Strategy#1* mediating the relationship. Regarding the 2 other adaptive practices, we observe that the covariance coefficient between *Strategy#2* and *Strategy#4* is positive but not significant. Thus it does not capture any particular taste for Cordia tree

association. Similarly there is no salient taste for increasing the shade tree density which is a practice shared by *Strategy#1*, *Strategy#3* and *Strategy#4*.

7.2 Preference regarding rewards

The results show significant and positive utility-parameters estimated for the subsidized-credit facility, the in-kind payment, the technical assistance and the cash payment. Each reward increases the mean probability of a take-up compared to the same alternative without it offered, meaning that each one of them is related to a gain in expected utility so that it has the potential to compensate for a proportional loss. With the exception of the continuous cash payment, the mean preferences for the rewards can be ordered as *Credit facility* \succeq *Technical assistance* \succeq *In-kind payment*.

As for the adaptive strategies, the gains in expected utility associated with the rewards are very heterogeneous amongst respondents, with all standard deviations being significant and large. Unlike the mean respondent, the share of the sample who has a negative utility-parameter for *Credit facility* is 18%, 14% for *In-Kind payment*, 15% for *Technical assistance* and finally, 14% of the sample prefer not to have any cash payment rather than to be offered one. Such a distaste for a reward attribute can be found in other articles. For instance, several Ugandan female coffee farmers in the study by Meemken, Veettil, and Qaim (2017) value as a loss in utility an attribute offering them a credit. Studying the preferences of a sample of Tanzanian farmers, Kaczan, Swallow, and Adamowicz (2013) evidenced that for 21% of them, the mean utility-parameter is zero for an in-kind payment. In the study by Kuhfuss, Preget, and Thoyer (2014), 24% of the sampled French farmers have a negative mean utility-parameter for technical assistance and do not value a cash payment as a gain in utility. Espinosa-Goded, Barreiro-Hurlé, and Ruto (2010) found that 27% of their sample of Spanish farmers has a negative utility-parameter for a cash payment, and 15% of them dislike an attribute offering them more flexibility.

Regarding the covariance matrices in Appendix 2.2, we observe no significant coefficient between rewards utility-parameters. Hence it appears that there is no salient taste pattern in the sample that would make the distributions of the utility-parameters of two different rewards attributes correlated with each other. Accordingly, the fact that some respondents have a negative utility-parameter for one reward attribute does not imply that they are likely to have negative utility-parameters for another reward attribute. If we consider that higher values would be attached to a reward by farmers who are subject to the market constraint targeted, this therefore suggests that the potential market constraints among respondents are randomly distributed. Besides, some significant correlations between the utility-parameters of the rewards attributes and the ones of the adaptive strategies are worth mentioning. The utility-parameters of *Credit facility* are significantly and positively correlated with the utility-parameters of *Strategy#3*. Hence the stronger a respondent's taste for the subsidized-credit facility is, the larger gain from *Strategy#3* he/she expects. Conversely, there may be a negative correlation between the taste for the subsidized-credit facility and the utility-parameters of *Strategy#2*, due to a negative coefficient of which the significance ap-

pears to be sensitive to specification. Similar lack of robustness is found on the always positive coefficient between *In-kind payment* and *Strategy#3*.

7.3 Preference regarding Status Quo alternative

The mean utility-parameter of the *ASC* intercept is significant and positive in Table 2.4. The mean estimates for *ASC* captures the effect on the take-up of all the factors making an hypothetical contract with no attribute different from the *Status Quo* option. In Table 2.4 all rewards variables are effects-coded with the exception of *Cash payment*. In such specification, the adopter of a hypothetical contract with no reward suffer losses in expected utility that are equal to $-(\beta_5 + \beta_6 + \beta_7)$. It is worth noting that the mean value of the utility-parameters for *ASC* is very close to $(\beta_5 + \beta_6 + \beta_7)$ and become not significantly different from zero when the reward attributes are dummy-coded (see MXL 1.3 in Appendix 2.1). This suggests that the positive effect of *ASC* only corrects for losses in expected utility due to the coding scheme. We can thus conclude that the mean expected utility of an hypothetical contract with no attribute is not significantly different from the expected utility obtained under the *Status Quo* option. Put differently, there is no Status Quo bias detected for the mean respondent.

Results also show that the standard deviation of the utility-parameters of *ASC* is significant and very large. Indeed around half of the respondents associate a gain in expected utility to a hypothetical contract with no attribute compared to the *Status Quo* option, whereas the other half value more the *Status Quo* option than the hypothetical contract with no attribute. Also this result is not intuitive, it is quite standard in CE studies using a PES framework (Kaczan, Swallow, and Adamowicz, 2013; Jaeck and Lifran, 2014; Villanueva et al., 2015; Kuhfuss et al., 2016; Costedoat et al., 2016; Jaung et al., 2016; Meemken, Veettil, and Qaim, 2017).

This result can be explained in several ways. First, the CE method is based on hypothetical choice situations so that it could be subject to the yes-saying and/or social desirability bias which would lead the respondents to over-declare some contracts preferred over the *Status Quo* option, to an extent that would be heterogeneous amongst individuals.

Second, a positive effect of *ASC* could also arise from a demand for attributes that are fixed over the alternatives and not offered on the local market such that the *Status Quo* option reflects a second-best equilibrium (Teskaye and Brouwer, 2012; Cranford and Mourato, 2014). This is unlikely to be observed in our CE because the fixed attributes we used to frame the CE did not include any valuable good or service consistently offered in every contracts. Nevertheless, knowing that i) for the mean respondent the expected utility of a hypothetical contract with no attribute is similar to the expected utility procured by the *Status Quo* option, while ii) *Strategy#3* is associated with a net gain in expected utility iii) which is, in addition, positively correlated to the respondents' distaste for the *Status Quo* option, the model estimates lead to the conclusion that a hypothetical contract requiring the implementation of *Strategy#3* without any reward would be preferred by the mean respondent over the *Status Quo*. Accordingly, *Strategy#3* appears as a more profitable option than his/her

Status Quo. This result signals an unfilled demand for it and thus an inefficiency in local input market to provide the hybrid seedlings, such that farmers may fail to reach their potential.

Third, it may indicate that each respondent has anchored its *Status Quo* option with its current farming practices rather than with the farming practices that are optimal on a longer term⁴. On the same line, the utility-parameter for *ASC* may capture the difference in expected utility of each respondent's current practices against a common characteristics over the hypothetical contracts, namely the adaptation to global changes through agroforestry. A positive utility-parameter may thus signal that the respondent value his/her current practices as outperformed by any adaptive strategy, indicating a need to shift from current practices to an adaptive strategy, no matter which one of the four suggested in the CE.

7.4 Welfare changes associated with attributes

Given the utilitarian interpretation of the β s, the ratio of two β s is simply the marginal rate of substitution of one attribute for the other. The ratio of the parameter of an attribute over the parameter associated with *Cash payment* is therefore a measure of the marginal change in welfare of that attribute expressed as a monetary value, and usually called marginal willingness-to-pay (MWTP). Positive values indicates that the respondents value the attribute enough to trade an amount of money off for it, whereas negative values signal that the respondents would not willingly accept the attribute without some form of incentive. The simplest and most common approach to calculate MWTP is to rely on the mean on the random parameters. Using all of the information associated with the random parameter is preferable, such simulations can however generate larger confidence intervals. Due to the coding scheme of all attribute variables but *Cash payment*, the estimates obtained have to be doubled to get the whole MWTP, no matter the method used. Results from both methods are presented in Table 2.5.

The MWTP estimates indicate that respondents are willing to pay on average 75,837 CRC (USD 143) per hectare and per year to adopt *Strategy#3*. Conversely, they do not consider that *Strategy#2* would improve their welfare, such that its adoption requires a financial support of 46,740 CRC (USD 88) per hectare and per year on average. *Strategy#4* is much more unfavorable, with a MWTP at -78,718 CRC (USD -148) on average. Respondents are estimated to be willing to pay on average 84,926 CRC (USD 160) for the credit facility, 33,624 CRC (USD 63) for the free trial of resistant coffee seedlings, and 46,176 CRC (USD 87) for technical assistance, per hectare and per year. These amounts are all very large and could cover for the support required for *Strategy#2* and *Strategy#4* to be adopted.

4. A choice between an hypothetical contract and the *Status Quo* option is suppose to be driven by the difference in expected utility for a time horizon covering at least the 5 years of the contract duration and even longer if the respondents take into account the durable effect of the technical requirement on a perennial plantation.

Table 2.5: Mean marginal willingness to pay for attributes (in CRC)

	MWTP ^a	[95% C.I.]	Simulated MWTP ^b	[95% C.I.]
<i>Strategy#2</i>	-46,740	[-107,439; 13,958]	-46,740	[-141,692; 9,273]
<i>Strategy#3</i>	75,837	[-3,861; 155,535]	75,837	[11,702; 218,626]
<i>Strategy#4</i>	-78,718	[-128,920; -28,516]	-78,718	[-149,660; -26,848]
<i>Credit facility</i>	84,926	[30,525; 139,327]	84,926	[45,989; 196,973]
<i>In-kind payment</i>	33,624	[6,983; 60,265]	33,624	[9,806; 78,444]
<i>Technical assistance</i>	46,176	[14,206; 78,145]	46,176	[14,579; 91,831]

^a: Estimated via Delta method.

^b: Estimated via Krinsky-Robb method, 10,000 replications.

8 Conclusion

In this Chapter, we used primary data from a choice experiment carried out with 207 coffee farmers in Costa Rica, in order to study their willingness to adopt various agroforestry systems under various types of support. Based on the assumption that improving risk management within agroforestry systems could reduce the opportunity cost of adopting the technology, the agroforestry systems studied included resistant coffee varieties and/or timber trees, *a priori* attractive options as part of risk-coping strategies that may better fit within local farming contexts. Revealed preferences suggest that most of the respondents do value the introduction of resistant varieties. In particular, they are willing to plant twice the number of trees in their plantations when these are combined with resistant varieties. The farmers were found to be willing to adopt this agroforestry-based system. Conversely, all agroforestry systems requiring timber trees to be planted are chosen significantly less often and on average, their adoption would require a compensation scheme. This compensation may be explained by the high level of carbon sequestration associated with timber trees. Our result therefore suggest that the choice of the technological package to be promoted is a central point for the cost-efficiency of climate change policies based on incentives.

Concomitantly, the study investigated the potential of three incentives to trigger a decision to adapt to climate change through agroforestry: the use of a subsidized credit, a free trial of resistant coffee seedlings and technical assistance. The results moreover showed that a large majority of respondents attach large monetary values to a contract offering a cash payment, a subsidized credit, a free trial of resistant coffee plants or technical assistance. Results also indicate that respondents who display a strong taste for the agroforestry system that combines resistant varieties also tend to be very responsive to the credit offer. This suggests that the adoption of such systems may therefore require enhanced access to financing. We did not however find any correlation patterns between the preferences for the three incentives. Since a farmer with a strong preference for one reward will not systematically be included in the subset of farmers attaching a high value to another type of incentive, a larger pool

of PES participants would be expected under an intervention that combines several types of incentives.

Appendices

2.1 Sensitivity to alternative MXL specifications

		MXL 1.1	MXL 1.2	MXL 1.3	MXL1.4	MXL 1
Mean	<i>Strategy#1</i>	0.290 ^a	0.133 ^a	0.404 ^a	0.325 ^a	0.325 ^a
	<i>Strategy#2</i>	-0.299* (0.168)	-0.178 (0.160)	-0.321* (0.177)	-0.306* (0.174)	-0.306* (0.180)
	<i>Strategy#3</i>	0.431** (0.180)	0.342** (0.162)	0.457** (0.186)	0.496** (0.201)	0.496** (0.209)
	<i>Strategy#4</i>	-0.422** (0.185)	-0.297* (0.163)	-0.541*** (0.195)	-0.515*** (0.190)	-0.515*** (0.193)
	<i>Credit facility</i>	0.483** (0.096)	0.545*** (0.087)	1.060*** (0.207)	0.555*** (0.099)	0.555*** (0.107)
	<i>In-kind payment</i>	0.206*** (0.074)	0.231*** (0.069)	0.428*** (0.162)	0.220*** (0.077)	0.220*** (0.080)
	<i>Technical assistance</i>	0.271*** (0.100)	0.272*** (0.088)	0.661*** (0.220)	0.302*** (0.107)	0.302*** (0.115)
	<i>Cash payment</i>	0.111*** (0.003)	0.011*** (0.003)	0.014*** (0.004)	0.013*** (0.004)	0.013*** (0.004)
	ASC (intercept)	1.041** (0.431)	1.153*** (0.418)	-0.318 (0.463)	0.994** (0.398)	0.994*** (0.384)
St.Dev.	<i>Strategy#2</i>	1.049*** (0.200)	1.062*** (0.197)	1.021*** (0.240)	1.047*** (0.248)	1.040*** (0.249)
	<i>Strategy#3</i>	1.334*** (0.264)	1.307*** (0.224)	1.369*** (0.332)	1.529*** (0.318)	1.457*** (0.290)
	<i>Strategy#4</i>	0.997*** (0.198)	1.111*** (0.204)	1.130*** (0.248)	1.107*** (0.270)	1.171*** (0.319)
	<i>Credit facility</i>	0.694*** (0.124)	0.736*** (0.110)	1.527*** (0.242)	0.810*** (0.116)	0.816*** (0.147)
	<i>In-kind payment</i>	0.304** (0.123)	0.358*** (0.131)	0.761*** (0.230)	0.388*** (0.121)	0.362** (0.189)
	<i>Technical assistance</i>	0.318** (0.158)	0.316* (0.170)	1.017*** (0.338)	0.470*** (0.156)	0.397*** (0.140)
	<i>Cash payment</i>	- (0.003)	0.018*** (0.004)	0.019*** (0.004)	0.024*** (0.004)	0.022*** (0.004)
	ASC (intercept)	4.122*** (0.452)	4.216*** (0.453)	4.471*** (0.684)	4.693*** (0.567)	4.216*** (0.453)
	N observations	4893	4893	4893	4893	4893
	Simulated log likelihood	-1270	-1281	-1264	-1264	-1264
	Wald χ^2 (LR χ^2 in MXL 1.4)	59.42***	69.60***	63.00***	877.93***	63.27***
	BIC	2847	2699	2902	2901	2901
	AIC	2613	2595	2616	2615	2615
	Fixed parameters	<i>Cash payment</i>	None	None	None	None
	All parameters correlated	Yes	No	Yes	Yes	Yes
	Reward attributes coding	Effects	Effects	Dummies	Effects	Effects
	Robust S.E. correction	Yes	Yes	Yes	No	Yes

Note: 2000 Halton draws. Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
^a: *Strategy#1* coefficient has been obtained by identification as $\beta_1 = -(\beta_2 + \beta_3 + \beta_4)$.

2.2 Sensitivity to the reference level for Technical requirement

		MXL 1	MXL 2	MXL 3	MXL 4
Mean	<i>Strategy#1</i>	0.325 ^a	0.286	0.299	0.281
		-	(0.236)	(0.246)	(0.249)
	<i>Strategy#2</i>	-0.306*	-0.312 ^a	-0.309*	-0.320*
		(0.180)	-	(0.182)	(0.188)
	<i>Strategy#3</i>	0.496**	0.514***	0.500 ^a	0.505**
		(0.209)	(0.200)	-	(0.207)
	<i>Strategy#4</i>	-0.515***	-0.486**	-0.490**	-0.466 ^a
		(0.193)	(0.201)	(0.210)	-
	<i>Credit facility</i>	0.555***	0.525***	0.519***	0.513***
		(0.107)	(0.102)	(0.115)	(0.097)
	<i>In-kind payment</i>	0.220***	0.214***	0.222***	0.217***
		(0.080)	(0.075)	(0.086)	(0.077)
	<i>Technical assistance</i>	0.302***	0.297***	0.297**	0.293***
		(0.115)	(0.110)	(0.130)	(0.110)
<i>Cash payment</i>	0.013***	0.013***	0.013***	0.013***	
	(0.004)	(0.004)	(0.004)	(0.004)	
<i>ASC (intercept)</i>	0.994***	1.114***	1.049**	1.164***	
	(0.384)	(0.407)	(0.472)	(0.452)	
St.Dev.	<i>Strategy#1</i>	-	1.888***	1.945***	1.886***
		-	(0.407)	(0.448)	(0.363)
	<i>Strategy#2</i>	1.040***	-	0.944***	1.021***
		(0.249)	-	(0.269)	(0.231)
	<i>Strategy#3</i>	1.457***	1.417***	-	1.443***
		(0.290)	(0.297)	-	(0.296)
	<i>Strategy#4</i>	1.171***	1.061***	1.188***	-
		(0.319)	(0.335)	(0.299)	-
	<i>Credit facility</i>	0.816***	0.756***	0.796***	0.742***
		(0.147)	(0.112)	(0.157)	(0.126)
	<i>In-kind payment</i>	0.362**	0.350***	0.317**	0.347***
		(0.189)	(0.112)	(0.153)	(0.117)
	<i>Technical assistance</i>	0.397***	0.411***	0.401**	0.412***
		(0.140)	(0.126)	(0.166)	(0.150)
<i>Cash payment</i>	0.022***	0.021***	0.023***	0.022***	
	(0.004)	(0.004)	(0.006)	(0.005)	
<i>ASC (intercept)</i>	4.216***	4.660***	4.525***	4.609***	
	(0.453)	(0.548)	(0.557)	(0.550)	
N observations		4893	4893	4893	4893
Simulated log likelihood		-1264	-1264	-1265	-1265
Wald χ^2		63.27***	60.89***	41.60***	64.79***
BIC		2901	2901	2903	2902
AIC		2615	2615	2618	2616
Reference level for Technical requirement attribute	Strategy#1	Strategy#2	Strategy#3	Strategy#4	

Note: All variables but Cash payment are effects coded. 2000 Halton draws. Correlated random parameters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

^a: the reference level coefficient has been obtained by identification as $\beta_1 = -(\beta_2 + \beta_3 + \beta_4)$ for instance for *Strategy#1* coefficient in MXL 1.

Covariance matrices from Mixed logit models in the previous table

MXL 2								
	<i>Strategy#1</i>	<i>Strategy#3</i>	<i>Strategy#4</i>	<i>Credit facility</i>	<i>In-kind payment</i>	<i>Technical assistance</i>	<i>Cash payment</i>	<i>ASC</i>
<i>Strategy#1</i>	3.566** (1.537)							
<i>Strategy#3</i>	-1.344* (0.708)	2.009** (0.842)						
<i>Strategy#4</i>	-1.442* (0.870)	-0.008 (0.442)	1.126 (0.710)					
<i>Credit facility</i>	-0.373 (0.308)	0.777*** (0.246)	-0.082 (0.198)	0.571*** (0.178)				
<i>In-kind payment</i>	-0.110 (0.199)	0.286* (0.171)	0.021 (0.137)	-0.006 (0.082)	0.122 (0.078)			
<i>Technical assistance</i>	-0.231 (0.247)	0.260 (0.216)	0.049 (0.139)	0.100 (0.092)	0.060	0.169 (0.052)	(0.103)	
<i>Cash payment</i>	0.015 (0.013)	-0.007 (0.008)	-0.004 (0.007)	-0.003 (0.004)	0.001 (0.003)	0.004 (0.003)	0.000** (0.000)	
<i>ASC</i>	-4.660** (2.063)	2.234* (1.294)	1.185 (1.409)	0.911 (0.624)	0.213 (0.452)	0.288 (0.626)	-0.028 (0.626)	21.711 *** (5.106)

MXL 3

	<i>Strategy#1</i>	<i>Strategy#2</i>	<i>Strategy#4</i>	<i>Credit facility</i>	<i>In-kind payment</i>	<i>Technical assistance</i>	<i>Cash payment</i>	<i>ASC</i>
<i>Strategy#1</i>	3.784** (1.742)							
<i>Strategy#2</i>	-0.709 (0.542)		0.892*					
<i>Strategy#4</i>	-1.799* (1.052)	0.457 (0.349)		1.410**				
<i>Credit facility</i>	-0.212 (0.460)	-0.431* (0.226)	0.052 (0.264)	0.633** (0.249)				
<i>In-kind payment</i>	-0.215 (0.252)	-0.094 (0.125)	0.017 (0.234)	-0.038 (0.094)	0.100 (0.097)			
<i>Technical assistance</i>	-0.233 (0.267)	-0.080 (0.151)	-0.014 (0.160)	0.122 (0.147)	0.018 (0.076)	0.161 (0.133)		
<i>Cash payment</i>	0.017 (0.017)	-0.007 (0.005)	-0.010 (0.009)	-0.004 (0.006)	0.001 (0.004)	0.004 (0.003)	0.001* (0.000)	
<i>ASC</i>	-4.709** (2.377)	1.259 (1.273)	1.564 (1.706)	0.844 (0.727)	0.088 (0.457)	0.144 (0.591)	-0.035 (0.032)	20.476 *** (5.044)

MXL 4								
	<i>Strategy#1</i>	<i>Strategy#2</i>	<i>Strategy#3</i>	<i>Credit facility</i>	<i>In-kind payment</i>	<i>Technical assistance</i>	<i>Cash payment</i>	<i>ASC</i>
<i>Strategy#1</i>	3.557*** (1.370)							
<i>Strategy#2</i>	-0.619 (0.567)	1.043** (0.473)						
<i>Strategy#3</i>	-1.428* (0.742)	-0.754 (0.516)	3.083** (0.854)					
<i>Credit facility</i>	-0.358 (0.356)	-0.344 (0.213)	0.787*** (0.288)	0.551*** (0.187)				
<i>In-kind payment</i>	-0.066 (0.193)	-0.167 (0.120)	0.251 (0.208)	-0.010 (0.090)	0.120 (0.081)			
<i>Technical assistance</i>	-0.169 (0.271)	0.013 (0.138)	0.184 (0.208)	0.090 (0.101)	0.067 (0.073)	0.170 (0.124)		
<i>Cash payment</i>	0.155 (0.013)	-0.003 (0.004)	-0.010 (0.010)	0.120 (0.081)	0.002 (0.003)	0.005 (0.003)	0.000** 0.000	
<i>ASC</i>	-4.456** (2.045)	1.099 (1.243)	2.348* (1.214)	0.826 (0.642)	0.127 (0.464)	0.261 (0.611)	-0.028 (0.028)	21.245*** (5.068)

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Livestock farmers' investment in climate-smart agriculture: impact of a national program in Costa Rica

3

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Abstract

Unlike National governments in developed regions, tropical countries rarely use economic incentives to encourage the adoption of eco-friendly technologies by farmers. As a consequence, little knowledge of the potential use of such incentives to tackle climate change issues in agriculture in the developing world is available to date. This chapter aims at contributing to fill this gap by evaluating a rare incentive scheme of this kind in a tropical region, namely the Recognition for Environmental Benefits (RBA) program in Costa Rica. It focuses on cattle-ranching systems in the Northwestern province of Guanacaste. The study area is composed of extensive, undercapitalized and low-profitable cattle-ranching systems which also include substantial forested lands that are highly vulnerable to deforestation when the profitability of cattle ranching increases. Relying on a Difference-In-Difference approach applied to a random sample composed of 32 ranchers who participated in the early RBA phase and 31 future beneficiaries at the time of the data collection, this chapter provides estimates of the additional effect of participating into the RBA program on both the technology adoption and the land use patterns. The results suggest that the program has been effective in increasing the adoption of the promoted technologies, in both quantities and diversity. In addition, it has fostered the ecological intensification of cattle-ranching systems, by inducing a reduction in the land used to feed cattle and probably by increasing stocking density too, while also sparing land from being grazed and trampled by cattle. The findings reported are relevant in the discussion about the potential of agricultural intensification to jointly achieve adaptation, mitigation and food security challenges. They are also important because they show that, in one of the poorest Costa Rican provinces, a state-funded intervention has been effective in stimulating the mitigation potential of an activity often pointed out as a major source of greenhouse gas emissions.

Keywords: Payment for Environmental Services, Agri-environmental Policy, Climate Change, Impact evaluation, Livestock Farming, Costa Rica.

1 Introduction

National governments in temperate regions have been using economic incentives to transform chemical-intensive agricultural systems into eco-friendlier and organic systems since decades (Claassen, Cattaneo, and Johansson, 2008). Some flagship programs are the Environmental Quality Incentives Program (EQIP) in the United States of America (USA), the Agri-Environmental Measures (AEM) as part of the European Union Common Agricultural Policy and the National Action Plan for Salinity and Water Quality in Australia (Baylis et al., 2008; Hajkowicz, 2009). These incentives are usually in the form of direct cash payments conditional upon the voluntary adoption of the production technology specified in the contract signed by both the payer and the beneficiary, just as Payments for Environmental Services (PES) (Engel, Pagiola, and Wunder, 2008).

Empirical findings from impact evaluations suggest that such incentives have been effective in inducing changes in production technology that would not have occurred without payment, meaning that the additional effect of several aforementioned programs has been evidenced. Mezzatesta, Newburn, and Woodward (2013) found additional adoption of all the practices they studied in Ohio (filter strips, hayfield planting, cover crops, grid sampling, grass waterways, conservation tillage), albeit to different extents. Results in Claassen, Duquette, and Smith (2018) support these findings for twenty-six States of USA. Pufahl and Weiss (2009) found an additional effect in the purchase of agrochemicals in German farms. In France, Chabé-Ferret and Subervie (2013) also evidenced impacts in crop diversity, cover crops use and filter strips, the highest additionality being estimated in areas converted into organic farming. Depending on the European country where the beneficiary farm is, additional effects in crop diversity and chemical input expenditures have been evidenced by Arata and Sckokai (2016).

Overall, these studies highlight that such programs can stimulate agricultural transitions. Therefore, these incentives could be instrumental to tackle climate change issues in agriculture, by targeting technological changes towards both the mitigation of and the adaptation to climate changes. However, these evaluations also warn that additionality may be context-specific and depend on the technology promoted. The technology adoption literature has put forward evidence why the incentives effectiveness may be jeopardized if they are replicated in countries where markets are inefficient or the decision context more uncertain. Specifically, when information about the technology and future climate conditions is deficient, the profitability of the technology may be unknown by the potential beneficiaries. In Zambia, Ashraf, Jack, and Kamenica (2013) showed that households respond less to an economic incentive in the absence of information about the promoted technology. Also in Zambia, Jack et al. (2015) found that uncertainty in the adoption profitability limits self-selection of farmers into an incentive program and lowers the incentive effectivity.

In tropical and subtropical countries, these incentives for the adoption of eco-friendly technologies are rarely found. PES programs usually target water services, biodiversity conservation and climate change mitigation through reforestation and

avoided deforestation (Ezzine-de Blas et al., 2016). Some rare examples are the programs implemented by the World Agroforestry Centre (ICRAF) in Malawi and Zambia and studied by Jack (2013b) and Jack et al. (2015). In Latin America, the limited list includes the Lake Fúquene PES scheme in Colombia (Quintero and Otero, 2006) and the pilot projects implemented as part of the Regional Integrated Silvopastoral Ecosystem Management Project (RISEMP) funded by the Global Environment Facility (Pagiola et al., 2004, 2007). The only scheme of this kind designed and implemented at the national scale is the Costa Rican program of Recognition for Environmental Benefits (RBA for *Reconocimientos de Beneficios Ambientales* in Spanish) (MAG, 2011; Bonin et al., 2018). RBA program is a particularly significant case study because of its ambition of encouraging ecological transitions in all Costa Rican agricultural systems by promoting a wide array of productive assets (e.g. living fences and windbreaks, improved pastures, communal tree nurseries, composting infrastructures, renewable energy equipments). Furthermore, the dual role of the targeted technologies in fostering mitigation and adaptation have been acknowledged such that the State agricultural policy introduced the program in its strategy to tackle climate change issues in agricultural (SEPSA/MAG, 2011). Although the program implementation started in 2007, to date there are no studies evaluating the additionality of the program.

This chapter aims at contributing to fill this gap by determining whether the RBA program triggered additional adoption among beneficiaries instead of only rewarding adopters who would have adopted the promoted technology in the absence of the program. The study focuses on cattle-ranching systems in the Northwestern province of Guanacaste. On the one hand, the harsh climate conditions and pasture degradation are associated with extensive, undercapitalized and low-profitable systems which can barely feed one animal per hectare (CORFOGA, 2012). On the other hand, retained tree cover on farms, including privately-owned forests, is highly vulnerable to an increment in the profitability of livestock production due to higher beef prices and gain in productivity (Kaimowitz and Angelsen, 2008; Calvo-Alvarado et al., 2009). In 2014, we collected original data from 32 ranchers who participated in the RBA program between 2007 and 2012 and from 31 ranchers who were not participant at the time of the survey but became participants afterwards. We use the Difference-In-Difference approach to estimate the impact of the RBA program on both technology adoption and land use patterns among early participants, using the future-participants as a comparison group.

Regarding the additionality in the technology adoption, the estimates suggest that the program has encouraged participants to both increase the aggregated quantities and diversity of assets that are eligible to RBA. Regarding the additionality in various land use indicators, the results do not exhibit any changes attributed to the participation into the program that can increase the vulnerability of forest patches to deforestation. Instead, they tend to confirm that RBA program has been effective in fostering the ecological intensification of cattle-ranching systems, by inducing a reduction in the land used to feed cattle and probably in increasing stocking density too, while also sparing land from being grazed and trampled by cattle. As a result, the participation into RBA program has translated into technological changes apparently

in favor of a higher resilience to climate hazards and also in favor of larger spared farmland for carbon sequestration through natural regeneration of forests.

These results are relevant in the discussion about the potential of agricultural intensification to jointly achieve adaptation, mitigation and food security challenges, whereas all objectives may be competing for land and resources (Burney, Davis, and Lobell, 2010; Bellassen et al., 2010; Lobell, Baldos, and Hertel, 2013). In particular for the livestock sector, these findings are of interest since increased efficiency in beef production combined with conversion from released pasture to forest can provide a sizable and cost-effective portion of the mitigation effort required to limit warming to below 2°C (Havlík et al., 2014; Griscom et al., 2017).

The rest of the chapter is organized as follows. Section 2 details the RBA program. Section 3 presents the study area and the specific features associated to the program implementation in the livestock sector. Section 4 describes the data used in the study and provides balancing checks. In Section 5, the identification strategy is discussed. Results of estimations are presented in Section 6, jointly with checks for robustness and main assumptions. Section 7 concludes.

