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Shades of Shade: Determinants of Conservation Practices in Coffee Plantations for Ecosystem Services Provision in Puerto Rico, a Preliminary Analysis

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Abstract- Ecosystems provide society with a wide range of services—from reliable flows of clean water to productive soil, carbon sequestration and biodiversity conservation among many others. However, private landowners typically lack the incentive to manage their land to provide ecosystem services because many of these benefits accrue to third parties. As a result, land management effects on ecosystem services are often not incorporated into private decision-making, perpetuating suboptimal outcomes that may even harm both human well-being and the environment. To tackle this inefficiency, the use of market instruments and other forms of incentive programs that target resource conservation and provision of ecosystem services in private lands have become increasingly prevalent in environmental policy.

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I. Introduction

Ecosystems provide society with a wide range of services—from reliable flows of clean water to productive soil, carbon sequestration and biodiversity conservation among many others. Individuals, companies, and communities rely on these services for raw inputs, production processes, food security, climate resilience and other benefits. However, private landowners typically lack the incentive to manage land to provide ecosystem services because many of these benefits accrue to third parties. As a result, land management effects on ecosystem services are often not incorporated into private decision-making, perpetuating suboptimal outcomes that may even harm both human well-being and the environment. To tackle this inefficiency, the use of market instruments and other forms of incentive programs that target resource conservation and provision of ecosystem services in private lands have become increasingly prevalent in environmental policy.

Several previous studies have examined the effects of incentive policies on carbon sequestration, biodiversity conservation, pollination services, habitat fragmentation, agricultural land prices, economic returns from different land-use patterns, provision of spatially dependent ecosystem services, and poverty amelioration in developing contexts.[1] In general, evidence of the effect of incentive programs on the adoption of conservation practices and the efficiency of conservation policies in accomplishing environmental and social development goals is mixed and context-specific. This study contributes to the existing literature devoted to this issue not only by adding another estimation testing the robustness of previous findings, but by exploring new linkages between competing policy instruments, adoption decisions and biodiversity conservation goals. In this paper, I develop a micro-econometric model that examines the factors affecting land-owner participation in a variety of biodiversity conservation and agricultural-land management programs and the impacts of these schemes on the adoption of conservation practices among commercial coffee farmers in Puerto Rico.

There is a broad consensus within the literature that adoption and diffusion of conservation practices are

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[1] See for example Lawler et al. (2014); Lewis and Wu (2014); Lewis (2010); Lin (2010); Polasky and Segerson (2009); Lewis and Plantinga (2009); Nelon et al. (2008); Lewis and Plantinga (2007); Kremen et al. (2007).

the result of a complex decision-making process, particularly when examined at the micro-economic level. Those decisions have been found to depend on a wide array of factors related to agro-ecological factors such as habitat fragmentation and spatial configuration of agricultural lands, farmer demographics and political, cultural and economic institutions of a particular social environment, among others.[2]In Puerto Rico, little research has been done about the status of coffee production, the influence of governmental policies on farming practices and the attitudes of farmers towards production practices that are beneficial to the environment. Therefore, a primary objective of this study is to investigate the factors that determine farmer participation in conservation programs and the impact of said programs on adoption of conservation practices in Puerto Rico.

The preliminary empirical results indicate that participation in agricultural-land management programs increases the probability of using conservation agriculture practices. In general, the results suggest that farmers who participate in conservation programs encouraging the cultivation of coffee under a shaded canopy are "newer" farmers who take advantage of quality differentials in their product to sell in specialty markets. In turn, the findings suggest that it may be "privileged" farmers who are more likely to adopt shade-management practices. Coffee producers in Puerto Rico face the decision to participate in federal incentive programs that encourage in situ biodiversity conservation or in antagonistic state programs that favor the use of monocrop-type-of coffee production methods that may be harmful for the environment. Based on the studied sample, federal environmental agencies interested in improving the targeting of existing programs should be wary of displacing antagonistic state programs, as these seem to be, paradoxically, the most important driver of the decision to adopt environmentally beneficial agricultural management practices.

This paper is organized as follows. Section 2 presents a short description of the agroecology of coffee production and introduces the concept of conservation agriculture and payments for ecosystem services (PES). Section 3 provides a brief review of the microeconomic literature on PES and biodiversity ecosystem services provision. Section 4 introduces and describes in detail the case of coffee farming and biodiversity conservation in Puerto Rico. In section 5, a theoretical framework is elaborated and key insights from this section are used to design and conduct the empirical work of this research. Section 6 presents the empirical methods followed in this study. Data description is followed by a discussion of the econometric methodology that was followed for estimation. This section ends with a presentation of the results from the econometric estimation. This paper ends with section 7 where conclusions and a short discussion of policy implications are presented.

II. The Agro-Ecology of Coffee Production

Coffee is an important commodity traded internationally. The commodity chain comprises growers, harvesters, processors, exporters, importers, shippers and roasters before the end product finally reaches consumers via supermarkets, specialist retailers and coffee shops. Coffee exporting alone is a USD $20 billion industry with tens of millions of people relying on coffee production as their primary form of employment around the world.[3]Coffee is produced and exported by approximately 55 countries, most of which are lower/middle income countries. The largest world producing region is Central and South America, with many of the leading world producers like Brazil, Colombia, and Mexico. Other important producers in the region are Peru, Guatemala, El Salvador, and Costa Rica. As far as production in North American countries goes, coffee plants grow commercially only in U.S. territories of Hawaii and Puerto Rico.[4]

The coffee tree is an evergreen tropical plant which grows in the tropics between latitudes 25°N and 25°S. There are over 60 species of coffee tree but only two dominate world production: Robusta and Arabica—which account for approximately 30% and 70% of world production, respectively. The world's largest producers of Arabica and Robusta coffee are, respectively, Brazil and Vietnam. Robusta coffee is a relatively resilient, high-yielding tree; highly resistant to disease but producing an inferior quality of bean.[5] Most of the global production of Robusta is used in the making of instant coffees.

Arabica, on the other hand, is a more delicate variety producing a more heterogeneous product, the quantity and quality of this bean varies significantly depending on soil, rainfall, altitude, temperature, amount of sunlight, and the cultivation practices followed by growers. Typically, Arabica beans sell for almost twice the price of Robusta beans in the market.

A typical coffee tree, Robusta or Arabica, takes about five years to yield a considerable crop and seven

[2] See the works by Page and Bellotti (2015); Greiner et al. (2009); Kauneckis and York (2009); Amsalud and De gRaffe (2008); De Graffe et al. (2008); Kumar (2007), Birol et al. (2006); Knowler and Bradshaw (2007).

[3] Cooper (2014).

[4] For more information visit the Wikipedia page on economics of coffee: https://en.wikipedia.org/wiki/Economics_of_coffee.

[5] Robusta has higher caffeine content than Arabica (almosttwice as much). Caffeine has a bitter taste butalsoserves as a chemicaldefense for the coffeeseed so that the quantity of caffeine in Robusta istoxic to insects.

to bear at full capacity (about a pound of coffee annually). Such rapid development of a tree that never becomes large suggests a short life. However, one coffee planting is typically unprofitable after 15-30 crops (more or less the same number of years, as coffee is generally harvested once a year).[6]There are four fundamental stages in coffee production: picking, processing (sorting), milling, and storing. Whenever coffee plantations are located in the mountains, which the most frequent case among Central and South American countries—except for Brazil, the picking of fruits (also called cherries) is mostly done by hand. There are two strategies for picking: (1) strip picking, where all coffee fruits are removed from the tree regardless of their maturation, and (2) selectively picking, where only ripe cherries are picked.[7] Selectively picking is very labor intensive because it requires pickers to visit the plantation every 8 to 10 days; therefore, it is only used for harvesting the finest Arabica beans.

A key feature of coffee production (and other fruit crops) is that the future yields from coffee plants decline (and maybe dramatically) when the plants are not maintained or when the coffee cherries are not harvested in a given year. If left unharvested, many "old" fruits will remain in place and limit the space for the formation of new flowers possibly causing significant damage to the tree's carrying capacity. In some cases, only significant investments can restore a coffee plantation where cherries have been left unharvested for a year.[8]

There are grossly two methods for managing a coffee plantation: farmers can produce coffee under a diverse and dense canopy of shade trees or grow the coffee trees without a shade cover. The coffee produced in a system with shade trees is called "shade coffee", its counterpart is called "sun coffee". In the past three decades, shade coffee cultivation has gained widespread attention for their crucial role in biodiversity conservation and ecosystem services provision.[9] Ecosystem services such as pollination, pest control, climate regulation, and nutrient sequestration are generally greater in shaded coffee farms. The botanical diversity contained in these systems provides shelter for a high biodiversity of other organisms—including birds and amphibians—and is therefore considered better for the environment. Other purported environmental benefits of shade management regimes include diminished crop exhaustion, improvement of soil fertility, and increased nutrient availability (due to fallen leaves).[10]

Despite the existence of positive environmental spillovers associated with shade cultivation, a recent trend in production in many coffee-growing regions is reducing the shade cover as this management practice proves economically unsustainable. Sun plantations are more economically attractive to coffee growers because, in the short run, sun-grown coffee trees are believed to produce higher yields than shade-grown trees. Additionally, as the forested structure of the farm makes it difficult to implement mechanized harvesting technologies, the harvesting shade plantations relies primarily on labor, therefore creating an additional dependence for coffee producers on the state of the labor market and the availability of complementary or substitutable inputs. Table 1 compares Sun and Shade Coffee production on various performance indicators. This information was obtained from a report on Mexican Shade Coffee presented to the WTO by Consumer's Choice Council in 2002.

[6] Perfec to and Vandermeer (2015).

[7]Unless climateisdry for anunusually long period of time, orunless some other stochastic in fluences that cause very heavy blossomingveryfast, there will be greenfruit of different ages on the tree at harvesting time.

[8] Batz et al. (2005).

[9] Jha et al. (2014).

[10] Borkhataria et al. (2012).

Table 1 : Comparison of shade and suncoffeeplantations

	Shade	Sun
Production		
Yield	Lower (~25-40%)	Higher
Plants/Hectare	1000-2000	3000-7000
Kg/Ha/Year	550	1600
Lifetime of Plants	24-30	12-15
Side Crops	High	
Flavor	Less Bitter	
Producers	Mostly, small-scale growers	Mostly, large-scale growers
Costs		
Weeding	Lower	Higher
Chemical Fertilizer	Lower	Higher
Pesticides	Lower	Higher
Irrigation	Lower	Higher
Labor*	Higher	Lower
Ecology		
Soil Erosion	Lower	Higher
Soil Acidification	Lower	Higher
Toxic Run-Off	Lower	Higher
Biology		
No. of Bird Species	150	20-50
Proportion Avifauna	2/3	~1/10
Mid-size Mammals	24 species	~0
Other	More species of ants, beetles, epiphytes, amphibians and other	Less species of ants, beetles, epiphytes, amphibians and other

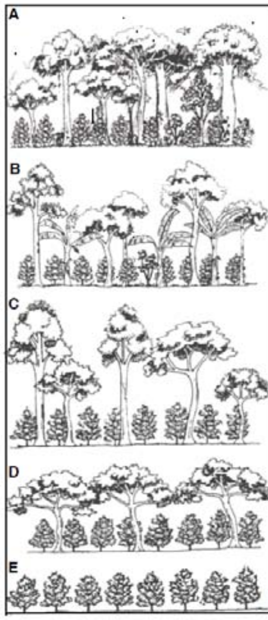
** Not included in the original table.*
Source: Seattle Audubon Society Shade-Grown Coffee Project available here: http://dnr.wi.gov/wnrmag/html/stories/2004/feb04/shadechart.htm

a) *Institutional Approaches to Promote Conservation Agriculture*

Given the economic, cultural and ecological importance of coffee in Latin America, the conservation/productivity trade-off presents an interesting opportunity to develop programs for sustainable development. Recently, several campaigns have been launched to promote the production and consumption of shade-coffee. One of the emerging strategies is shade coffee certification. Shade-coffee certification seeks to compensate farmers for the biodiversity conservation service provided by their shaded plantations. However, there is an important problem with the certification approach: a variety of shade management regimes exist in the coffee agro-ecosystem and it is not clear that all of them are necessarily good for maintaining biodiversity (see Figure 1). This is often called the "shades of shade" paradox. In general, there are three categories of agroforestry farms: rustic (coffee grown within the existing forest, the coffee plants have replaced some of the native plants); traditional polyculture (coffee is grown among native forest trees and intercropped with planted species that can generate additional income to farmers –like fruits and vegetables); and commercial polyculture (most native trees are removed to provide more space for coffee plants and coffee is mostly grown under planted timber and fruit trees). Such heterogeneity in performance would imply determining different premium prices for particular regions, or even particular farms—which is highly unrealistic and politically unpalatable.