2 RBA program

2.1 Program origins and scope

The appearance of institutional initiatives for Costa Rican agricultural sector merging both the production-oriented vision and the imperative of sustainability dates from the 1990s, after a decade of Green Revolution. Several pilot projects emerged on topics such as soil and water conservation, supported in particular by CATIE expertise (Tropical Agricultural Research and Higher Education Center) and funding facilities from Dutch cooperation. Based on these previous experiences, the extension services of the Ministry of Agriculture and Livestock were able to compile in 2000 a list of farm assets supposed to lead to a better productivity and to a better soil and water quality, as well as easily implementable for small and medium producers in most agricultural and livestock sectors (EPYPSA, 2010).

Over a first phase, this asset list founded the first and main component included in Ministry of Agriculture and Livestock (MAG)'s Program for promoting sustainable agricultural production (PFPAS for *Programa de Fomento de la Producción Agropecuaria Sostenible* in Spanish). Funded by a loan from the Inter-American Development Bank (IADB) signed in 2003, PFPAS was one of the first programs that integrate the notion of sustainable agriculture into the national agricultural agenda (Durey, 2010). It aimed at increasing competitiveness in small and medium conventional farms through assets that generate sustainable opportunities to improve productivity, while stimulating the provision of external environmental benefits (EPYPSA, 2010; MAG, 2011). Its normative framework explicitly named investments toward adaptation to and mitigation of climate change as an intermediate outcome (MAG, 2010).

First called “productive projects”, then “sustainable production projects” and from 2008 onwards, “recognition for environmental benefits” (RBA), the first PF-

PAS component has been operative from mid-2007. It has disbursed USD 6 millions in conditional cash transfers to more than 18,000 beneficiary families, equivalent to 58,000 farm hectares, until the extended time-period of the Inter-American Development Bank (IDB) loan expired in 2010 (EPYPSA, 2010; MAG, 2011). Then MAG decided to give continuity to the first PFPAS component, funding it from its regular budget and integrating it in the State agricultural policy for 2021 (SEPSA/MAG, 2011). In particular, for 2015-2018 RBA program was referred to as one of the strategic policy instruments while addressing the issue of adaptation to and mitigation of climate change in agriculture (SEPSA/MAG, 2015). For the second phase, its design has remained similar to before whereas the annual budget has dropped and the program scale has been reduced to three sectors, namely coffee, sugarcane and livestock productions.

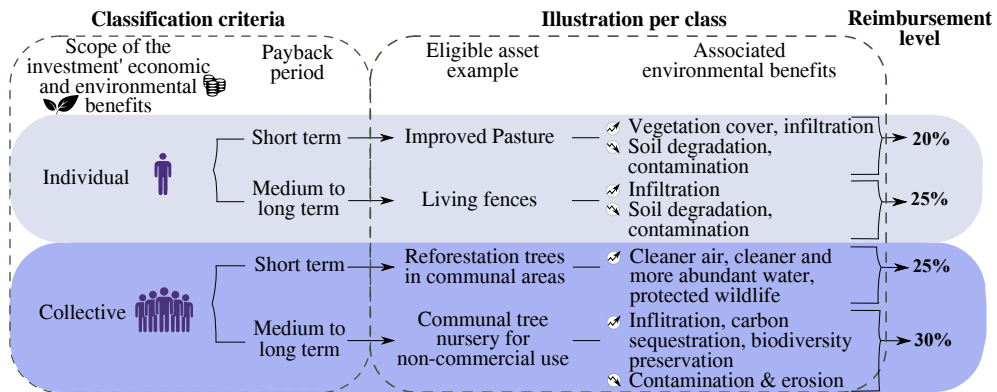
2.2 Description of the program

RBA program is based on a list of eligible farm assets that have been recommended by MAG extension services, according to the program double-aim (profitability and positive environmental impact) and its feasibility (availability and appropriability for small and medium producers, controllability). This heterogeneous list is composed of 81 assets, which are mainly specific to one commodity chain stage, from preproduction to commercialization. The list includes a majority of physical capital (animal traction equipment and infrastructure for residue recycling for example) but also some biological assets (shade trees in coffee plantations, fodder shrubs), some agricultural inputs (amendments to correct soil contamination problems) and even intangible assets (soil analysis) (MAG, 2010).

These eligible assets have been classified as schematized in Figure 3.1. The first classification criterion meets an economic rationale about the level of positive externalities produced by the required investment: the more collective the scope of the investment is, the more substantial its external effect is. Whereas the externality increments social welfare, the farmer's optimization process is assumed to not consider it. Four asset types result from this criterion combined with the payback period. Three RBA levels are associated to the types: 20, 25 and 30% correspond to the percentage of the investment cost (excluding labor cost) that MAG estimated as the amount that the program has to reimburse to the adopters with regard to the environmental benefit generated.

Following La Gaceta (2008), the operative rules to become a RBA beneficiary imply a collective, voluntary and multistage process. A RBA project arises from an initiative from a small and medium producers' organization and the local MAG extension service, i) either to invest in at least one eligible asset which benefits a collective production process (at the coffee processing stage for example), ii) or to gather several farm plans realized by some members of the producer organization assisted by local MAG technicians and picturing a future investment in one or several eligible assets (at the stage of the coffee plantation management for example), iii) or to plan various investments at both scales. In the three cases, participants in RBA program are voluntary. If the project proposal reaches some administrative requirements, an

Figure 3.1: Assets classification in RBA program: different reimbursement levels according to the scope and payback period of the investment



Source: MAG (2010)

agreement is signed between the producer organization and the Program Coordination Unit: it includes all the beneficiaries' names (the producer organization and/or the applying members), the eligible assets and the quantities in which each one has planned to invest, the estimated unitary investment cost and the RBA subsidy level applied to each asset according to the program classification.

During the following year, two or three MAG technicians realize at least two control visits to assess the realization rate of the project for each participant entity and each asset. Even if the technical assessments notify of the resulted individual RBA payment that each participant entity should receive, RBA program transfers the total amount to the producer organization in most of cases. Then, the producer organization reallocates it according to a clause of the previous agreement.

There is no eligibility criteria *per se* to select participants, except their membership to one of the 830 small and medium producers' organizations of the country (cooperatives, associations, chambers, local agriculture centers or certain companies) which defines as potential participants approximately 40,000 smallholders (de la Espriella and Bolaños Rojas, 2003). The law project expounded that 200,000 people could be affected by RBA program (de la Espriella and Bolaños Rojas, 2003), which corresponds to a seventh of the rural population in Costa Rica in 2003 (INEC, 2003). Even if theoretically RBA program is offered nationwide, the law project mentioned three priority regions (Guanacaste, Brunca and Huetar Norte) where RBA program planned to allocate 75% of its funds due to the high rate of rural poverty in these regions (de la Espriella and Bolaños Rojas, 2003).

3 Context

3.1 Guanacaste

Location

Situated in the Northwestern province of Guanacaste, the study site includes five neighboring cantons in the Tempisque basin for a total area of around 5,000 km². Particularly prone to severe drought, the “dry Pacific” province reported millions of dollars in income losses induced by the El Niño episodes in 1997-1998 and in 2015-2016 due to the effect of rainfall deficits of 60-80% on agriculture and livestock productions (MIDEPLAN/MAG, 2018; MAG, 2017). Climate changes are expected to make semiarid conditions become the norm in the study site, with precipitations expected to fall from 1500-2000 mm per year historically to 500-1000 mm per year by 2080s (IMN/MINAET, 2012). Recently, local social conflicts have been emerging as a consequence of strong rival demands for the resource from local communities and activities facing water scarcity and its contamination (MAG, 2017). Beach tourism booming since 2002 is involved not only by appropriating water but also by generating negative socioeconomic spillovers on local population as illustrated by the rise of prices for land, goods and services (Navas and Cuvi, 2015).

Guanacaste is a rural region where one third of the population lives under the poverty line. The incidence of extreme poverty is the highest in the country and represents almost three times the corresponding rate of the capital region (INEC, 2014a). The agriculture and livestock sectors are a major employer and their production plays a substantial part when considering food security and export issues in Costa Rica (SEPSA/MAG, 2014; MAG, 2017). Introduced by the first Spanish colonists arrived (Edelman, 1985), cattle ranching stands as the emblematic and still important economic activity of the region associated with cultural traditions in which livestock and land convey prestige.

Historical background

For several centuries, the extensive *Hacienda* system has dominated the Tempisque basin and shaped the agrarian landscape with abundant natural treeless grassland reclaimed mostly from prevailing savannah. Due to the long dry season, the success of a *Hacienda* depended on possessing large and diversified grazing areas, and burning techniques were facilitated for maintenance (Edelman, 1985). Pasture land were open such that wild and semi-domesticated herds, as well as transhumant beef cattle from Nicaragua could move freely in search of greener pastures (Edelman, 1985). From the late nineteenth century, the production technology slightly intensified through the improvement of some selected grazing areas by sowing more productive and resistant grass species, the introduction of heat-tolerant breed and the enclosure of pastures with barbed-wire fence (Edelman, 1985). This first wave of technological change was modest, since landholders investment capacity mainly relied on the herd's natural growth rate and the extensive system resulted in low fertility and high calf mortality (Edelman, 1985; Kaimowitz, 1996). Squatting and resistance

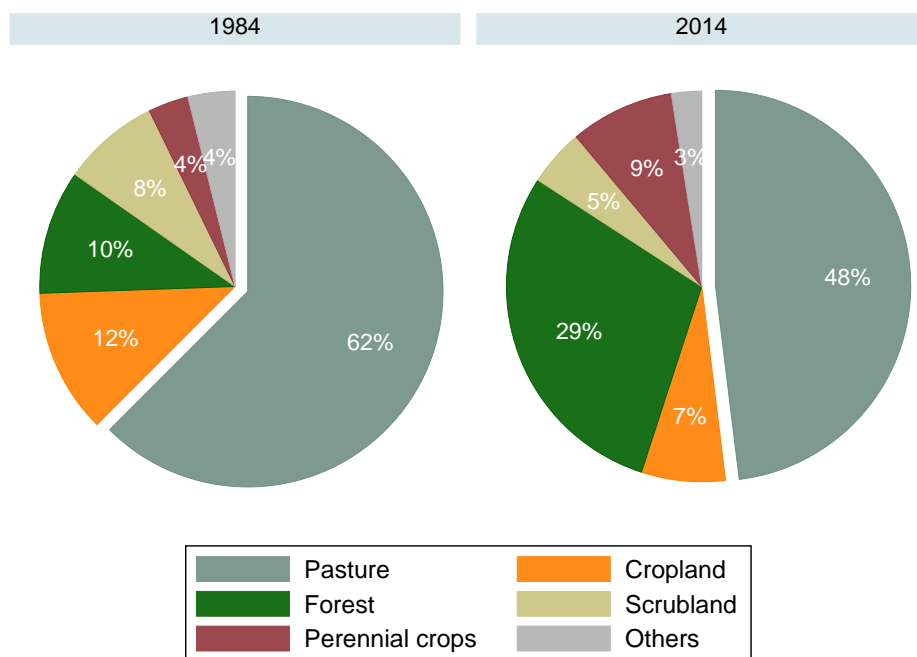
from local peasants were also involved in slowing the modernization process but faded away by the effect of land entitlement policies and the appearance of labor surplus after the 1930s Depression (Edelman, 1985).

From 1950s to 1970s, the livestock sector in Guanacaste has experienced an unprecedented expansion as it is incorporated into the international market after the price peak following the opening of beef exports to the United States (Calvo-Alvarado et al., 2009). The size of the national cattle herd tripled between 1950 and 1972, while in Guanacaste most of the tropical dry forests have been rapidly cleared and land under subsistence agriculture converted to pasture (Calvo-Alvarado et al., 2009). Land pressure together with titling process lead to some changes in tenure pattern characterized on the one hand by the fragmentation of *Haciendas* after selling plots or between family members, and on the other hand by the settlement of some small and medium holders supported by agrarian reforms embodied by the National Institute for Agrarian Development (IDA, former ITCO) (Edelman, 1985). The Guanacaste Chamber of ranchers was established in 1953 and gained political power (Kaimowitz, 1996). Concomitantly international agencies started promoting beef production for exports in Central America through large targeted loans (Kaimowitz, 1996). As a result, the Costa Rican State which was yet engaged in major transportation infrastructure projects in Guanacaste also intervened by providing subsidized credit for livestock farming, research and technical assistance, animal health services and slaughterhouses (Kaimowitz, 1996). Together with high sale prices and land security less uncertain, subsidized credit made farm investments and input use possible and attractive. As a consequence, the innovations appeared in the previous wave (improved pastures, improve breeds and fences) were widely incorporated into the production technology and accompanied with artificial insemination, use of veterinary inputs, fertilizers and herbicides, as well as ponds and wells construction (Kaimowitz, 1996). Weight gain was significantly faster and mortality rates reduced, still the improvement in stocking densities was minimal (Kaimowitz, 1996).

Since the mid-1970s onwards, market conditions for Guanacastecan beef production have been worsening and in the early 1980s Costa Rica faced its worst economic crisis since 1930s. While beef price was decreasing and government support falling, land and input prices as well as labor costs have increased resulting in outstanding arrears of cattle ranchers on credit repayment and technological regression (Kaimowitz, 1996). The contraction of the sector is materialized by the decline of the number of livestock farms and cattle population, with farm distributions clustering around medium areas and held sizes, and dairy and dual-purpose systems (producing milk and calves) gaining ground in Guanacaste (DGEC, 1984; Kaimowitz, 1996; Ibrahim, Abarca, and Flores, 2000; INEC, 2014a). Land uses in Guanacastecan farms have considerably changed as shown in Figure 3.2. Forest recovery clearly emerged as pasture land was transformed into timber or fruit plantations or abandoned and replaced by scrubland and then naturally regenerated forest. Concomitantly, conservation policies were implemented, including the 1996 Forest Law introducing restrictions (a permit system) and incentives (a payment for environmental services known as PSA-FONAFIFO) regarding forest cover on private land (Calvo-Alvarado et al., 2009). Cattle ranchers are nowadays the private owners of a substantial share of

Guanacastecan forest.

Figure 3.2: Land allocation between land uses over all farms from Guanacaste, 1984 and 2014



Source: DGEC (1984); INEC (2014a)

3.2 Specific features of RBA program

Current issues tackled by RBA program in respect to the livestock sector ensue from these historical trends explaining why extensive, undercapitalized and low-profitable systems still predominate in Guanacaste. First, productivity is low especially when considering the land use efficiency in cattle farms. The very low stocking density reported for the province shows that one hectare of pasture is far from feeding one animal (CORFOGA, 2012) and common practices during the dry season consist in moving the herds to rented summer pastures as well as buying fodder. It also reflects the observed high pasture degradation due to soil compaction, erosion and soil nutrient depletion (Ibrahim, Abarca, and Flores, 2000).

Secondly, the management of water resources and tree cover on the farm is poor. Reduced groundwater recharge and vanished water springs have been related with farming systems (MAG/MINAE, 1995; Ibrahim, Abarca, and Flores, 2000). Moreover, three Guanacastecan cattle farms over four do not make any effort to treat livestock manure (INEC, 2014a) which leads to the deterioration of water quality in the watershed as well as methane and nitrous oxide emissions. With regard to the tree

component in the system, farmers consider it for its commercial or use value as fence (as standing living trees or cut into wooden posts), timber, firewood as well as forage, but are unaware of some ecological services provided to the farm except shade for cattle to some extent (MAG/MINAE, 1995; Muñoz et al., 2003). As an illustration, Restrepo Sáenz et al. (2004) even found evidence of substitutability between trees in pastures and ones from private forests. The outlook does not seem to be on a positive track, with on the one hand limited regeneration of dispersed trees in pastures because of herbicides use, cattle grazing and trampling, and burning techniques (Harvey et al., 2011) and on the other hand, retained tree cover including forest is highly vulnerable to increase in demand for wood products (Villanueva et al., 2003) and to any increment in the profitability of cattle ranching including higher beef prices (Calvo-Alvarado et al., 2009) and gain in productivity (Kaimowitz and Angelsen, 2008).

Eligible assets for cattle ranching in RBA program are consistent with the overall objective of intensifying farming systems jointly with protecting water and tree cover (Ibrahim, Abarca, and Flores, 2000; Pagiola et al., 2004; Bonin et al., 2018). They represent technological packages setting a transition pattern to ecologically intensified systems including:

- silvopastoralism (dispersed trees in pasture, living fences, windbreaks),
- pasture rotation (living and electric fences, sheds, feeders, drinking troughs and pipes),
- improved feeding and water access (improved pastures, fertigation systems, fodder banks, harvesting equipment, fodder storage facilities, feeders, drinking troughs and pipes),
- enhanced value adding from byproducts and natural resources (compost piles, biodigesters, wind pumps, wind turbines, solar panels),
- and areas with high ecological value and vulnerability protected from grazing and trampling (living fences or reforestation for water sources, streams and ravines, drinking troughs and pipes, improved farm roads).

Furthermore, all the eligible assets imply to be implemented at the scale of an individual farm. The revision of past RBA projects implemented in the study site confirms that no collective investments were financed by the program meaning that the beneficiaries were exclusively individual ranchers.

4 Data

4.1 Sample

Our analysis relies on one survey that was conducted in 2014, few weeks after the Program Coordination Unit approved the 2013 project. The questionnaire includes a large set of variables that were constructed from recall-type questions. These variables are related to a pre-program year (2006), as well as to the year 2012. In order to foster respondents' remembrance and collect data on land uses and their reorganization, our questionnaire included a detail sketch of all land plots occupied for farming purposes in 2006 together with all changes operated until 2012 included, so that the

final sketch pictures land uses back in 2012. Following sections described farming practices, capital and sources of income and financing for 2006 and 2012 as well as on household's social characteristics and proximity with the local MAG agency and ranchers' organization.

Assisted by two enumerators, we collected data on 63 farms in the study site. 32 of them were randomly selected from a population of 222 ranchers identified from approved 2007-2012 projects. The other 31 were randomly selected from the 122 new entrants listed in the 2013 project after stratifying per canton.

4.2 Comparison of ranchers between sampled groups

Table 3.1 reports descriptive statistics from survey data and results of balancing tests for difference in means between the two groups of sampled ranchers. Results on general ranchers' characteristics suggest that the two groups are well-balanced in time-constant observables with no difference in means being significant.

Regarding the time-constant and pre-treatment observables that we consider as potential determinants of the inclusion into the group of 2007-2012 participants, their differences unsurprisingly appear to support the claim that RBA program was first offered to the ranchers in a closer relation with the ranchers' association and MAG agency. Most of them do not exhibit a significant difference in means between groups, still participants in 2007-2012 projects were found to require significantly less time to commute from their house to the ranchers' association and to have a more frequent attendance to the meetings of the association, compared to 2013 project participants. This unbalance is confirmed by a difference in distributions for the attendance to the meetings once compared with its standard deviations using the Kolmogorov-Smirnov test (D-statistic at 0.30 with a p-value at 0.08). The tests for difference in means also show that dairy farms in 2006 were more represented in the group of 2007-2012 participants than in the group of 2013 participants which can be also explained by historical political movements in some ranchers organizations. Regarding the total land area owned in 2006, means are also found to be significantly different between groups. Appendix 3.1 displays the results of probit regressions of the inclusion in the 2007-2012 projects group on the suspected determinants of the treatment. Probit estimates corroborate that commuting time, attendance to the association's meetings, the fact that the farm was exploited under a dairy system in 2006, total land area owned in 2006, the fact that the farm was inherited as well as an index for home assets in 2006 all affect the probability of treatment. They correctly predict the repartition between groups for almost three quarters of the ranchers which corresponds to a higher overall prediction accuracy than assuming random assignment.

Table 3.1 also reports the test results for the difference in means of exogeneous changes occurred between 2006 and 2012 that can drive variations in household finances over time. Whereas the pre-treatment comparison does not show a significant difference in means for the number of household's members working off-farm (difference at -0.15 with a standard error at 0.21), the variable differential over the period is significantly higher in the 2013 project group than in the 2007-2012 projects group. The other change that is significantly different in means between groups is

Table 3.1: Comparison of ranchers' characteristics by groups

	(1)		(2)		(3)	
	2007-2012 projects		2013 project		Difference (1)-(2)	
	Mean	(St.Dev.)	Mean	(St.Dev.)	Mean	(S.E.)
<i>Participant characteristics in 2006</i>						
Female participant (%)	12.5		12.9		-0.40	(8.52)
Age (years)	58.5	(13.1)	55.2	(12.6)	3.31	(3.25)
Schooling years (years)	8.3	(4.5)	8.3	(4.3)	0.01	(1.10)
First year of operations on the farm	1994	(12.9)	1993	(14.0)	0.91	(3.39)
Household's members (number)	3.5	(1.4)	4.0	(2.3)	-0.53	(0.47)
Credit for production received in 2006 or before (%)	25		13		12.10	(9.94)
<i>Potential determinants of participation</i>						
Time to commute to the ranchers' association (min)	27.5	(29.1)	48.4	(61.0)	-20.89	(11.99)*
Attendance to the last ten meetings of the ranchers' association (number)	6.9	(3.2)	5.1	(4.0)	1.84	(0.91)**
Member of the ranchers' association in 2006 (%)	59.4		45.2		14.21	(12.66)
Family member in charge at MAG or at the ranchers' association (%)	43.8		29.0		14.71	(13.01)
Technical assistance received from MAG (%)	68.8		54.9		13.91	(12.31)
PSA-FONAFIFO received in 2006 or before (%)	6.3		9.7		-3.43	(6.91)
Farm acquired by inheritance or from a relative (%)	40.6		54.8		-14.21	(12.66)
Farm acquired from the agrarian institute (%)	12.5		9.7		2.82	(8.04)
Dairy system exploited on the farm in 2006 (%)	31.2		9.7		21.57	(9.99)**
Total land area owned in 2006 (Ha)	29.5	(30.2)	63.1	(93.9)	-33.56	(17.47)*
Stocking density in 2006 (Livestock Units/Ha of grazing area)	1.2	(1.2)	0.9	(0.8)	0.29	(0.26)
Home assets index in 2006	33.5	(16.9)	38.3	(21.4)	4.74	(4.84)
<i>Changes in household finances between 2006 and 2012</i>						
Δ 12 to 60-year old household's members (number)	-0.38	(1.3)	-0.03	(1.7)	-0.34	(0.37)
Δ household's members working off-farm (number)	-0.06	(0.5)	0.26	(0.8)	-0.32	(0.16)*
Δ public aid received (-1/0/1)	0.09		0.19		0.10	(0.09)
Change in farming system exploited on the farm (%)	3.1		16.1		13.00	(7.33)*

° (p<0.15), * (p<0.1), ** (p<0.05), *** (p <0.01) for significance of difference in means in column (3).

No significant difference for continuous variables according to the Kolmogorov-Smirnov test for equality of distributions except for meeting attendance for which the equality of distributions is rejected at 10% level.

related to the farm system exploited on the farm. This result is likely to be caused by the aforementioned pre-treatment difference in the sample share represented by dairy farms, since in 2006 around one 2007-2012 participant over three has a dairy farm and that no dairy farm in the whole sample changed for another ranching system. Most reported system changes consist in less demanding conversions between beef and dual-purpose (producing milk and calves) systems. In addition, these changes are considered exogenous because they were clearly linked to international beef price fluctuations as described in Section 3. Other potential sources of income variations were explored such as land sale, land and machinery renting as well as remittances, but we identify them as marginal in our sample (5% or less of the whole sample).

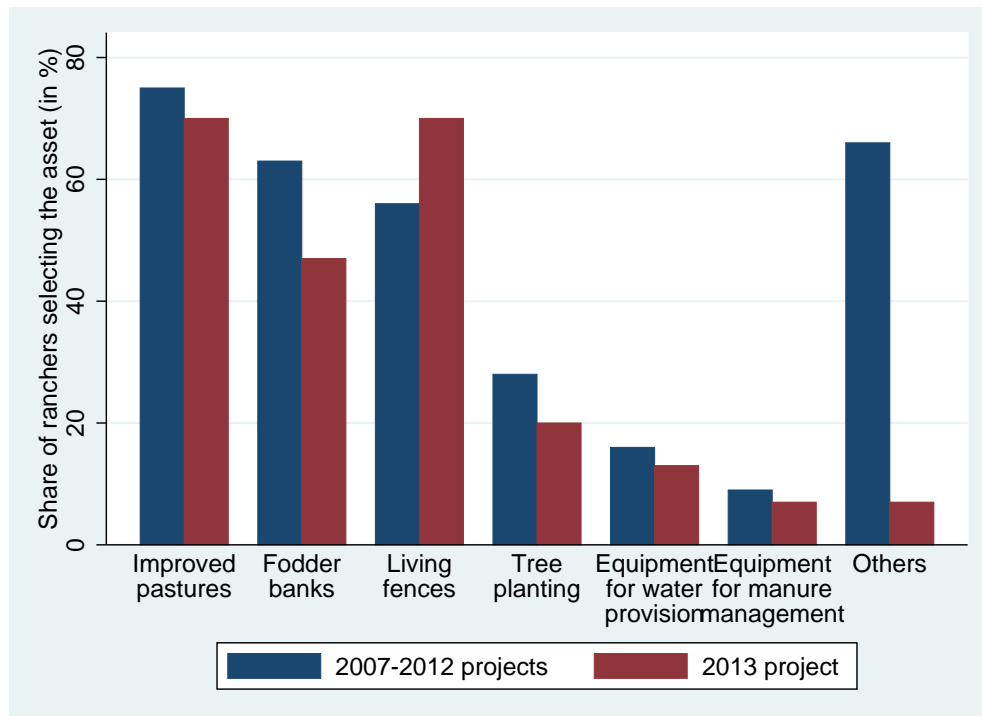
4.3 Outcome variables for eligible assets adoption

Furthermore, in order to explore the composition of the two sampled groups, we also rely on the applicants' investment plans described in RBA projects and identify the eligible assets in which the sampled ranchers have planned to invest. Since half of the sampled ranchers from 2007-2012 projects have participated in two or three RBA projects from 2007 to 2013 included, we select only the plans corresponding to their earliest application. Each plan is composed in average of three different eligible assets. Figure 3.3 displays the shares of applying ranchers by assets or asset categories, according to the year of their first participation.

It shows that the most popular assets in both groups are the improved pastures, fodder banks and living fences for which at least half of the ranchers in both groups applied. This combination is relevant because it brings out underlying ranchers' priorities related to overgrazing issues shared in both groups. From Figure 3.3, we can also notice the balance between groups in the proportions of applicants for assets oriented toward improvements in the tree component (dispersed trees in pastures and reforestation of riparian areas) as well as in the water provision (reservoirs and pumps) and manure management (compost piles and biodigesters). The only asset category for which the sampled groups substantially differ is an heterogeneous pool of all the other eligible assets (harvesting equipment, fodder storage facilities, electric fences, fertigation systems, feeders and drinking troughs, improved farm roads). We argue that this difference is mainly due to a refocusing of the program administration following the first years of operations and budget shrinkage, rather than to a change in new entrants' priorities. As an illustration, when half of the 2007-2012 plans include four assets or more, we notice that the maximum number of assets is four among all plans in 2013 project. Moreover, this difference is unlikely to be explained either by a lower investment capacity of 2013 participants since in average, the mean total cost for one of their plan (USD 2,062) is at least as high as in 2007-2012 projects (USD 1,652)¹. Expected RBA repayment in case of full completion of the plan is also

1. The resulting difference in mean investment costs between sampled groups is not significantly different from zero with a value at USD 410 and a standard error at 453.

Figure 3.3: Shares of sampled farmers selecting the asset as a planned investment in their first application files



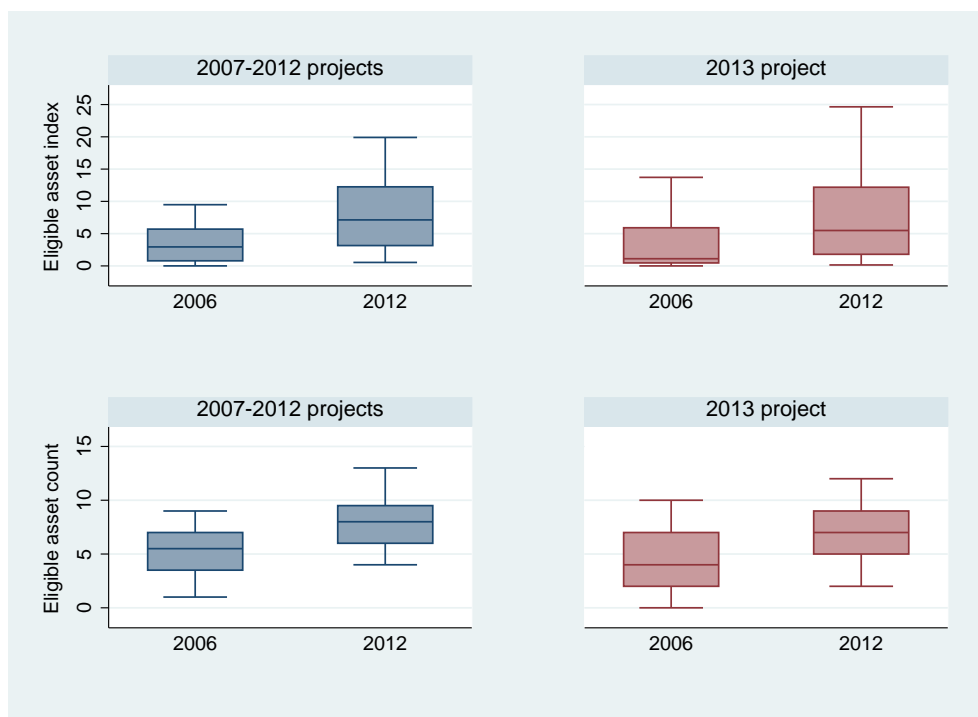
well-balanced in both groups, with mean amounts of USD 399 among 2007-2012 participants and USD 486 among 2013 participants².

Facing the large diversity of investment plans among 2007-2012 sampled participants, we are also confronted with the definition of the outcome variable supposed to capture the adoption of all eligible assets, as well as with potential measurement error as all data are declarative. We rely on suitable aggregation methods from demographic research on proxy measures of living standards based on households' assets in developing countries. Following Filmer and Pritchett (2001), we apply principal components to estimate the weight for the declared quantity of each eligible asset, after pooling 2006 and 2012 observations. The set and descriptive statistic of eligible asset variables before standardization is displayed in Appendix 3.3 jointly with measures of sampling adequacy. The first row in Figure 3.4 presents the resulting eligible asset index by years and sampled groups.

We also compute a count variable from the same set coded as the number of assets owned which is also a common approach according to Montgomery et al. (2000). The eligible asset count is presented by years and sampled groups in the second row of Figure 3.4. The correlation coefficient between the index and the count vari-

2. The resulting difference in mean expected RBA repayments is not significant either with a value of USD 87 and a standard error at 117.

Figure 3.4: Distributions by sampled groups of the eligible asset index and count for 2006 and 2012



ables ranges at 0.61. When testing for difference in means and distributions between groups, we do not find any significant differences for pre-treatment levels of both eligible asset variables³, still differences in means are larger for 2012 and even significant in the case of the count variable, indicating that ranchers in the treated group owned more items than sampled ranchers from the 2013 project⁴.

Finally, we also derive a binary variable from the count variable coded 1 when the value of the count variable in 2012 is strictly higher than its pre-treatment value, and 0 otherwise. This variable indicates that more sampled ranchers from 2007-2012 projects have adopted at least one additional eligible asset between 2006 and 2012 (84%) compared to ranchers from the 2013 project (71%) but this difference is not statistically significant⁵.

3. Difference at 3.21 with a standard error at 3.31 and D-statistic at 0.27 with a p-value at 0.15 for the index; difference at 0.92 with a standard error at 0.65 and D-statistic at 0.20 with a p-value at 0.49 for the count.

4. Difference at 4.50 with a standard error at 3.56 and D-statistic at 0.24 with a p-value at 0.25 for the index; difference at 1.42 with a standard error at 0.68 and D-statistic at 0.23 with a p-value at 0.28 for the count.

5. Difference not significant at 13.41 with a standard error at 10.51.

5 Identification strategy

5.1 Dealing with self-selection into the program

Following the common practice in the evaluation literature, we intend to measure the program impact defined as the average effect on an outcome indicator caused by the program among participants. Therefore we include a group of nonparticipants for comparison which is also a common practice and major challenge. We consider the following structural equations modeling individual heterogeneity through fixed effects at pre-treatment period $t = 0$:

$$y_{i0} = c + a_i + \beta_1 X_{i0} + \epsilon_{i0} \quad (3.1)$$

and at post-treatment period $t = 1$:

$$y_{i1} = c + a_i + \beta_1 X_{i1} + \beta_2 RBA_i + time + \epsilon_{i1} \quad (3.2)$$

where y_{it} is an outcome of interest for rancher i at period t , c is the constant term, a_i is the individual fixed effect related to time-constant characteristics for rancher i , X_{it} is a vector of individual characteristics at period t , RBA_i is the treatment variable coded 1 if rancher i is a participant in RBA program and 0 otherwise, $time$ is the period fixed effect and ϵ_{it} is the stochastic error term for rancher i . The unbiased measure of the average RBA effect on the participants will be given by the estimate of β_2 in Equation 3.2 only if the conditional exogeneity assumption holds. This will require that all factors linked to both treatment and outcome and representing potential rival explanations will be controlled for so that RBA_i will be not correlated with ϵ_{i1} .

All Guanacastecan ranchers who are members of a producers' organization can apply to RBA program according to its legal framework. Hence, heterogeneity in individual characteristics is unlikely to be balanced between RBA participants and the rest of the ranchers population, reflecting individual self selection into the program together with the assignment of opportunities to participate by producers' organizations and local MAG extension services. For instance, for a similar program in Costa Rica Garbach, Lubell, and DeClerck (2012) found evidence of farm capital (land, labor and herd), education and information network being correlated with both the individual participation and the presence of several RBA eligible assets in the farm. Such determinants could be controlled for in a model using a large set of observable variables.

Another concern relates to the suspected unobservable confounding determinants of both voluntary participation and adoption of eligible assets, such as the willingness to participate in the program (Jack, 2013b). Theoretically, the latter mainly relies on the individual opportunity cost of complying with the contract (Ferraro, 2008; Persson and Alpizar, 2013). While in PES schemes for forest conservation the opportunity cost of compliance can be approximated by returns from clearing land (Le Velly and Dutilly, 2016), in the case of RBA program the opportunity cost of compliance is harder to guess. Indeed, it encompasses a large number of productive considerations such as agro-ecological conditions of the farm, since the profitability of the adoption depends on a large set of parameters defining the expected utilities of adopting versus

not adopting. Facing the impossibility of measuring all the presumed confounding factors, we will be not able to explicitly control for them in the estimation and RBA_i variable in Equation 3.2 will not be exogeneous.

Therefore, we reduce the threat of uncontrolled confounding factors by first differencing the model variables in Equations 3.1 and 3.2 so that we get the following equation:

$$\Delta y_i = \beta_1 \Delta X_i + \beta_2 RBA_i + time + \Delta \epsilon_i \quad (3.3)$$

where $\Delta y_i = y_{i1} - y_{i0}$, $\Delta X_i = X_{i1} - X_{i0}$, $\Delta \epsilon_i = \epsilon_{i1} - \epsilon_{i0}$ and β_2 is the Difference in Difference (DID) estimator of the average RBA effect on the participants. DID approach corrects *de facto* for all time-constant additive confounding factors whether or not they are observable, and differences in pre-treatment means for these variables do not threaten anymore the internal validity of the estimate. Still it relies on the non-testable assumption of parallel trends since in this setting β_2 is the deviation from the trend line of y_{it} growth over time which is attributed to the program. Under parallel trends, the average outcome change between the two periods for the participants in the absence of the program would have been equal to the corresponding change observed for the nonparticipants.

5.2 Dealing with time-varying unobservables

Our empirical strategy takes into consideration the parallel trend assumption in several ways. First, time-varying confounding factors require to be all controlled for otherwise RBA_i will be still correlated with the error term. Shocks occurring between the two periods and affecting the adoption of eligible assets can be related to changes at the household level but also in the farming context. External shocks are a matter of great importance since extensive cattle ranching relies on forage crops and water from natural sources which are strongly sensitive to climate conditions. Confirmed by the information gathered from staffs in local MAG agencies, climate conditions would be a strong determinant of farm investments as well as household's finances. During the implementation of RBA program, severe damages on pastures and cattle herds in the study site have been reported in the declarations of emergency following 2007-2008 and 2009-2010 droughts and the heavy rainfalls occurring almost every winter (MIDEPLAN/MAG, 2018). Between 2006 and 2012, cumulative climate-induced losses in pastures and herds amount to almost USD 1,500 per farm in average over the study site and strongly vary between cantons (from USD 500 to 2,500 USD) despite the limited size of the study site and its relative agroecological homogeneity (INEC, 2014a; MIDEPLAN/MAG, 2018). These losses may have positively influenced the decision of adopting eligible assets since the latter can be used as a response to adapt to harsh climate conditions or in the short run, to rebuild the productive capacity of the farm after the damages. Conversely, a disincentive effect could occur with damages discouraging farm investments toward more capital intensive systems. In the empirical literature on sustainable practice adoption at the farm scale, stresses on production have been found to be a non-negligible factor (Teklewold, Kassie, and Shiferaw, 2013).

In order to reduce the risk of climate shocks exposure being a source of correlation for the error term, we apply a stratification by canton when sampling the group of nonparticipants so that the exposure will be better balanced between the two groups, and include canton dummy variables in the regressions to control for correlated shocks at the canton level. In addition of climate-related shocks, canton fixed effects will also capture the effect of all non-ignorable shocks at the canton level which is the relevant administrative unit for both MAG extension services and ranchers' organizations.

The effect of climate shocks is not only presumed to be heterogeneous according to the farm location across the study site, it also depends on the preexisting vulnerability of the farm to the physical shock. Since the vulnerability status of a farm can moderate the climate shocks exposure and then be a source of time-varying unobservable heterogeneity, it has to be accounted for. For this purpose, we exploit features of the RBA program implementation. Between 2007 and 2012, one or two RBA projects were completed in each of the five cantons, in the name of the cantonal ranchers associations. In addition, new participants from all cantonal ranchers associations were included in a project set up during 2013 and approved at the end of the year by the Program Coordination Unit. We believe that forming a pipeline comparison group with ranchers sampled from the list of 2013 participants who were not involved in previous projects will provide an appropriate counterfactual for the path of the previous participants until the end of 2012 if they would not have been treated. As argued in Chase (2002) and Ravallion (2007), individuals in the pipeline for a program are more likely to represent an accurate counterfactual for the participants because (i) on the one hand, they have self-selected into the program, (ii) on the other hand they have been selected by the program administration, and (iii) at the same time, they have not been affected by the program.

Points (i) and (ii) make that participants and nonparticipants will be more likely to share non-ignorable characteristics including their vulnerability to climate shocks, as indicated by their revealed willingness to participate and adopt eligible assets. This will also ensure that all participants and nonparticipants will be members of the same ranchers associations, when the empirical literature evidenced that the membership of farmers' organizations plays a role in adoption of sustainable technologies (Wollni, Lee, and Thies, 2010).

In relation to points (ii) and (iii), two potential issues have to be discussed. First, the unmissable distinction in the participation timing between both groups may not be an exogenous source of variation in the sense that the assignment of opportunities to participate by producers' organizations and local MAG extension services may reflect some implicit priority criteria related to the vulnerability of farms. Second, the group of 2013 participants may have been affected by the program before 2013 because of leakages from 2007-2012 projects or because of a strategical delay from their part consisting in postponing all investments that they would have realized between 2007 and 2012 in anticipation of their participation.

We argue that these issues are unlikely to occur due to the weak capabilities of both local MAG services and ranchers' associations. Local ranchers' associations have a very limited role in the program while the program promotion and project

supervision were the charge of the few cantonal field extension workers who have difficulties to make time for it⁶. Offers to participate in a project were mostly communicated to potential participants during farm visits in the framework of the extension workers' ordinary duties or hastily before the deadline for sending the list of participants to the Program Coordination Unit. Most likely non random, the assignment of opportunities to participate may be influenced by ranchers' proximity to the local MAG extension worker rather by their vulnerability to climate shocks. Since being close to MAG services may mitigate climate shocks through an enhanced access to guidance and assistance and evidence of the effect of information access on technology adoption (Bandiera and Rasul, 2006), we take into account it.

Combined with the very low population densities (30 inhabitants per km²), lack of information media (one farmer in four declared that he/she does not receive any agricultural information), low access to technical assistance (6% of the farms covered, primarily from MAG services) and weak producers' organizations (70% of the farmers do not belong to any association) in the study site (MIDEPLAN/MAG, 2018; INEC, 2014a), the restricted program promotion also erases suspicions of anticipations from the group of nonparticipants. The potential contamination of this group by leakages from previous RBA projects seems also unrealistic due to the aforementioned reasons. Nonetheless, relying again on the program enrollment process, our identification strategy benefits from the existing differences in farm coverage from the program between cantons (from 2% of the cattle farms in the canton before 2013, to 25%). Therefore, canton fixed effects will account for the fact that a higher coverage may have resulted in a higher probability that peer effects have emerged locally and supported the adoption of eligible assets in both participants and nonparticipants populations.

Our final consideration about the parallel trend assumption relates to the dynamics of capital accumulation on the farms. Because the investment in eligible assets is likely to include nonlinear processes as any technical change in agriculture (Foster and Rosenzweig, 1995, 1996), specifying the differenced function to be linear as in Equation 3.3 will result in a violation of the parallel trend assumption if pre-treatment stock of assets are not similar between participants and nonparticipants.

Given these consideration about the parallel trend assumption, we thus estimate the following equation:

$$\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + d_j + \Delta \epsilon_{ij} \quad (3.4)$$

where subscript j specifies the canton where the farm of rancher i is located and d_j is the fixed effect associated with canton j . ΔX_{ij} includes changes in household

6. "Other factor influencing the efficacy level [of RBA program] occurred at the supply side and in particular from the program promotion agents. The design did not provide for proper incentive to the field extension workers involved, which has caused a certain lack of interest from some of the extension workers regarding the program promotion toward potential beneficiaries."(p.97, EPYPSA (2010)) "The [program] evaluation considers that this management system in which the extension workers located in the provinces have to share their time and central duties with administrative tasks and others, without proper incentives, diverts their implementation capabilities from activities and commitments such as the ones implied by the program."(p.99, EPYPSA (2010))

finances that are not caused by farm investments. Z_{ij} is a vector of pre-treatment or time-constant individual characteristics related to the proximity to MAG services of rancher i in canton j . Ranchers with $RBA_{ij} = 1$ are the 2007-2012 participants and ranchers with $RBA_{ij} = 0$ are 2013 participants. 2006 stands for $t = 0$ and 2012 for $t = 1$.

6 Results of the impact evaluation

6.1 Impact on eligible assets aggregated quantities

Following our identification strategy, we estimate Equation 3.4 with OLS regressions of the differential in eligible asset index. Based on the data exploration we carried out, we include as covariates in addition to the RBA dummy variable all proxies for changes in household finances over time, as well as the pre-treatment level of the outcome variable and canton dummy variables. To address the selection bias, we introduce as covariates the set of variables from probit model (2) in Appendix 3.1 that were identified as relevant determinants of the inclusion in the 2007-2012 sampled group. We exclude the variables that we added to get model (3) from the analysis since none of them has a detectable effect on the inclusion in the 2007-2012 projects and jointly their parameters are not significant either⁷. Both information criteria also support that claim. However, we test the inclusion of the propensity score predicted by probit model (3) as a covariate in an additional alternative adjustment for the selection bias in OLS regressions. Following Rosenbaum and Rubin (1983), adjusting for the selection bias by controlling for the set of treatment determinants or for the propensity score predicted by the same variables can be equivalent in linear models. This specification could hence limit over-parametrization threat while adjusting for all potential treatment determinants, still it can also perform poorly so we discuss this issue when analyzing the model results.

Table 3.2 presents the results of selected OLS regressions of the differential in eligible asset index between 2006 and 2012. Model (1) shows that the participation into 2007-2012 RBA projects combined with the pre-treatment level of the index poorly explain the variability in the differential in indexes over time alone. In model (2), we regress the dependent variable on the pre-treatment level of the index and RBA variable as well as the proxies for changes in household's finances. Jointly all parameters are highly significant as proved by the F test and adjusted R^2 reaches 0.205 yet. Since in model (1), the time constant term is large and significant (3.269 with a robust standard error at 0.786) whereas it is not in model (2), all time-variant covariates (including RBA variable) thus account for all the unexplained trend in the dependent variable. This specification leads to estimate an effect of RBA program that is significantly different from zero when all other time-variant variables are controlled for and when we assume a random assignment of the treatment. The estimated parameter suggests that on average the program implies an increase by 3.1 points in the differential in eligible asset index for the participants. This increase appears sub-

7. LR test statistic at 0.91 with a p-value at 0.99.

stantial since the pre-treatment index levels of the middle 50% treated ranchers range from 0.8 to 5.7 as shown in Figure 3.4.

Starting from model (3), we try to address the selection bias. In model (3), we introduce all relevant treatment determinants. Jointly they are barely significant at a 15% level (F statistic at 1.85 with a p-value at 0.107). However, when we progressively introduce them (see Appendix 3.4), we detect that the pre-treatment levels of owned land area and home assets index have an effect on the dependent variable and thus appear as confounding factors for RBA effect if not controlled for. This result is intuitive since owning more land can increase the profitability of additional investment and be used as a collateral for credit, and its positive effect has been evidenced in the empirical literature on the adoption of soil and water conservation practices (Bekele and Drake, 2003; Amsalu and de Graaff, 2007; Marennya and Barrett, 2007). Home assets is a common measure for household's expenditures and since we control for the variability in all income sources, its effect results to be negative on the dependent variable. For our case study, our main preoccupation concerns the effect of the inclusion of land area and home assets on the RBA parameter. Following the inclusion of land area, the RBA parameter increases and its standard error is reduced (see model (2) in Appendix 3.4), suggesting that because treated ranchers have smaller farms other things being equal and then, less interest in additional investment and possibly less credit access, the RBA effect may be under-estimated when the model does not control for the differences in farm sizes. Still the land size effect is partially captured by the pre-treatment level of the dependent variable as its parameter drops following the inclusion of land area in model (see also model (7) in Table 3.2). Regarding home assets, the reverse is observed: RBA parameter decreased whereas the estimate for pre-treatment level of the eligible asset index increased (see model (7) in Appendix 3.4), as a result of treated ranchers having smaller home assets indexes other things being equal combined with home assets affecting negatively the dependent variable. Besides, the inclusion of home assets brings out a negative effect from farm inheritance on the dependent variable. Consequently, model (3) in Table 3.2 shows a reduced but still large and significant effect of RBA program on the differential in eligible assets index after adjusting for all treatment determinants.

From model (4), we add canton fixed effects to take into account all shocks that are correlated at the canton level. RBA effect is again reduced, suggesting that the heterogeneous distribution of shocks between cantons may have inducing more additional investments in eligible assets within the treated sample than within the control group. However, the adjusted R squared is slightly penalized and the p-value at 0.43 of the F test associated with the four canton variables parameters indicates that their joint insignificance cannot be rejected while none of their parameter is individually significant. Since the inclusion of the four canton dummy variables also altered most of the model estimates, further models try to limit over-parametrization issue.

We scale up the degrees of freedom in the regressions by applying an alternative adjustment method for the selection bias consisting in replacing the set of treatment determinants by a propensity score. Propensity scores represent predicted probabilities of being included in the treated group based on the observed pre-treatment and time-constant characteristics that explain treatment assignment. We rely on

Table 3.2: OLS model estimates of the differential in eligible asset index between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Δ Index	Δ Index	Δ Index	Δ Index	Δ Index	Δ Index	Δ Index
RBA	1.274 (1.275)	3.130** (1.299)	2.315** (1.100)	1.920* (1.113)	1.894* (1.121)	2.202* (1.246)	1.916* (1.118)
Index in 2006	0.00601 (0.0424)	0.0387 (0.0487)	0.0236 (0.0455)	0.00869 (0.0565)	0.00609 (0.0591)	0.0289 (0.0621)	-0.00675 (0.0461)
Δ 12-60 y/o household members		0.0410 (0.353)	0.0404 (0.386)	0.0948 (0.382)	0.0912 (0.385)	0.0602 (0.347)	-0.00737 (0.364)
Δ Household members off-farm		2.307** (0.871)	2.243*** (0.795)	1.701° (1.065)	1.643° (1.109)	1.987° (1.239)	1.460 (1.048)
Δ Public aid received		5.111** (2.529)	4.523* (2.555)	3.810 (2.770)	3.659 (2.910)	4.626* (2.756)	3.628 (2.901)
Change in farming system		5.362*** (1.587)	3.627** (1.534)	3.308** (1.397)	3.268** (1.452)	5.192*** (1.670)	4.238** (1.647)
Land area owned in 2006			0.0197 (0.0138)	0.0184 (0.0132)	0.0210 (0.0170)		0.0242** (0.0113)
Farm inherited			-2.138° (1.279)	-2.246* (1.335)	-1.779 (2.368)		
Dairy farm in 2006			1.654 (1.510)	1.225 (1.719)	0.560 (2.870)		
Meeting attendance			0.117 (0.180)	0.125 (0.173)	0.0292 (0.361)		
Commuting time			-0.00363 (0.0130)	-0.00389 (0.0136)	0.00234 (0.0250)		
Home assets in 2006			-0.0563* (0.0287)	-0.0568* (0.0322)	-0.0406 (0.0710)		
Propensity score from probit model (3)					2.167 (7.752)	1.640 (2.257)	4.253** (2.092)
Constant	3.269*** (0.786)	0.683 (0.837)	2.660* (1.537)	4.177° (2.578)	2.844 (5.854)	0.339 (3.292)	-1.022 (2.674)
Canton dummy variables	NO	NO	NO	YES	YES	YES	YES
<i>N</i>	63	63	63	63	63	63	63
<i>adj. R</i> ²	-0.015	0.205	0.283	0.260	0.244	0.203	0.288
<i>F</i> statistic against null	0.54	4.23***	5.03***	3.87***	3.64***	3.72***	3.92***

Robust standard errors in parentheses. ° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

F statistic for all canton dummy variables having parameters jointly insignificant in model (4) at 0.98 with a p value at 0.43.

F statistic for all treatment determinants excluding land area owned in 2006 having parameters jointly insignificant in model (4) at 1.25 with a p value at 0.30.

F statistic for all treatment determinants excluding land area owned in 2006 having parameters jointly insignificant in model (5) at 0.34 with a p value at 0.89.

the propensity score from the most inclusive probit model being model (3) in Appendix 3.1. Appendix 3.2 displays the distributions of all estimated propensity scores by sampled groups. Following Rosenbaum and Rubin (1983), this method of adjustment can be equivalent to a regular inclusion of all relevant treatment determinants as covariates. First, we include the propensity score jointly with all previous treatment determinants and obtain estimated parameters of model (5) in Table 3.2. All parameters of treatment determinants are strongly affected such that their estimated value get closer to zero and their standard errors are increased, except for land area. All other parameters remain relatively stable. Whereas the p-value associated with the F test for joint insignificance of all treatment determinants parameters (excluding land area) was at 0.30 for model (4), the corresponding p-value for model (5) is 0.89. Afterward we specify a model without treatment determinants but the propensity score, such that the propensity score is supposed to account for all of them. This model is presented as model (6). We find that the model is not fitting the data as good as model (4) as indicated by the lower adjusted R squared. Since land area is a weak treatment determinant as evidenced in probit models (3) and (4) in Appendix 3.1 and besides, its estimates is even incremented following the introduction of the propensity score in model (5), we argue that model (6) does not properly correct for the differences in land areas that were observed between both sampled groups in Section 4. As previous evidence indicated that land area may directly affect the dependent variable, we thus reintroduce it jointly with the propensity score in model (7), which reaches an adjusted R squared similar to the one obtained when all treatment determinants were included (model (4)). Model (7) also estimates a RBA parameter similar to the one in model (4) and shows that its added degrees of freedom do not alter it.

Therefore, all models reveal that RBA dummy variable has a significant and positive effect on the dependent variable. The effect is robust to covariance adjustments for selection bias and also holds after the inclusion of any one of the variables from Table 3.1 in model (7) (not displayed). Relatively to the mean pre-treatment and post-treatment levels of the eligible assets index among treated ranchers, the estimate of 1.92 for β_2 in model (4) and (7) suggests that on average, the participation into RBA projects from 2007 to 2012 is responsible for 41% of the increase in the index experienced among treated ranchers between 2006 and 2012. With 500 replications, the bootstrapped 90% confidence interval blocked by sampled groups for RBA estimate (model (4)) ranges from 0.00 to 3.83, supporting that the magnitude of the effect would rather represent from 0% to 83% of the observed increase in the index among 2007-2012 participants, once uncertainty on the estimate is considered.

6.2 Impact on eligible assets diversity

We apply the same identification strategy with the count differential and binary variable as dependent variables. Their coding scheme does not reflect observed quantities of each eligible asset but they state the evolution of the number of eligible assets between 2006 and 2012. The count differential represents how much additional assets were incorporated into the production technology and the dummy value is one if the rancher adopted at least one additional asset during the period. Since both de-

pendent variables are limited, we use ML estimations exploiting the structure of the data, namely Poisson and Probit for the count and the binary variable respectively.

Count differential

Table 3.3 displays the results on the count differential. Model (1) fits poorly the data, as the Pearson's goodness of fit statistic ranges at 80.44 with a p-value at 0.04. After the inclusion of all proxies for changes in household's finances, Pearson's statistic reaches 58.48 with a p-value at 0.38. Results are shown as model (2) and confirm that the log of the count differential depends on the pre-treatment count level, highlighting the nonlinear dynamics of eligible assets accumulation on farm. RBA estimate is positive and significant at 1% level. Its marginal effect for the mean treated rancher is 1.38, suggesting that the participation into 2007-2012 RBA projects resulted in the adoption of more than one additional eligible asset that the mean participant would not have adopted without the program.

In model (3) we introduce the treatment determinants to adjust for the selection bias. Appendix 3.5 presents their progressive introduction. We identify three factors affecting both treatment assignment and the outcome, namely farm inheritance, the fact that the farmer was exploiting a dairy system in 2006 and the home assets index in 2006. The consecutive adjustments for each one of them result in RBA parameter being reduced, which is consistent with the direction of the selection bias jointly with the signs of their parameters in model (3). Consequently, the marginal effect of the program for the mean participant drops below one additional asset. Finally, model (4) includes the cantons fixed effects. The RBA parameter is no longer estimated as significantly different from zero, indicating that the RBA effect on the number of eligible assets for the mean treated rancher is negligible.

Regarding how the covariance adjustment for selection bias performs, some criticism is worth noting. Since the fact that the farm was exploited under a dairy system appears to be a strong predictor for the log of the count differential while the variable is dummy coded and unbalanced between the treated and control groups with a very small number of ranchers from the control group having dairy farms in 2006, we argue that covariance adjustment may not properly correct for this confounding factor based on findings from Rubin (1973), Rubin (1979) and Rubin and Thomas (2000). Similarly to a multicollinearity problem, this issue implies that regression models make predictions based on a large extrapolation process from a 10%-dairy group to a 30%-dairy group. In order to improve the adjustment, we introduce an interaction term between the treatment and the dairy farm variable. Results are presented as model (6) in Table 3.3. The term is not swamped by the variance of the treatment, its parameter is significantly different from zero instead. The additive variable for the fact that the farm was a dairy farm in 2006 has no longer a significant parameter which is not surprising considering the reduced number of dairy farms in the control group. This prevents us from interpreting the parameter on the interaction term as an heterogeneous effect of RBA program depending on the system exploited on farm. Regarding RBA effect, its estimate suggests that the difference between the log of expected count differentials between all 2007-2012 participants and 2013 participants

Table 3.3: Poisson ML model estimates of the differential in eligible asset count between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)
	Δ Count	Δ Count	Δ Count	Δ Count	Δ Count
RBA	0.255 ^o (0.163)	0.497*** (0.164)	0.267* (0.162)	0.220 (0.156)	0.123 (0.151)
Count in 2006	-0.120*** (0.0333)	-0.114*** (0.0322)	-0.101*** (0.0301)	-0.105*** (0.0306)	-0.0926*** (0.0306)
Δ 12-60 y/o household members		0.0331 (0.0408)	0.0379 (0.0372)	0.0330 (0.0291)	0.0444 ^o (0.0276)
Δ Household members off-farm		0.257** (0.120)	0.279*** (0.104)	0.288*** (0.0928)	0.402*** (0.0981)
Δ Public aid received		0.635*** (0.217)	0.581*** (0.204)	0.597*** (0.177)	0.766*** (0.157)
Change in farming system		0.467*** (0.168)	0.322** (0.143)	0.368** (0.151)	0.342** (0.145)
Land area owned in 2006			0.0000633 (0.00122)	-0.000375 (0.00116)	-0.00112 (0.00117)
Farm inherited			-0.359** (0.145)	-0.359*** (0.139)	-0.293** (0.133)
Dairy farm in 2006			0.411** (0.169)	0.332** (0.167)	-0.316 (0.421)
Meeting attendance			-0.000376 (0.0204)	0.00449 (0.0202)	0.00840 (0.0194)
Commuting time			-0.000167 (0.00135)	-0.000234 (0.00122)	-0.000155 (0.00120)
Home assets in 2006			-0.00878** (0.00401)	-0.0103*** (0.00389)	-0.00923** (0.00372)
RBA x Dairy farm in 2006					0.800* (0.436)
Constant	1.650*** (0.174)	1.305*** (0.200)	1.760*** (0.256)	1.769*** (0.386)	1.612*** (0.397)
Canton dummy variables	NO	NO	NO	YES	YES
<i>N</i>	63	63	63	63	63
<i>Log likelihood</i>	-128.56	-119.89	-114.10	-111.70	-110.52
<i>pseudo. R</i> ²	0.070	0.133	0.178	0.192	0.200
<i>Wald</i> χ^2	13.33***	47.40***	96.79***	136.50***	185.88***
<i>CAIC</i>	272.55	275.78	295.07	315.98	318.76
<i>BIC</i>	269.55	268.78	282.07	297.98	299.76

Odds ratios. Robust standard errors in parentheses. ^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

LR test statistic for (3) against (2) at 11.57 with a p-value at 0.07 supporting that all the treatment determinants in (3) have parameters that are jointly significant.

LR test statistic for (4) against (3) at 4.80 with a p-value at 0.31 supporting that the canton dummy variables in (4) are likely to have parameters that are not jointly significant.

is likely to be zero. The bootstrapped 90% confidence interval with 500 replications for RBA estimate provides average marginal effects conditional on the mean treated rancher' characteristics ranging from -0.37 to 0.54.

Therefore, regressions of the eligible assets count variable provide blurry results due to the status of confounding factor of the dairy farm variable. As a consequence of the unbalance of dairy farms between both sampled groups and our small sample size, we are not able to identify if the larger increase in eligible assets counts observed in the 2007-2012 participants sample compared to 2013 participants is whether caused by an heterogeneous program impact depending on the farm system or by the the farm system itself. Intending to get around the problem, we rely on regressions of the binary indicator accounting for the adoption or not of additional eligible assets between 2006 and 2012.

Binary variable

Results are presented in Table 3.4. We use the pre-treatment level of the count variable to allow non-linear dynamics. Model (1) already reaches a pseudo R squared at 0.36, mainly due to the pre-treatment count covariate. RBA parameter is positive and significant, the corresponding marginal effect for the mean treated rancher represents an increase by 26% of the predicted probability of adoption, and a 37% increase after controlling for the other time-variant covariates (model (2)). The inclusion of treatment determinants in model (3) leads to identify land area, farm inheritance and the home asset index as potential confounding factors they are not properly taken into account. Even when we inspect the results of intermediary models (see Appendix 3.6, we do not find evidence of the dairy farm variable being one of the potential confounding factors, since RBA parameter appears to be not affected by its inclusion in the model and none model leads to reject the hypothesis that its parameter is zero.

Nonetheless, the large pseudo R squared points out that the model is likely to be overfit whereas canton fixed effects are not introduced yet. In order to test if we can rely on a propensity score to correct for the selection bias, we first introduce it jointly with all other treatment determinants. Results are presented as model (4). It shows that most of the changes in predicted probability that can be attributed to the treatment determinants are captured by the variance of the propensity score. None of the parameter estimate of the potential confounding factors is significant. We then estimate model (2) on a sample where observations are weighted according to their propensity scores predicted by probit model (3) of RBA reception, following Hirano, Imbens, and Ridder (2003). The balance between both sampled groups is improved within the estimation sample, such that we expect that it removes the correlation between treatment determinants that are omitted and included variables. Results are displayed as model (5).