Another policy instrument that is increasingly popular for the conservation and sustainable management of natural resources in Latin America are schemes of Payments for Ecosystem Services (PES). PES are economic incentives offered to farmers or landowners in exchange for managing their agricultural and forest lands to provide some sort of ecological service. PES programs circumvent some of the problems encountered by the certification approach. Explicitly, these conservation programs (whether they are governmental or non-governmental) provide funds or other form of payment (sometimes they are paid in the form of agricultural inputs), increasing the profitability of productive lands without passing on higher prices to consumers. Additionally, PES programs can be tailored as pro-poor development schemes, enabling low-income farmers to earn a reliable stream of income by adopting more sustainable land management practices.

PES programs are popular in Central America and in the Amazon region—particularly for addressing matters of agro-forestry and water management. Nevertheless, and in spite of the push by many international organizations to promote shade coffee production, little is known about how coffee farmers make decisions about take-up, maintenance, harvest, and abandonment, and therefore about their responses to policies that promote this production practice. In this study, I seek to aid the design of sound policy instruments in the region and improve the scientific understanding of producers' decision-making process by carefully reviewing the particular case of Puerto Rican coffee growers that choose whether or not to participate in conservation programs offered by federal agencies and whose decision may help further broader conservation and environmental goals.



MANAGEMENT SYSTEM	%SHADE* COVER	SHADE TREE* RICHNESS
RUSTIC	71-100	> 50
TRADITIONAL POLYCULTURE	41-70	21-50
COMMERCIAL POLYCULTURE	31-40	6-20
SHADED MONOCULTURE	10-30	1-5
UNSHADED (SUN) MONOCULTURE	0	0

Modiefied from: Moguel and Toledo 1999; Rain Forest Alliance.

* Figures for percent shade and tree species richness are approximates based on studies cited by Moguel and Toledo, 1999 and our own research (Perfecto et al. 2003).

Figure 1 : Types of shade management systems with shadecover and shade tree richness. Source: Perfecto et al. (2007)

III. Literature Review

In neoclassical economic theory, the existence of market failures justifies regulatory intervention. In general, market failures are situations in which something prevents the market from reaching an efficient allocation of goods and services. In other words, there exists an alternative outcome where someone can be made better off without making someone worse off (in economics lingo, it is said there is an opportunity for a Pareto improvement). The coarse nomenclature of market failures includes externalities, public goods, imperfect information, and existence of market power. The study of the causes of market failures and the possible means of correcting it have important implications for public policy decisions. Policy interventions, such as taxes, price controls, and quotas, are often used to address market failures and reach a more efficient allocation of the resources in question. The case of ecosystem service provision in private lands is one of environmental externalities and impure public goods—goods that are neither wholly public nor wholly private.

The idea behind the PES concept is to provide additional incentives for private landowners to do more, or less, of the target activity in order to produce the socially optimal level of ecosystem services—the level that maximizes social value. In this sense, PES behave as a Pigouvian subsidy for providers of ecosystem services and biodiversity conservation.[11] Theoretically, if the level of payment is set correctly, private agents can reach a socially efficient outcome by means of engaging in otherwise undistorted market interactions. The microeconomic foundations of PES can be visually summarized in Figure 2.

The economic literature studying Pigouvian approaches to solve environmental problems is long, rich and sound. However, the application of Pigouvian approaches to integrate economics and ecology in the study of ecosystem services is a newer initiative and its interdisciplinary nature makes it a vibrant topic in the environmental economics field. Over the past decade, academic progress in the natural resources fields has improved the scientific community's understanding of how ecosystems provide services and how service

[11] A Pigouviansubsidy is a subsidy provided to anactivity that generate sexternal benefits. The logic behind this policy is to to incentivize the production of something whose producto on process generates benefits to third parties. For more detailsee https://en.wikipedia.org/wiki/Pigovian_tax.

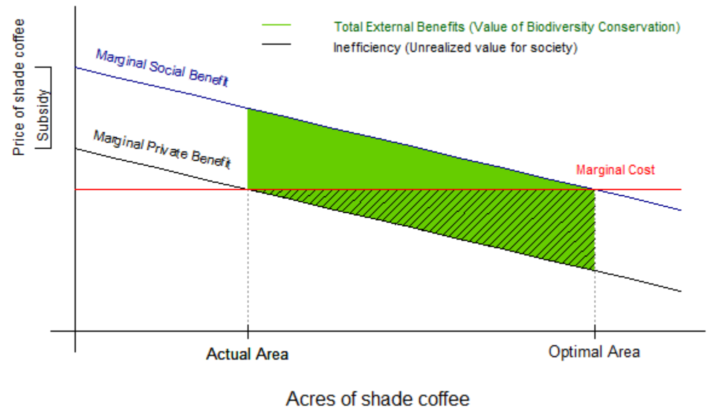


Figure 2 : Illustration of a Pigouvian Subsidy

provision translates into economic value.[12] Yet, there is much criticism over the approaches and assumptions used to study the relation between nature and economics. Common approaches to valuation often lack scientific foundation, or that lead to research that provides information that is largely irrelevant for answering complex policy question. Thus, moving from general pronouncements about the benefits nature provides to credible, quantitative estimates of ecosystem service values has been difficult.[13]

Nevertheless, recent advancements in computer technology and increased computer power has allowed researchers to incorporate more and more diverse information into scientific analysis, triggering an enormous amount of activity among focal natural resources researchers including environmental economists, ecologists, geographers, biologists and earth scientists. Between 2002 and 2015 the interdisciplinary literature examining ecosystem services provision and biodiversity conservation from a microeconomics framework grew rapidly. Recent studies have examined the effects of incentive policies on carbon sequestration, biodiversity conservation, pollination services, habitat fragmentation, agricultural land prices, economic returns from different land-use patterns, provision of spatially dependent ecosystem services, and poverty amelioration in developing contexts.[14] In general, evidence of the effect of incentive programs on the adoption of conservation practices and the efficiency of conservation policies to meet environmental and social development goals is not definite.

The problem of how to optimally allocate habitat for species conservation has been addressed previously.[15] The objective of these studies is to select reserves to maximize the number of protected species subject to a constraint on the total area of reserved land. Economists have also contributed to this literature.[16] Several authors have examined questions of optimal targeting of conservation incentives (including voluntary incentives) for furthering some environmental goal—such as reducing forest or habitat fragmentation, or enhancing the provision of ecosystem services like carbon sequestration and pollination.[17] However, few studies have developed methods to explicitly connect policy impacts on private land-use decisions and the resulting change ecosystem services provision.

Among the most complete and sophisticated works found in the recent literature, is the study conducted by Lewis et al. (2011) which addresses the efficiency of voluntary incentive-based policies in achieving biodiversity conservation objectives. In this study, researchers build off of their previous works on conservation planning and incentive-based policies.[18] The researchers develop a sound method that integrates an econometric model of private land-use decisions, landscape simulations, spatially explicit data, a biological model that estimates species persistence, and an algorithm that approximates a set of efficient solutions. The general result from this study is that voluntary incentive-based policies are often highly

[12] The field of research on topics of ecosystem services provision has benefited from support of large initiatives such as the EPA's establishment of the Science Advisory Board to study the valuation and protection of ecological systems and services in 2003, the 2005 UN Millennium Ecosystem Assessment, and joint ventures among private institutions like the Natural Capital Project which was launched in 2006.

[13] Nelson et al. (2009).

[14] See for example Lawler et al. (2014); Lewis and Wu (2014); Lewis (2010); Lin (2010); Polasky and Segerson (2009); Lewis and Plantinga (2009); Nelon et al. (2008); Lewis and Plantinga (2007); Kremen et al. (2007).

[15] See for example, Kirkpatrick (1993); Vane-Wright, Humphries and Williams (1991); Fischer and Church (2003); and Onal and Briers (2003).

[16] Ando et al.(1998); Wy, Zilberman and Babcock (2001); Polasky, Camm and Garber-Yonts(2001); Costello and Polasky(2004); Newburn, Berck and Merenlender(2006); and Polasky et al. (2008).

[17] Lewis and Plantinga(2007); Lewis et al. (2009); Lubowski et al. (2006); Kremer et al., 2007).

[18] see Lewis and Plantinga(2007); Nelson et al. (2008); Polasky et al. (2008); and Lewis et al. (2009).

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inefficient in achieving conservation objectives with the inefficiency of incentives in improving biodiversity arising primarily from the inability of regulators to control the spatial pattern of landscapes with a voluntary payment mechanisms.

As for the literature examining adoption and diffusion of conservation practices, there is a broad consensus within the literature that these decisions are the result of a complex process, particularly when examined at the micro-economic level. Those decisions have been found to depend on a wide array of factors related to agro-ecological factors such as habitat fragmentation and spatial configuration of agricultural lands, farmer demographics and political, cultural and economic institutions of a particular social environment, among others.[19]

For the particular case of Puerto Rico, little research has been done about the status of coffee production, the influence of governmental policies on farming practices and the attitudes of farmers towards sustainable production practices. The most recent study on farming practices and attitudes towards conservation was conducted by Borkhataria et al. (2012). The findings in this paper suggest that farmers prefer to grow shade coffee but grow sun coffee in order to qualify for incentives established by Puerto Rico's Department of Agriculture. In the following section, the specific case of coffee farming and incentive programs for and against biodiversity conservation in Puerto Rico is explored in detail. As it is understood from reviewing the rich history of research and experimentation in the area of environmental policy, in conducting this study, I stand on the shoulders of giants. Nevertheless, as the field of environmental economics grows more dynamic and computer savvy, it becomes apparent that the present study is more than "new wine for old bottles". In incorporating new methodologies and tools into the sturdy foundations of neoclassical economic theory, this study contributes to the development of the fields of economics, ecology, and policy-making.

IV. The Case of Habitat Conservation among Puerto Rico's Coffee Producers

In 2013, the Puerto Rico Department of Natural and Environmental Resources (PR DRNA) published its new habitat conservation strategy, which seeks to ensure the long-term persistence of resident species of birds and amphibians. As part of the strategy, the DRNA requires an increase in the share of protected habitat area in the island from 8% to 15% (that increase would require another 62,250 hectares of land). The Department established a priority for targeting five of the eleven habitats in the island (the five habitats for which less than 15% their area is currently covered by the standing boundaries of official protected areas). These five habitats are, in essence, variations of the secondary wet forest habitat and share similar geographical location in the island, the central south west (see Figure 3).

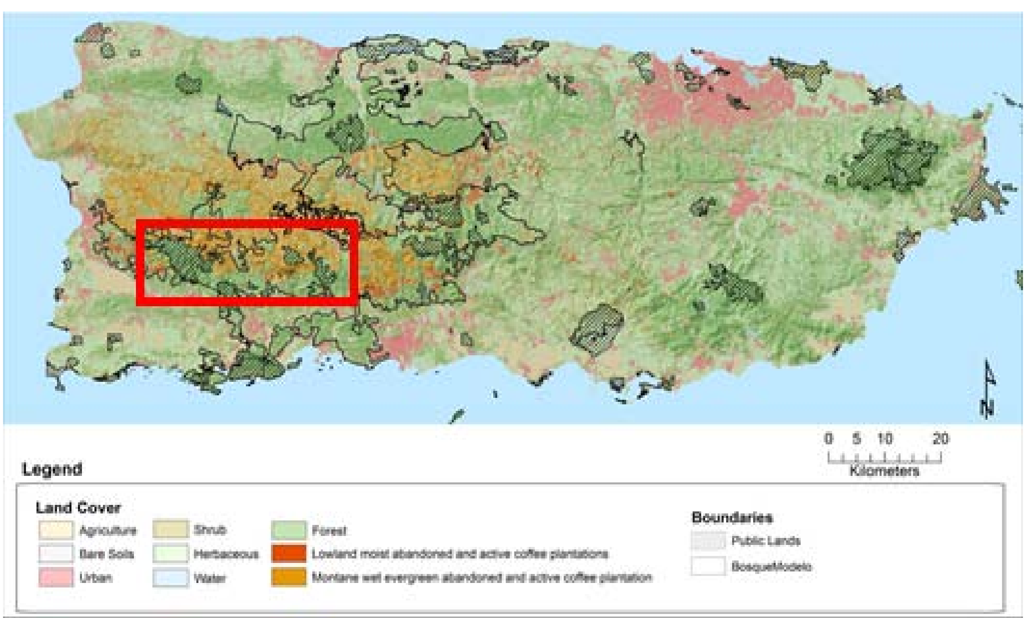

Figure 3 : General Target Area

[19] See the works by Page and Bellotti (2015); Greiner et al. (2009); Kauneckis and York (2009); Amsalud and De gRaffe (2008); De Graffe et al. (2008); Kumar (2007), Birol et al. (2006); Knowler and Bradshaw (2007).