In model (5), we observe that the weighting on propensity score estimate for RBA treatment effect is reduced compared to the unweighted estimate of model (2). Its parameter is barely significant at 15%. The corresponding marginal effect for the mean treated rancher represents an increase by 21% of the predicted probability of adoption, which is relatively close to the marginal effect associated to model (1). In

Table 3.4: Probit model estimates of the adoption of at least one additional eligible asset between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)	(6)
	<u>Count_d</u>	<u>Count_d</u>	<u>Count_d</u>	<u>Count_d</u>	<u>Count_d</u>	<u>Count_d</u>
RBA	1.026** (0.455)	1.453*** (0.505)	2.175*** (0.689)	2.160*** (0.682)	0.913° (0.604)	2.403** (1.041)
Count in 2006	-0.420*** (0.0982)	-0.462*** (0.134)	-0.600*** (0.169)	-0.593*** (0.170)	-0.438*** (0.138)	-0.637** (0.264)
Δ 12-60 y/o household members		-0.0676 (0.0969)	0.0356 (0.153)	0.0386 (0.152)	-0.0915 (0.132)	-0.0638 (0.148)
Δ Household members off-farm		0.617° (0.377)	1.290*** (0.414)	1.293*** (0.420)	0.206 (0.378)	1.121* (0.616)
Δ Public aid received		0.662 (0.718)	2.313** (1.167)	2.276* (1.171)	-0.761 (0.675)	0.309 (0.791)
Change in farming system		0.189 (0.504)	-0.465 (0.544)	-0.371 (0.700)	0.167 (0.624)	0.902 (0.887)
Land area owned in 2006			0.00801* (0.00452)	0.0112 (0.0105)		
Farm inherited			-1.825*** (0.589)	-1.421 (1.357)		
Dairy farm in 2006			-0.174 (0.519)	-0.927 (2.409)		
Meeting attendance			0.104 (0.0884)	0.0208 (0.285)		
Commuting time			-0.000668 (0.00657)	0.00683 (0.0244)		
Home assets in 2006			-0.0368** (0.0147)	-0.0228 (0.0493)		
Propensity score from probit (3)				2.006 (6.531)		
Constant	2.682*** (0.596)	2.560*** (0.828)	4.640*** (1.141)	3.184 (4.823)	2.977*** (0.978)	2.167 (1.913)
Canton dummy variables	NO	NO	NO	NO	NO	YES
<i>N</i>	63	63	63	63	63	63
<i>Log likelihood</i>	-21.33	-19.18	-14.91	-7.84		
<i>pseudo R</i> ²	0.361	0.425	0.553	0.554		
<i>Wald χ</i> ²	19.34***	19.22***	30.90***	85.71***		
<i>CAIC</i>	58.09	74.37	96.69	108.25		
<i>BIC</i>	55.09	67.37	83.69	90.25		

Robust standard errors in parentheses. ° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In models (5) and (6), observations weights derived from the inverse of the propensity score predicted in probit model (3).

Adjusted Wald test at 1.43 with a p-value at 0.23 for canton dummy variables in model (5), indicating that their parameters are likely to be simultaneously equal to zero. Still one of them is significant at a 5% level.

final model (6), we introduce the canton fixed effects. Whereas previous results from regressions of the index and count differentials indicated that the inclusion of canton dummy variables tended to shrink RBA estimate, estimates in model (6) shows the opposite effect in the regression of the binary outcome variable. One of the canton fixed effect is large and significant at a 5% level. As a result of weighting for the selection bias and controlling for canton fixed effects, we obtain a RBA parameter estimate large and significant at a 5% level. The marginal effect of the program for the mean treated rancher represents an increase by 48% of the predicted probability of adopting at least one additional eligible asset between 2006 and 2012, with a 95% confidence interval ranging from 19% to 77%. Besides, both magnitude and significance of RBA estimate hold after the inclusion of any one of the variables from Table 3.1 in model (6) (not displayed).

The analysis of the evolution of the diversity in eligible asset ownership between 2006 and 2012 shows that RBA program enhanced the probability of the sampled participants from 2007-2012 projects to adopt at least one additional asset class. However, we were not able to properly identify whether or not this impact was also reproduced as a larger increase in the number of eligible assets owned for the mean rancher sampled from 2007-2012 projects.

6.3 Internal validity

In order to assess the validity of our estimations, we propose some tests related to DID assumptions. The first one is related to the parallel trend assumptions, while the second one is referred to as the Stable Unit of Treatment Value assumption and states that there is no diffusion effects from the program that would have affected the ranchers from the control group.

Placebo test

First, we apply a Placebo test which consists in applying the same identification strategy to outcomes that should not be affected by the program. We estimate the program impact on indicators related to households' investment, computed following the same aggregation methods than our three eligible assets indicators, but not directly affected by the program. We opt to study a set of home assets which appeared earlier in the study in the form of a pre-treatment index used as a covariate to control for households' wealth. This index was based on a set of seventeen durable goods and characteristics of housing commonly used for such purpose (vehicles, domestic electrical appliances, phones and internet contract, number of rooms and type of material for own houses) and weights derived from principal components. The overall measure of adequacy among the variable set (KMO index at 0.70) was comparable to the measure obtained with the set of RBA eligible assets. A count and a binary variable were also derived from the same set of home assets. We checked for equality of pre-treatment means for the index in Table 3.1, as well as for the count indicator⁸.

8. Difference at -0.69 with a standard error at 0.72.

Table 3.5: Placebo tests: RBA parameter estimates in regressions of the differential in home assets between 2006 and 2012 (index, count and dummy indicators)

	Model (1)	Model (2)	Model (3)	Model (4)
on Δ H-index:	1.278 (2.724)	2.907 (2.878)	1.216 (2.743)	1.879 (3.204)
on Δ H-count:	0.0238 (0.0707)	0.0607 (0.0738)	-0.00188 (0.0676)	0.00597 (0.0716)
on H-count_d:	0.284 (0.334)	0.580 ^o (0.377)	0.440 (0.428)	0.691 (0.512)

Odds ratios for estimates on Δ H-count. Robust standard errors in parentheses. ^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Model (1): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_2 RBA_{ij} + time + \epsilon_{ij}$.

Model (2): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + time + \epsilon_{ij}$.

Model (3): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + \epsilon_{ij}$.

Model (4): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + d_j + \epsilon_{ij}$.

The rationale of the test is based on the following working hypotheses. If RBA parameter estimate is significant and negative, two rival conclusions would arise, the first asserting that RBA program has also an indirect impact on the variation of households' ownership of home assets over time, and the second stating that our identification strategy is biased toward the under-estimation of RBA impact on all investment-related indicators. None of the two conclusions would question our result on the positive impact of RBA program on the differential in eligible assets index. If we find a significant and positive parameter estimate of RBA on the home assets indicators, then an indirect impact of RBA might also be detected or our identification strategy might rather be biased toward the over-estimation of RBA impact on all investment-related indicators. Therefore, our previous results would be seriously challenged. The third and last possible case would be to find a RBA parameter estimate not significantly different from zero. Thus, even if there may be indirect RBA impacts that are offsetting one another in that case, we would have no evidence that would motivate to question our identification strategy.

Table 3.5 presents the results of RBA estimates on the three indicators for the variation of households' ownership of home assets over time. The only parameter estimate that may be significant is obtained from the probit regression of the binary dependent variable accounting for the presence of at least one additional home asset class in 2012 compared to 2006, when the treatment assignment is assumed to be ignorable and when no covariate controls for correlated shocks at the canton level. Models (3) and (4) tend to confirm that the identification strategy do neutralize the correlation between the RBA variable and treatment determinants, since in model (3) the covariance adjustment performed results in the RBA parameter being no longer

significantly different from zero for that dependent variable. In addition, we also apply model (2) jointly with canton fixed effects on an estimation sample using weights derived from the propensity score predicted by probit model (3) as we did in model (6) on eligible asset adoption (see Table 3.4) and the resulting estimate for RBA is again not significant and even negative (parameter at -0.025 with a standard error at 0.451).

Therefore, the Placebo test results do confirm the absence of RBA impact on the variation of households' ownership of home assets over time when our identification strategy is applied. They provide no evidence that our identification strategy leads to overestimate or underestimate the RBA impact. It is worth mentioning that the test results are unlikely to mean that RBA program has no indirect effects on participants' wealth. Due to the fact that most of ranchers from the treated sample have not participated in RBA projects earlier than in the 2012 project, potential indirect effects on welfare indicators are more than likely to be lagged and for that reason our strategy does not allow for a proper identification of these effects.

Test for diffusion effects

Secondly, in order to test whether or not the ranchers from the control group have been affected by the program before their participation into 2013 RBA project, we rely on the existing variability in farm coverage from RBA program between cantons. Taken into account in our estimations by canton fixed effect as explained in Section 5, we explore the effect of the prevalence of treatment among ranchers populations as an omitted variable bias when no canton fixed effects are included in the regressions of eligible assets indicators. The variable we use as coverage is the shares of ranchers participating into 2007-2012 RBA projects in each canton and comes from the lists approved by the Program Coordination Unit and from 2014 agricultural census (INEC, 2014b). We also use a proxy for shocks correlated at the canton level that measures the cumulative economic losses reported as climate-induced damages on cattle and pastures in each canton between 2006 and 2012 (MIDEPLAN/MAG, 2018), and divided by the population size of cattle ranchers in the canton. The correlation coefficient between both canton variables is very close to zero (-0.0045).

The test is based on RBA coverage being a reliable proxy for the probability that diffusion effects have emerge locally, such that it may be an important variable in that it may determine the eligible asset indicators. For instance, externalities of learning about the correct use of eligible assets and other peer effects are likely to depend on how many adopters are in the social network (Bandiera and Rasul, 2006). Since ranchers sampled from 2007-2012 projects are in a closer relation with the ranchers' association and MAG agency compared to the ranchers from 2013 project, these social effects may also be a discriminant between both sampled groups. Therefore, when the coverage variable is excluded from regression models, RBA parameter estimates are measuring the effect of receiving the treatment compared to not receiving it, as well as all diffusion effects related to the program coverage and unbalanced between both sampled groups. When the coverage variable is included as a covariate, the sign of its parameter jointly with the comparison of RBA estimates before and af-

ter the inclusion provides useful indications about the captured diffusion effects and direction of the induced bias of RBA estimates.

If introducing the coverage variable reveals that RBA estimate is upward biased when it is excluded, but the coverage effect on eligible assets indicators is positive, one interpretation could be that a share of the increase in eligible assets indicators for ranchers sampled from 2007-2012 projects that we attributed to the program was in fact explained by some favorable factors depending on the canton coverage, so possibly social effects. As mentioned in Section 5, one particularly preoccupying case would arise if the upward bias is combined with a negative estimate as coverage effect. In that case, we could not exclude the possibility that a number, increasing with canton coverage, of sampled ranchers from 2013 project were aware of the program before 2013 such that they anticipated their participation and delay some investments in eligible assets. Considering the cases of downward bias of RBA estimates, the omission of more detailed variables on social networks would not challenge the positive RBA estimates we found in the regressions.

Table 3.6 displays the parameters of interest obtained from regressions of the differential in eligible assets index, then of the differential in eligible assets count and finally, of the binary indicator for adopting at least one additional eligible asset between 2006 and 2012. All models are based on the features of our identification strategy aiming at correcting for the selection bias. Nonetheless only model (5) include the canton fixed effects. In both model (2) and model (4), the coverage variable is introduced. The difference between model (2) and (4) is that in model (4) the losses variable is another covariate at the canton level which represents the incidence of climate-related stresses and was first introduced alone in model (3). Overall, both canton variable appear to account for the main confounding factors correlated at the canton level, as the RBA estimates from model (4) are all very close to the ones obtained with model (5). When the RBA estimates are compared between models (1) and (2), as well as between models (3) and (4), the differences indicates that the omission of the coverage variable leads to underestimating the RBA parameter in regressions of the differential in eligible assets index and of the binary indicator, whereas in regressions of the differential in eligible assets count, the RBA estimates appear to be upward biased when coverage is not included. Nevertheless, the upward bias is not combined with a negative sign on the coverage estimate so that it rather suggests that the positive effect of coverage was affecting mainly the treated ranchers.

While testing if the ranchers from the control group have been affected by the program before their participation into 2013 RBA project, we did not find evidence that if they have been, our previous results would have to be questioned. This result is not surprising since the treatment determinants introduced in our models may also capture the degree of integration of ranchers into social networks to some extent. We did not find reasons to undermine our findings either when performing a Placebo test for the parallel trend assumptions on household's ownership of durable goods and characteristics of housing. It is worth mentioned that the latter test suggests also that contamination of the sampled group from 2013 project by general equilibrium effects is unlikely as we do not detect any short term effects of RBA program on treated households wealth between 2006 and 2012.

Table 3.6: Parameters of interest when testing for the inclusion of RBA coverage at the canton level in regressions of eligible assets indicators

		Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
on Δ Index:	RBA	2.222** (1.054)	2.331** (1.078)	1.870* (1.031)	1.967* (1.056)	1.916* (1.118)
	Coverage		-0.0533 (0.0714)		-0.0421 (0.0666)	
				(0.00063)	(0.00062)	
	Canton dummy variables	NO	NO	NO	NO	YES
on Δ Count:	RBA	0.180 (0.156)	0.131 (0.157)	0.168 (0.160)	0.112 (0.163)	0.123 (0.151)
	Coverage		0.0110 (0.00905)		0.0120 (0.00928)	
	Losses			-0.00004 (0.00009)	-0.00005 (0.00009)	
	Canton dummy variables	NO	NO	NO	NO	YES
		(0.602)	(0.584)	(0.673)	(1.050)	(1.041)
			(0.0383)		(0.0538)	
			(0.00038)	(0.00063)		
	Canton dummy variables	NO	NO	NO	NO	YES

Odds ratios for estimates on Δ Count. Robust standard errors in parentheses.

^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Model (1): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + \epsilon_{ij}$.

Model (2): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + \beta_4 Coverage_j + \epsilon_{ij}$.

Model (3): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + \beta_5 Losses_j + \epsilon_{ij}$.

Model (4): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + \beta_4 Coverage_j + \beta_5 Losses_j + \epsilon_{ij}$.

Model (5): $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + d_j + \epsilon_{ij}$.

Exception for models on Count_d where Z_{ij} are not included as covariates but the estimator uses weights derived from the propensity score predicted by probit model (3).

6.4 Further impacts: spatial organization and land-use efficiency

According to Kaimowitz and Angelsen (2008), general equilibrium effects are in fact of great concern for our case study, since in the long run, if livestock production becomes more profitable thanks to the adoption of the eligible assets, the sector may attract capital and labour as it occurred from 1950s to 1970s. Once ranchers cease to be constrained, Kaimowitz and Angelsen (2008) argue that livestock intensification can encourage pasture expansion, instead of spatial structures sparing land for forests as formalized by Bonin et al. (2018).

In order to analyze the short run impact of RBA program on spatial dynamics among treated farms, we track ten indicators related to land uses and land use efficiency between 2006 and 2012. Total land represents the total area in hectares used for farming purposes, including the entire farm and potential summer grazing areas, without distinction of property status. Mean land unit size is the area of an average plot homogeneous in its land use and differentiated from neighboring plots by its land use and/or by fences. Grazing area represent the share of total area that is used for forage by cattle during the year. Feeding area is the grazing area increased by the share of total area covered with fodder banks. Stocking density, yet mentioned as a potential treatment determinant in Table 3.1, is the number of livestock units per hectare of grazing area. Weights used for the conversion of the different types of bovines are commonly used in Costa Rican surveys CORFOGA (2012). Land uses of interest are the shares of total area dedicated to improved pastures, natural pastures, fodder banks, shrublands and finally, forested lands (primary, secondary and riparian forests - plantations are excluded). We checked for equality of pre-treatment means and distributions for all of them.

All these variable are susceptible to be correlated as a consequence of measurement error and by construction. Therefore, applying linear regressions in a seemingly unrelated regression (SUR) system appears as the appropriate model in order to gain efficiency in estimations. Table 3.7 presents RBA estimates that we obtained with the SUR system of the ten linear regressions of the land use indicators. In each linear regression, the full identification strategy is applied. For robustness, we also report results from individual OLS regressions in Appendix 3.7.

The estimate obtained in the regression of the differential in total land indicates that the participation into 2007-2012 RBA projects reduces total land area by seven hectares. For both treated and control ranchers, most of the cases of land release were related to summer pastures that were rented. Still, since these summer pastures covered large amounts of land and cases of their release were not frequent enough, the large estimate suggests that almost 70% of the total land reduction observed in the mean treated farm can be attributed to the participation into the program, but the effect is not significant with a wide 90% confidence interval lying from a reduction by twenty hectares to an increase by six hectares.

The following estimate corresponds to the RBA impact on the mean land use unit size. It indicates that the program accounts for a decrease by 1.5 hectare between 2006 and 2012, which is half of the decrease observed in the mean treated farm

Table 3.7: Estimates of RBA parameters from SUR system of linear regressions of the differential in land use indicators between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)
	Δ Total <u>land</u>	Δ Mean land <u>use unit size</u>	Δ Grazing <u>area</u>	Δ Feeding <u>area</u>	Δ Stocking <u>density</u>
RBA	-7.076 (7.866)	-1.499 ^o (1.034)	-6.390 ^o (4.190)	-4.980 ^o (3.358)	0.249 (0.182)
R^2	0.492	0.800	0.495	0.609	0.362
<i>F statistic against null</i>	3.31***	12.06***	3.91***	5.17***	2.14***
	(6)	(7)	(8)	(9)	(10)
	Δ Improved <u>pastures</u>	Δ Natural <u>pastures</u>	Δ Fodder <u>banks</u>	Δ Shrub <u>lands</u>	Δ Forested <u>lands</u>
RBA	16.86* (8.660)	-1.276 (5.464)	1.430 (1.695)	-1.726 (1.687)	0.613 (3.524)
R^2	0.565	0.645	0.186	0.961	0.649
<i>F statistic against null</i>	3.95***	9.39***	1.36	87.54***	5.99***

Robust standard errors in parentheses. ^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Covariance matrix computed using small-sample adjustment.

Linear model applied: $\Delta y_{ij} = \beta_0 y_{ij0} + \beta_1 \Delta X_{ij} + \beta_2 RBA_{ij} + \beta_3 Z_{ij} + time + d_j + \epsilon_{ij}$.

between 2006 and 2012. This effects is probably not only due to the release of the large summer pastures, as the 90% confidence interval is narrower, from a reduction by 3 hectares to a small increase by one fifth of an hectare, and the p-value associated with the estimate is lower than 15%. The frequent adoption of eligible assets from the technological package related to pasture rotation is likely to be involved as stated by Bonin et al. (2018), as well as some rare cases of construction of fences on the edge of water sources or streams.

The third RBA parameter estimate represents the program impact on the share of total land being grazed and trampled by cattle and measures a reduction by 6.3 percentage points. It is almost the double of the mean reduction observed in the treated group between 2006 and 2012, indicating that the model would have predicted an increase in grazing area based on the observable characteristics of the treated ranchers, if they would not have been treated. Still, this reduction attributed to the program is barely significant at 15%, with a 90% confidence interval ranging from a reduction by 13 percentage points, to an increase by 0.5 point. The reduction of land being grazed and thus trampled can also be related to the same drivers explaining the reduction in the mean land use unit size.

As the main land use grazed in the sampled farms, pastures are affected by RBA program toward their intensification. RBA estimate (6) shows an increase by 17 percentage points in the share of total land covered by improved pastures that can be attributed to the program., which represents two thirds of the observed differential in the mean treated farm. The effect is significant at 10% and the 90% confidence interval lies from an increase by 2.6 percentage points to an increase by 31 point. Conversely, a decrease by 1 point percentage in the share covered by natural pastures is due to the program according to RBA estimate (6). The 90% confidence interval for this estimate is wide, from a decrease by 10 points to an increase by 7 points. Whereas the observed differential in the mean treated farm was an increased in natural pastures by 8 points, the model thus predicts that the mean treated farmer would have expanded natural pastures even more in the absence of the program. It is worth mentioning that the magnitude of its parameter is incremented in the SUR model compared to the OLS regression (see Appendix 3.7). This may be related to regression (1) of the total land denominator. Since most of the land release that can be attributed to the program was related to large summer natural pastures, the OLS estimate on the share of the remaining land covered by natural pastures appears to be downward biased. This signals that the reduction in natural pastures explained by RBA participation is likely to be not only due to summer pasture release, but also to land use conversion on farm, probably into improved pastures.

RBA impact on the differential of the share of total land dedicated to feeding animals indicates that the program is estimated as a decrease by 5 percentage points. Again, this effect is exceeding by far the mean decrease in feeding area observed among treated ranchers between 2006 and 2012, suggesting that based on their observable characteristics, they would have increased this share without the program, according to the model. This result is mainly due to the previous result on grazing land, and their difference can be explained by the increase in fodder banks that can be attributed to the program, as indicated by the RBA estimate (7) on the differen-

tial in shares of total land covered by fodder banks. The p-value associated with the estimate of RBA impact on feeding area is lower than 15% and the 90% confidence interval ranges from a decrease by 13 percentage points to an increase by 0.5 point.

Regarding the stocking density, its regression estimates that an increase by 0.25 livestock unit per hectare of grazing land is explained by the participation into 2007-2012 RBA projects. This is merely the mean increase observed among treated ranchers. The 90% confidence interval lies from a decrease by 0.05 to an increase by 0.55 livestock unit per hectare. As described in Section 3, the very low stocking densities in the study site are critical. The mean density among treated ranchers in 2006 is 1.2 livestock units per hectare grazed, such that the RBA estimated impact is of major importance. Compared to the standard error of the OLS estimate (see Appendix 3.7), the standard error from the SUR model is higher such that the parameter is no longer significant at 15%. An explanation which is consistent with previous estimates of RBA impacts from SUR model may rely on the fact that the RBA impact on stocking density is mainly due to the reduction in grazing area yet attributed to the program. This explanation would be also consistent with the fact that the potential indirect effects of RBA program on the cattle size (enhanced profitability or reduced mortality for example) are likely to be temporally lagged.

Finally, RBA estimates (9) and (10) measure the RBA effect on unproductive land uses, namely the shares of shrublands and forests respectively. The estimate on shrublands indicates that a decrease by almost 2 percentage points in shrublands can be attributed to the program, with a 90% confidence interval from -4.5 to +1 percentage points. Conversely, the RBA effect on forested lands for the mean treated rancher is positive, representing an increase by 0.6 percentage points, but highly uncertain with a wide 90% confidence interval ranging from a decrease by 5 points to an increase by 6.5 points. As the observed mean value of the differential in forest share is -3.3 percentage points among treated ranchers, the positive estimate for forest signals that the model would have predicted a larger reduction of the forest share for the mean treated rancher in the absence of the program, based on observable characteristics. The comparison of the RBA estimates on shrublands and on forests suggests that if the RBA program supported the conversion of shrublands into forests, this would not explained all the reduction in shrublands due to the program. Most of it would be more likely related to the increase in improved pastures attributed to the program.

Overall, RBA estimates tend to confirm that the program induced a reduction in total land and a decrease in the remaining land being dedicated to feeding cattle for the mean participant sampled from 2007-2012 RBA projects. The release of large summer natural pastures is likely to be not the only driver of that effect. Lesser uncertain estimates suggest that on the mean treated farm, division and improvement of pastures were also involved in that process and related to the program. Whereas the model would have predicted a larger increase in productive lands, in particular natural pastures, and a higher rate of deforestation for the mean treated rancher in the absence of the program, the program seems to have rather encouraged the conversion of suitable lands formerly covered by natural pastures and shrublands into even more intensified land uses, namely improved pastures and to as lesser extend fodder banks. As a consequence, a large proportion of the increase in the mean stocking density

observed among treated farmers would be attributed to the enhanced productivity of productive lands induced by the program. In addition, this may have spared some forested patches from the conversion into pastures or supported the natural conversion from shrublands formerly grazed and trampled into secondary forests, still the effect is not detectable. In the hypothesis of natural regeneration, this effect would be likely to be temporally lagged again.

7 Conclusion

The Recognition for Environmental Benefits program implemented in Costa Rica is the result of years of pilot experiences on production technologies for small and medium holders across the country enhancing productivity and provision of environmental services. More recently, it was referred as one of the strategic instruments in the State agricultural policy while addressing the issue of adaptation to and mitigation of climate change in farming systems. Based on a list of heterogeneous eligible assets, it supports ecological transitions by reimbursing twenty to thirty percents of the investment cost to individual farmers and producers' organizations who adopt such assets. In order to determine whether the program triggered additional effects among beneficiaries instead of only rewarding adopters who would have adopted the assets in the absence of the program, we estimate the average impact of participating into RBA projects on the case of livestock production in Guanacaste. Particularly prone to severe drought, the study site is characterized by extensive, undercapitalized and low-profitable systems that encompass a substantial amount of forested lands. Eligible assets related to livestock production represent technological packages toward ecologically intensified systems based on silvopastoralism, pasture rotation and improved feeding and water access.

We apply common impact assessment methods on original data collected from 63 ranchers, 31 of them forming a pipeline comparison group. We detected additional effects on the adoption of eligible assets evidencing that RBA program has led to an increase in investments toward ecologically intensified systems. In particular, the program has encouraged participants to both increase the aggregated quantities and diversity of eligible assets on farm. It was responsible for a significant share of the investment occurred in average among the participating ranchers, ranging from 0% to 83%. In addition, participating ranchers were 19% to 77% more likely to diversify the eligible assets owned on farm thanks to the program. We presented evidence in favor of the internal validity of these results. Therefore, our findings suggest that the program has accelerated the investment process toward more ecologically intensified systems, still its estimated effect on diversification appears to be limited. The increased probability to diversify the set of eligible assets due to the program was lower than 100% and the program effect on the number of eligible assets was negligible for the mean participating rancher. Based on these results, the program appears as a more adequate instrument to support technological adoption on the intensive margin rather than on the extensive margin, such that it would have had a lower cost-efficiency if it would have aimed at promoting radical innovations.

We also presented evidence that the participation into RBA program has translated into changes in land uses that are all very consistent with an intensification of livestock systems based on cattle rotation between more productive pastures, despite of the uncertainty in the magnitude of our estimates. Concomitantly, the program induced a reduction in the land used to feed cattle and probably an increase in stocking density too. The findings reported here are important because they show that, in Costa Rica, a state-funded intervention has been effective in improving development outlook for the livestock sector in one of its poorest province, while also sparing land from being grazed and trampled by cattle whereas historical trends highlight the vulnerability of private forests to the development of this activity. It should be noted, however, that in the longer run, market equilibrium effects could offset or even invert this impact. Since on the one hand, the program enhances land and water efficiency and on the other hand, the production technology that is promoted is more labor and capital intensive, further research could assess that risk by studying local market imperfections and determining in which factors participating ranchers will be rapidly constrained.

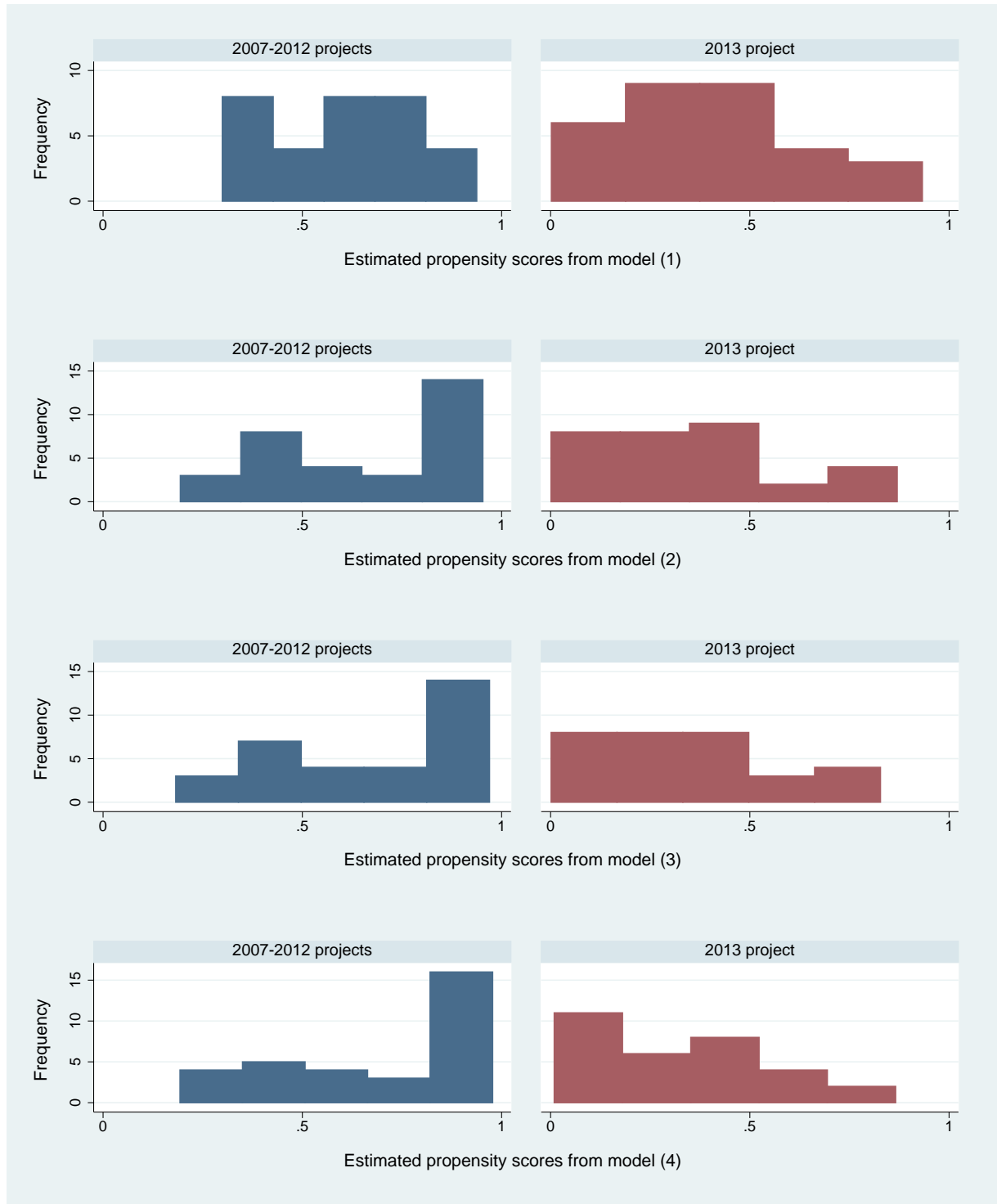
Appendices

3.1 Probit model estimates of receiving RBA program between 2007 and 2012

	(1)	(2)	(3)	(4)
	<u>RBA</u>	<u>RBA</u>	<u>RBA</u>	<u>RBA</u>
Time to commute to the ranchers' association	-0.00737* (0.00446)	-0.0124** (0.00531)	-0.0126** (0.00601)	-0.0112** (0.00439)
Attendance to the last ten meetings of the ranchers' association	0.110** (0.0501)	0.136** (0.0532)	0.149** (0.0645)	0.152*** (0.0516)
Dairy system exploited on the farm in 2006	0.767° (0.488)	1.040** (0.470)	1.035** (0.481)	1.146** (0.516)
Total land area owned in 2006	-0.00608** (0.00292)	-0.00505* (0.00289)	-0.00547° (0.00337)	-0.00404 (0.00285)
Farm acquired by inheritance or from a relative		-0.665* (0.375)	-0.705* (0.414)	-0.645° (0.393)
Home assets index in 2006		-0.0244** (0.0102)	-0.0266** (0.0112)	-0.0212* (0.0114)
Member of the ranchers' association in 2006			-0.163 (0.485)	
Family member in charge at MAG or at the ranchers' association			-0.163 (0.485)	
Technical assistance received from MAG			-0.158 (0.410)	
PSA-FONAFIFO received in 2006 or before			-0.213 (0.555)	
Farm acquired from the agrarian institute			0.0173 (0.618)	
Stocking density in 2006			-0.0571 (0.236)	
Constant	-0.296 (0.362)	0.841 (0.592)	1.104° (0.732)	-0.0948 (0.985)
Canton dummy variables	NO	NO	NO	YES
<i>N</i>	63	63	63	63
<i>Log likelihood</i>	-35.77	-31.92	-31.63	-30.35
<i>pseudo R</i> ²	0.181	0.269	0.275	0.305
<i>Wald χ</i> ²	10.43**	21.32***	26.41***	30.76***
<i>CAIC</i>	97.25	99.84	130.14	122.42
<i>BIC</i>	92.25	92.84	117.14	110.42
<i>Correct classification (% in both groups)</i>	69.84	73.02	73.02	73.02
<i>False negatives (% of 2007-2012 participants)</i>	31.25	34.38	31.25	28.13
<i>False positives (% of 2013 participants)</i>	29.03	19.35	22.58	25.81

Odds ratios. Robust standard errors in parentheses. ° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
LR test statistic for (3) against (2) at 0.91 with a p-value at 0.99 supporting that the extra parameters in (3) are not jointly significant.

3.2 Distributions by sampled groups of the estimated propensity scores from models in Appendix 3.1



3.3 Set and descriptive statistics of eligible assets variables used to compute the eligible asset index (N=126)

	<u>Mean</u>	<u>St. Dev.</u>	<u>Min</u>	<u>Max</u>	<u>KMO^a</u>
Living fences (m)	1457.7	2341.5	0	12000	0.60
Sheds for fodder storage (m ²)	15.2	43.5	0	288	0.54
Improved pasture area (Ha)	16.9	31.6	0	138	0.59
Fodder banks are (Ha)	1.3	3.6	0	24	0.71
Silos (m ³)	0.16	1.25	0	10	0.52
Feeders (m)	8.0	30.0	0	300	0.75
Pasture area with more than trees/Ha (Ha)	14.3	25.2	0	125	0.28
Irrigation or fertigation system (%)	4.0		0	1	0.44
Improved farm roads (m)	163.2	493.7	0	3000	0.65
Harvesting equipments (number)	0.33	0.51	0	2	0.81
Biodigesters (m ³)	48.1	325.1	0	3000	0.54
Solar panels (m ²)	0.10	0.39	0	2	0.56
Water pipes (m)	189.4	341.6	0	1500	0.39
Water reservoirs (m ³)	5.3	45.4	0	500	0.21
Diesel pumps (number)	0.22	0.45	0	2	0.28
Drinking troughs (m)	6.4	17.9	0	100	0.80
Wind pumps (number)	0.06	0.23	0	1	0.85
Electric fences (%)	9.5		0	1	0.71
Cattle sheds (m ²)	15.2	55.4	0	350	0.85
Artificial salt licks (m)	2.8	12.8	0	100	0.75
Sheds for compost piles (m ²)	3.3	22.8	0	180	0.37
Riparian forest area (Ha)	2.0	6.1	0	40	0.41

^a: Kaiser-Meyer-Olkin index measuring the proportion of variance that is shared with other variables.

3.4 Additional OLS regressions of the differential in eligible asset index between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Δ Index	Δ Index	Δ Index	Δ Index	Δ Index	Δ Index	Δ Index
RBA	3.130** (1.299)	3.519*** (1.229)	3.197** (1.219)	3.004** (1.305)	2.935** (1.277)	2.995** (1.327)	2.315** (1.100)
Index in 2006	0.0387 (0.0487)	0.0191 (0.0318)	0.0326 (0.0382)	0.0199 (0.0386)	0.0174 (0.0403)	0.0194 (0.0434)	0.0236 (0.0455)
Δ 12-60 y/o household members	0.0410 (0.353)	-0.0337 (0.370)	0.0800 (0.367)	0.0862 (0.367)	0.0932 (0.373)	0.103 (0.398)	0.0404 (0.386)
Δ Household members off-farm	2.307** (0.871)	1.939** (0.734)	2.111*** (0.745)	2.050** (0.770)	2.053** (0.788)	2.089** (0.856)	2.243*** (0.795)
Δ Public aid received	5.111** (2.529)	4.480* (2.610)	4.383* (2.443)	4.419* (2.571)	4.505* (2.607)	4.618° (2.828)	4.523* (2.555)
Change in farming system	5.362*** (1.587)	4.304*** (1.481)	3.582** (1.403)	3.778*** (1.383)	3.764** (1.418)	3.607** (1.491)	3.627** (1.534)
Land area owned in 2006		0.0200* (0.0109)	0.0193* (0.0106)	0.0200* (0.0111)	0.0195° (0.0120)	0.0189 (0.0135)	0.0197 (0.0138)
Farm inherited			-1.743 (1.235)	-1.670 (1.230)	-1.629 (1.297)	-1.586 (1.305)	-2.138° (1.279)
Dairy farm in 2006				1.293 (1.412)	1.286 (1.451)	1.221 (1.603)	1.654 (1.510)
Meeting attendance					0.0412 (0.172)	0.0412 (0.173)	0.117 (0.180)
Commuting time						0.00289 (0.0140)	-0.00363 (0.0130)
Home assets in 2006							-0.0563* (0.0287)
Constant	0.683 (0.837)	-0.109 (0.809)	0.925 (0.888)	0.746 (0.853)	0.546 (1.195)	0.412 (1.392)	2.660* (1.537)
Canton dummy variables	NO	NO	NO	NO	NO	NO	NO
<i>N</i>	63	63	63	63	63	63	63
<i>adj. R</i> ²	0.205	0.266	0.282	0.279	0.266	0.252	0.283

Robust standard errors in parentheses. ° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

3.5 Additional Poisson ML regressions of the differential in eligible asset count between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Δ Count	Δ Count	Δ Count	Δ Count	Δ Count	Δ Count	Δ Count
RBA	0.497*** (0.164)	0.498*** (0.165)	0.418*** (0.147)	0.378** (0.149)	0.393** (0.162)	0.402** (0.161)	0.267* (0.162)
Count in 2006	-0.114*** (0.0322)	-0.115*** (0.0332)	-0.104*** (0.0310)	-0.112*** (0.0283)	-0.107*** (0.0299)	-0.105*** (0.0305)	-0.101*** (0.0301)
Δ 12-60 y/o household members	0.0331 (0.0408)	0.0325 (0.0410)	0.0508 (0.0405)	0.0541 (0.0415)	0.0536 (0.0412)	0.0555 (0.0410)	0.0379 (0.0372)
Δ Household members off-farm	0.257** (0.120)	0.256** (0.126)	0.285** (0.112)	0.273** (0.108)	0.272** (0.106)	0.276*** (0.107)	0.279*** (0.104)
Δ Public aid received	0.635*** (0.217)	0.632*** (0.221)	0.599*** (0.193)	0.638*** (0.223)	0.618*** (0.233)	0.635*** (0.238)	0.581*** (0.204)
Change in farming system	0.467*** (0.168)	0.464*** (0.161)	0.318** (0.145)	0.372*** (0.139)	0.374*** (0.135)	0.354** (0.149)	0.322** (0.143)
Land area owned in 2006		0.00006 (0.00109)	-0.00008 (0.00094)	0.00007 (0.00095)	0.00018 (0.00108)	0.00002 (0.00127)	0.00006 (0.00122)
Farm inherited			-0.308** (0.142)	-0.294** (0.142)	-0.304** (0.152)	-0.296* (0.155)	-0.359** (0.145)
Dairy farm in 2006				0.327* (0.177)	0.329* (0.174)	0.316* (0.181)	0.411** (0.169)
Meeting attendance					-0.00824 (0.0215)	-0.00922 (0.0209)	-0.000376 (0.0204)
Commuting time						0.00047 (0.00157)	-0.00017 (0.00135)
Home assets in 2006							-0.00878** (0.00401)
Constant	1.305*** (0.200)	1.304*** (0.199)	1.457*** (0.195)	1.421*** (0.183)	1.440*** (0.188)	1.416*** (0.199)	1.760*** (0.256)
Canton dummy variables	NO	NO	NO	NO	NO	NO	NO
<i>N</i>	63	63	63	63	63	63	63
<i>Log likelihood</i>	-119.89	-119.89	-117.98	-116.29	-116.22	-116.19	-114.10
<i>pseudo R</i> ²	0.133	0.133	0.146	0.159	0.159	0.159	0.175
<i>Wald</i> χ^2	47.40***	51.61***	65.14***	74.99***	79.01***	75.63***	96.79***
<i>CAIC</i>	275.78	280.92	282.25	284.00	289.02	294.10	295.07
<i>BIC</i>	268.78	272.92	273.25	274.00	278.02	282.10	282.07

Odds ratios. Robust standard errors in parentheses. ^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

3.6 Additional Probit regressions of the adoption of at least one additional eligible asset between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Adoption	Adoption	Adoption	Adoption	Adoption	Adoption	Adoption
RBA	1.453*** (0.505)	1.527*** (0.532)	1.704*** (0.560)	1.717*** (0.574)	1.694*** (0.569)	1.799*** (0.645)	2.175*** (0.689)
Count in 2006	-0.462*** (0.134)	-0.489*** (0.147)	-0.563*** (0.170)	-0.558*** (0.167)	-0.581*** (0.169)	-0.582*** (0.171)	-0.600*** (0.169)
Δ 12-60 y/o household's members	-0.0676 (0.0969)	-0.0712 (0.100)	0.00816 (0.126)	0.00732 (0.126)	0.0111 (0.127)	0.0368 (0.143)	0.0356 (0.153)
Δ Household members off-farm	0.617° (0.377)	0.627° (0.393)	0.797* (0.412)	0.804* (0.413)	0.819** (0.409)	0.900** (0.421)	1.290*** (0.414)
Δ Public aid received	0.662 (0.718)	0.731 (0.764)	1.057 (0.923)	1.084 (0.912)	1.023 (0.853)	1.238 (1.012)	2.313** (1.167)
Change in farming system	0.189 (0.504)	0.0235 (0.529)	-0.218 (0.494)	-0.245 (0.517)	-0.227 (0.538)	-0.265 (0.529)	-0.465 (0.544)
Land area owned in 2006		0.00353 (0.00332)	0.00466 (0.00417)	0.00462 (0.00413)	0.00437 (0.00426)	0.00464 (0.00475)	0.00801* (0.00452)
Farm inherited			-1.038** (0.431)	-1.033** (0.429)	-1.028** (0.428)	-1.062** (0.441)	-1.825*** (0.589)
Dairy farm in 2006				-0.104 (0.546)	-0.0770 (0.540)	-0.158 (0.520)	-0.174 (0.519)
Meeting attendance					0.0300 (0.0689)	0.0279 (0.0688)	0.104 (0.0884)
Commuting time						0.00390 (0.00740)	-0.00067 (0.00657)
Home assets in 2006							-0.0368** (0.0147)
Constant	2.560*** (0.828)	2.554*** (0.847)	3.486*** (0.996)	3.471*** (0.980)	3.427*** (0.984)	3.286*** (1.104)	4.640*** (1.141)
Canton dummy variables	NO	NO	NO	NO	NO	NO	NO
<i>N</i>	63	63	63	63	63	63	63
<i>Log likelihood</i>	-19.18	-18.89	-17.10	-17.09	-17.02	-16.93	-14.91
<i>pseudo R</i> ²	0.425	0.434	0.488	0.488	0.490	0.493	0.553
<i>Wald χ</i> ²	19.22***	17.49***	25.37***	27.21***	27.32***	26.54***	30.90***
<i>CAIC</i>	74.37	78.93	90.49	85.60	90.62	95.59	96.69
<i>BIC</i>	67.37	70.93	71.49	75.60	79.62	83.59	83.69

Robust standard errors in parentheses. ° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

3.7 OLS regressions of the differential in land-use outcomes between 2006 and 2012

OLS regressions of the differential in land-use efficiency indicators between 2006 and 2012

	(1)	(2)	(3)	(4)	(5)
	Δ Total land	Δ Mean land use unit size	Δ Grazing area	Δ Feeding area	Δ Stocking density
RBA	-7.023 (5.685)	-1.519 ^o (0.947)	-6.281 ^o (4.054)	-4.817 (3.404)	0.249 ^o (0.168)
2006 level of the dependent variable	-0.480 ^o (0.287)	-0.716*** (0.100)	-0.403*** (0.149)	-0.453*** (0.155)	-0.310*** (0.0987)
Δ 12-60 y/o household's members	0.651 (1.462)	0.00384 (0.255)	0.469 (1.131)	0.821 (1.092)	0.0579* (0.0341)
Δ Household's members off-farm	-2.906 (7.400)	-0.834 (0.798)	-4.381 ^o (2.691)	-4.120* (2.424)	0.195* (0.105)
Δ Public aid received	-4.491 (7.926)	0.862 (1.693)	-3.342 (4.447)	-4.211 (4.174)	0.203 (0.192)
Change in farming system	-8.700 (11.21)	-3.421** (1.625)	8.243 (7.083)	6.219 (5.623)	0.0775 (0.356)
Land area owned in 2006	0.512* (0.286)	0.0536*** (0.0129)	-0.0914** (0.0345)	-0.105*** (0.0298)	-0.00114 (0.00121)
Farm inherited	1.544 (4.651)	0.328 (0.816)	-2.676 (3.915)	-5.307* (3.127)	-0.00746 (0.155)
Dairy farm in 2006	8.441 (8.211)	-0.327 (0.958)	0.305 (4.269)	-0.646 (3.117)	0.324* (0.178)
Meeting attendance	0.0726 (0.543)	-0.234* (0.117)	-0.143 (0.459)	-0.195 (0.442)	0.0446** (0.0194)
Commuting time	0.0832 (0.0975)	-0.00202 (0.0106)	-0.0806* (0.0410)	-0.0627* (0.0338)	-0.00101 (0.00180)
Home asseets in 2006	-0.229 (0.163)	0.00327 (0.0227)	0.0197 (0.0933)	0.0313 (0.0741)	0.00152 (0.00303)
Constant	23.28 (20.51)	1.219 (2.331)	43.54** (17.29)	54.00*** (17.39)	-0.140 (0.347)
Canton dummy variables	YES	YES	YES	YES	YES
<i>N</i>	63	63	63	63	63
<i>adj. R</i> ²	0.326	0.744	0.331	0.503	0.140

Robust standard errors in parentheses. ^o $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

OLS regressions of the differential in land uses (in % of the total land occupied for farming purposes) between 2006 and 2012

	(6)	(7)	(8)	(9)	(10)
	Δ Improved pastures	Δ Natural pastures	Δ Fodder banks	Δ Shrub lands	Δ Forested lands
RBA	16.83* (9.123)	-0.714 (4.865)	1.441 (1.806)	-1.725 (1.904)	0.862 (3.376)
2006 level of the dependent variable	-0.381*** (0.117)	-0.533*** (0.0933)	-0.00697 (0.0582)	-1.012*** (0.0258)	-0.401*** (0.103)
Δ 12-60 y/o household's members	11.00*** (2.375)	2.544° (1.628)	0.529 (0.421)	0.0127 (0.373)	0.376 (0.684)
Δ Household's members off-farm	-0.517 (6.342)	-7.027* (4.049)	0.0981 (0.610)	-0.384 (0.598)	4.907° (3.197)
Δ Public aid received	5.386 (12.22)	-8.078 (9.591)	0.279 (1.400)	-1.890 (1.439)	13.44** (5.831)
Change in farming system	25.48 (17.61)	2.998 (7.626)	2.194 (1.515)	-0.0131 (3.521)	-13.58° (8.261)
Land area owned in 2006	-0.0636° (0.0424)	-0.0711* (0.0360)	-0.00277 (0.00905)	-0.0101° (0.00667)	0.101*** (0.0301)
Farm inherited	-19.57** (8.330)	-5.247 (4.582)	-2.425° (1.646)	-2.539 (1.768)	3.920 (3.268)
Dairy farm in 2006	0.379 (10.17)	1.484 (5.022)	0.916 (1.571)	-1.791 (1.420)	2.674 (3.857)
Meeting attendance	1.142 (0.956)	0.991° (0.670)	0.170 (0.167)	0.243 (0.167)	-0.0383 (0.443)
Commuting time	0.0475 (0.110)	-0.0292 (0.0544)	-0.00717 (0.0138)	0.00873 (0.0187)	0.0872** (0.0382)
Home assets in 2006	-0.0500 (0.202)	-0.0615 (0.133)	-0.0199 (0.0313)	-0.0241 (0.0299)	-0.0698 (0.0851)
Constant	35.50** (16.96)	43.83*** (15.50)	3.149 (2.809)	4.144 (2.917)	2.484 (8.134)
Canton dummy variables	YES	YES	YES	YES	YES
<i>N</i>	63	63	63	63	63
<i>adj. R</i> ²	0.413	0.535	-0.032	0.948	0.534

Robust standard errors in parentheses. ° $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

General conclusion

This dissertation explored the adoption of agroforestry and silvopastoralism by Costa Rican smallholders in the two main farming systems of the country, namely high-quality coffee plantations and extensive cattle-ranching farms. Smallholders' ability to secure food supplies is severely challenged by climate change and at the same time, their role is crucial for the achievement of mitigation efforts. In this dissertation, I present the results of three studies that use original data to investigate opportunities and challenges for scaling-up agroforestry and silvopastoralism as potential CSA technologies. To conclude the thesis, I outline the main findings, I then draw some conclusions from a policy perspective, and finally I discuss the limits and possible extension of the dissertation for future research.

1 Main findings

Far from being limited to the externality issue related to mitigation efforts, CSA adoption raises many concerns and open questions. One of them relates to the capacity of smallholders from developing regions to maintain agricultural yields while, simultaneously, dealing with the increasing uncertainty about future developments of climate, prices, pests and diseases. Some risk-coping strategies that they may implement in this context are more likely to threaten food supplies than to favor investments in technologies that hold promises for successful maintenance of yields given predicted changes in climate conditions.

Once evidence about potential barriers putting strain on CSA technology adoption by rural households in the developing world was presented, the dissertation brought out three critical challenges for academics to inform debates on agricultural transformation towards CSA. First, it became critical to identify and evaluate technologies that can be promoted within the CSA framework, not only based on plot-scale experimental trials, standard household surveys and a partial vision of the adoption concept (Andersson and D'Souza, 2014; Glover, Sumberg, and Andersson, 2016). Second, given the agroecological heterogeneity of farms and socio-economic heterogeneity of rural households, the identified technologies are likely to only ever

provide the expected benefits to a subset of farmers. A further challenge would be thus to accurately target these farmers (ISPC, 2018). Finally, since the rapid and broad-scale adoption of CSA technologies requires institutional arrangements and funding mechanisms (Harvey et al., 2014), evidence on the effectiveness of such policies still has to be demonstrated.

Chapter 1 was an application of the first challenge to the case of coffee agroforestry. Increasing shade tree cover in coffee plantations is well-documented as a promising practice to avoid production and quality loss from heat, water stress and some climate extremes, due to the buffering effect of shade tree crowns on the microclimate of a plantation. At the same time, literature confirms that shade trees in coffee plantations can be significant sinks of atmospheric carbon mainly by sequestering carbon in their aboveground biomass. However, it often entails reduced coffee yields due to limited sunlight.

By developing a farm model based on yield data from an experimental coffee trial conducted in Costa Rica and measuring a yield penalty under shade trees, this study suggested that agroforestry was not an optimal choice for a representative coffee smallholder under current conditions. Simulation results indeed pointed out that adopting agroforestry was costly and its opportunity cost as assessed was high, from USD 800-1,200 per hectare and per year. More problematic, adopting agroforestry could limit the farmer's capacity to adjust to price signals in the short term, whereas the market risk is a salient concern among coffee farmers, as proven later in Chapter 2. The meager profits (below the poverty line) combined with a reduced resilience when facing adverse price shocks makes adopting agroforestry a riskier decision threatening food security goals, not only by lower supplies but for the household itself. An incentive-based intervention would thus have to compensate for both lower profits and a risk premium, which would imply substantial costs for the program.

Chapter 2 built on these conclusions and the challenge of dealing with farmers' heterogeneity. It investigated the acceptability in the real world of diverse agroforestry systems, jointly with various types of incentives that could be used to promote agroforestry adoption. Based on the assumption that improving risk management within agroforestry systems could reduce the opportunity cost of adopting the technology, the adaptive strategies that were tested included resistant coffee varieties and/or timber trees that may be attractive farming practices to deal with risks, in addition to a shade tree cover of various densities.

Applied to original data from a choice experiment conducted in the Los Santos Valley on a large sample of coffee farmers, the econometric models explicitly considered preference heterogeneity among respondents. The results suggested that most of the respondents did value the introduction of resistant varieties such that they were willing to plant twice more trees in their plantations if combined with resistant varieties. Conversely, all agroforestry systems implying to plant timber trees were significantly less popular and, on average, their adoption would require a compensation scheme. This compensation might be justified by the superior carbon

sequestration associated with timber trees. The analysis moreover showed that a large majority of respondents were responsive to a contract offering a cash payment, a subsidized credit, a free trial of resistant coffee plants or technical assistance. Results also pointed out that respondents with a strong taste for the agroforestry system combining resistant varieties also tended to be very responsive to the credit offer. This result suggested that the adoption of such systems might require an enhanced access to financing and, in consequence, be slowed down in its absence.

Finally, since in Chapter 2 coffee farmers appeared to be responsive to economic incentives, Chapter 3 evaluated the impact of a cost-share program promoting the adoption of CSA-like technologies, namely the Recognition for Environmental Benefits program. Such programs are rare in tropical regions, as is evidence of their effectiveness. The study focused on cattle-ranching systems in the Northwestern province of Guanacaste. The study area is composed of extensive, undercapitalized and low-profitable cattle-ranching systems which include substantial forested lands that are highly vulnerable to deforestation when the profitability of cattle ranching increases. The technologies promoted for cattle ranching were technological packages consistent with silvopastoralism-based intensification.

Relying on a Difference-In-Difference approach applied to a random sample composed of beneficiaries who participated in the early RBA phase and ranchers who were not participant at the time of the survey but became participants afterwards, Chapter 3 provided estimates of the additional impact of participating into the RBA program on both the technology adoption and the land use patterns. The results suggested that the program has been effective in increasing the adoption of the promoted technologies, in both quantities and diversity. In addition, it has fostered the ecological intensification of cattle-ranching systems, by inducing a reduction in the land used to feed cattle and probably by increasing stocking density too, while also sparing land from being grazed and trampled by cattle. Overall, the finding reported showed that, in one of the poorest Costa Rican provinces, a state-funded intervention has been effective in stimulating CSA adoption in an activity representing a major source of greenhouse gas emissions.

2 Policy perspective

From a policy perspective, the dissertation has shed light on several challenges and opportunities for scaling-up CSA in tropical countries.

First, the results of this dissertation all stressed that the autonomous adoption of the studied technologies was costly, despite the private benefits cited in the literature. In Chapter 1, the technology had associated a substantial opportunity cost. Despite a moderate discount rate measured, it was also highlighted that the time horizon of the smallholder was relatively short, such that long-term private benefits would have little impact on the decision of technology adoption. Moreover, two of the adaptive strategies discussed in Chapter 2 would require a substantial compensation. The other two strategies would not, yet they were not implemented in the light of the current

practices of coffee farmers, not even the strategy for which a willingness to pay has been estimated. Finally, in Chapter 3, the producers would not have invested that much in the technological package in the absence of the program evaluated.

On the one hand, and despite the magnitude of the predicted impacts of climate change, deviating from current farming practices was not always a first-best choice that would be constrained by market failures, as evidenced by the results of Chapter 1. The underperformance of agroforestry was first justified by the lower yields it entailed, then, to a lesser extent, by the reduced flexibility it offered to adjust to price signals. The resulting welfare differential was high, so waiting for the yield gap to go down will require some time. Thus, even in a context of perfect markets, deviating from current practices to adopt new technologies would not improve the farmers' situation.

On the other hand, market frictions were a second clear determinant of non-adoption. This was especially salient in Chapter 2, where farmers were not currently growing resistant plants under a dense shade tree canopy despite the positive value given to this agroforestry system. Their decision can reasonably be explained by the costs to access distributors offering these newly developed seedlings, combined with an information deficit. In the case of the producer facing market instability as discussed in Chapter 1, the risk premium considered due to the lack of flexibility of the technology was clearly exacerbated by the lack of financial markets in the modeling. Finally, the impact induced by the program evaluated in Chapter 3 can hardly be associated with relaxed credit constraint because repayment takes place after the implementation of the technology. However, the role of extension agents can not be excluded from the intervention. On the contrary, it was an integral part of the program because of the information they disclose, and in the context of discussions about behavioral nudges, their role can be explained in many ways.

This dissertation raised a major opportunity for public policies, that of encouraging producers in tropical countries to adopt these technologies through economic incentives. However, these interventions are rarely used in developing countries so far. Chapter 3 has shown that such a program has led to a transformation of farming systems that is consistent with the integration of the challenges of adaptation, mitigation and food security all together. In Chapter 2, it was further highlighted that these interventions could be non-monetary and indirect, by relaxing market constraints, as long as they are conditional on the adoption of the technology promoted. This option could be both attractive for producers and for program planners, who, for many non-governmental organizations at least, prefer to offer inputs and capital rather than transferring cash to beneficiaries.

Finally, in terms of cost efficiency, the choice of the technology promoted should be a central point of the discussion on climate change policies. In the absence of efficient financial markets, a technology that is not flexible (that does not allow to adjust to price signals for instance, as discussed in Chapter 1), is associated with a risk premium that the incentive have to compensate for to encourage voluntary participation. Rethinking technological packages in a resilience perspective in the face of adverse shocks is crucial for the cost-effectiveness of incentive-based programs, as

well as for the permanence of their effects. This process could focus on technologies useful for this purpose that are available, but poorly known or not easily accessible by producers, as explored in Chapter 2 and as possibly realized in Chapter 3.

3 Prospects for future research

Different methodologies have been mobilized in this dissertation and several limits of scope have emerged from both methodologies and focuses applied. Prospects for future research are in turn multiple.

First, the coffee farm model developed in Chapter 1 only considered market risks and did not mention weather variability, pest attacks and diseases. Combining different sources of risks in a model is challenging, but could help to go further in assessing the potential of complex technologies since they are likely to interact with all of these sources of risk. The salient obstacle to properly model complex decisions and provides satisfying simulation results is mainly due to the lack of relevant technical coefficients on yields and farm operations. For instance, the yield data we used clearly drove our results but similar measures in different agro-climatic conditions were not available for testing if the results hold in these conditions. One direction for further research relies on coupling economic optimization processes with eco-physiological models. Introducing feedbacks between processes represents an avenue for studying adoption as a sequential and dynamic process, as well as its outcomes and effects of innovative institutional arrangements.

Second, the choice experiment that we carried out for Chapter 2 was particularly useful to understand farmers heterogeneity. It represents a rigorous approach to test the local demand for innovative technologies and interventions as it currently stands. However, farmers heterogeneity in preferences, adoption constraints and family structures may be time-varying, something that should be taken into account when evaluating individuals' choices under a risky context that is continually evolving. This approach neglects the dynamic process of adopting and learning, in the sense that it cannot deal very well with cases where farmers would try the technology for few seasons and then abandoned it, or use it on an ongoing basis but on a small scale or on marginal lands, or else not use it at first and adopt it later. In an uncertain context with risky outcomes of technology experimentation by farmers, self-selection was indeed limited. The choice experiment pictured the adoption problem only partially. Further research could seriously address it using randomized control trials to frequently track well-chosen adoption measurements of farmers receiving combined indirect interventions conditionally on adoption.

Finally, the RBA evaluation described in Chapter 3 suffered from two major limitations, namely the size of the sample used and the duration of the monitoring period. Together, these two limitations entailed that the impact observed on land uses was quite uncertain. Its relevance in the debate on the intensification of livestock systems, however, deserves a continuity of the study. This would require the addition of a control group and the inclusion of the control group previously used as beneficiaries in a second monitoring period, with the effect of increasing the number of

observations. Unfortunately, there have been no new beneficiaries in the region since 2013, which prevents the construction of the new control group consistently with the identification strategy applied. Further developments could however address the permanence of the transformation observed by studying local market imperfections and determining in which factors beneficiaries were rapidly constrained.

Overall, the three essays illustrated a possible archetype of a research project aiming at assessing the costs and benefits of a promising CSA technology, testing the acceptability of potential adopters for it, and finally evaluating a public intervention promoting it. Since the choice of technologies to be promoted in the CSA framework is likely to condition the achievement of climate change and food security challenges, such research projects call for refinement and development by case studies in which the interpretation of local conditions would be based on a more rigorous conceptualization of the problem of technological adoption in agriculture. Despite the aforementioned limits and its Costa Rican settings, the thesis provided insights into this “puzzle” that could be relevant in other risky contexts with market frictions.