Interestingly, the focal area of the conservation project, where these five priority habitats are found, overlaps with the strongest coffee producing region of the island. The DRNA has limited resources and is therefore interested in finding a way to reach the conservation target area without having to purchase private land. An attractive alternative is to take advantage of the ecological benefits that conservation agriculture practices offer. Thus, the DRNA has expressed interest in improving the efficiency of existing biodiversity conservation programs that target land-management practices among coffee growers.

In 2013, the DRNA selected an interdisciplinary group of researcher to conduct a comprehensive study to guide the Department's decisions regarding the allocation of funds and efforts to meet the agency's goal: to increase the conservation area from 8% to 15% in the region of the island where most of the secondary wet forest habitats are. The project involves state, federal, academic and NGO agencies, including researchers from North Carolina State University (NCSU), the South East Climate Science Center (SECSC), PR Department of Agriculture (PRDA), the US Fish and Wildlife Service (USFWS), the National Resources Conservation Service (NRCS), and Puerto Rico's Centro para la Conservación del Paisaje (CCP) and Casa Pueblo.

Between 2013 and 2015, a team of ecologist and geographers gathered data to determine the "optimal area of influence" of the project. Said area was defined as the patch of private land that performed best at meeting the following four conditions: maximizing the area within the "Bosque Modelo" (a political definition of certain zoning class in the island); maximizing the area of natural conservation areas already protected; hosting secondary wet forest habitats (priority habitats); and being located where the dominant economic activity is coffee agriculture. The final selection of land consisted of 44,174 hectares (18,076 short of the DNRA target). Based on the results of the geographical analysis, a socioeconomic survey was distributed to a random sample of coffee farmers within the selected area. The sample included 124 coffee farms in 12 municipalities. Figures 4-9 illustrate the process followed for finding the target area from which farmers were randomly selected.

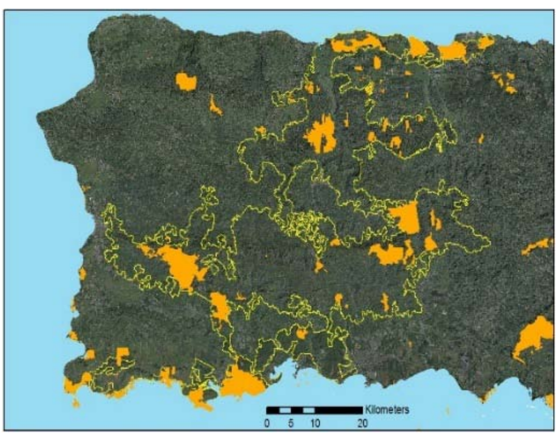

Figure 4 : Conservationzones (orange)

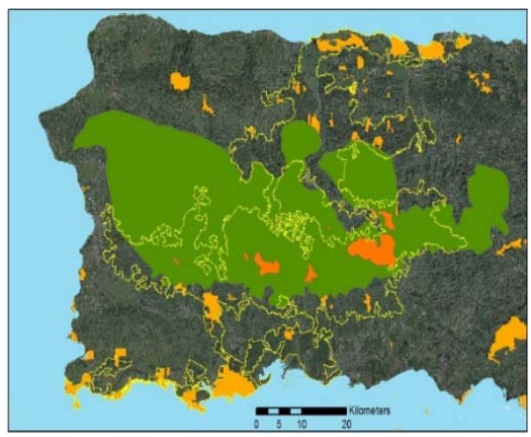

Figure 5 : Secondarywet forest

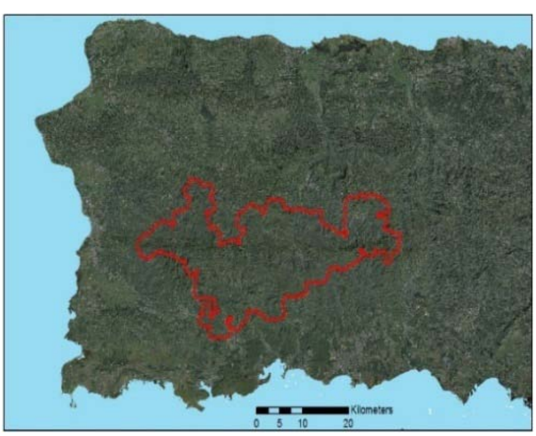

Figure 6 : Target Area

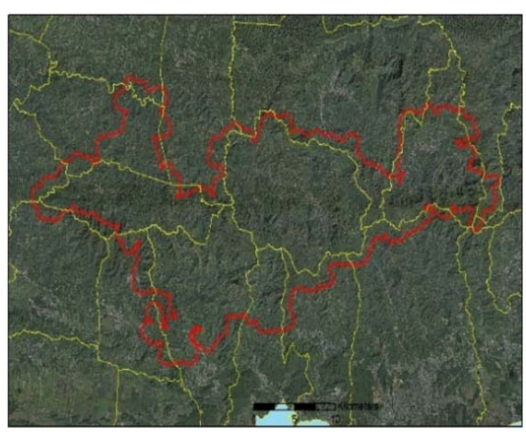

Figure 7 : Target Area and boundaries

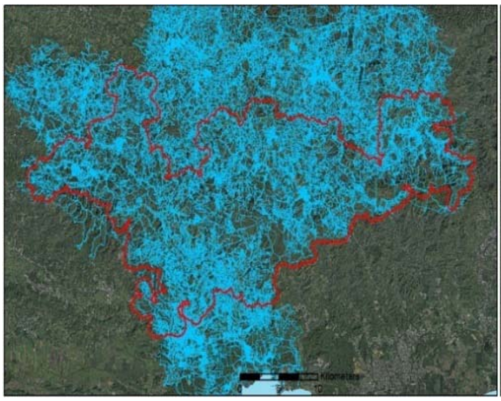

Figure 8 : Target Area and Properties

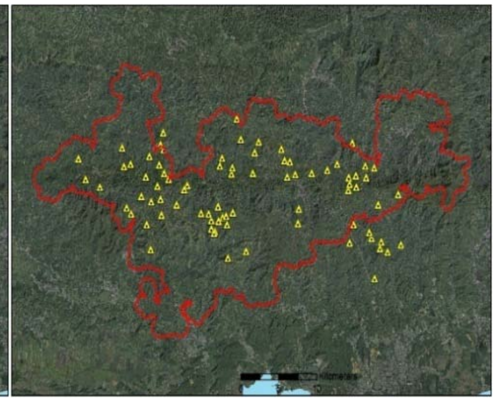

Figure 9 : Target Area and SurveySites

a) The Economic Incentives of Coffee Farming in Puerto Rico

As presented so far, the case of conservation agriculture in Puerto Rico seems entirely ecological. However, there are standing, and competing, economic institutions and incentives of both governmental and non-governmental nature, which can ultimately determine whether the DNRA's strategy to increase the conservation area succeeds or fails.

Traditionally, coffee has been an essential commodity for Puerto Rican consumers and producers, and coffee cultivation in the island has a long history of government involvement.[20] In the recent past, support for the crop has included guaranteed price floors to producers, protection against international competition though the imposition of high tariffs, crop insurance, extension programs, wage subsidies and direct government payments. Since the late 1960s, the Department of Agriculture of Puerto Rico (PRDA) has encouraged coffee farmers to take up intensive farming without auxiliary shade trees in the plot to increase yields. To encourage sun coffee cultivation, the government uses subsidy programs and conditional insurance terms.

Government subsidy programs involve conditional cash and in-kind assistance (farmers receive fertilizer or pesticides). They also include economic aid for investment in specialized machinery, distribution of fertilizers and pesticides, access to extension services, and wage subsidies to reduce the costs of labor to farmers. In turn, the PRDA offers insurance products that focus on ameliorating costs from catastrophic environmental events, like hurricanes. Producers of sun and shade coffee have access to insurance and at the same cost. However, the perception is that shade coffee is of high risk to the coffee plants during catastrophic events (for example, falling trees will damage the crop during a hurricane). Therefore, growers of shade-coffee face less attractive insurance terms; for instance, shade coffee growers receive less insurance money back in the event of a catastrophe and, in addition, the cost of replacing the shade trees is not covered by the insurance.

Government programs seemed to have had certain success. Figure 10 shows farmland devoted to shade and sun coffee between 1980 and 2007, and Figure 11 shows total number of coffee farms growing shade and sun coffee in the same period of time.

[20] Borkhataria et al. (2012).

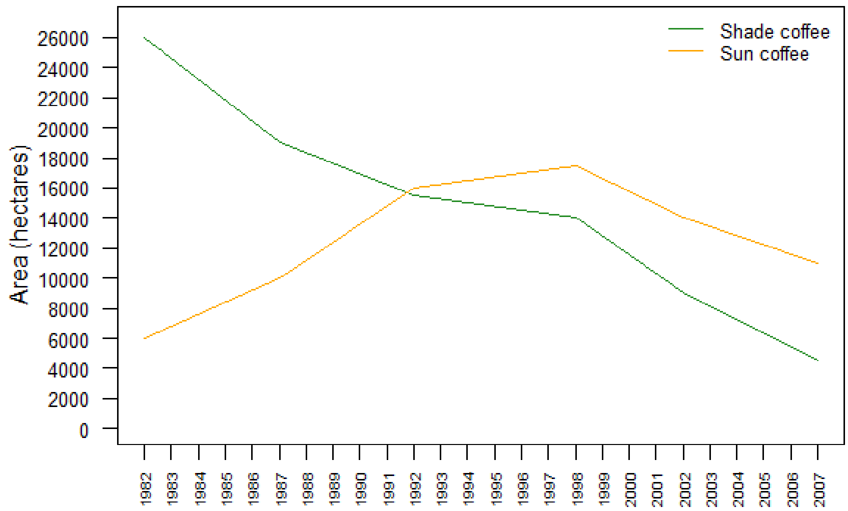

Figure 10 : Farmlandundershade and suncoffee. Source: USDA Census, 2012

Figure 11 : Farms growing shade and suncoffee. Source: USDA Census, 2012

The apparent increase in farms practicing of sun monoculture has inspired concern among conservation agencies and since the early 2000 a consortium of organizations that include the NRCS and the USFWS has been involved in restoring the shading canopy in coffee plantations in the island. The restoration project in Puerto Rico focuses on promoting the transition from sun to shade coffee among farmers by providing the shade trees, funds and technical assistance. Under the NRCS and USFWS subsidy program, farmers are required to convert at least a third of their farm to shade. Beneficiaries receive the shade trees for free and some fixed amount of money ($8) per tree planted. The number of trees a farmer receives depends on the land that is converted to shade coffee. Also, the support is only offered once, upon adoption.

It is unclear whether federal programs targeting biodiversity conservation have been successful at nudging farmers to transition from sun to shade cultivation practices. There is a general lack of coordination between the agencies and the data collection and record is unorganized. Furthermore, there appear to be other incentive programs in place but their definition and function is rather unclear to farmers and researchers. An imperative threat to the validity of the findings resulting from the current investigation involves the confounding effect of these uncertain programs.

A preliminary review of the socioeconomic survey distributed by CCP in 2015, shows that 18% of farmers do not participate in any of the incentive programs (for sun or shade), 29% receive subsidies for cultivating both sun and shade coffee, 50% receive only PRDA (sun) incentives and 3% receive only federal (shade) incentives. According to this survey, the most popular incentive program is the PR Department of Agriculture's fertilizer subsidy program with 93% of participants applying and receiving benefits from this program, followed by the wage subsidy program (53%), the assistance for new sun coffee farmers (48%), the NRCS shade coffee program (27%), and the DA's subsidy for returning sun farmers (13%). Table 2 shows the percentage of program participants that receive benefits from a particular agency involved in distributing incentives.

Table 2 : Program participants by provider agency. Source: CCP Surveys, 2015.

USFWS	NRCS	PRDA	NRCS+PRDA	USFWS+PRDA	PRDA+NRCS+USFWS
0%	1%	60%	30%	3%	6%

b) Coffee Markets in Puerto Rico

Puerto Ricans consume around 30 million pounds of coffee per year—that's nearly 8.3 pounds per person per year. However, the island only produces a fraction of what it demands. Once a strong coffee producer with large markets in both the U.S. and Europe, Puerto Rico's coffee sector has been in sharp decline in the last decades, with growers increasingly leaving the coffee business and abandoning coffee farms. Figure 12 shows a time series of area harvested, tons of coffee produced and coffee yield in Puerto Rico between 1961 and 2012. The contraction of the industry is undeniable. Since 1990, production has fallen by 63% and total land area devoted to coffee has declined more or less by half (from 32,114 ha to 15,144). In this time, the land devoted to shade coffee decreased nearly by 80% while cultivated sun coffee area increased by 65% (see Figures 10 and 11).

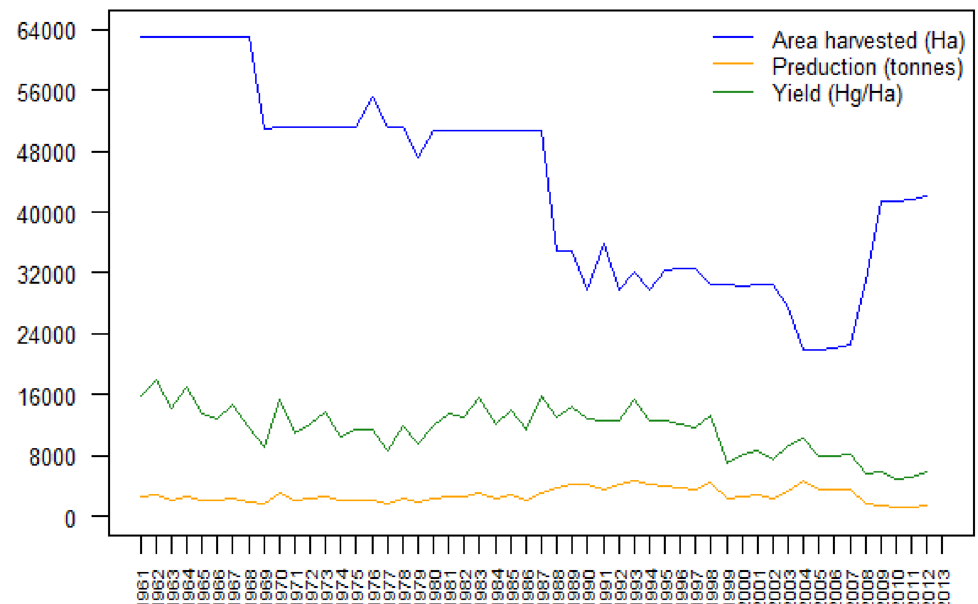

Figure 12 : Coffee Production in Puerto Rico (1961-2012). Source: FAO, 2015

The recent decline in coffee production may have something to do with the PR Department of Agriculture incentives programs (initiated in the 60s) and the conditional insurance; however, there is reason to suspect that many other more structural causes tightly related to Puerto Rico's economic model are behind the recent decline. Large up-front costs, a tight labor market, sluggish markets for fertilizer and seeds, pest emergence, and output market rigidities could be among the important obstacles that coffee growers face.

One of the main problems for Puerto Rican coffee growers is the lack of hirable "pickers". The harvesting/picking of coffee cherries is one of the most important stages in coffee production, not only because it determines current final output but because it has implications for future harvests.[21] In addition, Puerto Rico's coffee plantations are located in the mountains; therefore, the picking of fruits (cherries) is mostly done by hand. Informal local sources report that as much as 35% of the crop is lost every year because there are no workers to pick it.[22] To some extent, the shortage of coffee workers may be caused by rigidities in input markets and government price controls. More

[21] A key feature of coffee production is hat the future yields from coffee plants decline—may be even dramatically—when plants are not maintained or when the coffee cherries are not harvested in a given year.

[22] "Puerto Rico faces lowest coffee production ever". Jamaica Observer (May 24, 2013). Accessed April, 2016. Found here: http://m.jamaicaobserver.com/mobile/digicel/business/Puerto-Rico-faces-lowest-coffee-production-ever_14323278

specifically, the fact that Puerto Rico is a U.S. territory means that it is covered by US federal minimum wage laws, making a labor-intensive activity like coffee production uncompetitive relative to neighboring Caribbean nations and therefore unattractive as a business. The case may be even worse for growers of shade coffee as shade plantations require more labor than sun plantations—partially for maintenance of the canopy and partially because it is more technically challenging to implement mechanized harvesting technologies.

Lack of seeds, increases in the cost of fertilizer and emergence of pests are also blamed for the drop in production (not to mention the lack of workers to spray fields with pesticides and fertilizer). In the output market, other factors affecting the profitability of the coffee industry include regulations and government imposed rigidities. In Puerto Rico, coffee prices are fixed and are kept artificially low. Only growers producing a sufficiently high quality of bean are able to export their product and therefore receive higher prices that will keep them competitive.[23]

Shade coffee is of better quality than sun coffee and, in theory, growers of shade coffee should be able to sell their product for a premium. In practice, however, market failures like transportation costs and presence of monopsonistic power, prevent farmers from reaching high-value markets. Reaching the gourmet market almost certainly entails the farmer processing, grinding, roasting and certifying its own product. Becoming a certified coffee producer is an imminent hurdle for first time coffee farmers, and even though the industry has seen a trend towards vertical integration, the majority of farmers still simply sell bags of unprocessed mixed coffee beans.[24] Furthermore, in Puerto Rico there are few large coffee processing corporations with monopsonistic power that can "coerce" growers into selling their good quality coffee for low prices.[25]

Other relevant up-front costs keeping farmers from reaching high-price markets may be related to current management practices. For instance, if top soils are depleted due to the long-term use of sun cultivation practices, farmers may have to incur in large expenses to rehabilitate the land. Additionally, if farmers wish to transition from sun to shade coffee, they will have to wait around five years after the first planting to see the first useful harvest of coffee cherries (although it takes a plant 2-4 years to produce cherries that are ripe enough to harvest).

As described above, the reasons behind the recent drop in production are many and possibly inter-related. The data collected by CCP, together with commentary data from the USDA and other sources may offer an opportunity to explore the importance of these institutional factors in explaining the overall decline in coffee production at the macro-economic level and in explaining farmer behavior at the micro-economic level. The completion of this analysis remains a secondary goal of the current study but may be revisited in future research.

V. Theoretical Discussion

At the microeconomic level, the agents of interest in this problem of ecosystem services provision in Puerto Rico are coffee farmers. The fundamental assumption of economic theory is that the objective of coffee farmers is to maximize the value of their plantation for as long as they are in the business of coffee production—this is what economists call *rational behavior*. Coffee farmers choose what to do with their land in order to meet their economic goal: to maximize the stream of expected discounted profits their land can support. In a given year, coffee farmers consider current and historic values of net revenues in all alternative economic uses to their land to form static expectations of future returns. Every year, based on these expectations, farmers choose to continue their current practices, to change management practices, or to switch to different economic activities altogether.

The Puerto Rican coffee farmer problem can be modeled as an adoption problem in presence of environmental externalities. In this model, farmers choose whether or not to adopt the shade management regime or to abandon their plantation altogether based on expected market performance and government subsidies when available. In addition to predicting farmer behavior, this theoretical framework allows for the explicit characterization of the decision-making process, facilitating researchers to address questions of policy efficiency. With this simple model, the optimal level of PES can inferred—the level of payments that nudges farmers to grow the amount of shade coffee leading to the socially efficient provision of ecosystem services. Of course, the answering of this question entails knowing the ecological functions of coffee farm systems and the social value of the ecosystem services produced in coffee farms.

The strategy for answering the questions posed in this paper is to find the stream of expected discounted profits that makes a farmer indifferent

[23] In 2015, imported coffee was set at $3.22 per pound while prices for local coffee beans were $3.79 per pound.

[24] According to a Marketing study, Puerto Rican farmers mostly sold their products to local supermarkets (73%), ordirectly to the consumer (32%). Of those farmers selling to supermarkets, 54% were large farmers, 30% small farmers and 15% médium farmers. The majority (89%) of small farmers reported selling through other channels such as Internet sales ordirectly to the consumer in farmer markets (Alamo et al., 2006).

[25] Since 2013, the Puerto Rico Coffee Roasters company, a branch of Coca-Cola, owns around 85% of Puerto Rico'scoffeebrands ("Coca Cola and the Puerto Rico Coffee Industry: A Double-EdgedSword?" May, 2016.https://repeatingislands.com/2013/06/23/coca-cola-and-the-puerto-rico-coffee-industry-a-double-edged-sword/).

between cultivating shade and sun coffee. Having estimated the monetary difference, the goal is to derive an expression for the value of the external benefits from shade plantations that justifies different levels of a subsidy on low-yielding shade coffee. In what remains of this section I will formulate a simplified version of the coffee farmer's decision-making problem. In the design of the model I will assume separability between consumption and production decisions; complete labor, credit and insurance markets (although the latter may not be the case according to some anecdotal evidence); fixed output prices for coffee; and no quality differentials (see discussion on accessing premium price markets). Further, I will assume there are no distortions in the input markets (labor, land, fertilizer, pesticides and irrigation water).[26] I will also assume there are no land quality differentials between farmers and that once a farmer chooses to grow shade or sun coffee he devotes all his "coffee-land" to one or the other but not both. Finally, it will be assumed that shade increases longevity of coffee plants so that shaded plantations are profitable for more crops than sun plantations and farmers have a longer stream of expected profits; that the type of trees used for shade eliminate farmers' need for pesticides, fertilizer and irrigation water;[27] and that yields from shade plantations are 30% lower than those from sun plantations.

a) A simple Model of Adoption in Presence of Externalities

From the above discussion, it follows that a farmer adopts shade management practices if he considers this to be a more profitable practice over time. For illustration purposes, I will present the adoption of shade-management regime decision as a multiple stage problem where adoption occurs at the first stage. In this illustrative exercise, a farmer that uptakes the shade-plantation strategy foregoes 5 years of coffee revenues and once the plantation starts producing at full capacity, yields are lower than yields from an analogous sun coffee farm. However, the adopting farmer will receive a stream of profits that outlasts those of the sun plantation by up to $T+5$ periods, where T is the lifespan of a sun plantation.

Take F to represent fixed costs of transitioning from sun to shade cultivation. Then, the expected, discounted, stream of profits from transitioning to a shade farm is:

$$E_0 \sum_{t=0}^{2T+5} \delta^t \pi_{sh} = -F + 0 + 0 + 0 + 0 + E[\delta^6 \pi_{sh} + \delta^7 \pi_{sh} + \cdots + \delta^{2T+5} \pi_{sh}] \quad (1)$$

And the stream of profits from a sun farm is:

$$E_0 \sum_{t=0}^{T} \delta^t \pi_{su} = \pi_{su} + E[\delta \pi_{su} + \delta^2 \pi_{su} + \cdots + \delta^T \pi_{su}] \quad (2)$$

A farmer will adopt the shade regime if (1) is larger than (2). In this case, the positive externality of the shade plantation is realized. The social benefit has two components: increased agricultural wealth via spill-over effects onto the productivity of other farms and the intrinsic value of biodiversity. On the contrary, if (2) is greater than (1) a farmer will cultivate sun coffee. It is under this scenario where it is relevant to address the question of what value of external benefits justifies different levels of subsidies nudging farmers to grow the less profitable variety of coffee.

The specific questions of interest in this study are the following:

1. When is (1)≦(2)?
2. If (1) < (2), what level of subsidy will bring (1) to equal (2) plus a miniscule additional benefit that is enough for the farmer to prefer shade over sun coffee?

If some structure is imposed to the analysis, a brief pick at equations (1) and (2) may reveal useful insights. For instance, assuming that the yield differential between sun and yield coffee is of 30% and that this yield differential directly translates into a profits differential of 30%[28]; further assuming a discount factor of 0.99, and a lifespan of 15 years for coffee trees grown under a sun regime ($T=15$), then equations (1) and (2) are equal when:

$$-F + E_0 \sum_{t=6}^{2T+5} \delta^t \pi_{sh} = E_0 \sum_{t=0}^{T} \delta^t \pi_{su} \quad (3)$$

$$-F + 0.7 \cdot E_0 \sum_{t=6}^{35} 0.99^t \pi_{su} = E_0 \sum_{t=0}^{15} 0.99^t \pi_{su} \quad (4)$$

$$0.7 \cdot E_0 \sum_{t=16}^{35} 0.99^t = 0.3 \cdot E_0 \sum_{t=6}^{15} 0.99^t + \frac{F}{\pi_{su}} \quad (5)$$

$$10.85 = 2.7 + \frac{F}{\pi_{su}} \quad (6)$$

$$8.15 \pi_{su} = F \quad (7)$$

[26] Although in reality there are wage subsidies to farmers, in the mean time, I will abstract from this fact to make the model more tractable.

[27] Depending on the trees used to create a dense shadecanopy, the shade trees can reduce farmers' costs. Certain trees can help fix nitrogen to the soil, reducing the need for fertilizer. Also, if the trees helpsoak more wáter in to the soil, farmers of shade coffee do not need to apply as muchwater to theirplots. Additionally, the trees can help reduce farmers' need for pesticides in two ways. First, the shade and fallen leaves help suppressw eeds and fungi; and second, by providing an enhanced habit at for ants, birds, and lizards the tree shelp decrease the abundance of insect pests in coffee plantations(Borkhataria et al., 2012).