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Supplementary Materials

1 Résumé

L'agriculture se situe au carrefour des stratégies d'atténuation et d'adaptation, en particulier dans les régions tropicales. Premièrement, les systèmes agricoles contribuent largement au changement climatique en émettant des gaz à effet de serre (GES). Tubiello et al. (2014) estime que les émissions mondiales de GES associées secteur agricole ont augmenté de 14% entre 2001 et 2011 et que cette augmentation a eu lieu presque intégralement dans les pays en développement où les petits et moyens propriétaires prédominent. De manière concomitante, les écosystèmes tropicaux - y compris les terres agricoles et les pâturages - offrent des opportunités considérables de mettre en place des mesures d'atténuation peu coûteuses afin de limiter l'accumulation atmosphérique de GES (Griscom et al., 2017). Deuxièmement, le changement climatique affecte la production agricole dans le monde entier ainsi que d'autres services écosystémiques vitaux et menace la sécurité alimentaire, en particulier dans les régions de faible latitude (Smith, Schellnhuber, and Mirza, 2001; Morton, 2007). Les populations toujours croissantes exacerbent la gravité de la menace que représente le changement climatique. Des technologies adaptatives pour réduire le risque de pertes agricoles existent, mais la mise en œuvre rapide de ces mesures est peu probable dans de nombreux pays en raison de contraintes socio-économiques (Tompkins and Adger, 2005; Howden et al., 2007; Klein et al., 2014). Ainsi, les efforts d'atténuation et les mesures d'adaptation visant au moins à maintenir les rendements et les revenus agricoles face au changement climatique contribueront à éradiquer l'extrême pauvreté et la faim (Sanchez and Swaminathan, 2005).

Une attention particulière est actuellement portée aux systèmes agroforestiers et sylvopastoraux dans le cadre de l'approche intégrée de l'Agriculture Climate-Intelligente (CSA) visant le triple défi de l'atténuation, l'adaptation et la sécurité alimentaire (Verchot et al., 2007; FAO, 2010; Matocha et al., 2012). L'agroforesterie et le sylvopastoralisme sont des systèmes qui combinent, sur un même terrain agricole, des arbres avec des cultures agricoles et du bétail respectivement. Dans de tels systèmes, les arbres sont délibérément intégrés dans l'écosystème agricole

afin de générer des services écologiques qui soutiennent la production (par exemple, les légumineuses fournissent de l'azote aux cultures et aux pâturages) et procurent des avantages économiques directs aux ménages (par exemple, produits pour l'autoconsommation ou à la vente).

Comme pour l'agroforesterie et le sylvopastoralisme, la plupart des technologies agricoles qui rentrent dans le cadre de la CSA ne sont pas nouvelles. Néanmoins, une partie du défi de la CSA consiste à surmonter les obstacles à l'adoption de telles technologies chez les agriculteurs, en particulier les petits exploitants des pays en développement. Dans la littérature sur l'adoption de technologie, l'incidence des défaillances du marché a été largement impliquée pour expliquer pourquoi les agriculteurs préfèrent souvent des technologies peu performantes ou bien plus coûteuses sur le plan économique que d'autres. Des mécanismes de marché inefficaces peuvent induire des niveaux d'adoption sous-optimaux, que ce soit pour la société ou pour les agriculteurs. De plus, le changement climatique rend le contexte des décisions de production plus incertain à bien des égards, en raison de conditions météorologiques plus irrégulières, de prix alimentaires plus variables et d'attaques de parasites et de maladies plus intenses et imprévisibles (Morton, 2007).

La thèse souligne trois défis critiques pour la recherche afin d'éclairer les débats sur la transformation agricole vers la CSA. Tout d'abord, il est devenu essentiel d'identifier et d'évaluer les technologies pouvant être promues dans le cadre de la CSA, non seulement par des essais expérimentaux à l'échelle de la parcelle, des enquêtes standard auprès des ménages et une vision partielle du concept d'adoption (Andersson and D'Souza, 2014; Glover, Sumberg, and Andersson, 2016). Deuxièmement, étant donné l'hétérogénéité agroécologique des exploitations et l'hétérogénéité socioéconomique des ménages ruraux, les technologies identifiées ne fourniront probablement les avantages escomptés qu'à un sous-ensemble d'agriculteurs. Un autre défi serait donc de cibler avec précision ces agriculteurs (ISPC, 2018). Enfin, l'adoption rapide et à grande échelle des technologies de l'ASC nécessitant des arrangements institutionnels et des mécanismes de financement, il convient encore de démontrer l'efficacité de ces politiques.

Cette thèse explore l'adoption de l'agroforesterie et du sylvopastoralisme par les petits exploitants du Costa Rica dans les deux principaux systèmes agricoles du pays, à savoir les plantations de café et les systèmes extensifs d'élevage de bétail. Le changement climatique est déjà une réalité en Amérique Centrale. L'agriculture est un secteur clef de l'économie du pays, employant 13% de la population active, représentant 7% du produit intérieur brut et contribuant aux recettes d'exportations. Conjointement avec les ananas et les bananes, le café est une culture d'exportation majeure, généralement cultivée par les petits exploitants (WB, 2014). Les pâturages représentent la principale utilisation des terres productives (25% du pays), avant les plantations de café, et couvraient autrefois la moitié du pays (WB, 2014). 41% des émissions de GES d'origine agricole proviennent du bétail et 25% proviennent de petites exploitations de café, principalement en raison de leur utilisation intensive d'engrais azotés (WB, 2014).

Dans cette thèse, je présente les résultats de trois études qui utilisent des données originales pour étudier les possibilités et les défis liés à l'adoption de l'agroforesterie

et du sylvopastoralisme par les petits producteurs Costariciens. Dans la suite, ces trois études sont synthétisées.

Résumé du Chapitre 1

Le café reste un produit agricole de premier plan pour de nombreux pays en développement et est principalement produit par des petits producteurs. A l'échelle locale, de lourds impacts du changement climatique sur les plantations de café sont attendus, cependant le lien entre la culture du café et le changement climatique ne se limite pas à ces impacts directs. La volatilité des prix se trouve également être un canal de transmission d'événements climatiques lointains affectant les moyens de subsistance des agriculteurs des régions tropicales. Ce Chapitre évalue les coûts d'opportunité liés à l'adoption d'une potentielle technologie "CSA" pour les petits producteurs de café, qui doivent faire face à une volatilité croissante des prix. Un modèle représentatif d'allocation des terres entre technologies de production est utilisé pour explorer l'arbitrage entre l'adoption de l'agroforesterie du café - une option documentée comme ayant des bénéfices pour l'atténuation et l'adaptation - et la gestion risque de marché.

Sur la base des données originales collectées dans la Vallée de Los Santos au Costa Rica et d'autres provenant d'un essai expérimental, les résultats des simulations montrent que l'adoption de l'agroforesterie est coûteuse (800-1 200 USD par hectare et par an) principalement en raison d'une pénalité de rendement. De manière très préoccupante, l'adoption de l'agroforesterie réduit également la résilience face aux chocs de prix défavorables. Des estimations de l'élasticité de l'offre par rapport aux prix attestent que la capacité des producteurs de café à s'adapter aux prix à court terme est très limitée. Les résultats suggèrent également que leur horizon de planification est court. En outre, les résultats rapportés fournissent des indications pour la discussion sur l'utilisation d'incitations économiques telles qu'un programme de Paiement pour Services Environnementaux afin de favoriser l'adoption de l'agroforesterie dans les plantations de café du Costa Rica.

Mots-clés: Paiements pour Services Environnementaux, Risque de Marché, Changement Climatique, Modèle de Ferme, Café, Costa Rica.

Résumé du Chapitre 2

Nous utilisons des données originales issues d'une expérience de choix menée auprès de 207 producteurs de café au Costa Rica, afin d'étudier leur consentement à adopter différents systèmes agroforestiers sous diverses formes d'incitation. Nous testons quatre stratégies d'adaptation basées sur l'introduction de variétés de café résistantes, la production d'espèces d'arbres à bois et/ou l'augmentation de la densité des arbres d'ombrage.

Les préférences révélées suggèrent que la plupart des répondants accordent une valeur à l'introduction de variétés résistantes. Ils consentent à planter deux fois

plus d'arbres dans leurs plantations lorsque ceux-ci sont associés à des variétés résistantes. À l'inverse, tous les systèmes d'agroforesterie impliquant des arbres à bois sont significativement moins populaires et leur adoption nécessiterait en moyenne une compensation. Nous constatons en outre qu'une grande majorité des personnes interrogées est très sensible aux récompenses non monétaires, à savoir un crédit subventionné, un lot gratuit de caféiers résistants ou une assistance technique. Nous concluons que chacune de ces incitations pourrait être utilisée pour inciter des changements d'usage des terres.

Mots-clés: Paiement pour Services Environnementaux, Incitations Non-monétaires, Changement Climatique, Expérience de Choix, Café, Costa Rica.

Résumé du Chapitre 3

Contrairement aux gouvernements des régions développées, les pays tropicaux utilisent rarement des incitations économiques pour encourager les agriculteurs à adopter des technologies respectueuses de l'environnement. Par conséquent, on dispose à ce jour de peu de connaissances sur l'utilisation potentielle de ces incitations face aux problèmes liés aux changements climatiques dans les systèmes agricoles des régions en développement. Ce Chapitre vise à contribuer à combler ce manque de connaissances par l'évaluation d'un cas rare de programme d'incitation de ce type dans une région tropicale, à savoir le programme de Reconnaissance des Bénéfices Environnementaux (RBA) au Costa Rica. L'étude se concentre sur les systèmes d'élevage de bétail dans la province du Guanacaste, au nord-ouest du pays. La zone d'étude se compose de systèmes extensifs, sous-capitalisés et peu rentables d'élevage de bétail, qui comprennent également d'importantes surfaces de forêts hautement vulnérables à la déforestation lorsque la rentabilité de l'élevage augmente.

S'appuyant sur une approche en Différences-en-Différences appliquée à un échantillon aléatoire composé de 32 éleveurs ayant participé à la phase initiale du RBA et de 31 en voie de devenir bénéficiaires au moment de la collecte des données, ce Chapitre fournit des estimations de l'effet additionnel de la participation au RBA sur l'adoption de technologie productive et sur l'usage des terres. Les résultats suggèrent que le programme a réussi à accroître l'adoption des technologies promues, à la fois en quantité et en diversité. En outre, elle a favorisé l'intensification écologique des systèmes d'élevage, en induisant une réduction des terres utilisées pour nourrir les bovins et probablement aussi en augmentant la densité du cheptel, cela tout en épargnant certaines surfaces d'être pâturées et piétinées par le bétail. Les résultats rapportés sont pertinents dans le cadre de la discussion sur le potentiel de l'intensification de l'agriculture pour répondre de manière conjointe aux défis que représentent l'adaptation au et l'atténuation du changement climatique, ainsi que la sécurité alimentaire. Les résultats sont également importants car ils montrent que, dans l'une des provinces les plus pauvres du Costa Rica, une intervention financée par l'État a réussi à stimuler le potentiel d'atténuation d'une activité souvent désignée comme une source majeure d'émissions de gaz à effet de serre.

Mots-clés: Paiements pour Services Environnementaux, Mesures Agro-Environnementales, Changement Climatique, Évaluation d'impact, Élevage, Costa Rica.

Les résultats de cette dissertation tendent tous à confirmer que l'adoption autonome de technologies étudiées est coûteuse, malgré les bénéfices privés cités dans la littérature. Dans le Chapitre 1, la technologie étudiée est associée à un coût d'opportunité très important. Par ailleurs et malgré un taux de décompte pourtant modéré, il a été également mis en évidence que l'horizon temporel du petit producteur était relativement court, de sorte que les bénéfices privés à long terme n'auraient que peu d'incidence sur la décision d'adoption de technologie. De surcroît, deux des stratégies étudiées au Chapitre 2 requièrent elles aussi un paiement, et les stratégies pour lesquelles une compensation n'est pas requise ne sont pas mises en place au regard des pratiques actuelles des caféiculteurs interviewés, pas même celle pour laquelle un consentement à payer a été mesuré. Au Chapitre 3 enfin, il a été montré que sans l'intervention publique étudiée, les producteurs n'auraient pas autant investi dans le paquet technologique en l'absence du programme.

Dans chacun des cas d'étude, l'adaptation autonome au changement climatique par les technologies étudiées semblent être compromise. Si son adoption peut apparaître sous-optimale étant donné l'ampleur des impacts prédits du changement climatique, la technologie n'est pas pour autant toujours un choix individuel optimal qui serait contraint par des défaillances de marché, comme en attestent les résultats du Chapitre 1. La sous-performance de l'agroforesterie est d'abord justifiée par les rendements plus faibles qu'elle entraîne, avant d'être expliquée, et ce dans une moindre mesure, par la flexibilité réduite qu'elle offre pour s'ajuster aux signaux de prix. Ainsi, même dans un contexte de marchés parfaits, l'adoption ne serait toujours pas optimale du point de vue du producteur.

D'autre part, les frictions de marché représentent un second déterminant évident de la non-adoption. Particulièrement saillant dans le Chapitre 2, le fait que les producteurs ne cultivent pas aujourd'hui de plants résistants sous un couvert dense d'arbre d'ombrage malgré la valeur positive accordée à ce système agroforestier peut raisonnablement être expliqué par le coût d'accès aux distributeurs offrant ces plants récemment développés, combiné à un déficit d'information. Dans le cas du producteur faisant face à l'instabilité des marchés comme étudié au Chapitre 1, la prime de risque envisagée du fait du manque de flexibilité de la technologie est clairement exacerbée par l'absence de marchés financiers dans la modélisation. Enfin, l'impact induit par le programme évalué au Chapitre 3 peut difficilement être expliqué par un relâchement de la contrainte de crédit du producteur du fait que le remboursement ait lieu après l'implémentation de la technologie, par contre le rôle des services d'extension n'est pas à exclure de l'intervention. C'est à l'inverse une partie intégrante du programme de part l'information qu'ils divulguent, et dans le cadre des discussions sur les nudges comportementaux, leur rôle peut s'expliquer de multiple façons.

Néanmoins, cette dissertation soulève une opportunité majeure pour les politiques publiques, celle d'inciter économiquement les producteurs des pays tropicaux

à adopter ces technologies. Ces interventions sont pourtant rarement appliquées dans les pays en développement. Le Chapitre 3 a montré qu'un tel programme avait induit une transformation des systèmes agricoles cohérente avec l'intégration des défis de l'adaptation, de la mitigation et de la sécurité alimentaire. Au Chapitre 2, il a été mis en évidence de plus que ces interventions pouvaient être indirectes et porter sur le relâchement des contraintes de marché, dès lors qu'elles sont conditionnelles à l'adoption de la technologie promue. Cette option pourrait être à la fois attractive pour les producteurs et pour les gestionnaires de projets, qui, pour beaucoup d'ONG du moins, préfèrent offrir des intrants et du capital plutôt que de transférer du cash aux bénéficiaires.

Enfin, en terme d'efficience-coût, il a été montré que le choix de la technologie promue est primordial. En l'absence de marchés financiers efficaces, une technologie peu flexible pour s'ajuster aux signaux de prix comme dans le cas étudié au Chapitre 1, est associée à une prime de risque que l'incitation doit compenser pour susciter une participation volontaire. Repenser les paquets technologiques dans une perspective de résilience face aux chocs averses est crucial pour l'efficience-coût d'un programme ainsi que pour la pérennité de ses effets, en particulier dans les cas où des technologies allant dans ce sens sont disponibles mais mal connues ou peu accessibles par les producteurs, comme exploré au Chapitre 2 et comme possiblement réalisé au Chapitre 3.

Cette thèse illustre un archétype possible d'un projet de recherche visant à évaluer les coûts et les avantages d'une technologie prometteuse de la CSA, à tester l'acceptabilité des adoptants potentiels et à évaluer une intervention publique en faisant la promotion. Étant donné que le choix des technologies à promouvoir dans le cadre de la CSA conditionnera probablement la réalisation des défis liés au changement climatique et à la sécurité alimentaire, ces projets de recherche requièrent des études de cas où l'interprétation des conditions locales s'appuierait davantage sur une conceptualisation rigoureuse du problème de l'adoption technologique dans l'agriculture. En dépit de certaines limites et de son contexte costaricien, cette thèse propose des éléments de réponse sur ce "puzzle" qui pourraient être pertinents dans d'autres contextes risqués avec des marchés inefficients.

2 Questionnaires

Planes de Manejo Adaptativo del café al cambio climático: una encuesta para conocer las preferencias de los productores

Conformando a la ley seguida por el INEC (Instituto Nacional de Estadística y Censos de Costa Rica), los datos obtenidos serán **estrictamente confidenciales**: no podrán ser suministrados ni publicados en forma individual, sino como parte de cifras globales. Estos datos tampoco podrán ser suministrados con propósitos fiscales ni de otra índole.

Instrucciones



Escribir en letras o números









Marcar sólo una propuesta



Marcar una o varias propuestas

Sección 1 / Características personales y profesionales

1.1 SUS DATOS	
¿Cuál es su nombre?	 [_____]
¿Cuáles son sus apellidos?	 [_____]
¿En qué número de teléfono la/lo podríamos contactar?	 [_ _ _ _] - [_ _ _ _]
Usted es :	 <input type="checkbox"/> una mujer <input type="checkbox"/> un hombre
¿Cuál es su edad?	 [_ _] años
¿Cuántos años de estudio tiene Usted en total (de la escuela primaria a la universidad)? Por ejemplo: si nunca estuvo en la primaria, la respuesta es 0 año; si acabó la secundaria, la respuesta es 11 años.	 [_ _] años de estudio

1.2 SU HOGAR






¿Cuántos miembros en total, incluido Usted, conforman su hogar?

 [_ _] miembros del hogar en total

Entre los miembros del hogar, incluido Usted, ¿cuántas personas tienen entre 12 y 60 años?

 [_ _] miembros del hogar entre 12 y 60 años

Entre los miembros del hogar, incluido Usted, ¿cuántas personas :

- participan en sus plantaciones en el cultivo de café?  [_ _] miembros del hogar
- trabajan en su finca pero en otra actividad agrícola, ganadera o forestal?  [_ _] miembros del hogar
- trabajan afuera de su finca, en un trabajo agrícola, ganadero o forestal?  [_ _] miembros del hogar
- trabajan afuera de su finca, en un trabajo asalariado?  [_ _] miembros del hogar
- trabajan afuera de su finca, en un negocio?  [_ _] miembros del hogar

En el ingreso anual total de su hogar, los ingresos adicionales que no vienen de la venta del café representan en general :



- casi nada, porque todos los ingresos vienen de la venta del café
- alrededor del 10%, y el 90% viene de la venta del café
- alrededor del 20%, y el 80% viene de la venta del café
- alrededor del 30%, y el 70% viene de la venta del café
- alrededor del 40%, y el 60% viene de la venta del café
- la mitad, y la otro mitad viene de la venta del café
- la mayoría de sus ingresos, porque la venta del café trae menos de la mitad de sus ingresos


¿Es dueño de un microbeneficio?



- sí
- no

¿Colabora en actividades de campo no remuneradas con familiares u otros miembros de la comunidad? Si la respuesta es sí, ¿cuántas veces al año?



- sí, unas  [_ _] veces al año
- no

1.3 SUS CAFETALES

¿Cuál es la área total de plantaciones de café que Usted maneja?
Elige una unidad entre hectáreas y manzanas.



[_ _] . [_ _ _]



hectáreas

manzanas

De esta área de plantaciones, ¿cuál área es propiedad propia o en usufructo?

O sea, que Usted no maneja para un patrón si es peón, que no alquile, que no esté prestada y que no ocupe sin derecho particular.

Elige una unidad entre hectáreas y manzanas.



[_ _] . [_ _ _]



hectáreas

manzanas

En promedio, estas plantaciones se encuentran a una altura:



- menor a 1000 metros de altitud
- entre 1001 y 1500 metros de altitud
- entre 1501 y 2000 metros de altitud
- mayor a 2001 metros de altitud

En promedio, estas plantaciones se encuentran sobre:



- terrenos llanos
- laderas de pendiente baja
- laderas de pendiente mediana
- laderas de pendiente fuerte
- laderas de pendiente muy fuerte

¿Alrededor de qué hora se levanta el sol por la mañana sobre sus plantaciones?



[_ _] horas y [_ _] minutos


Además de sus cafetales, ¿Usted tiene montaña y/o charrales en sus tierras, en este momento? Si tiene, elige una unidad entre hectáreas y manzanas, marca una "X" y escribe la área.




hectáreas

manzanas



bosque y/o montaña, para una área de  [_ _] . [_ _ _]

tacotales, charrales y/o cafetales muy degradados, para una área de  [_ _] . [_ _ _]

¿Cuáles son las variedades que Usted cultiva en sus plantaciones, en este momento? Puede elegir varias.



- caturra
- catuaí
- catimor (Costa Rica 95 incluido)
- otra variedad no híbrida
- otra variedad híbrida

• Si ha marcado que sí, cultiva catimores u otra variedad híbrida, Usted las está:



- probando sin estar muy seguro de introducirlas como variedades importantes.
- cultivando en este momento como una variedad importante.

• Si ha marcado que no, no cultiva ni catimores ni otra variedad híbrida, Usted:



- ya probó una variedad híbrida y la dejó de producir.
- puede obtener fácilmente unas plántulas/plantones de híbridos pero nunca lo hizo.
- nunca probó una variedad híbrida y además, sería muy difícil para Usted obtener unas plántulas/plantones de híbridos.

En promedio, ¿cuál es la densidad de siembra del café en sus plantaciones?

Elige una unidad entre número de plantas por hectárea y número de plantas por manzana.











[_ _ _ _] plantas




















- por hectárea.
- por manzana.

¿Cuáles son las especies de árboles presentes en sus plantaciones, en este momento? Marca una "X" si hay. Para las especies que sí son presentes, ¿cuántos metros separan 2 árboles de la misma especie O cuántos palos de cada especie hay en total por manzana?



- Poró, cada  [_ _] metros O [_ _] palos por manzana
- Banano y plátano, cada  [_ _] metros O [_ _] palos por manzana
- Eucalipto, cada  [_ _] metros O [_ _] palos por manzana
- Aguacate, cada  [_ _] metros O [_ _] palos por manzana
- Guaba, cada  [_ _] metros O [_ _] palos por manzana
- Otro(s) frutal(es), cada  [_ _] metros O [_ _] palos por manzana
- Laurel, cada  [_ _] metros O [_ _] palos por manzana
- Maderable(s), cada  [_ _] metros O [_ _] palos por manzana




<p>En promedio para la producción 2014/2015, ¿cuáles son las cantidades de agroquímicos que echó Usted en sus cafetales, por unidad de área y por año? Elige entre hectárea y manzana.</p>	
	<input type="checkbox"/> por hectárea y por año <input type="checkbox"/> por manzana y por año
<ul style="list-style-type: none"> • Producto formulado (formula completa y/o siembra): 	 [_ _] sacos echados
<ul style="list-style-type: none"> • Abono de refresco, urea y/o nitrato de amonio: 	 [_ _] sacos echados
<ul style="list-style-type: none"> • Atomizaciones para control de plagas y enfermedades: 	 [_ _] atomizos efectuados
<p>Para la parte administrativa de su producción en 2014/2015, ¿cuántas personas que no sean miembros del hogar empleó Usted de manera permanente?</p>	
	[_ _] empleados para la administración
<p>Para toda la fase de recolección del grano en 2014/2015, ¿cuántos peones empleó Usted, en total de la temporada y para todos sus lotes? ¿Durante cuántos días? <small>O sea, sumando los cortadores, caporales y vigilancia.</small></p>	
	[_ _] peones para la recolección, durante  [_ _ _] días
<p>Para todas las labores de cultivo en 2014/2015, ¿cuántos peones empleó Usted, en total de la temporada y para todos sus lotes? ¿Durante cuántos días? <small>O sea, sumando la mano de obra para todo el manejo y mantenimiento de las plantaciones, la sanidad y la nutrición.</small></p>	
	[_ _] peones para las labores de cultivo, durante  [_ _ _] días
<p>¿Cuál fue el número de fanegas que Usted sacó en total, para la producción de grano en 2014/2015?</p>	
	[_ _] fanegas
<p>En general, ¿a cuál(es) beneficio(s) Usted entrega su café? Puede elegir varios. Si entrega a varios beneficios, ¿cuál sería el orden de estos beneficios a quienes entrega su café, del más importante en término de cantidad de café entregado (número 1), al menos importante (hasta el número 6)?</p>	
	<input type="checkbox"/> CoopeLlanoBonito, como el número  [_]
	<input type="checkbox"/> CoopeTarrazú, como el número  [_]
	<input type="checkbox"/> CoopeDota, como el número  [_]
	<input type="checkbox"/> otra cooperativa, como el número  [_ _]
	<input type="checkbox"/> un microbeneficio, como el número  [_]
	<input type="checkbox"/> una empresa privada exportadora, como el número  [_]

1.4 SU EXPERIENCIA DE PRODUCTOR DE CAFE

¿Cuántos años tiene Usted de estar a cargo del manejo de una plantación?

 [_ _] años


En los últimos 5 años, debido a unas plagas, ¿cuál fue la área de sus lotes que tuvo que renovar por haber estado afectada por el hongo de la roya y/o del ojo de gallo?

 [_ _] . [_ _ _]  hectáreas
 manzanas

En los últimos 5 años, debido a unos eventos climáticos extremos (por ej. inundaciones, sequias, heladas, huracanes, tormentas), ¿cuál fue la área de sus lotes que tuvo que renovar por haber estado dañada?

 [_ _] . [_ _ _]  hectáreas
 manzanas



En su opinión, ¿estima Usted que el fenómeno del Niño tiene un efecto sobre sus rendimientos de café que es:

-  positivo
 neutro
 negativo

En los 12 últimos meses, ¿en cuántos talleres de capacitación participó Usted en total, sobre un tema relacionado al café?

 [_ _] talleres de capacitación el año pasado

¿Ha usted ya participado en un proyecto tipo “Pago por servicios ambientales”, en el que recibió un pago (en efectivo o en especie) en contra de un cambio en sus tierras que favorezca al medioambiente? Puede elegir varios.

-  Fonafifo para reforestación
 Fonafifo para regeneración natural
 Fonafifo para sistemas agroforestales
 Reconocimientos por Beneficios Ambientales del MAG para la inversión amigable con el ambiente
 Otro ¿Podría indicar de quién recibió el pago y en contra de cuál mejora de su parte?  _____
 Nunca ha participado en este tipo de proyecto.

Para financiar una inversión en sus plantaciones, ¿ha Usted recibido un crédito formal? Puede elegir varias fuentes de crédito.



- Sí, de un banco u otra institución formal (por ej.: IDA, FONECAFE, FIDAGRO).
- Sí, de un beneficio o una cooperativa (en efectivo y/o en insumos).
- Sí, de una empresa privada exportadora (en efectivo y/o en insumos).
- Nunca ha recibido un crédito que no sea un prestamista o un préstamo informal.

- Si ha marcado que sí, ha recibido un crédito del banco, el monto del (de los) crédito(s) que recibió:

















- fue el monto que quiso.
- fue menos que lo que quiso.

- Si ha marcado que no, nunca ha recibido un crédito formal, ¿por qué nunca recibió un crédito de un banco u otra institución formal?





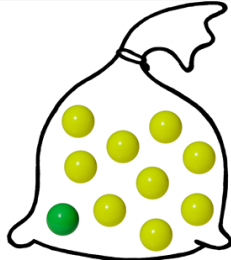
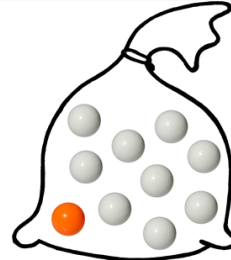







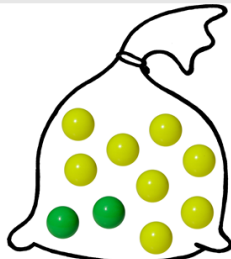


- Usted solicitó un crédito y lo/la rechazaron.
- Usted nunca solicitó un crédito, porque sabe que no cumple con las garantías exigidas para que el banco se lo otorgue, o porque sería demasiado costoso cumplir con todos los requisitos que pide el banco.
- Usted nunca pidió un crédito porque no lo/la interesa.





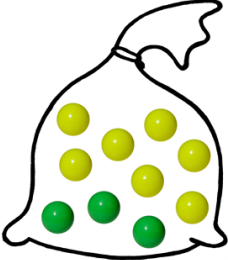
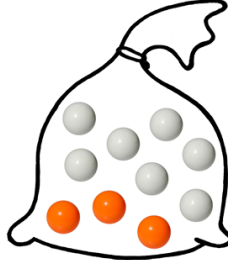
Sección 3 / Sus comentarios sobre las propuestas

¿Nos podría brindar su opinión propia sobre las propuestas siguientes?						
		Total- mente de acuerdo	De acuerdo	Neutro	En desa- cuerdo	Total- mente en desa- cuerdo
Las predicciones de cambio climático que acaban de ser presentadas son realistas y creíbles:		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Es necesario cambiar el plan de manejo de un cafetal frente al cambio climático:		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Introducir variedades híbridas es un plan de manejo realista:		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Asociar el laurel con el café es un plan de manejo realista:		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Aumentar el número de árboles de sombra es un plan de manejo realista:		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Comprometerse, mediante un contrato de 5 años, en implementar uno de los 4 planes de manejo propuestos es algo realista:		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
¿Podría ordenar sus preocupaciones mayores en cuanto al futuro de la actividad cafetalera? Elige las 3 preocupaciones mayores dentro de las propuestas siguientes y asígnalas un número del 1 al 3 (el número 1 siendo lo que le preocupa lo más).						
las plagas		[_]				
la subida de las temperaturas		[_]				
la disminución de las lluvias		[_]				
la reducción de la mano de obra disponible		[_]				
el aumento del precio de los agroquímicos		[_]				
la incertidumbre sobre la evolución del precio del café		[_]				
el aumento del número de tormentas y huracanes		[_]				

Sección 4 / Loterías arriesgadas

SORTEO N° 1		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 1 chance de 10	 1 chance de 10
Chances de ganarse el segundo premio:	9 chances de 10	9 chances de 10
 Pregunta: ¿cuál boletín elige Usted?	Boletín A <input type="checkbox"/>	Boletín B <input type="checkbox"/>

SORTEO N° 2		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 2 chances de 10	 2 chances de 10
Chances de ganarse el segundo premio:	8 chances de 10	9 chances de 10
 Pregunta: ¿cuál boletín elige Usted?	Boletín A <input type="checkbox"/>	Boletín B <input type="checkbox"/>





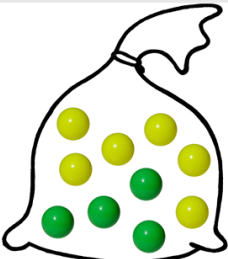

SORTEO N° 3		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 3 chances de 10	 3 chances de 10
Chances de ganarse el segundo premio:	7 chances de 10	7 chances de 10



Pregunta: ¿cuál boletín elige Usted?