[28] These parameters are taken from the literature documenting yields of sun and shade coffee plantations in Mexico (see Table 1).

According to this naïve arithmetic exercise, a farmer will be indifferent between growing shade and sun coffee if the annual profits are 8.15 times the costs the farmer bears for transitioning into shade coffee. Thus, a subsidy program looking to achieve this end would provide the farmer with lump sum payments with the present value of $8.15\pi_{su}$.

Of course, this is not an accurate result as it ignores changes in input choices and the substitutability between labor and capital inputs under different production regimes. To account for this differences, it is precise to find the optimal levels of labor and fertilizer a farmer chooses when growing sun or shade coffee. To derive comparative statics that pin down this substitutability between labor and capital inputs (fertilizer/pesticide/irrigation) and the change in costs, it is useful to set up the farmer's decision-making process as a standard profit maximization problem. A simple model of conservation practice adoption in presence of externalities is included in the Appendix section of this paper.

b) *Insights from Modeling*

If it were possible to parameterize and solve explicitly the model presented above, it would also be possible to compare the stream of profits a Puerto Rican farmer expects to attain by growing shade or sun coffee. In turn, the optimal level of subsidy for ecosystem services (improved soil fertility, increased habitat for wildlife, and decreased erosion) would correspond to the amount that would make a farmer indifferent between these two streams.

Under the highly restrictive model (included as an Appendix), the key to find the optimal level of subsidy is to pin down the change in production costs to a farmer that chooses to transition from sun to shade coffee. Specifically, the parameters that will allow the assessment of this transition are the elasticity of substitution between labor and the capital input in the production of sun coffee, and the size of the externality. If the reduction in capital input costs outweighs the increase in labor input costs that would be necessary to keep production of shade coffee on par with yields from a non-shaded plantation, and if the subsidy allows a farmer to cover the upfront fixed costs of planting the shade canopy and forgone profits of the first 5-7 years of production, then a Puerto Rican coffee farmer should find it lucrative to switch into a shade management regime. On the other hand, if increases in labor requirement translate into substantial increases in cost (particularly relevant given the scarcity of labor), a farmer would only choose to grow shade coffee is the subsidy not only covered the upfront cost and forgone profits of the first 5 years, but also the annual economic losses for the following 30 years.

On a final note, and looking ahead towards future research, it seems important to explore the role of potential income effects on production decisions. Apparently, Puerto Rican coffee farmers are increasingly willing and able to become small producers and processors of specialty/gourmet coffee.[29] This trend may be partially explained by the increased importance of non-farm activities as sources of household income. Said shift in livelihood orientation may impact attitudes towards risk and risky farming practices (such as growing shade coffee). If the impact to be positive, then we may find that the level of subsidy necessary to incentivize farmers to grow shade coffee is actually lower than anticipated. The opposite is true if non-farm wages are associated with tighter liquidity constraints and higher risk aversion among coffee farmers.

VI. Empirical Analysis

In this section a description of the datasets used for estimating the effect of policies on adoption of conservation practices. Data description is followed by a discussion of the econometric methodology that was followed for estimation. Finally, this section ends with a presentation of the results from the econometric estimation.

a) *Data*

For the preliminary empirical analysis of this project I use cross-section farmer data from a survey conducted by the Centro para la Conservaciondel Paisaje (CCP) in 2015. Ideally, in the near future I will complement this dataset with historical agricultural data from the USDA census and historical records of program participants and benefit receipts made available by the US FWLS, NRCS and PRDA.[30] Below I describe the survey data.

Between September and December, 2015, the CCP conducted interviewed 89 coffee farmers in 12 Puerto Rican municipalities in the west-central region of Puerto Rico—Adjuntas, Ciales, Guayanilla, Jayuya, Juana Diaz, Lares, Las Marias, Maricao, Ponce, Sabana Grande, Utuado and Yauco.[31]Farmers in the survey ranged in age from 12 to 86, with the average age being 59. About a third of respondents had a bachelor's degree or higher, another third high-school degrees, and the remaining third had below middle school attainment. The majority of them were land owners (82%) and although there was reasonable variance in length of ownership (fairly uniformly distributed between 0 and 40 years), the majority had substantial experience

[29] Alamo et al. (2006).

[30] Unfortunately, at the moment such data is unavailable. It turns out that finding "public" data in digital format for Puerto Rico is much more difficult than one would expect. Currently, there are no spreadsheets available containing PR Agricultural Census Historic data; the data is only available in pdf format of the original publications. In addition, permission is needed from the territory's officials to access the US FWLS and NRCS data.

[31] Information about the CCP's involvement in the DRNA's project can be found here: http://ccpaisaje.org/node/59.

with coffee growing activities with more than two thirds of the sample having grown coffee for more than 20 years.

The average farm size was 65 acres but farms varied between 2 and 750 acres. On average, 51% of total farmland was planted with coffee, the remaining land was forested land or was used for other purposes. About 34% respondents were growers of both sun and shade coffee, 28% only produced sun coffee, while the remaining reported producing coffee under shade or semi-shade conditions (22% and 16%, respectively).

Farmers in the sample were primarily producers for commercial purposes—74% of respondents sold coffee beans, and of those, 9.5% sold their coffee to gourmet markets; 19% of all interviewees had processing equipment; and 7% had equipment for coffee milling. The average price received per pound of coffee cherries of average quality was $0.52, but it varied according to buyers from $0.46 to $0.58.Most farmers planted a variety of other crops with their coffee trees. About 12% of respondents reported using all their farmland for coffee farming, but of those that planted other crops, the majority kept their produce for personal consumption.[32]

Table 3 : Characteristics of farmers in the CCP Survey by participation status

	Total Sample	Any Program	FWS incentives	NRCS incentives	PRDA incentives	PRDA wage-subsidy
Percentage of farmers involved		82%	5%	31.5%	80.9%	43.8%
Percentage growing sun coffee only	34.8%	35.6%	20%	21.4%	36.1%	38.5%
Av. land size (in cuerdas)*	67.14	72 cuerdas	91.6	116.42	71.77	90.13
Av. land holdings	70.67	76.3	120.4	123	75.72	97.42
Av. time as manager (years)	20.9	20.68	16	16.79	20.97	21.03
Av. area in coffee cultivation	22.53	26.16	76	39.68	25.414	36.43
Av. age	58.63	57.51	64	56.61	57.93	59.15
Av. Farm income (annual)	16,000	18,300	60,000	28,000	18,600	30,100

** 1 cuerda = 0.9 acres*

Farm incomes were low in general—below $30,000 for 82% of the respondents, and below $10,000 for 49% of respondents. Not surprisingly, respondents reported non-farm sources of income had become increasingly important for coffee growers. About 78% of the respondents were participants in local state incentives (favoring sun coffee), 32% participated in federal programs (favoring shade coffee), and 18% did not participate in any program. Around 29% of the simple received benefits from both federal and state program. Table 3 provides a summary of the profile of participant and non-participant farmers surveyed by CCP in 2015.

To complete building the profile of a typical coffee farmer in the coffee-producing region of the island, I will use results from a comparable survey from a recent study of 96 farmers in three Puerto Rican municipalities in the central region—Ciales, Utuado and Jayuya.[33] This study found that coffee growers relying mostly on coffee profits as their source of income had been in decline. Apparently, 34% of farmers in their study made the majority of their income from coffee in 1992; 16.8% did so in 2002, and 23.6% in 2007. Importantly for the project at hand is that for the majority of farmers (93%), family was an important source of labor. Of these 93%, 73% complemented family labor with hired labor during harvest. The remaining 9% had permanent employees.

Finally, responses in this complementary study, show that hurricanes were perceived as the most important obstacle to coffee production. Other obstacles reported as important included lack of capital, unavailability of workers, erosion, insect damage, nutrient deficiencies, and fungal damage. About half of the respondents had some crop insurance. More sun coffee farmers insured their crops than did farmers of shaded coffee (56% of sun growers against 34%of shaded coffee growers) but few farmers had difficulties finding insurance and the different impediments reported did not differ significantly between plantation types.

b) Econometric Methods

Participation in conservation programs (like the FWS or NRCS programs) and land management practices (like the use of a shade canopy) are likely to affect one another and be determined simultaneously. Thus, to evaluate the impact of participation conservation programs on land management practices, in this preliminary analysis, I follow the three-stage framework presented in Wissen and Golob (1990) and estimate a system of two simultaneous equations

[32] Commonly cultivated produce included oranges, bananas, plantains, rootplants, breadfruit, squash, pigeon peas, papayas, and avocadoes.

[33] Details of the survey are found in Borkhataria et al. (2012).

involving binary endogenous variables. I follow a bivariate probit estimation procedure and instrumental variables to correct for endogeneity.

The three-stage procedure is the following. In a first stage, the structural equation is expressed in reduced form—that is, it is expressed only in terms of exogenous variables and random disturbances. The reduced model is estimated to retrieve the predicted parameters via Maximum Likelihood Estimation. In the second stage, the structural equation is estimated by replacing the endogenous right-hand side variables with the continuous fitted latent instruments constructed in the first stage. The methodology described above provides consistent and unbiased estimates. However, given the use of instruments in the second stage, the reported standard errors are not accurate. Hence, the final stage of the procedure involves correcting the variance-covariance matrix of estimated disturbances to compute the adequate standard errors.

The structural econometric representation of the joint decision model is defined as follows:

$$P_{ij}^* = \delta_1 Shade_i^* + \sum_{k\neq j} \alpha_k P_{ik} + \alpha_0 + \alpha_1 X_i + \alpha_2 Y_i + \alpha_3 Z_i + \alpha_5 p_i^c + \varepsilon_{1i}$$

$$Shade_i^* = \delta_2 P_{ij}^* + \sum_{k\neq j} \beta_k P_{ik} + \beta_0 + \beta_1 X_i + \beta_2 Y_i + \beta_3 Z_i + \beta_5 p_i^c + \varepsilon_{2i}$$

The dependent latent variables are P_i^* and $Shade_i^*$. P_i^* is a binary measure of participation decision by farmer i in program j that takes on the value of 1 if the farmer is a current participant in the j^{th} incentive program available to Puerto Rican farmers. There are over 30 such programs, thus, for analytic convenience I bundle them by provisionary agency. In total there are 3 types of programs: FWS programs, NRCS programs and PRDA programs. The former two offer shade incentives, while the latter offers incentives to grow sun coffee. $Shade_i^*$ is also binary and it signals whether farmer i uses a shaded canopy in his coffee plantation. Variable p_i^c represents the price per pound of coffee received by farmer i.[34] P_{ik} are binary variables taking the value of 1 if farmer i participates in any of the alternative incentive programs available to him.

Vectors X_i, Y_i, and Z_i consist of exogenous variables and include farmer-specific attributes, farm-specific variables, and land farmer managerial characteristics, respectively. The variables included in vector X_i are age, gender, and indicator variables for different levels of educational attainment. Vector Y_i includes variables that characterize the production capacity of the farm. These include total land owned, area under coffee cultivation,[35] farm income, whether the farm is large enough to sell its produce by bulk (this is measured by an indicator variable that equals 1 if the farmer reports selling his product by the quintal—100 lbs.), and whether the farmers sells his product in specialty markets.

Vector Z_i includes variables that define farmers' managerial aptitues and attitutes. Variables included here are ownership status, number of years that farmer i has managed the farm, whether the farmer grows only coffee, whether the farmer intercrops, whether the farmer leaves land undeveloped for forest, the farmer's the farmer's current management practice (sun, shade, part sun and part shade, or semi-shade), whether the farmer has changed from sun to shade or vice versa, and whether the is also involved in any of the coffee processing stages. Lastly, ε_{ni} is the error term. Summary statistics of the variables included in the econometric estimation are presented in Table 4.

[34] Various important simplifying assumptions of this model are reflected in this price term. The first is that the coffee market is competitive and that consumers compete in prices for the product. Thus, a farmer with higher quality product can find a buyer that is willing to pay a premium for this specialty product. Also, it is assumed that the coffee industry is vertically integrated; meaning that all farmers are producers of an intermediary good. In other words, it assumed that coffee producers are not coffee processors, thus, any variation in received should only reflect differences in the quality of coffee cherries. In reality, these assumptions are highly questionable—at least in the case of Puerto Rico's coffee industry.

[35] In this analysis, I do not use actual productivity of the farm because that question was missing from the interviews. However, from the open-ended questions I induce that one cuerda of land (0.9 acres) can yield between 20-25 quintals (one quintal has 100 lbs. of coffee) of coffee. In this study, land area can be used as a proxy for productivity.