Boletín A

Boletín B





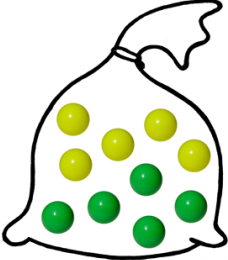
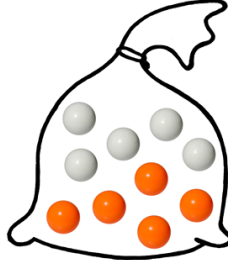
SORTEO N° 4		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 4 chances de 10	 4 chances de 10
Chances de ganarse el segundo premio:	6 chances de 10	6 chances de 10



Pregunta: ¿cuál boletín elige Usted?

Boletín A

Boletín B





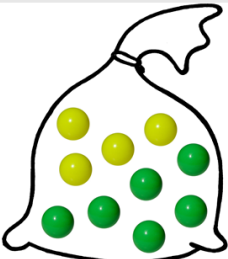

SORTEO N° 5		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 5 chances de 10	 5 chances de 10
Chances de ganarse el segundo premio:	5 chances de 10	5 chances de 10



Pregunta: ¿cuál boletín elige Usted?

Boletín A

Boletín B





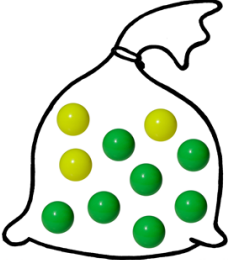
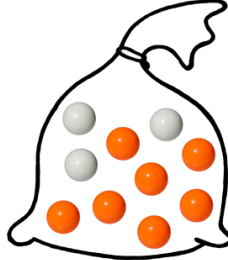
SORTEO N° 6		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 6 chances de 10	 6 chances de 10
Chances de ganarse el segundo premio:	4 chances de 10	4 chances de 10



Pregunta: ¿cuál boletín elige Usted?

Boletín A

Boletín B





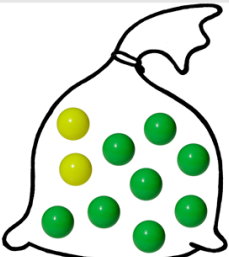
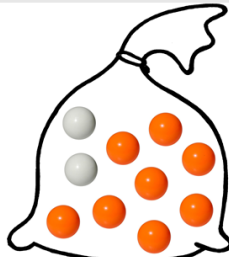
SORTEO N° 7		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 7 chances de 10	 7 chances de 10
Chances de ganarse el segundo premio:	3 chances de 10	3 chances de 10



Pregunta: ¿cuál boletín elige Usted?

Boletín A

Boletín B





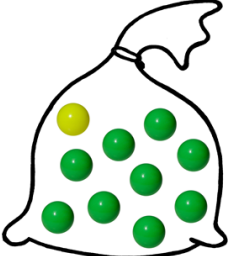

SORTEO N° 8		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 8 chances de 10	 8 chances de 10
Chances de ganarse el segundo premio:	2 chances de 10	2 chances de 10



Pregunta: ¿cuál boletín elige Usted?

Boletín A

Boletín B


SORTEO N° 9		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 9 chances de 10	 9 chances de 10
Chances de ganarse el segundo premio:	1 chance de 10	1 chance de 10



Pregunta: ¿cuál boletín elige Usted?

Boletín A

Boletín B

SORTEO N° 10		
	Boletín A	Boletín B
Primer premio:	 10 000 ¢	 19 250 ¢
Segundo premio:	 8 000 ¢	 500 ¢
Chances de ganarse el primer premio:	 10 chances de 10	 10 chances de 10
Chances de ganarse el segundo premio:	0 chance de 10	0 chance de 10




Pregunta: ¿cuál boletín elige Usted?

Boletín A


Boletín B

Sección 5 / Juego de paciencia

¿Cuál es el número de teléfono de prepago que quiere recargar?

 [_ _ _ _] - [_ _ _ _]

¿En cuál compañía?

 Kölbi

Claro

Movistar

PRUEBA N° 1		
	Premio A	Premio B
Valor:	2 000 ¢	2 200 ¢
Fecha de recepción:	Hoy + 30 días	Hoy + 60 días



Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 2		
	Premio A	Premio B
Valor:	2 000 ¢	2 400 ¢
Fecha de recepción:	Hoy + 30 días	Hoy + 60 días



Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 3		
	Premio A	Premio B
Valor:	2 000 ¢	2 600 ¢
Fecha de recepción:	Hoy + 30 días	Hoy + 60 días



Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 4

Premio A

Premio B

Valor:

2 000 ¢

2 800 ¢

Fecha de recepción:

Hoy + 30 días

Hoy + 60 días

Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 5

Premio A

Premio B

Valor:

2 000 ¢

3 000 ¢

Fecha de recepción:

Hoy + 30 días

Hoy + 60 días

Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 6

Premio A

Premio B

Valor:

2 000 ¢

3 200 ¢

Fecha de recepción:

Hoy + 30 días

Hoy + 60 días

Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 7

Premio A

Premio B

Valor:

2 000 ¢

3 400 ¢

Fecha de recepción:

Hoy + 30 días

Hoy + 60 días

Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 8

	Premio A	Premio B
Valor:	2 000 ¢	3 600 ¢
Fecha de recepción:	Hoy + 30 días	Hoy + 60 días



Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 9

	Premio A	Premio B
Valor:	2 000 ¢	3 800 ¢
Fecha de recepción:	Hoy + 30 días	Hoy + 60 días



Pregunta: ¿cuál premio elige Usted?

Premio A

Premio B

PRUEBA N° 10

	Premio A	Premio B
Valor:	2 000 ¢	4 000 ¢
Fecha de recepción:	Hoy + 30 días	Hoy + 60 días




Pregunta: ¿cuál premio elige Usted?


Premio A

Premio B

Conclusión y agradecimiento


¿Desea Usted permanecer en contacto con el proyecto MACACC y recibir los resultados de este estudio?

 Sí, por mensajes de texto

Sí, por correo electrónico a la dirección siguiente:
 _____

No gracias

Mensaje en expresión libre.

 _____

Luego hacemos el sorteo de la lotería y compartimos un refresco.

¡Gracias de parte de todo el equipo MACACC!

ANAIS LAMOUR











Estudiante de doctorado, pasante de la escuela de posgrado del CATIE











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8938-3775







PROPUESTA N° 1

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuaí  Laurel 50 por Ha	 Caturra/catuaí  Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	37 500 ¢ Por hectárea y por año	37 500 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] . [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] . [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 2

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido Laurel 100 por Ha	 Caturra/catuaí Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	62 500 ¢ Por hectárea y por año	25 000 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] . [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] . [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 3

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido  Poró 400 por Ha	 Híbrido  Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	62 500 ¢ Por hectárea y por año	50 000 ¢ Por hectárea y por año	
Acceso a un crédito		✗	
250 plántulas		✗	
Asistencia técnica	✗	✗	
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 4

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuái  Laurel 50 por Ha	 Híbrido  Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	0 ¢ Por hectárea y por año	87 500 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] . [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] . [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	






PROPUESTA N° 5

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuái  Laurel 50 por Ha	 Caturra/catuái  Laurel 50 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	75 000 ¢ Por hectárea y por año	12 500 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	









PROPUESTA N° 6

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuái  Laurel 50 por Ha	 Híbrido  Laurel 100 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	12 500 ¢ Por hectárea y por año	75 000 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 7

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido  Poró 400 por Ha	 Caturra/catuái  Laurel 50 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	87 500 ¢ Por hectárea y por año	12 500 ¢ Por hectárea y por año	
Acceso a un crédito		✗	
250 plántulas	✗	✗	
Asistencia técnica	✗	✗	
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	





PROPUESTA N° 8

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido Laurel 100 por Ha	 Caturra/catuái Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	75 000 ¢ Por hectárea y por año	50 000 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 9

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuaí  Poró 400 por Ha	 Híbrido  Laurel 100 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	25 000 ₡ Por hectárea y por año	0 ₡ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	








PROPUESTA N° 10

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido Laurel 100 por Ha	 Caturra/catuái Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	87 500 ¢ Por hectárea y por año	0 ¢ Por hectárea y por año	
Acceso a un crédito	✗	✗	
250 plántulas	✗		
Asistencia técnica		✗	
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[- -] . [- - -] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[- -] . [- - -] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 11

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido  Laurel 100 por Ha	 Híbrido  Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	50 000 ¢ Por hectárea y por año	37 500 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 12

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido  Poró 400 por Ha	 Caturra/catuái  Laurel 50 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	50 000 ¢ Por hectárea y por año	62 500 ¢ Por hectárea y por año	
Acceso a un crédito		✗	
250 plántulas		✗	
Asistencia técnica	✗		
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	











PROPUESTA N° 13

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuái  Poró 400 por Ha	 Híbrido  Laurel 100 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	12 500 ¢ Por hectárea y por año	87 500 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	








PROPUESTA N° 14

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Híbrido  Poró 400 por Ha	 Híbrido  Poró 400 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	37 500 ¢ Por hectárea y por año	62 500 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	

PROPUESTA N° 15

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuái  Poró 400 por Ha	 Caturra/catuái  Laurel 50 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	0 ¢ Por hectárea y por año	25 000 ¢ Por hectárea y por año	
Acceso a un crédito			
250 plántulas			
Asistencia técnica			
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	

PROPUESTA N° 16

	Opción A	Opción B	Opción C
Plan de Manejo requisito	 Caturra/catuái  Poró 400 por Ha	 Híbrido  Laurel 100 por Ha	Ni la opción A, Ni la opción B
Pago en efectivo	25 000 ¢ Por hectárea y por año	75 000 ¢ Por hectárea y por año	
Acceso a un crédito	✗		
250 plántulas	✗		
Asistencia técnica	✗		
Pregunta 1: ¿su elección preferida?	Opción A <input type="checkbox"/>	Opción B <input type="checkbox"/>	Opción C <input type="checkbox"/>
Pregunta 2: Si su respuesta fue A o B, ¿cuál superficie en esta opción?	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	[_ _] · [_ _ _] <input type="checkbox"/> hectáreas <input type="checkbox"/> manzanas	

RBA cuestionario hogar

Presentación y consentimiento de la persona principal que responde

- Yo vengo de la UNA, la Universidad Nacional, con el apoyo de la dirección regional del MAG Chorotega y de las oficinas locales
- Un estudio sobre las prácticas ganaderas en Chorotega y las inversiones que los ganaderos hicieron para mejorar las condiciones de producción de la carne y de la leche
- Relacionado con el programa de Reconocimientos por Beneficios Ambientales del MAG
- Encuesta confidencial y para la investigación: su nombre no aparecerá en ningún dato o informes que estén disponible al público o al MAG

Sección 0 / Personal a cargo de la entrevista y del manejo de datos

	Código	Fecha	Firma
Entrevistador	[_] ENCOD	[__ / __] ENDIA / ENMES	_____
Supervisor 1	[_] SUP1COD	[__ / __] SUP1DIA / SUP1MES	_____
Digitador de datos	[_] DICOD	[__ / __] DIDIA / DIMES	_____
Supervisor 2	[_] SUP2COD	[__ / __] SUP2DIA / SUP2MES	_____

(1=Adriana, 2=Noelia, 3=Anais)

Grupo de la muestra:	[_] GRUPO	Telefono: _____
<i>(0=beneficiario RBA 2013, 1=beneficiario RBA 2006-2012, 2=no beneficiario)</i>		
Nombre del finquer@:	_____ NOM	
Apellidos del finquer@:	_____ APEL1	_____ APEL2

Parte introductoria / Charla informal

Principio del estudio: sacar 2 fotos de su finca, una en 2012 (punto de referencia: el terremoto de Septiembre) y una en 2006 (punto de referencia: la elección presidencial de Óscar Arias Sánchez en Febrero) para investigar los cambios que hizo en su finca






1. Nombre del entrevistado: _____

2. Vínculo con el finquer@: [_] VINCRESP
(1=finquer@ mism@, 2=conyugue, 3=hij@, 4=peon agrícola, 5=otro parentesco, 6=otro)

Hora al empezar la entrevista: _____ HR1

Mapa en 2012 (punto de referencia: el terremoto de Septiembre) de los apartos de la finca dibujada por el entrevistado: no importa si es fea y no proporcional, debe incluir **todas las tierras que ocupa, aunque no tenga derechos de propiedad**

Mapa de la finca en el año 2012

	<i>Símbolo</i>	<i>Color</i>
Apartos o áreas de uso		Negro
Casa		Negro
Infraestructura productiva		Negro
Rio		Azul
Naciente, pozo		Azul

Otro: _____

Otro: _____

Designación del aparto (especificar el nombre dado por el entrevistado)	Área Y unidad (1=Hectáreas, 2=Manzanas, 3=m ²)	Pendiente del terreno / relieve (1=Plano, 2=Pendiente moderada, 3=Pendiente fuerte (no puede utilizar maquinas))	2012		2006	
			Tipo de tenencia (0=No hace parte de la finca aquel año, 1=Propia, 2=Alquilada, 3=Prestada/usufructo, 4=Otro)	Uso de la tierra (01=Pastura natural, 02=Pastura mejorada, 03=Granos básicos, 04=Café, 05=Otro cultivo comercial (especificar), 06=Plantación de árboles frutales (especificar), 07=Plantación de árboles maderables (especificar), 08=Banco forrajero de gramíneas (pastos o caña de corte), 09=Banco forrajero de leñosas (leñosas para corte), 10=Bosque ribereño (vegetación natural a la orilla de ríos de ancho>4m), 11=Bosque primario (bosque nativo sin intervención en +30 años), 12=Bosque secundario (bosque nativo>10m ²), 13=Tacotal, charral o tierra en descanso, 14=Infraestructura, patio) USO_12	Tipo de tenencia	Uso de la tierra
PARC	AREA _UNI	PEND	PROP_12	USO_12	PROP_06	USO_06
#1	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#2	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#3	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#4	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#5	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#6	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#7	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#8	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____

Designación del apto	Área Y unidad	Pendiente del terreno / relieve	2012	Uso de la tierra	2006	Uso de la tierra
			Tipo de tenencia		Tipo de tenencia	
#9	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#10	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#11	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#12	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#13	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#14	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#15	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#16	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#17	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#18	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#19	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#20	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#21	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
#22	___ [_]	[_]	[_]	[_] _____	[_]	[_] _____
TOTAL	___ [_]					

Parte I / Características de la finca

Ahora, me gustaría escuchar acerca de lo que hacía para generar ingresos y lo que tenía en su hogar, hace 2 años en 2012 (punto de referencia: el terremoto de Septiembre), y hace 8 años en 2006 (punto de referencia: la elección presidencial de Óscar Arias Sánchez en Febrero)

3. ¿Cuál fue el primer año en que Ud. estuvo a cargo de esta finca (toma de decisiones)? _____ ANOEXPE

4. ¿Cuál era el tipo de la actividad ganadera principal de su finca? En 2012: [_] ACTIGANA12

En 2006: [_] ACTIGANA06

(1=doble-propósito, 2=leche, 3=desarrollo y cría, 4=carne/engorde, 5=crianza de otros animales)

5. ¿Cuáles son los animales que tenía en su finca en 2012 y 2006?		2012 _12	2006 _06
Bovinos	Terneras y terneros (<1 año)	TERN	_____
	Novillas y novillos (1-2 años)	NOVI	_____
	Vacas paridas y secas	VACA	_____
	Toros, bueyes y sementales	TORO	_____
Caballos	Adultos	CABA	_____
Burros	Adultos	BURRO	_____
Caprinos	Adultos	CABRA	_____
Ovinos	Adultos	OVEJA	_____
Cerdos	Adultos	CERDO	_____
Aves de corral	Adultos	AVE	_____
Colmenas		COLME	_____

6. ¿Era el propietario de estos animales (al menos la mayoría)? (0=No, 1=Si) En 2012: [_] PROPA12

En 2006: [_] PROPA06

7. Dígame más acerca de sus prácticas con respeto al manejo de su hato (del especie de animales principal):

2012
_12

2006
_06

¿Cuál era el método de manejo reproductivo utilizado? (1=monta natural, 2=inseminación artificial)	PRAGANA1	[_]	[_]
¿Cómo manejaba las excretas? (1=sin manejo, en las praderas, 2=pilas con deposito diario, 3=pilas, abono o lombriz, almacenado y apilado en seco) 4=en biofertilizantes (almacenado liquido/lechoso)	PRAGANA2	[_]	[_]

<i>5=biodigestor)</i>				
¿Ha usado registros... (0=No, 1=Si)	...productivos (rendimiento)?	PRAGANA3	[_]	[_]
	...económico (gastos, beneficio neto)	PRAGANA4	[_]	[_]
	...sanitarios (med/vet)?	PRAGANA5	[_]	[_]
	...reproductivos (monta, partos)?	PRAGANA6	[_]	[_]

8. ¿Cuál fue su producción diaria en 2012 y 2006, en cada época?		2012 _12		2006 _06	
		Invierno _LL	Verano _SEC	Invierno _LL	Verano _SEC
Litros de leche por vaca por día (sin lo que queda para los terneros)	RENDEC	_____	_____	_____	_____
Rendimiento del queso (Unidad: _____)-UNI	RENDQUE	_____	_____	_____	_____
Ganancia de Peso Vivo en gramos por animal por día	RENDCARN	_____	_____	_____	_____

9. ¿Cuántas cabezas de ganado ha perdido y por qué?		2012 _12	2006 _06
Enfermedades	PERDENF	_____	_____
Robo o destace	PERDROBO	_____	_____
Nutrición insuficiente	PERDNUTRI	_____	_____
Otra razón (especificar: _____)-SPEC	PERDOTRO	_____	_____

10. Dígame más acerca de sus prácticas con respecto al manejo de pastos y forrajes, y a la agricultura:		2012 _12		2006 _06	
¿Ha regado? (0=No, 1=Por surcos en contorno, 2=Por inundación, 3=Por aspersión (como lluvia), 4=Por canales de infiltración, 5=Por goteo / fertiriego, 6=Por drenaje)	RIEG	MODO	PARC	MODO	PARC
		1 [_]	[_ _]	1 [_]	[_ _]
		2 [_]	[_ _]	2 [_]	[_ _]
		3 [_]	[_ _]	3 [_]	[_ _]
		4 [_]	[_ _]	4 [_]	[_ _]
		5 [_]	[_ _]	5 [_]	[_ _]
		6 [_]	[_ _]	6 [_]	[_ _]
Si la respuesta no fue 0, especificar el número de los apartos que corresponden al método de riego:					

¿Ha quemado (después de una cosecha, para crear un nuevo portero, etc.)? <i>(0=No, 1=Si)</i>	QUEM	[_]	[_]
Si la respuesta fue si, especificar los números de los apartos quemados	QUEM_PARC	[_ _] [_ _] [_ _]	[_ _] [_ _] [_ _]
¿Ha comprado algún fertilizante además del estiércol/urea de su hato? <i>(0=No ha comprado, 1=Urea, 2=NPK, 3=DAP (fosfato de amonio), 4=CAN (nitrato de amonio calcáreo), 5=fosfato de roca, 6=mezcla local, 7=varios tipos)</i>	FERT	MODO PARC	MODO PARC
Si la respuesta no fue 0, especificar el número de los apartos que corresponden al fertilizante:	FERT_CUAN	_____ quintales por hectárea por año	_____ quintales por hectárea por año
Y en cual cantidad total:	FERT_MAQ	[_]	[_]
Y si ha utilizado una máquina para aplicarlo <i>(0=No, 1=Si)</i> :			
¿Ha aplicado pesticidas o herbicidas? <i>(0=No, 1=Si)</i>	PEST	[_]	[_]
Si la respuesta fue si, especificar los números de los apartos tratados:	PEST_PARC	[_ _] [_ _] [_ _] [_ _] [_ _] [_ _]	[_ _] [_ _] [_ _] [_ _] [_ _] [_ _]
Y en cual cantidad total:	PEST_CUAN	_____ litros por hectárea por año	_____ litros por hectárea por año
Y si ha utilizado una máquina para aplicarlo <i>(0=No, 1=Si)</i> :	PEST_MAQ	[_]	[_]
¿Ha utilizado máquinas para la preparación de la tierra? <i>(0=No, 1=Si)</i>	MAQPREP	[_]	[_]
Si la respuesta fue si, especificar los números de los apartos:	MAQPREP_PARC	[_ _] [_ _] [_ _] [_ _] [_ _] [_ _]	[_ _] [_ _] [_ _] [_ _] [_ _] [_ _]
¿Ha utilizado máquinas para la siembra (pastos mejorados, cultivos, etc.)? <i>(0=No, 1=Si)</i>	MAQSIEM	[_]	[_]
Si la respuesta fue si, especificar los números de los apartos:	MAQSIEM_PARC	[_ _] [_ _] [_ _] [_ _] [_ _] [_ _]	[_ _] [_ _] [_ _] [_ _] [_ _] [_ _]
¿Ha utilizado máquinas para la cosecha / el chapeo? <i>(0=No, 1=Si)</i>	MAQCOS	[_]	[_]

Si la respuesta fue si, especificar los números de los apartos:	MAQCOS_PA RC	[_] [_] [_] [_] [_] [_]	[_] [_] [_] [_] [_] [_]
¿Ha utilizado máquinas para picar el pasto o el forraje? (0=No, 1=Si)	MAQPICA	[_]	[_]
¿Ha utilizado técnicas de conservación de alimentos para el ganado (bonificación y ensilaje)? (0=No, 1=Si)	ENSI	[_]	[_]
Para los productores que tienen apartos con cultivos:			
¿Ha tenido su producción agrícola alguna certificación (calidad, sostenibilidad, orgánica, etc.)? (0=No, 1=Si)	CERT	[_]	[_]
Si la respuesta fue si, especificar cual cultivo y cual tipo de certificación:	CERT_SPEC	_____	_____
¿Ha aplicado una rotación de sus cultivos entre parcelas... (0=No, 1=Si)	ROTA	...entre 2007 y 2012? [_]	...en 2006 y antes? [_]
Si la respuesta fue si, especificar los números de los apartos en rotación:	ROTA_PARC	[_] [_] [_] [_] [_] [_]	[_] [_] [_] [_] [_] [_]
¿Ha establecido unos cultivos de cobertura / cobertura vegetal? (0=No, 1=Si)	COBER	[_]	[_]
Si la respuesta fue si, especificar los números de los apartos con cobertura:	COBER_PARC	[_] [_] [_]	[_] [_] [_]

11. ¿Compró Usted la finca o fue una herencia de un familiar? [_] HERENC
(1=Compró, 2=Herencia, 3=Otro: _____)

12. ¿Qué tanta influencia tienen otras personas sobre lo que Usted decide para su finca? (1=Poca, 2=Media, 3=Mucha)	2012 _12	2006 _06
Del padre	INFLPADRE [_]	[_]
De otra persona (especificar: _____)	INFLOTRO [_]	[_]

Parte II / Red social y acceso a la información

13. ¿Cuántos kilómetros hay entre su finca y el pueblo más cercano? _____ km DISTPUEB

14. En 2012 y 2006, ¿en cuáles organizaciones de productores participaba usted o cualquier miembro del hogar?

		2012 _12		2006 _06	
		0=No, 1=Si	Si la respuesta fue si, especificar _SPEC	0=No, 1=Si	Si la respuesta fue si, especificar _SPEC
Cámara de ganaderos	OPCAM	[_]	_____	[_]	_____
Cooperativa	OPCOOP	[_]	_____	[_]	_____
Centro Agrícola Cantonal	OPCAC	[_]	_____	[_]	_____
Asociación de productores	OPASO	[_]	_____	[_]	_____
Otra organización de productores	OPOTRO	[_]	_____	[_]	_____

15. ¿Cuánto tiempo se necesitaba para llegar a la sede de la Cámara por su medio usual de transporte de 2012 y de 2006 (desde la casa donde vivían)? En 2012: _____ TMPCAM12

En 2006: _____ TMPCAM06

16. En los últimos 10 años, ¿a cuantas asambleas de la Cámara participó Usted (sin las asambleas extraordinarias)? _____ AGNUM

17. En promedio, ¿cuántas personas del hogar, incluido Usted, asisten a la asamblea? _____ AGPERS

18. ¿Usted o cualquier miembro del hogar ya tuvo una responsabilidad en la Cámara, en la Federación de Cámaras de Guanacaste, en Corfoga o en el MAG, en la junta directiva o una comisión, o como personal en general? (0=No, 1=Si) [_] RESPCAM

19. En promedio en los últimos 10 años, ¿en cuántos talleres de capacitación al año participa Usted o cualquier miembro del hogar? _____ CAPANUM

20. De los talleres de capacitación en los cuales participó Usted o cualquier miembro del hogar en el pasado, ¿cuáles fueron los temas los más importantes/útiles para Usted, **que no sea a propósito de los RBA** (máximo 3)?

(0=ninguno

1=asuntos contables o empresariales

2=uso de desechos/tratamiento de excretas

3=nutrición animal/manipulación de alimentos

4=producción de pastos y forrajes

5=lechería/manejo de ordeño/higiene y salud

6=inseminación artificial/técnica de reproducción animal/mejoramiento genético

7=otro: especificar: _____)

[_]
CAPA1

[_]
CAPA2

[_]
CAPA3

21. ¿Ha recibido en el pasado asistencia técnica o ha participado en un proyecto agropecuario **que no**

sea a propósito de los RBA? [_] ASTEC1 [_] ASTEC2 [_] ASTEC3

(0=No, 1=Técnicos del MAG, 2=Técnicos de una organización de productores en que es miembro, 3=Asistencia externa privada, 4=Técnicos del CATIE, INA, o cualquier centro de investigación público)

23. En 2012 y 2006, ¿Usted o cualquier miembro del hogar, pertenecía a un grupo, asociación, cooperativa o comité de desarrollo local trabajando o relacionado al manejo de recursos naturales o a la producción en general (financiamiento, mercadeo, etc.)?

(00=No/ninguno,
01=Viveros forestales / sembrar árboles,
02=Colectar productos del bosque,
03=Gestión para captación de agua,
04=Prácticas de mejoramiento / conservación de suelo,
05=Introducción o sustitución de cultivos,
06=Irrigación,
07=Ahorros y/o crédito,
08=Mercadeo/venta de productos agropecuarios (ganadería, cultivos, árboles o pesca),
09=Aumento de la productividad (ganadería, cultivos, árboles o pesca),
10=Producción por mujeres,
11=Apicultura,

12=Protección de cuenca o fuente de agua,
13=Producción de semilla,
14=Producción de vegetales/hortalizas,
15=Otro (especificar: _____))

En 2012: [_ _] [_ _] [_ _]

GRP1_12 GRP2_12 GRP3_12

En 2006:

[_ _] [_ _] [_ _]
GRP1_06 GRP2_06 GRP3_06

Parte III / Tecnologías de producción pecuaria

24. ¿Cuáles de las siguientes infraestructuras tenía?

	2012 _12		2006 _06		Si hubo una inversión, ¿cómo lo ha financiado? (1=Pago por servicios ambientales (no RBA) , 2=Crédito, 3=Donaciones y regalías, 4=Fondos propios) _FINA
	Cantidad total (numero, superficie o capacidad) _CUAN	Estado general (1=Malo, 2=Regular, 3=Bueno) _ESTA	Cantidad total (numero, superficie o capacidad) _CUAN	Estado general (1=Malo, 2=Regular, 3=Bueno) _ESTA	
Galerones, corrales, bodegas y silos					
Corral con manga para bovinos o caballos	MANG	_____m ² [_]	_____m ² [_]	[_]	[_]
Otros corrales para bovinos o caballos	CORR	_____m ² [_]	_____m ² [_]	[_]	[_]
Porqueriza, corral/galerón de especies menores	PORQ	_____m ² [_]	_____m ² [_]	[_]	[_]
Galerón para suplementación / alimentación / (semi)estabulación	ESTAB	_____m ² [_]	_____m ² [_]	[_]	[_]

Galerón para la producción de abono orgánico / manejo de desechos	GABO	_____m ² [_]	_____m ² [_]	[_]
Bodega / galerón para almacenar forraje	GFOR	_____m ² [_]	_____m ² [_]	[_]
Silos de montón	SILO	_____m ³ [_]	_____m ³ [_]	[_]
Lechería con ordeño mecánico	LMEC	_____m ² [_]	_____m ² [_]	[_]
Lechería con ordeño manual	LMAN	_____m ² [_]	_____m ² [_]	[_]
Quesería	QUES	_____m ² [_]	_____m ² [_]	[_]
Otra bodega (para medicina veterinaria, etc.)	BODE	_____m ² [_]	_____m ² [_]	[_]
Comederos, abrevadores, saladeros				
Comederos “robustos” (cemento, canoa de láminas de inoxidable, polietileno, etc.)	COMT	_____m [_]	_____m [_]	[_]
Otros comederos (bolsas, jantas, etc.)	COM	_____m [_]	_____m [_]	[_]
Saladeros /salitres entechados o adentro de un galerón, y que no sirvan de comederos)	SALT	_____m [_]	_____m [_]	[_]
Otros saladeros, y que no sirvan de comederos)	SAL	_____m [_]	_____m [_]	[_]
Bebedores / abrevaderos / pilas		_____m [_]	_____m [_]	[_]
Caminos internos de la finca				
Caminos con gavetas de infiltración	CGAV	_____m	_____m	[_]
Caminos de lastre, baldosa, cemento, etc.	CLAST	_____m	_____m	[_]
Caminos de tierra en mal estado / lavados	CLAVA	_____m	_____m	[_]
Otro camino interno	COTR	_____m	_____m	[_]
Otra infraestructura				
Terrazas y barreras en contorno de ladera	TERR	_____m [_]	_____m [_]	[_]
Tanque enfriador	TRESF	_____litros [_]	_____litros [_]	[_]
Cargadero o embarcadero	EMBA	[_] [_]	[_] [_]	[_]
Biodigestor	BIOD	_____m ³ [_]	_____m ³ [_]	[_]
Estercolero / aboneras	ESTER	_____m ³ [_]	_____m ³ [_]	[_]

Paneles solares para cercas eléctricas o calentamiento de agua	PASOL	_____ m ² [_]	_____ m ² [_]	[_]
Planta eólica para producción de electricidad	EOLI	[_] [_]	[_] [_]	[_]
Infraestructuras para turistas	ITURI	[_] [_]	[_] [_]	[_]
Infraestructura o máquinas para producir artesanías	IARTE	[_] [_]	[_] [_]	[_]
Otra: _____	IOTR1	_____ [_]	_____ [_]	[_]
Otra: _____	IOTR2	_____ [_]	_____ [_]	[_]

25. ¿Cuáles de las siguientes maquinas tenía?