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Table 4 : Variable Definition and SummaryStatistics

Varible	Description	Mean	Median	Std. Dev.
Participant	Binary variable equals 1 if respondent participates in any incentive program	0.82	1	0.386
FWS	Binary variable equals 1 if respondent participates in any FWS pro-shade incentive program	0.05	0	0.231
NRCS	Binary variable equals 1 if respondent participates in any NRCS pro-shade incentive program	0.3146	0	0.4669
PRDA	Binary variable equals 1 if respondent participates in any PRDA pro-sun incentive program	0.809	1	0.395
PRDA_wage	Binary variable equals 1 if respondent participates in PRDA's pro-sun wage-subsidy incentive program	0.4382	0	0.498
Age	Continuous, age of respondent	58.63	60	13.189
Gender	Binary, equals 1 if masculine	0.9438	1	0.231
Basic education	Binary, equals 1 if maximum educational attainment is middle school	0.3034	0	0.462
High school education	Binary, equals 1 if maximum educational attainment is high school	0.2697	0	0.446
College education	Binary, equals 1 if maximum educational attainment is a university degree	0.3146	0	0.4669
Graduate education	Binary, equals 1 if maximum educational attainment is a graduate degree	0.089	0	0.287
Farm size	Continuous, measures size of farm in cuerdas (1 cuerda = 0.9 acres)	67.14	25	109.76
# land holdings	Continuous, number of landholdings managed by respondent	1.1691	1	0.548
Total land managed	Continuous, area of landholdings managed by respondent	70.67	27	109.46
Annual farm income	Categorical, 1 if annual farm income is between 10,000-19,999; 2 if between 20,000-29,999; etc.	1.607	0	2.2744
Coffee area	Are of farm devoted to coffee cultivation measured in cuerdas	22.53	11	25.728
Sells in large scale[+]	Binary, equals 1 if farmer reports selling by quintal instead of almud.	0.1685	0	0.376
Sells in specialty markets	Binary, equals 1 if the farmer sells coffee in specialty markets	0.1236	0	0.33
Price per pound[*]	Average price received per pound of coffee	0.9853	0.5357	1.2144
Ownership status	Binary, equals 1 if respondent is owner, 0 if sharecrops	0.82	1	0.386
Years as manager	Continuous, time managing the farm	20.9	20	14.97
Main crop	Categorical, 1=coffee, 2=coffee and plantain or citrus, 3 = not coffee	1.281	1	0.62
Intercrop	Binary, equals 1 if farmer practices intercropping	0.8652	1	0.343
Forest land	Binary, equals 1 if farmer leaves uncultivated areas for forest	0.5506	1	0.5
Current management practice	Categorical, 1=sun, 2=shade, 3=part sun and part shade, 4=semi-shade	2.315	2	1.124
Change in management practices	Binary, equals 1 if farmer has switch from sun to shade or vice versa.	0.5843	1	0.49
Caficultor	Binary, equal 1 if farmer only grows coffee	0.7303	1	0.446
Beneficiado	Binary, equal 1 if farmer is involved in initial stage of coffee processing	0.191	0	0.395
Torrefactor	Binary, equals 1 if farmer is involved in all processing stages	0.0674	0	0.252

[*] *In Puerto Rico, the price of coffee is fixed by the Department of consumer affairs (DACO). However, in the data, we do observe variation in the prices received by farmers. The variation seems correlated with farm capacity and processing of the beans done in situ.*

[+] *The definition of these units used by the USDA is the following 1 quintal=100 lbs., and 1 almud=28 lbs. However, the use of these metrics may be an issue of concern. Therefore, this variable is left out from the regression.*

c) Results

Results from the simultaneous bivariate probit estimation procedure described earlier are reported in Tables 5—7. Table 5 shows the results of various regression on a subsample of the data where farmers are primarily coffee growers, while table 6 shows results of the same regressions on the entire sample. The differences between these two are minimal—particularly on the variables of interest; therefore, only the results corresponding to Table 5 will be discussed. The first two columns in Table 5 show the results of the bivariate simultaneous probit regression when participation in any

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program (pro-sun or pro-shade) is considered. The third and fourth column show the results corresponding the analysis when only participation in conservation programs (offered by the FWS or NRCS) is considered. The last two columns show the similar results when participation in the DA's pro-sun incentive programs is analyzed. In turn, table 7 shows the transformed coefficients to reflect estimated marginal effects for the variables that were significant in the regressions explored and summarized in Table 5.

Based on the sample data, very little can be said with confidence about the determinants of farmer participation in any program. In general, it can be concluded that none of the explanatory variables examined is related to the decision of whether or not to participate in any sort of agricultural incentive program. On the other hand, farmers that do not leave undeveloped land for forest, who are involved in some stage of coffee processing and who have graduate-level education are significantly more likely to follow shade management practices in their coffee plantations. However, the effects are small—circling around a 25% increase in probability of adopting shade-management regimes.

When only participation in conservation programs is examined, the results are slightly different. As columns three and four of Table 5 show, a farmer is more likely to participate in conservation programs if he leaves some of his farmland undeveloped for forest, if he owns the farm, if he sells his product in specialty markets, if he has larger area of his land devoted to coffee cultivation, if he has basic rather than higher education (farmers with high-school degrees are 18% less likely to participate in incentive programs than farmers with basic education attainment), and, interestingly, if he has spent less time managing the farm (although this effect is very small). Not much changes in the adoption of shade-management practice equation when only participation in conservation programs is examined.

Finally, the results corresponding to the decision to participate in DA's programs favoring sun coffee management practices are more in line with economics intuition. In general, variables describing economic capacity of the farm, like farm income, whether the farmer sells by bulk (quintal), and whether he is involved in the processing of the coffee cherries, become significant determinants of the participation decision. In turn, education indicators, and whether the farmer leaves land undeveloped for forest are variables that remain related to the adoption of shade-management practices. Interestingly, in this analysis, participation in the incentive program examined is also significant. When the coefficient estimates are adjusted to reflect marginal effects, it turns out that the probability of adopting shade management practices increases by77% if farmers participate in DA's pro-sun incentive programs. This result is interesting and rather counter-intuitive as it suggests that farmers who participate in pro-sun incentive programs are also more likely to adopt a shade management practice. Although this result is somewhat surprising, it is well supported by the fact that 39% of the interviewed farmers receive both types of subsidies (see Table 2).

Age, college education, farm size, number of plots owned, and total land holdings, are never significant determinants of either of the two decisions. Surprisingly, neither are the dummy indicator of changes in management practice (from sun to shade or from shade to sun) nor the indicators of intercropping or high-level processing of the cherries (if he is a "torrefactor" who grinds his own coffee beans). Finally, shade cultivation is never significantly related with program participation.

Table 5 : Results simultaneous bivariate probit. Sumbsample of coffee growers (Maincrop==1)

	Any Incentive program				Conservation Program				DA's pro-sun Program			
Explanatory Variables	Participation		Shade Coffee Management		Participation		Shade Coffee		Participation		Shade Coffee	
	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
Shade	268.4	88240			2.257	2.1002			-0.800	2.805		
Participates			0.896	0.939			1.159	1.684			8.366	3.606 *
Intercept	-182.7	2.28E+07	-198	3.20E+05	2.123	14.407	-164.3	9.11E+05	2.977	4130	-336.9	2.29E+05
Age	3.38	818.1	-0.016	0.021	0.016	0.028	-0.025	0.022	0.000	0.037	-0.004	0.033
High-school	-22.38	5.05E+03	0.44	0.692	-1.46	0.85 .	0.12	0.63	-1.38	0.75 .	3.45	1.69 *
College	95.14	2.00E+04	-0.719	0.74	0.757	0.896	-0.834	0.7597	1.41	1.091	-1.29	0.88
Graduate	-105.8	4.75E+04	1.9	1 .	-1.642	1.470	1.674	1.004 .	-0.133	2.851	4.03	1.70 *
Farm size	19.23	2.31E+03	-5.57	519	-0.424	0.704	-4.665	531.4	0.1845	0.1245	-9.15	565.50
Plots owned	210.80	4.76E+04	-115	1.09E+04	-10.33	15.026	-96.52	1.12E+04	1.826	1.948	-186.9	1.18E+04
Land	-19.98	2.47E+03	5.57	519	0.428	0.704	4.672	531.4	-0.159	0.1275	9.15	565.50
Income	8.80	2.31E+03	0.105	0.20	0.19	0.16	0.06	0.19	1.12	0.55 *	-0.29	0.29
Area coffee	12.93	1.73E+03	-0.02	0.02	0.05	0.02 .	-0.02	0.02	0.00	0.03	-0.04	0.02
Sells specialty	203.00	2.11E+07	0.535	1.16	3.121	1.395 *	0.3339	1.174	8.493	4155	-1.43	1.63
Sells quintal	-24.98	2.34E+04	-33.5	3.19E+05	1.13	1.48	-29.02	9.10E+05	-10.37	3.89 **	-52.56	2.28E+05
Ownership	20.72	4.26E+03	-0.179	0.71	3.31	1.43 *	-0.15	0.81	0.23	0.78	-1.40	1.05
Time	0.94	1.08E+02	-0.007	0.023	-0.050	0.025 *	0.004	0.023	-0.010	0.021	0.01	0.03
Intercrops	-433	2.28E+07	313	3.21E+05	1.630	1.473	262.1	9.11E+05	-5.571	4130	518.60	2.30E+05
Forest land	72.98	3.38E+04	-1.81	0.70 **	3.21	1.01 **	-1.99	0.91 *	1.20	1.13	-4.43	1.57 **
Change	41.15	4.37E+03			-0.46	0.74			1.10	0.75		
Beneficiado	-2.22	1.65E+07	1.94	1.08 .	-1.44	1.37	1.77	1.08	11.62	3.95 **	3.20	1.46 *
Torrefactor	-191.7	2.11E+07	-8.81	2.00E+04	-2.643	1.932	-8.794	2.08E+04	-14.44	4155	-5.77	9665
N	82		82		82		82		82		82	
K	20		19		20		19		20		19	
AIC	40		77.224		75.839		77.815		73.469		65.323	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 6 : *Results simultaneous bivariate probit. All farmers (Maincrop==1, 2 or 3)*

Explanatory Variables	Any Incentive program				Conservation Program				DA's pro-sun Program			
	Participation		Shade Coffee Management		Participation		Shade Coffee		Participation		Shade Coffee	
	Coeff.	Std. error	Coeff.	Std. error	Coeff	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
Shade	268.4	8.82E+04	-186	3.42E+05	0.703	1.86			-0.269	2.149		
Participates			1.678	1.171			0.8098	1.613			6.386	2.473 **
Intercept	-198.1	3.20E+05	-185.6	3.42E+05	2.53	9.63	-156.3	4.84E+05	-2.79	3.31	-212.6	1.63E+07
Age	-0.02	0.02	-0.01	0.02	0.01	0.03	-0.03	0.02	-0.01	0.03	-0.01	0.03
High-school	0.44	0.69	0.58	0.70	-1.47	0.86 .	0.09	0.60	-1.52	0.76 *	2.18	1.07 *
College	-0.72	0.74	-1.17	0.79	0.80	0.80	-0.93	0.72	1.58	1.09	-2.32	1.01 *
Graduate	1.90	1 .	1.94	1.10 .	-0.45	1.05	1.18	0.99	-2.79	1.45 .	4.56	1.80 *
Farm size	-5.57	519	-5.17	478.90	-0.43	0.48	-4.41	499.20	0.18	0.11	-6.02	456.10
Plots owned	-115	1.09E+04	-106.4	1.01E+04	-10.2	10.3	-91.14	1.05E+04	2.25	1.69	-122.1	9.58E+03
Land	5.573	519	5.184	478.9	0.44	0.48	4.422	499.2	-0.176	0.111	6.028	456.1
Income	0.105	0.196	-0.262	0.210	0.32	0.15 *	-0.171	0.195	0.680	0.264 *	-0.799	0.335 *
Area coffee	-0.021	0.019	-0.028	0.022	0.04	0.02 .	-0.020	0.022	0.025	0.021	-0.040	0.024
Sells specialty	0.535	1.164	0.261	1.311	3.156	1.49 *	0.548	1.311	11.33	473.9	-1.545	1.966
Sells quintal	-33.47	3.19E+05	-32.84	3.42E+05	0.02	1.40	-28.04	4.84E+05	-6.48	2.14 **	-47.90	1.63E+07
Ownership	-0.179	0.706	-0.058	0.68	3.51	1.48 *	0.023	0.792	-0.203	0.784	-0.291	0.778
Time	-0.007	0.023	1.22E-04	0.022	-0.05	0.03 .	0.007	0.022	-0.013	0.021	0.014	0.025
Intercrops	313.4	3.21E+05	291.3	3.43E+05	1.96	1.46	248.4	4.85E+05	0.72	1.39	330.8	1.63E+07
Forest land	-1.81	0.70 **	-1.73	0.64 **	2.68	0.82 **	-1.59	0.78 *	1.95	0.94 *	-3.71	1.18 **
Change	1.94	1.08 .			-0.68	0.71			1.34	0.72 .		
Beneficiado	-8.81	2.00E+04	2.60	1.16 *	-0.91	1.34	2.10	1.10 .	9.04	3.31 **	4.21	1.52 **
Torrefactor	0.90	0.94	-7.79	1.93E+04	-3.65	2.37	-7.86	2.01E+04	-13.53	473.9	-6.31	1.85E+04
N	89		89		89		89		89		89	
K	20		19		20		19		20		19	
AIC	40		81.728		80.072		83.754		84.721		74.705	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 7 : Marginal effects significant variables in Table 5 (Only coffee growers)