2012 _12		2006 _06		Si hubo una inversión, ¿cómo lo ha financiado? (1=Pago por servicios ambientales (no RBA), 2=Crédito, 3=Donaciones y regalías, 4=Fondos propios) _FINA
Cantidad total (numero o capacidad) _CUAN	Estado general (1=Malo, 2=Regular, 3=Bueno) _ESTA	Cantidad total (numero o superficie) _CUAN	Estado general (1=Malo, 2=Regular, 3=Bueno) _ESTA	

Máquinas agrícolas				
Carros y camionetas para la finca	VEHI	_____ [_]	_____ [_]	[_]
Camión de carga	CAMI	_____ [_]	_____ [_]	[_]
Carreta, remolques, traylers	REMO	_____ [_]	_____ [_]	[_]
Tractor	TRAC	_____ [_]	_____ [_]	[_]
Rastra	RASTRA	_____ [_]	_____ [_]	[_]
Arado	ARADO	_____ [_]	_____ [_]	[_]
Yunta de bueyes / montura / aperos de animales	APERO	_____ [_]	_____ [_]	[_]
Otro equipo de tracción animal (especificar: _____)	TRAOTR	_____ [_]	_____ [_]	[_]
Maquinas cortadoras	MCORT	_____ [_]	_____ [_]	[_]
Picadora de pastos / caña	MPICA	_____ [_]	_____ [_]	[_]
Romana de pesar el ganado	BALAN	_____ [_]	_____ [_]	[_]

Maquinaria e instalaciones para manejo de agua						
Bombas de agua con energía solar	BSOLAR	_____	[_]	_____	[_]	[_]
Bombas de agua con energía de viento / molino	BVIENT	_____	[_]	_____	[_]	[_]
Bombas de agua de otro tipo (electricidad, gasolina)	BOTRO	_____	[_]	_____	[_]	[_]
Tanques para coleccionar agua	TANQ	_____m3	[_]	_____m3	[_]	[_]
Reservorios y estanques de agua	RESERV	_____m3	[_]	_____m3	[_]	[_]
Sistema de riego por goteo / fertiriego	GOTEO	_____Ha	[_]	_____Ha	[_]	[_]
Cañería	CANE	_____m	[_]	_____m	[_]	[_]
Surcos en contorno	SURCO	_____m	[_]	_____m	[_]	[_]
Otra maquinaria para la finca						
Otra: _____	MOTR1	_____	[_]	_____	[_]	[_]
Otra: _____	MOTR2	_____	[_]	_____	[_]	[_]
Otra: _____	MOTR3	_____	[_]	_____	[_]	[_]

Parte IV / Tierras y aguas

Dígame más acerca del pastoreo de su ganado (todas las especies de animales) entre los distintos apartos de la finca, según el periodo del año.

28 ¿Cuáles son los apartos (bosques incluidos) en que el ganado ha pastado de manera continuada (365 días)? En 2012: [__] [__] [__] [__] [__] [__] [__] [__]

En 2006: [__] [__] [__] [__] [__] [__] [__] [__]

29. ¿Cuáles son los apartos (bosques incluidos) en que el ganado ha pastado de manera rotacional (con días de recuperación)? En 2012: [__] [__] [__] [__] [__] [__] [__]

En 2006: [__] [__] [__] [__] [__] [__] [__]

Si hubo unos, ¿cuál fue el ciclo aplicado, en promedio de los potreros involucrados, según el periodo del año?

En 2012:

<u>Invierno</u> _LL		<u>Verano</u> _SEC	
¿Cuántos días continuos ha pastado el ganado en los potreros? DIAPAST	¿Cuántos días continuos han recuperado /descansado los potreros? DIARECUP	¿Cuántos días continuos ha pastado el ganado en los potreros? DIAPAST	¿Cuántos días continuos han recuperado /descansado los potreros? DIARECUP
___ días	___ días	___ días	___ días

En 2006:

<u>Invierno</u> _LL		<u>Verano</u> _SEC	
¿Cuántos días continuos ha pastado el ganado en los potreros? DIAPAST	¿Cuántos días continuos han recuperado /descansado los potreros? DIARECUP	¿Cuántos días continuos ha pastado el ganado en los potreros? DIAPAST	¿Cuántos días continuos han recuperado /descansado los potreros? DIARECUP
___ días	___ días	___ días	___ días

30. Entre 2006 y 2012, ¿hubo algún cambio en el manejo de sus bovinos con respecto a su nutrición y su salud, y cuáles fueron las razones? (0=No, 1=Si) ¿Porqué? (si la respuesta fue si, especificar)

¿Ha dado suplementos nutricionales a más tipos de bovinos durante la época de lluvia en 2012 que en 2006?	SUPLCAT_LL	[_]	_____
¿Ha dado a sus bovinos suplementos nutricionales en mayor cantidad y/o calidad durante la época de lluvia en 2012 que en 2006?	SUPLMAS_LL	[_]	_____
¿Ha dado suplementos nutricionales a más tipos de bovinos durante la época seca en 2012 que en 2006?	SUPLCAT_SEC	[_]	_____
¿Ha dado a sus bovinos suplementos nutricionales en mayor cantidad y/o calidad durante la época seca en 2012 que en 2006?	SUPLMAS_SE C	[_]	_____
¿Ha dado más medicinas veterinarias a sus bovinos en 2012 que en 2006?	VETMAS	[_]	_____

31. Dígame más acerca de las cercas

Tipo de cercas	2012 ⁻¹²		2006 ⁻⁰⁶	
	Cantidad total en la finca (metros) CANTI	Modo de regeneración de los arboles (1=Sembrados, 2=Regeneración natural, 3=Ambos) ARBOREGE	Cantidad total en la finca (metros) CANTI	Modo de regeneración de los arboles (1=Sembrados, 2=Regeneración natural, 3=Ambos) ARBOREGE
Cerca viva nueva, con podas o discontinuada	___ m	[_]	___ m	[_]
Cerca viva con diferentes especies, vigor o barrera rompavientos	___ m	[_]	___ m	[_]

30. Dígame más acerca del estado de los potreros de la finca (*apartos que llenar=los en que el ganado ha pastado=los de la tabla arriba*)

Numero de los apartos	2012 ⁻¹²		2006 ⁻⁰⁶	
	¿Cuál es el porcentaje de su aparto que los animales pueden consumir, en verano (lo que queda puede ser malezas no-comestibles o piedras, etc.)? <i>(1=más de 70%, 2=entre 50 y 70%, 3=menos 50%)</i>	¿Tipo de cerca? <i>(1=Eléctrica, 2=Muerta / alambre de púas, 3=Viva nueva o discontinuada, 4=Viva continua y con vigor, 5=Varios tipos)</i>	¿Cuál es el porcentaje de su aparto que los animales pueden consumir, en verano (lo que queda puede ser malezas no-comestibles o piedras, etc.)? <i>(1=más de 70%, 2=entre 50 y 70%, 3=menos 50%)</i>	¿Tipo de cerca? <i>(1=Eléctrica, 2=Muerta / alambre de púas, 3=Viva nueva o discontinuada, 4=Viva continua y con vigor, 5=Varios tipos)</i>
	DEGR	CERC	DEGR	CERC
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]
#___	[_]	[_]	[_]	[_]

30. Dígame más acerca del manejo de las fuentes de agua para las actividades agropecuarias:

		2012 _12			2006 _06		
		¿A cuál fuente de agua ha tenido acceso? (0=No, 1=Si)	¿Había alguna protección de la fuente? (0=No, 1=Vegetación natural, 2=Arboles sembrados o cercas vivas, 3=Cercas muertas o eléctricas, 4=Construcción de cemento, etc.)	¿Consumía agua el ganado allí? (0=No, 1=Si)	¿A cuál fuente de agua ha tenido acceso? (0=No, 1=Si)	¿Había alguna protección de la fuente? (0=No, 1=Vegetación natural, 2=Arboles sembrados o cercas vivas, 3=Cercas muertas o eléctricas, 4=Construcción de cemento, etc.)	¿Consumía agua el ganado allí? (0=No, 1=Si)
Pozo	POZO	[_]	[_]	[_]	[_]	[_]	[_]
Naciente	NACIE	[_]	[_]	[_]	[_]	[_]	[_]
Ríos, quebradas	RIO	[_]	[_]	[_]	[_]	[_]	[_]
Laguna artificial	LAGU	[_]	[_]	[_]	[_]	[_]	[_]
Humedal	HUMED	[_]	[_]	[_]	[_]	[_]	[_]
Bebederos, cañería	BEBED			[_]			[_]
Otra (esp.: _____)	FOTRO	[_]	[_]	[_]	[_]	[_]	[_]

30. ¿Cuáles son los potreros que fueron recientemente sembrados por arboles? En 2012: [_] [_] [_] [_] [_]

En 2006: [_] [_] [_] [_] [_]

31. ¿Cuáles son los apartos (bosques incluidos) donde había entre 1 y 30 árboles arboles por hectáreas?

En 2012: [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_]

En 2006: [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_]

32. ¿Cuáles son los apartos (bosques incluidos) donde había más de 30 árboles por hectáreas?

En 2012: [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_]

En 2006: [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_]

33. ¿Cuáles son los apartos donde no había ningún árbol por hectáreas?

En 2012: [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_]

En 2006: [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_] [_]

Parte V / Motivaciones

31. ¿Cuándo, por quién, por cual modo conoció el programa de Reconocimientos por Beneficios Ambientales y el proyecto de su cámara?

	Mes y año en que lo conoció	Persona u organización que se lo hizo conocer <i>(1=Amigo o vecino que había participado, 2=Amigo o vecino que quería participar, 3=Algún responsable de su cámara, 4=Algún técnico del MAG; 5=Otra: _____)</i>	Medio de comunicación utilizado <i>(1=Conversando con amigos, 1=Por teléfono, 2=Por un taller sobre los RBA, 3=Por un taller sobre otro tema, 4=Por una visita de algún responsable de la cámara o de un técnico; 5=Otra: _____)</i>
	_MES _ANO	_PERS	_MEDIO
Programa de RBA	CONORBA	[_] [_] / [_] [_]	[_] [_]
Proyecto de RBA de la cámara	CONOPROY	[_] [_] / [_] [_]	[_] [_]

32. ¿Cuándo empezó a construir y a hacer las compras previstas en su proyecto de finca?

¿Cuándo se acabó? (00/00 =no empezaron o no acabaron ya)

[_] [_] / [_] [_]
PRINCMES / PRINCANO

[_] [_] / [_] [_]
FINMES / FINANO

Si respondió una fecha de acabo:

32b. Si no ha ejecutado la totalidad de lo que había previsto en su proyecto de finca inicial, ¿cuál fueron las razones? (0=Ha ejecutado 100% de los cambios, 1=No había recursos económicos, 2=No había mano de obra disponible para realizar los trabajos, 3=El clima/tiempo impidió

implementarlo de buena manera, 4 =Otra razón (especificar: _____)) [_] EJEPARCIA

32.c Si respondió una fecha de principio, ¿ha recibido todo el monto que corresponde a los cambios ejecutados, o dio una comisión a la cámara? (0=No recibió nada hasta ahora, 1=Recibió todo de lo que tenía que recibir, 2=Dio una comisión a la cámara, 3=Dio una parte a otra persona u organización

(especificar: _____) [_] RECEPPARCIA

Si la respuesta fue 2 o 3: ¿cuánto dio a otra persona u organización? _____ colones RBACOM

33. De manera general, ¿cómo calificaría su experiencia personal con los RBA? [_] RBASATIS

(1=fue muy decepcionante, 2=fue decepcionante, 3=fue poca satisfactoria, 4=fue satisfactoria, 5=fue muy satisfactoria) ¿Por qué?

34. Gracias a su experiencia y a su parecer, ¿qué piense que le falte al programa? ¿En qué podrían mejorarlo?

35. ¿Hubiera querido hacer las inversiones que hizo con los RBA en su finca antes? ¿Aun sin el apoyo económico que recibió? (0=No, 1=Si con apoyo, 2=Si aun si apoyo) [_] RBAANTES

¿Por qué si o no? _____

37. Gracias a su experiencia y a su parecer, ¿qué otro tipo de apoyo o incentivo podría ser útil para desarrollar el sector agropecuario (línea de crédito, pago por servicios ambientales, asistencia técnica y capacitación, certificación de productos, etc.)?

Ahora me gustaría que ordene las siguientes propuestas sobre temas del medioambiente. El número 1 representa lo más importante o lo más obvio para Usted.

38. Cuando le mencionan la palabra biodiversidad, ¿con qué idea la asocia? (de 1 a 4)

Orden de importancia según el entrevistado	Propuestas	
[_]	Variedad de animales y plantas	BIO1
[_]	Cuidar el ambiente y recursos naturales de una región	BIO2
[_]	Protección de las fuentes de agua	BIO3
[_]	Mejor apariencia de su finca	BIO4

39. ¿Cuáles serían para Usted los señales que una tierra es de buena calidad? (de 1 a 4)

Orden de importancia según el entrevistado	Propuestas	
[_]	Unos buenos rendimientos de cultivo	SUE1
[_]	Muchos lombrices, hormigas, termitas,... viven en el suelo	SUE2
[_]	No hay muchas malezas	SUE3
[_]	El suelo retiene mucha agua de la lluvia	SUE4

40. ¿Cómo Usted reconoce si una fuente de agua es de buena calidad? (de 1 a 5)

Orden de importancia según el entrevistado	Propuestas	
[_]	Los animales vienen beber allí	AGU1
[_]	El agua es transparente y no huele feo	AGU2
[_]	No hay basuras a la orilla	AGU3
[_]	Hay árboles que la protegen	AGU4
[_]	Los campos alrededor no son tratados por agroquímicos	AGU5

41. ¿Cuáles son sus planes para su finca en los próximos 5 años? (de 1 a 8)

Orden de importancia según el entrevistado	Propuestas	
[_]	Incrementar el tamaño de su hato	EMPR1
[_]	Reducir el tamaño de su hato	EMPR2
[_]	Cambiar de tipo de actividad bovina	EMPR3
[_]	Con más infraestructuras, maquinas o prácticas que mejoran la productividad sin proteger el ambiente	EMPR4
[_]	Con más infraestructuras, maquinas o prácticas que protegen el ambiente sin mejorar la productividad	EMPR5
[_]	Aprovechando los efectos de los cambios que ya hizo en el pasado sin cambiar otra cosa	EMPR6
[_]	Comprar más tierra	EMPR7
[_]	Vender la tierra	EMPR8

42. De las siguientes fincas, ¿cuál tiene mayor valor económico para Usted? (de 1 a 4)

Orden de importancia según el entrevistado	Propuestas	
[_]	Finca con predominio de pasturas mejoradas sin arboles	FINC1
[_]	Finca con predominio de pasturas mejoradas con arboles	FINC2
[_]	Finca con predominio de bosques y cercas vivas	FINC3
[_]	Finca con predominio de bosques y pasturas mejoradas	FINC4

43. En su opinión, ¿su finca tiene muchos animales silvestres, insectos o animales voladores (pájaros, mariposas, abejas, colibrís, etc.)? [_]^{BIOCAL}

44. ¿Considera Usted que esos animales en 2006 eran menos / igual / más que en 2012 en su finca?

(1=menos, 2=igual, 3=mas) [_]^{BIOEVO}

¿Porque? _____

45. En su opinión, ¿sus tierras son de buena calidad? [_]^{SUECAL}

46. ¿Considera Usted que la calidad de sus tierras en 2006 era peor / igual / mejor que en 2012?

(1=peor, 2=igual, 3=mejor) [_]^{SUEEVO}

¿Porque? _____

47. En su opinión, ¿el agua con que realiza las actividades de la finca es de buena calidad? [_]^{AGUCAL}

48. ¿Considera Usted que la calidad del agua en 2006 era peor / igual / mejor que en 2012?

(1=peor, 2=igual, 3=mejor) [_]^{AGUEVO}

¿Porque? _____

49. En su opinión, ¿la productividad de sus actividades ganaderas es alta? [_]^{PRODCAL}

50. ¿Considera Usted que su productividad en 2006 era peor / igual / mejor que en 2012?

(1=peor, 2=igual, 3=mejor) [_]^{PRODEVO}

¿Porque? _____

51. ¿Usted cree que en su finca hay algún atractivo para que atraiga a los visitantes? (no solo atractivos turísticos, sino visitas de aprendizaje de algo innovador o particular en su finca) [_]^{ATTRACT}

(0=No, 1=Si)

Si la respuesta fue si, mencione cual: _____

52. ¿Le gustaría recibir visitantes/turistas en su finca? [_]^{TURIST}

(0=No, 1=Si)

Si la respuesta fue si, ¿qué tipo de visitantes?:

(0=No, 1=Si)

Otros productores, estudiantes, técnicos

TURIST1

[_]

Turistas que quieran recoger su finca y observar aves, fuentes de agua	TURIST2	[_]
Turistas que solo buscan alojamiento en fincas quietas	TURIST3	[_]
Turistas que quieran pasar más de una noche en su finca y que además quieran hacer actividades diarias con Usted y la familia	TURIST4	[_]

53. ¿Estaría dispuesto a dejar en regeneración natural áreas que se encuentran en laderas con relieve fuerte, o que se ubican cerca de las nacientes o toma de aguas? (otro ej.: impedir que el ganado pase por áreas degradadas o bosques)

(0=No, 1=Si) [_] CONSERV

54. ¿Estaría dispuesto a comprometerse por escrito mediante un acuerdo a conservar la vegetación natural y el agua en su finca? (0=No, 1=Si) [_] COMPRO

Parte VI / Características socio-económicas del hogar

Para clarificar la definición del hogar

55. ¿Sexo de la cabeza de familia? (1= varón, 2=mujer) [_] HHSEX

56. ¿Edad? _____ HHEDAD

57. ¿Estado civil? (1=soltero, 2=casado, 3=divorciado, 4=viudo, 5=unión libre) [_] HHESTA

58. ¿Cuántas personas, incluido usted, otros adultos y niños conformaban su hogar... en 2012? _____ HHT12
en 2006? _____ HHT06

59. ¿Cuántas personas de la familia tenían menos de 12 años... en 2012? _____ MEN1212
...en 2006? _____ MEN1206

60. ¿Cuántas personas de la familia tenían más de 60 años... en 2012? _____ MAY6012
...en 2006? _____ MAY6006

61. ¿Cuántos años de estudios tiene Ud en total (de la escuela primaria a la universidad)?: _____ HHEDUC

62. ¿Cuántos miembros de la familia estudian o estudiaron en una escuela técnica de agricultura o ganadería, en la universidad o en una secretaria? _____ EDUCSUP

63. ¿Cuántos jornales por mes necesitaba cada actividad de su finca?

2012

_12

¿Cuántos jornales por meses?
¿Quién trabajó en 2012? (número de personas de cada tipo)
Familiares Empleados (incluido Ud)

2006

_06

¿Cuántos jornales por meses?
¿Quién trabajó en 2012? (número de personas de cada tipo)
Familiares Empleados (incluido Ud)

		_MES	_FAM	_EMPL	_MES	_FAM	_EMPL
Trabajo de la ganadería bovina en la finca	ACTBO	___jXm	___pers	___pers	___jXm	___pers	___pers
Trabajo de la ganadería menor (aves, cerdos, etc.) en la finca	ACTME	___jXm	___pers	___pers	___jXm	___pers	___pers
Trabajo agrícola (granos, café, frutas, vegetales, forraje, etc.) en la finca	ACTAG	___jXm	___pers	___pers	___jXm	___pers	___pers
Transformación de productos agropecuarios (queso, café, conservas, etc.)	ACTTRA	___jXm	___pers	___pers	___jXm	___pers	___pers
Trabajo forestal	ACTFOR	___jXm	___pers	___pers	___jXm	___pers	___pers

64. ¿Cuántas horas tiene un jornal para Ud? _____ JORNALUNI

65. ¿Cuánto se paga por jornal en la zona? _____ JORNALPRECIO

66. Durante los 12 meses de 2012 y de 2006, ¿cuántos familiares trabajaron afuera de la finca o en un negocio que no sea a propósito de los productos de su finca?

		2012 _12	2006 _06
		¿Cuántas personas? _PERS	¿Cuántas personas? _PERS
Trabajo agropecuario asalariado fuera de la finca propia	SALAGRO	___p.	___p.
Otro trabajo asalariado fuera de la finca propia	SALOTRO	___p.	___p.
Negocio (otro que no sea venta de productos animales o agrícolas de la finca)	NEGO	___p.	___p.

67. ¿Durante los 12 meses de 2012 y de 2006, recibió otro ingreso de dinero en efectivo? (0=No, 1=Si)

		2012 _12	2006 _06
Renta de maquinaria propia (ej. tractor, trilladora, bomba, etc.) o animales de tracción	INGRRENTA	[_]	[_]
Alquilar tierra de su propiedad a otro	INGRALQUI	[_]	[_]
Prestamos/ crédito de un banco u otra institución formal (micro-crédito, programas, cooperativas, asociaciones) QUE NO SEA PARA FINANZAR UN PROYECTO DE RBA	INGRBANC	[_]	[_]
Y en el pasado, ¿tuvo uno...	CREDBANC	...entre 2007 y 2011? [_]	...antes de 2006? [_]
Préstamo / crédito de una fuente informal (prestamistas, familiares, etc.) QUE NO SEA PARA FINANZAR UN PROYECTO DE RBA	INGRINF	[_]	[_]
Y en el pasado, ¿tuvo uno...	CREDINF	...entre 2007 y 2011? [_]	...antes de 2006? [_]

Donaciones, remesas o regalos (dinero o en especies, p. ej. de un migrante familiar fuera de Costa Rica)	INGRREME	[_]	[_]
Pago por servicios ambientales (en efectivo, como descuento de impuestos, pagos; o en especies, como ejemplo plántulas, herramientas, comida) Si la respuesta fue si, especificar los números de parcelas que permiten recibir el pago:	INGRPSA	[_] [_ _] [_ _]	[_] [_ _] [_ _]
Y en el pasado, ¿tuvo uno... (Especificar los números de parcelas en la línea arriba)	PSAINF	...entre 2007 y 2011? [_]	...antes de 2006? [_]
Otros beneficios económicos a través de proyectos / gobierno, incluyendo dinero y aquellos en especie (ej. pensiones, ayuda de programas, subsidios, bonos, etc.) SALVO LOS RBA	INGRGOB	[_]	[_]
Otro fuente de ingreso (especificar)	INGROTRO	_____	_____

68. ¿Cuál es el porcentaje del ingreso total familiar que perciben por la actividad ganadera?

en 2012? _____% PCTGANA12

en 2006? _____% PCTGANA06

69. ¿Cuál era la distancia entre su finca y la casa donde vivía... en 2012?. _____km FINCASA12

en 2006? _____km PCTGANA06

70. De los siguientes bienes, ¿cuáles tuvo en 2012 y 2006 y en qué cantidad?

		2012 _12	2006 _06
Automóvil (que no sea para la finca)	BIENAUTO	_____	_____
Motocicleta	BIENMOTO	_____	_____
Bicicleta o triciclo	BIENBICI	_____	_____
Refrigerador	BIENREFRI	_____	_____
Cocinas/estufas de gas mejoradas	BIENGAS	_____	_____
Computadora con acceso a internet	BIENNET	_____	_____
Computadora	BIENCOMPU	_____	_____
Radio	BIENRADIO	_____	_____
Televisión por satélite	BIENSAT	_____	_____
Televisión	BIENTELE	_____	_____
DVD	BIENDVD	_____	_____

Teléfono celular	BIENCELU	___	___
Aire acondicionado	BIENAIRE	___	___
Ventilador eléctrico	BIENVENT	___	___
Lavadora	BIENLAVA	___	___
Cuenta bancaria	CUENTABANC	___	___

71. ¿Cuál de la siguientes estructuras/facilidades tenía su hogar? (0=No, 1=Si)

		2012 _12	2006 _06
La finca			
Carretera de acceso a finca pavimentada / de lastre	ACCELAST	[_]	[_]
Carretera de acceso a finca destapada	ACCETIER	[_]	[_]
La casa donde vivían			
Casa propia	CASA	[_]	[_]
Grifo de agua potable en casa o agua potable por tubería	SERVAGUA	[_]	[_]
Pozo (agua para el hogar)	POZO	[_]	[_]
Tanque almacenamiento de agua para uso doméstico (> 500 litros)	TANQ	[_]	[_]
Electricidad (de la red)	SERVELEC	[_]	[_]
Alcantarillado público	SERVALC	[_]	[_]
Servicio de recolección de basura	SERVDESE	[_]	[_]
¿Cuántos aposentos con paredes de concreto o fribrolit había en su casa (excluidos los baños, cuarto de pilas, pasillos, corredores y garajes)?	CUARTOSM	___	___
¿Cuántos aposentos de madera había en su casa?	CUARTOSO	___	___

Parte conclusiva / Observaciones adicionales

71. ¿Algo que añadir a propósito del tema?

Agradecer por su tiempo, respuestas de gran calidad que nos ayudan mucho

Hora al terminar la entrevista: _____ HR2
Observaciones sobre el cuestionario: _____
Observaciones sobre el hogar/la finca que no aparecen: _____
Observaciones sobre como paso la entrevista: _____

3 Photos



A farm with banana trees associated with coffee plants, Tarrazu.



Coffee grown under the shade of Erythrinass, Leon Cortes.



A living fence between pastures, Guanacaste.



Cattle at the drinking trough, Guanacaste.

ABSTRACT

Smallholding agriculture lies at the crossroads of mitigation and adaptation strategies. Both mitigation efforts to limit the atmospheric accumulation of greenhouse gases and adaptation measures that aim to at least maintain agricultural yields and incomes in the face of climate change will be instrumental in eradicating extreme poverty and hunger. This dissertation explores the adoption of climate-smart technologies by Costa Rican smallholders in the two main farming systems of the country, namely high-quality coffee plantations and extensive cattle-ranching farms. I present the results of three studies that use primary data to investigate opportunities and challenges for scaling-up agroforestry and silvopastoralism. Potential barriers that put strain on technology adoption by rural households in the developing world are outlined in the introduction. In the first Chapter, a representative coffee farm model of land allocation between production technologies is used to explore the tradeoff between adopting coffee agroforestry - a well-documented option for both mitigation and adaptation - and dealing with market risks. Based on a Choice Experiment conducted with 207 farmers, Chapter 2 assesses the willingness of coffee farmers to adopt various agroforestry-based strategies, under various types of support. Chapter 3 evaluates the effectiveness of a national cost-share program promoting the adoption of technological packages consistent with silvopastoralism-based intensification among cattle ranchers. It provides estimates of the impact of participating into the program on both the technology adoption and the land use patterns. Overall, the results of these studies suggest that the adoption of agroforestry and silvopastoralism is costly and can be slowed down due to market frictions. Public interventions can in turn be effective in encouraging smallholders to adopt these technologies through economic incentives. The choice of the technology to be promoted is found to be crucial for the cost-efficiency of such interventions, stressing the relevance of the research conducted.

Keywords: Adoption of Agricultural Technology, Climate Change, Payment for Environmental Services, Coffee, Cattle Ranching, Costa Rica.

RESUMÉ

L'agriculture se situe au carrefour des stratégies d'atténuation et d'adaptation, en particulier dans les régions tropicales. Les efforts d'atténuation pour limiter l'accumulation de gaz à effet de serre dans l'atmosphère et les mesures d'adaptation visant à au moins maintenir les rendements et les revenus agricoles face au changement climatique contribueront à éradiquer l'extrême pauvreté et la faim. Cette thèse explore l'adoption de technologies climato-intelligentes par les petits exploitants du Costa Rica dans les deux principaux systèmes agricoles du pays, à savoir les plantations de café et les systèmes extensifs d'élevage de bétail. Je présente les résultats de trois études qui utilisent des données originales pour étudier les possibilités et les défis liés à l'extension de l'agroforesterie et du sylvopastoralisme. Les obstacles potentiels à l'adoption de technologies par les ménages ruraux dans les pays en développement sont décrits dans l'introduction. Dans le premier chapitre, un modèle représentatif d'allocation des terres entre les technologies de production des exploitations de café est utilisé pour explorer le compromis entre l'adoption de l'agroforesterie - une option bien documentée pour l'atténuation et l'adaptation - et la gestion des risques de marché. Basé sur une expérience de choix menée avec 207 agriculteurs, le chapitre 2 évalue la volonté des producteurs de café d'adopter diverses stratégies basées sur l'agroforesterie, sous différents types d'incitation. Le chapitre 3 évalue l'efficacité d'un programme national de partage des coûts favorisant l'adoption de paquets technologiques compatibles avec l'intensification fondée sur le sylvopastoralisme chez les éleveurs de bovins. Il fournit des estimations de l'impact de la participation au programme sur l'adoption des technologies et sur l'utilisation des terres. Dans l'ensemble, les résultats de ces études suggèrent que l'adoption de l'agroforesterie et du sylvopastoralisme est coûteuse et peut être ralentie en raison des frictions du marché. L'intervention publique par le biais d'incitations économiques peut en réponse être efficace afin d'encourager les petits exploitants à adopter ces technologies. Le choix de la technologie à promouvoir se révèle crucial pour l'efficacité de ces interventions, soulignant la pertinence des études proposées.

Mots-Clés : Adoption de Technologie Agricole, Changement Climatique, Paiement pour Services Environnementaux, Café, Elevage, Costa Rica.