Explanatory Variables	Participation in any incentive program	Shade Coffee Management Practice	Participation in conservation program	Shade Coffee Management Practice	Participation in DA's pro-sun-coffee program	Shade Coffee Management Practice
	Marginal effect	Marginal effect	Marginal effect	Marginal effect	Marginal effect	Marginal effect
Participates in program						0.770 *
High-school			-0.18 .		-0.15 .	0.32 *
Graduate		0.2545 .		0.226 .		0.37 *
Farm income					0.13 *	
Area in coffee			0.01 .			
Sells specialty			0.386 *			
Sells Quintal					-1.15 **	
Ownership			0.41 *			
Time managing			-0.006 *			
Forest land		-0.24 **	0.40 **	0.27 *		-0.41 **
Beneficiado		0.259 .			1.13 **	0.29 *

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

VII. Conclusions

As far as the decision to participate in conservation programs goes, the empirical analysis suggests that farmers are about 40% more likely to participate in conservation programs if the sell their product in specialty markets, if they leave land undeveloped for forest growth, and if the own their farm. There are other significant factors in this relation but their effect is rather small. For instance, participation in conservation programs increases by 1% as their area under coffee cultivation increases. Also, farmers with higher than basic education are 18% less likely to participate (probably because they do not need the additional economic assistance). Finally, as coffee growers spend more time managing their farm they become 0.6% less likely to participate in conservation programs.

On the other hand, variables related to participation in Department of Agriculture's pro-sun incentive programs are, in general, indicators of economic performance of the farm. For instance, as farm income increases, farmers are 13% more likely to participate in the DA's programs. Also, farmers that process their coffee cherries are 113% more likely to receive DA's assistance. However, if farmers sell by bulk they are 115% less likely to participate in pro-sun programs. These results are somewhat contradictory, but I offer the following interpretation. It appears that larger farmers may not need additional economic assistance, however, more vertically integrated farmers—those involved in some of the processing stages—may be more closely related to the DA.

In regards to the decision of shade-management practices, the results suggest that it may be "privileged" farmers who are more likely to adopt them. For instance, farmers with higher education attainment are consistently more likely to adopt shade management practices. Also, farmers that do not have undeveloped land are 41% more likely to grow their coffee under shade. Finally, what is perhaps the most interesting result from this analysis, is that vertically integrated farmers and farmers participating in pro-sun incentive programs are also more likely to adopt shade management practices. The main rationale behind vertical integration is to increase the overall efficiency and reduce costs of production. It is possible that farmers who control more of the production process and have access to additional farm income are more profitable and therefore can afford switching to practices to become producers of shade coffee.

a) *Policy Implications for environmental services and biodiversity conservation programs*

In 2013, the Puerto Rico Department of Natural and Environmental Resources (PR DRNA) published its new habitat conservation strategy which seeks to ensure the long-term persistence of resident species of birds and amphibians. The DRNA is interested in improving the efficiency of existing biodiversity conservation programs that target land-management practices among coffee growers to increase the area of certain protected habitats in the island.

There is a broad consensus within the literature that adoption and diffusion of conservation practices are the result of a complex decision-making process, particularly when examined at the micro-economic level. In Puerto Rico, little research has been done about the status of coffee production, the influence of governmental policies on farming practices and the attitudes of farmers towards sustainable production practices. A primary objective of this study was to investigate the factors that determine farmer participation in conservation programs and the impact of said programs on adoption of conservation practices. A secondary goal was to explore new linkages between competing policy instruments, adoption decisions and biodiversity conservation goals. The empirical results indicate that participation in agricultural-land management programs increases the probability of using conservation agriculture practices.

Based on the studied sample, federal environmental agencies interested in improving the targeting of existing programs should be wary of displacing antagonistic state programs, as these seem to be, paradoxically, the most important driver of the decision to adopt environmentally beneficial agricultural management practices.

In general, the results suggest that farmers who participate in conservation programs encouraging the cultivation of coffee under shade are "newer" farmers who take advantage of quality differentials in their product to sell in specialty markets. In turn, the findings suggest that it may be "privileged" farmers who are more likely to adopt shade-management practices. The level of distortion in the Puerto Rican coffee market is striking; thus, it is possible, that simple income-transfer programs that allow farmers to afford switching from sun to shade coffee may be the less distortionary, and perhaps more efficient, way to promote biodiversity conservation practices. However, this proposition is not verifiable given the data or the estimation methods chose for this study.

b) Note from the author: Additional considerations and recommendations for policy design

In conducting my study, I ran into several inconsistencies in the data that raised my awareness of additional structural factors in a rather complex system of which coffee farmers are a small component. If the intention is to use agricultural policy to further environmental goals, the environmentalist agencies will need to gain much deeper understanding of institutional idiosyncrasies governing the microeconomics of coffee production in Puerto Rico. With the risk of overstepping, I will discuss two examples that illustrate how difficult it will be to successfully intervene in Puerto Rico's coffee sector in order to improve biodiversity conservation and environmental service provision in the is land.

The first issue is an example of what could be the prevalence of pernicious incosystency in monitoring, recording and measuring of economic performance in thecoffee sector. Coffee in Puerto Rico is sold by *almuds* or *quintals*. These are non-standard metrics that have different definitions—and indeed, are used to measure different properties (say volumen instead of mass) —across LatinAmerica and the Caribbean. The USDA defines these units as one almud equaling 28 pounds, and one quintal equaling 100 pounds. However, after speaking with officials and researchers, there is reason to believe that farmers, researchers, government agents, and consumers may have different ideas of what exactly these units constitute. The lack of transparency in the metric system itself may be enough reason to worry about some agents taking advantage of the system to exploit illicit profits. Although I have no evidence of illicit profiting, in the data I do find that average coffee prices vary drastically depending on whether the farmer sells by almud of quintal. The average price per pound that farmers selling by quintal received was $3.16 (with standard deviation of 1.37); on the other hand, the corresponding figure for farmers selling by almud was 0.54 (with standard deviation of $0.49). Although, theoretically those receiving $3.16 are "beneficiadores" (business that are in charge of processing the coffee at a comercial scale) selling coffee beans, while farmers receiving $0.5 are growers selling coffee cherries; there is no certainty over this issue and the data does not support this distinction entirely. This large discrepancy in prices is reason of concern, particularly for distributional considerations and compensatory public policy.

The second issue that clearly reflects the level of convolution in the system, shows how uncertainty as to the implementation of public policy by one state agency can escálate rapidly and affect the actions of other regulatory agencies and the industrial organization of coffee markets itself. In Puerto Rico, the Department of Consumer Affairs (DACO) sets the price of coffee. By law, since 1973, the DACO is supposed to review the price of coffee every 5 years and fix an increase based on recommendations by the Department of Agriculture and the University of Puerto Rico through the Agricultural Science Department and the Agricultural Extension Service. However, coffee prices have not been reviewed systematically.[36]

[36] It took 13 years since the enactment of the "Ley Organica del Departamento de Asuntos del Consumidor" for DACO to adjust coffee prices. In 1986 it set them to $3.12 per pound. In 1991, the price was adjusted to $3.64 per pound. Then, in 2005, prices were raised by 20%. The last time DACO reviewed coffee prices was in 2015. Then, DACO set the price of ripe coffee cherries to $0.52 per pound (and $0.35 for green cherries) and the price of coffee beans to $379 per quintal—or $3.79 per pound.

The DACO is also in charge of systematically setting import tariffs on coffee. Historically, imported coffee had been taxed heavily, keeping its Price artificially higher than that of local coffee. However, since 2015, DACO signed an order imposing a Price ceiling of $322 per quintal of imported coffee—making local coffee less competitive from a pricing standpoint. DACO's neglect and apparent favoritism for coffee consumers—local and multinational—over local producers has likely had an impact on subsequent political actions taken by interested parties such as the Department of Agriculture and certain large multinational companies operating in Puerto Rico. In turn, these actions may have spurred interactions with existing disruptions and inefficiencies of the market, making the situation for coffee farmer seven more complicated. I will elaborate on these thoughts to make their meaning more explicit.

With the objective of relieving some of farmers' financial pressures, since 2001, the Department of Agriculture has established a series of incentives programs in addition to the existing programs subsidizing seeds, fertilizer and labor. The effectiveness of these new programs is highly questionable based on anecdotal observations. Certain legal records document the flaws in these programs. Among them, high uncertainty as to the priority given by the administration to the appropriation of funds to said programs. Additionally, payments conceded by these new schemes are often received late, and sometimes never. Yet, with in the last year, DACO's failure to revise the prices systematically has risen legislation proposals to have the PR Department of Agriculture establish coffee prices instead.[37]

On the other hand, DACO's neglect is certainly not helping farmers who are facing higher input prices and a fiercer competition from abroad. However, anartificially low price of coffee may be disproportionally benefiting large consumers. Although I have no evidence and no way of showing that monopsonistic power is related to DACO's public policy, it is a worry supported by recent news and media analysis.[38]

The coffee industry in Puerto Rico has been struggling in the last few decades. The reasons behind this collapse are multiple and likely to be interrelated. From natural reasons (like pests and hurricanes) to shocks in the labor market to public policy initiatives to market organization, these reasons obscure the fundamental factors determining farmer behavior and thus, make matters ever more complicated for parties interested in targeting coffee producers to further environmental objectives. I want to conclude this paper with the following thought. Although much progress has been made in the areas of economics and ecology in terms of understanding the micro-economic foundations of human behavior and the interactions between humans with the environment in an economic setting, taking these lessons to action will ultimately depend on the functionality, reliability and transparency of political and legislative systems.

[37] "Sen. Ruiz Proposes Agriculture Department Set Coffee Prices." May, 2016. http://cb.pr/sen-ruiz-proposes-agriculture-department-set-coffee-prices/

[38] Since 2013, Puerto Rico Coffee Roasters (which is domain of Coca-Cola Co.) controls 80% of the coffee market.

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Appendix

The profit-maximization problem framework applied to Puerto Rican coffee farmers

In this appendix I develop a simple model of conservation practice adoption in presence of externalities. Here I introduce the definition of variables used in the mathematical expression and describe the relevant equations in the system that the model represents. Then, I make explicit certain simplifying assumptions. A discussion of the model's insights for guiding the empirical work in found in the theoretical section of the main text.

Variable Definition

Define the variables in this model as follows:

Q_t: Coffee production, this is the state variable of the model
X_t: Non-coffee crop production
A: Area of the farm devoted to shade-coffee
A_j: Area of an adjacent farm devoted to shade-coffee
$\sum A_j = \overline{A}$: Total area of adjacent farms devoted to shade-coffee.
Z_t: Composite technology/capital inputs (fertilizer, pesticides and irrigation water)
L_t: Labor input, this is the control variable of the model
L_t^f: Household's farm-labor
L_t^{nf}: Household's non-farm labor
L_t^h: Hired labor
π_t: Net revenues at time t
B_t: Borrowings at time t
M_t: Income at time t
Y_t: Cash at hand at time t
γ_t: A penalty term that reduces output at time t depending on the level of previous produce that was left unharvested and the area of plot that was not maintained.

I_t: Indicator variable, it takes the value of 1 when a farmer grows shade coffee, and of zero otherwise.
D_t: Dividend term that represents benefits to any farmer from the environmental spill-overs generated by the group of farmers growing shade-coffee. This term depends on the total area devoted to shade-coffee plantations that is adjacent to a particular farmer's land.

β_{PES}: Subsidy provided for growing shade-coffee
w: Wage in the labor market[39]
w_z: Price of a composite technology input
P_q: Price of coffee (assumed to be constant)
P_x: Price of non-coffee crop (also assumed to be exogenous and fixed)
i: Interest rate
F: Fixed cost of transforming a sun plantation to a shade plantation
δ: Discount rate
ω: A binary outcome that takes the value of 1 when a particular plot with shade coffee is adjacent to the farmer's land.
ε_t^L: Exogenous shock to labor market (for example, out migration changes amount of hirable labor).
ε_t^N: Exogenous shock to natural conditions (for example, a hurricane).

Model Equations

The model developed here is best represented by a system of equations relevant for each farmer i. For notational simplicity the index i is left out. The equations that characterize this system are the following:

Coffee production function

$$Q_t(L_t, Z_t, \gamma_t; A, \overline{\mathrm{A}}) = \gamma_t \cdot f_i(L_t, Z_t; A, \overline{\mathrm{A}}) \,, \tag{8}$$

Coffee production depends on labor, capital inputs, fixed land, the amount of land devoted to shade coffee in adjacent farms, and a penalty term that depends on previous produce was left unharvested and the area of plot that was not maintained. The hypothesis is that $f_i(L_t, Z_t; A)$ will be different for shade than for sun coffee (thus, i = shade, sun), but that for the same level of inputs $f_{shade} = 0.7 f_{sun}$.

Equation for penalty γ_t

$$\gamma_t = \gamma(Q_{t-1}(L_{t-1}, Z_{t-1}, A), L_{t-1}, Y_{t-1}) + \varepsilon_{t-1}^N,$$

with $\gamma_t \in (0,1)$ and $\varepsilon_t^N iid \sim N(0, \sigma^2)$, (9)

The level of fruits that is left unharvested and the size of the plot that is not maintained is determined by the amount of labor available, available liquidity to pay cherry pickers, and an exogenous shock to natural conditions (like hurricane or landslide).

Non-Coffee crop production function

$$X_t(L_t, Z_t, I_t; A, \overline{\mathrm{A}}) = g_i(L_t, Z_t; A, \overline{\mathrm{A}}) + \xi g_i(L_t, Z_t; A, \overline{\mathrm{A}}) I_t, \tag{10}$$

Non-Coffee production depends on labor, capital inputs, fixed land, adjacent land devoted to shade-coffee, and a term that captures the increased productivity of the non-coffee crop by virtue of growing shade coffee (captures the spill-over benefit on own farm).

[39] US Federal mínimum wage applies in Puerto Rico. Although the government offers a wage subsidy to ameliorate labor costs to coffee farmer, this distortion will be ignored for the moment.

Profit equation

$$\pi_t = P_q Q_t(\cdot) + P_x X_t(\cdot) - wL_t - w_z Z_t + wL_t^{nf} + I_t \beta_{PES} A + D_t(\sum \omega A_j) \quad (11)$$

Profit is the revenue from shade coffee production, net the costs, plus off-farm income, plus whatever subsidy is provided for growing shade-coffee, plus a dividend term that represents benefits to any farmer from the environmental spill-overs generated by the group of farmers growing shade-coffee in adjacent land. The transfer benefit is zero for farmers growing sun coffee. This term depends on the total area devoted to shade-coffee plantations that is adjacent to a particular farmer's land (ω denotes when a particular plot with shade coffee is adjacent to the farmer's land).

Income equation

$$Y_t = \pi_t + B_t - (1+i)B_{t-1} \quad (12)$$

Income equals cash at hand equals profit plus borrowings minus payments on standing debt.

Labor supply equation

$$L_t = (L_t^f + L_t^{hired})\varepsilon_{t-1}^L, \text{ with } \varepsilon_t^L iid \sim N(0,\sigma^2), \quad (13)$$

Total labor dedicated to farm production is the sum of own-household labor and hired labor. These are considered perfect substitutes. Labor employed depends on an exogenous shock to the labor market that may increase or decrease the amount of available hirable labor. This level need not equal labor demand for a given time period.

Time Constraint

$$T_t = L_t^f + L_t^{nf} \quad (14)$$

Each farmer is endowed with T time, and it is allocated among labor on- and off-farm

Model formulation and solution

Using with the definitions presented above, the economic model can now be formulated. A farmers' objective function is to maximize expected, discounted stream of profits derived from working on and off the farm. Farm work includes cultivation of coffee and other crops. In every period, the farmer chooses whether to continue its current management practice (shade or sun), to switch management practices (to sun or shade), or to abandon coffee production altogether. In addition to choosing a use for their land, farmers choose the level of inputs that will be used for the chosen purpose.

$$\max_{Q_{t+1}(\cdot), X_{t+1}(\cdot), L_t, A} E_0 \sum_{t=1}^{T+\tau} \delta^t \pi(X_t, Q_t, L_t^{nf}, A, \bar{A})$$

Where $\tau = 0$ for sun coffee plantations and $\tau \in [0,T]$ for shade coffee plantations.

Consider a simplified version of the model where farmers only grow coffee in their land. This version also abstracts from off-farm labor and credit markets. Finally, I will impose convenient structural forms for the unknown functions $(Q_t, f_i, \gamma_t, \varphi_t)$.

Let f_i and γ_t take convenient Cobb-Douglas forms:

$$f_{sh} = a + L_t^{\alpha_1} A^{\alpha_2}, \text{ where } a \geq 0 \quad (15)$$

$$f_{su} = b + L_t^{\beta_1} A^{\beta_2} Z_t^{\beta_3}, \text{ where } b \geq 0 \text{ and } b \leq a \quad (16)$$

$$\gamma_t = \gamma(Q_{t-1}(L_{t-1}, Z_{t-1}, A), L_{t-1}, Y_{t-1}) + \varepsilon_{t-1}^N, \text{ with } \gamma_t \in (0,1) \text{ and } \varepsilon_t^N iid \sim N(0,\sigma^2) \quad (17)$$

Using all the structure above, the current time profit and total profit stream equations corresponding to farmers currently growing shade coffee take the following form:

$$\pi_t^{sh} = P_q \gamma_t(\cdot)\left(a + L_t^{\alpha_1} A^{1-\alpha_1}\right) - wL_t - F + \beta_{PES} A + D_t(\sum \omega A_j) \quad (18)$$

and

$$E_0 \sum_{t=6}^{2T+5} \delta^t \pi_{sh} = E_0 \sum_{t=6}^{2T+5} \delta^t \{P_q \gamma_t(\cdot)(a + L_t^{\alpha_1} A^{1-\alpha_1}) - wL_t - F + \beta_{PES} A + D_t(\sum \omega A_j)\} \quad (19)$$

The First Order Conditions (FOC's) are:

$$(L_t): \alpha_1 P \gamma_t L_t^{\alpha_1 - 1} A^{1-\alpha_1} - w + E\left[\delta P \frac{\partial \gamma_{t+1}}{\partial L_t} \cdot Q_{t+1}\right] = 0 \quad (20)$$

which imply an optimal level of labor input, an optimal output level, and an optimal per period profit that look as follows:

$$L_*^{Sh} = \left[\frac{\alpha_1 P \gamma}{w - \delta P\left[E \frac{\partial \gamma_{t+1}}{\partial L_t} Q_{t+1}\right]}\right]^{\frac{1}{1-\alpha_1}} \cdot A, \quad (21)$$

$$Q_*^{Sh} = Q(a, \alpha_1, P, w, \gamma, A, A_j, E\frac{\partial \gamma_{t+1}}{\partial L_t}, EQ_{t+1}, D_t(\cdot)) \quad (22)$$

and

$$\pi_*^{Sh} = \pi\left(a, \alpha_1, P, w, \gamma, A, A_j, E\frac{\partial\gamma_{t+1}}{\partial L_t}, EQ_{t+1}, \beta_{PES}, D_t(\cdot)\right) \tag{23}$$

Similarly, for farmers currently growing sun coffee, the current time profit and total profit stream equations take the following form:

$$\pi_t^{su} = P_q\gamma_t(\cdot)(b + L_t^{\beta_1}Z_t^{\beta_2}A^{1-\beta_1-\beta_2}) - wL_t - w_zZ_t + D_t(\sum\omega A_j) \tag{24}$$

and

$$E_0\sum_{t=6}^{2T+5}\delta^t\pi_{sh} = E_0\sum_{t=6}^{2T+5}\delta^t\{P_q\gamma_t(\cdot)(b + L_t^{\beta_1}Z_t^{\beta_2}A^{1-\beta_1-\beta_2}) - wL_t - w_zZ_t + D_t(\sum\omega A_j)\} \tag{25}$$

The FOC's are:

$$(L_t)\text{: } \beta_1P\gamma_tL_t^{\beta_1-1}Z_t^{\beta_2}A^{1-\beta_1-\beta_2} - w + E\left[\delta P\frac{\partial\gamma_{t+1}}{\partial L_t}\cdot Q_{t+1}\right] = 0 \tag{26}$$

$$(Z_t)\text{: } \beta_2P\gamma_tL_t^{\beta_1}Z_t^{\beta_2-1}A^{1-\beta_1-\beta_2} - w_z + E\left[\delta P\frac{\partial\gamma_{t+1}}{\partial Z_t}\cdot Q_{t+1}\right] = 0 \tag{27}$$

Which imply optimal levels of labor and capital inputs, coffee output, and per period profits:

$$L_*^{Su} = \frac{1}{\beta_2}\left[\frac{\frac{\partial\gamma_{t+1}}{\partial Z_t}}{\frac{\partial\gamma_{t+1}}{\partial L}}(\beta_1Z_*^{Su} - w) + w_z\right] \text{and} \qquad Z_*^{Su} = \frac{1}{\beta_1}\left[\frac{\frac{\partial\gamma_{t+1}}{\partial L_t}}{\frac{\partial\gamma_{t+1}}{\partial Z_t}}(\beta_2L_*^{Su} - w_z) + w\right], \tag{28-9}$$

$$Q_*^{Su} = Q(b, \beta_1, \beta_2, P, w, w_z, \gamma, A, A_j, E\frac{\partial\gamma_{t+1}}{\partial L_t}, EQ_{t+1,}D_t(\cdot)) \tag{30}$$

and

$$\pi_*^{Su} = \pi\left(b, \beta_1, \beta_2, P, w, w_z, \gamma, A, A_j, E\frac{\partial\gamma_{t+1}}{\partial L_t}, EQ_{t+1}, D_t(\cdot)\right) \tag{31}$$

Comparative Statics

Ultimately, the goal of this theoretical exercise is to compare the stream of profits a Puerto Rican farmer expects to attain by growing shade coffee to those he would receive from growing sun coffee. However, interesting behavioral responses may arise given the public goods aspect of the problem. In particular, it would be interesting to assess the following theoretical relations:

$$\frac{\partial\pi^{Sh}}{\partial\beta_{PES}} = \sum_{t=6}^{2T+5}\delta^t A + \sum\omega\frac{\partial A_j}{\partial\beta_{PES}}\cdot D \tag{A}$$

This relationship measures whether or not shade-coffee farmers are benefiting by a subsidy program, and if so to what extent. Intuitively, this comparative static should be positive. Furthermore, recognizing there is a relationship between the size of the lump-sum subsidy and the area devoted to shade coffee by other farmers, it is possible that the overall effect is larger than the direct effect of the subsidy alone.

$$\frac{\partial\pi^{Sh}}{\partial A_j} = \sum\omega\frac{\partial D}{\partial A_j} \gtreqless 0 \tag{B}$$

Comparative static (B) examines whether or not there are positive externalities to a shade-coffee farmer from other farmers' choice of management regime. Although the ecology argument is that this relation is positive over the long-run, it is possible that market factors, such as increased competition for scarce labor, will make the sign in this relationship ambiguous. The spatial aspect of the problem is relevant for distributional effects given that for farmers to capitalize on the ecosystem services it is more convenient to have large adjacent areas of secondary-forest (shade plantations) than many scattered farms.

$$\frac{\partial Q^{Sh}}{\partial A_j} \gtreqless 0 \tag{C}$$

The way the model is designed, has (C) equal zero. However, allowing for this relationship is interesting because it indicates the existence of sorting behavior or some type of learning process. It would be useful to identify this effect in a spatial analysis of distributional impacts and would serve as guide for policy-makers for a target population.

$$\frac{\partial\pi^{Su}}{\partial A_j} = \sum\omega\frac{\partial D}{\partial A_j} \gtreqless 0 \tag{D}$$

Comparative static (D) identifies whether or not sun-coffee farmers are substantial beneficiaries of the externality. This is important as it reflects the public goods nature of the problem. Perhaps, positive externalities actually serve as incentives for farmers to switch to sun the more profitable, and now better nourished sun coffee.

$$\frac{\partial \pi^{Su}}{\partial \beta_{PES}} = \sum \omega \frac{\partial D}{\partial A_j} \frac{\partial A_j}{\partial \beta_{PES}} \gtreqless 0 \qquad \text{(E)}$$

Finally, comparative static (E) examines contemplates a situation where the subsidy program may incentivize some farmers to free ride on the ecosystem services provided by shade-coffee adopters. If the type of farmer that free-rides happens to "dis-adopt" shade coffee, the program may in fact constitute a loss to the ecological objective (especially if the farmer owns large farm areas).